











THE  
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OF THE  
ROYAL DUBLIN SOCIETY.

New Series.



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VOLUME XV.

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THE SUBSIDENCE OF TORSIONAL OSCILLATIONS  
AND THE FATIGUE OF IRON WIRES WHEN  
SUBJECTED TO THE INFLUENCE OF ALTER-  
NATING MAGNETIC FIELDS OF FREQUENCIES  
UP TO 250 PER SECOND.

BY

WILLIAM BROWN, B.Sc.,

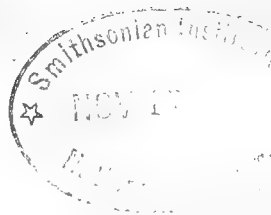
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[*Authors alone are responsible for all opinions expressed in their Communications.*]

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1916.

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# Royal Dublin Society.

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THE  
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THE ROYAL DUBLIN SOCIETY.

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I.

THE SUBSIDENCE OF TORSIONAL OSCILLATIONS AND THE  
FATIGUE OF IRON WIRES WHEN SUBJECTED TO THE  
INFLUENCE OF ALTERNATING MAGNETIC FIELDS OF  
FREQUENCIES UP TO 250 PER SECOND.

BY WILLIAM BROWN, B.Sc.,  
Professor of Applied Physics, Royal College of Science for Ireland, Dublin.

[Read NOVEMBER 23, 1915. Published JANUARY 25, 1916.]

SECTION I.

IN November of last year and in January of this year the present writer brought before this Society the results of some experiments on the fatigue and on the subsidence of torsional oscillations of iron wires when they were subjected to the influence of alternating magnetic fields of frequency 50 per second.<sup>1</sup>

The present communication gives some results on fatigue and on torsional subsidence, obtained with iron wires, when alternating magnetic fields of frequencies up to 250 per second were employed.

For a description of the apparatus used, and of the general methods of experiment, reference should be made to the author's papers already published.<sup>2</sup>

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<sup>1</sup> *Scient. Proc. Roy. Dub. Soc.*, 1915, vol. xiv, No. 26, p. 336, No. 32, p. 393.

<sup>2</sup> *Ibid.*, 1911, vol. xiii, No. 3, pp. 31 and 37, and 1915, vol. xiv, No. 26, p. 337.

As in the case of similar experiments with nickel wires,<sup>1</sup> the iron wires were subjected in every case—unless otherwise stated—to the same longitudinal load, viz.,  $1.5 \times 10^5$  grammes per sq. centimetre, which corresponds to the middle value of the loads employed in previous work on iron wires.

It has been shown, for the case of iron wires, that the magnetic field which must be round the wire in order to get the maximum effects for torsion, fatigue, and subsidence of torsional oscillations is independent of the longitudinal load on the end of the wire.<sup>2</sup> This is not so in the case of nickel wires where the magnetic field changes with the load, so that in all the present experiments the one magnetic field, 2.8 c.g.s. units, which gives these maximum effects was used.

The iron wires employed were each 226 cms. long, and 0.163 cm. in diameter; and the millimetre scale for reading off the amplitude of oscillation in the *subsidence* experiments, or the steady deflection in the *fatigue* experiments, was placed at a distance of 167 cms. from the plane mirror on the vibrator or load on the end of the wire. The maximum deflection of the light-spot which was used in the *subsidence* experiments was at the distance marked 300 on the scale, which corresponded to a torsion or twist of the lower end of the wire equal to an angle of about  $5^\circ 10'$  on each side of the zero.

In the course of the experiments on "fatigue," the direct current *through* the wire was in each case equal to *one* ampere.

The wire first tested was in the physical condition in which it was received from the manufacturer, and when measured it was found to have a simple rigidity of about  $815 \times 10^6$  grammes per sq. centimetre. It was placed in the solenoid with the longitudinal load on the lower end equal to  $1.5 \times 10^5$  grammes per sq. cm., and was tested (1) for fatigue, (2) for subsidence of torsional oscillation when subjected in both cases to continuous (D. C.) and alternating (A. C.) magnetic fields of value 2.8 c.g.s. units.

The results obtained for the fatigue with the different values of the frequency are shown in Table I, and two of the sets of observations are shown in the form of curves in fig. 1. In the table, *d* means the steady deflection of the light-spot on the scale, and *F* the fatigue, and the frequency of the magnetic field is indicated by  $n = 50$ , &c.

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<sup>1</sup> *Scient. Proc. Roy. Dub. Soc.*, 1915, vol. xiv, No. 39, p. 521.

<sup>2</sup> *Ibid.*, 1910, vol. xii, No. 36, p. 484.

TABLE I.  
Rigidity  $\doteq 815 \times 10^6$  grammes per sq. cm.

| Time<br>Mins. | $n = 50$ |      | $n = 100$ |      | $n = 250$ |       |
|---------------|----------|------|-----------|------|-----------|-------|
|               | $d$      | $F$  | $d$       | $F$  | $d$       | $F$   |
| 0             | 4        | 0    | 4         | 0    | 4         | 0     |
| 0.5           |          |      |           |      | 3.6       | 0.100 |
| 1.0           |          |      |           |      | 3.4       | 0.150 |
| 2             | 3.6      | 0.10 | 3.5       | 0.12 | 3.1       | 0.232 |
| 3             |          |      |           |      | 2.9       | 0.276 |
| 4             | 3.4      | 0.16 | 3.2       | 0.20 | 2.8       | 0.300 |
| 6             | 3.2      | 0.20 | 3.1       | 0.23 | 2.8       | 0.300 |
| 8             |          |      | 2.9       | 0.28 |           |       |
| 10            | 3.0      | 0.25 | 2.8       | 0.30 |           |       |
| 15            | 2.8+     | 0.29 | 2.8       | 0.30 |           |       |
| 20            | 2.8      | 0.30 |           |      |           |       |
| 25            | 2.8      | 0.30 |           |      |           |       |

From the values in Table I it will be seen that, as in the case of nickel wire, the time taken to attain the maximum fatigue is *inversely proportional to the frequency of the applied alternating magnetic field.*

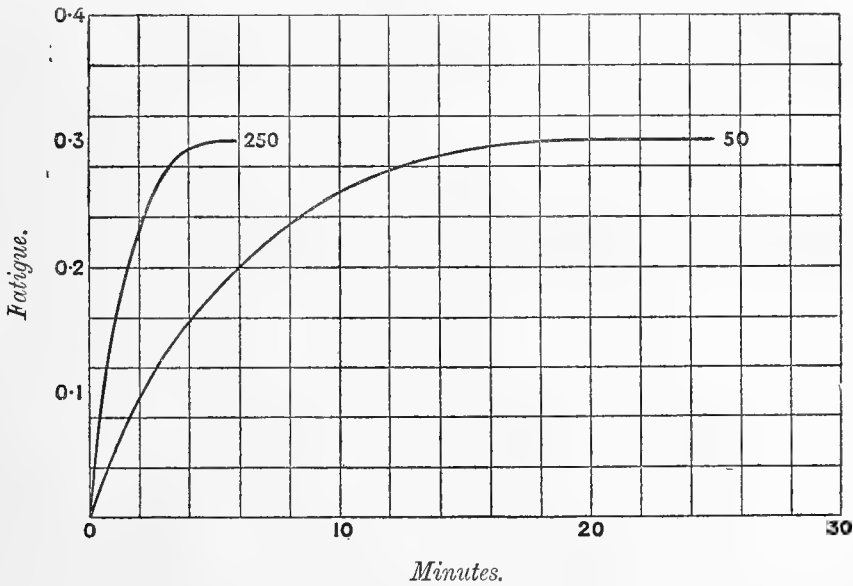


FIG. 1.

In the case of iron, however, the value of the maximum fatigue is the *same* for all the frequencies; whereas, for nickel, the value of the maximum fatigue *increases* with the frequency, up to a certain value of the frequency.<sup>1</sup>

The wire was tested for subsidence of torsional oscillations in this hard state: it was then taken down and heated, when hanging freely in a vertical position, from the top downwards by means of a broad Bunsen flame. When cold, it was cleaned up, the rigidity measured, and again put into the solenoid and tested for torsional subsidence. The wire was then taken down and the same process of heating gone through, the rigidity measured, and the torsional subsidence again observed, and so on, so that the wire was tested when in five different states of rigidity, as indicated below.

The following five tables (II–VI) give only a few of the values observed, which are perhaps sufficient to show the general trend that the curves would take, with the wire in the various states of hardness, if the values were plotted with the number of vibrations as abscissæ, and the corresponding amplitudes of oscillation as ordinates.

In the tables, the mark D. C. means that the wire was subjected to the influence of a direct longitudinal magnetic field, and A. C. that it was under the influence of an alternating magnetic field at the different frequencies.

TABLE II.

Rigidity  $\doteq$   $815 \times 10^6$  grammes per sq. cm.

| Number of Vibrations | D. C. | A. C.    |           |           |
|----------------------|-------|----------|-----------|-----------|
|                      |       | $n = 50$ | $n = 100$ | $n = 250$ |
| 0                    | 300   | 300      | 300       | 300       |
| 30                   | 271   | 262      | 264       | 265       |
| 70                   | 237   | 220      | 221       | 223       |

<sup>1</sup> *Scient. Proc. Roy. Dub. Soc.*, 1915, vol. xiv, No. 39, p. 525.

TABLE III.

Rigidity  $\doteq 805 \times 10^6$  grammes per sq. cm.

| Number of Vibrations. | D. C. | A. C.    |           |           |
|-----------------------|-------|----------|-----------|-----------|
|                       |       | $n = 50$ | $n = 100$ | $n = 250$ |
| 0                     | 300   | 300      | 300       | 300       |
| 30                    | 256   | 246      | 247       | 248       |
| 70                    | 206   | 187      | 188       | 189       |

The fatigue of the wire was also tested when in the state of hardness indicated in Table III, with an alternating magnetic field of frequency 50, and was found to be 0.095, and was attained in 20 minutes.

TABLE IV.

Rigidity  $\doteq 780 \times 10^6$  grammes per sq. cm.

| Number of Vibrations. | D. C. | A. C.    |           |           |
|-----------------------|-------|----------|-----------|-----------|
|                       |       | $n = 50$ | $n = 100$ | $n = 250$ |
| 0                     | 300   | 300      | 300       | 300       |
| 30                    | 220   | 204      | 204.5     | 205       |
| 70                    | 147   | 122      | 123       | 124       |

The maximum fatigue in this case (Table IV) was found to be 0.04, and took place in 25 minutes, with an alternating magnetic field of frequency 50.

TABLE V.

Rigidity  $\doteq 770 \times 10^6$  grammes per sq. cm.

| Number of Vibrations. | D. C. | A. C.    |           |           |
|-----------------------|-------|----------|-----------|-----------|
|                       |       | $n = 50$ | $n = 100$ | $n = 250$ |
| 0                     | 300   | 300      | 300       | 300       |
| 30                    | 205   | 184      | 182       | 179       |
| 70                    | 124   | 100      | 99        | 98        |

TABLE VI.

Rigidity  $\doteq 760 \times 10^6$  grammes per sq. cm.

| Number of Vibrations. | D. C. | A. C.    |           |           |
|-----------------------|-------|----------|-----------|-----------|
|                       |       | $n = 50$ | $n = 100$ | $n = 250$ |
| 0                     | 300   | 300      | 300       | 300       |
| 30                    | 180   | 171      | 170       | 169       |
| 70                    | 80    | 78       | 76        | 75        |

From the values in Tables II to VI it will be seen that as the simple rigidity of the wire *decreases*, the damping or subsidence of the torsional oscillations *increases*, roughly as a straight line law, and that increasing the frequency of the alternating magnetic field to five times has very little effect on the damping of the oscillations, in each state of hardness. When the wire is fairly hard, as in Tables II, III, and IV, the damping is slightly less when the frequency of the magnetic field is increased; whereas when the wire is slightly softer, as in Tables V and VI, the damping is slightly increased for increased frequency. The turning-point seems to lie between the values of the rigidity, 780 and  $770 \times 10^6$  grammes per sq. cm., as will be seen from the following table, in which are collected the amplitudes of the 70th vibration when the wire was in different states of hardness, and for both direct and alternating magnetic fields at the different frequencies; the amplitude of the starting vibration being at the distance marked 300 on the scale in each case.

TABLE VII.

| Rigidity grammes per sq. cm. | D. C. | A. C.    |           |           |
|------------------------------|-------|----------|-----------|-----------|
|                              |       | $n = 50$ | $n = 100$ | $n = 250$ |
| $815 \times 10^6$            | 237   | 220      | 221       | 223       |
| 805 „                        | 206   | 187      | 188       | 189       |
| 780 „                        | 147   | 122      | 123       | 124       |
| 770 „                        | 124   | 100      | 99        | 98        |
| 760 „                        | 80    | 78       | 76        | 75        |



## SECTION II.

It has already been shown in the torsional subsidence of iron wires that the *difference in the amplitudes of the 70th vibration*, when the wire is under the influence of a direct longitudinal magnetic field, and when under the influence of an alternating magnetic field of frequency 50 per second, *diminishes* as the load *increases*, and that at a certain load this difference vanishes.<sup>1</sup> In order, therefore, to ascertain if this principle held with higher frequency alternating magnetic fields, a new wire was taken from the same batch, and tested when it was *hard* and when it was fairly *soft*. The experiments made were identical with those described above: the wire was tested when it was subjected to six different longitudinal loads and when under the influence of a direct magnetic field, as well as under that of alternating magnetic fields of frequency 50 and 250 per second, the field strength in each case being 2.8 c.g.s. units.

A few of the results obtained with the wire in the *hard* state are given in Table VIII, and in Table IX are recorded more detailed observations obtained when the wire was in the *soft* state, that is, in the latter case there are sufficient values given so that one may draw the curves if required.

TABLE VIII.

Rigidity  $\doteq 812 \times 10^6$  grammes per sq. cm.

| Load in grammes per sq. cm. | Number of Vibrations. | D. C. | A. C.    |           |
|-----------------------------|-----------------------|-------|----------|-----------|
|                             |                       |       | $n = 50$ | $n = 250$ |
| $1 \times 10^5$             | 0                     | 300   | 300      | 300       |
|                             | 70                    | 238   | 221      | 226       |
| 1.5 ,,                      | 0                     | 300   | 300      | 300       |
|                             | 70                    | 237   | 220      | 221       |
| 2 ,,                        | 0                     | 300   | 300      | 300       |
|                             | 70                    | 233   | 213      | 217       |
| 3 ,,                        | 0                     | 300   | 300      | 300       |
|                             | 70                    | 228   | 210      | 214       |
| 4 ,,                        | 0                     | 300   | 300      | 300       |
|                             | 70                    | 225   | 208      | 211       |

<sup>1</sup> *Scient. Proc. Roy. Dub. Soc.*, 1915, vol. xiv, No. 32, p. 398.

TABLE IX.

Rigidity  $\doteq 770 \times 10^6$  grammes per sq. cm.

| Load in<br>grammes<br>per sq. cm. | Number of<br>Vibrations. | D. C. | A. C.    |           |
|-----------------------------------|--------------------------|-------|----------|-----------|
|                                   |                          |       | $n = 50$ | $n = 250$ |
| 0.5 × 10 <sup>6</sup>             | 0                        | 300   | 300      | 300       |
|                                   | 10                       | 274   | 259      | 261       |
|                                   | 20                       | 251   | 225      | 229       |
|                                   | 50                       | 193   | 151      | 157       |
|                                   | 70                       | 163   | 116      | 123       |
| 1.0 ,,                            | 0                        | 300   | 300      | 300       |
|                                   | 10                       | 269   | 260      | 258       |
|                                   | 20                       | 242   | 225      | 222       |
|                                   | 50                       | 177   | 148      | 145       |
|                                   | 70                       | 143   | 111      | 110       |
| 1.5 ,,                            | 0                        | 300   | 300      | 300       |
|                                   | 10                       | 263   | 255      | 252       |
|                                   | 20                       | 231   | 217      | 214       |
|                                   | 50                       | 159   | 135      | 133       |
|                                   | 70                       | 125   | 100      | 96        |
| 2 ,,                              | 0                        | 300   | 300      | 300       |
|                                   | 10                       | 262   | 254      | 250       |
|                                   | 20                       | 229   | 216      | 211       |
|                                   | 50                       | 155   | 136      | 130       |
|                                   | 70                       | 120   | 100      | 95        |
| 3 ,,                              | 0                        | 300   | 300      | 300       |
|                                   | 10                       | 256   | 252      | 248       |
|                                   | 20                       | 219   | 213      | 206       |
|                                   | 50                       | 139   | 129      | 121       |
|                                   | 70                       | 103   | 92       | 86        |
| 4 ,,                              | 0                        | 300   | 300      | 300       |
|                                   | 10                       | 250   | 249      | 244       |
|                                   | 20                       | 209   | 208      | 200       |
|                                   | 50                       | 124   | 121      | 114       |
|                                   | 70                       | 87    | 84       | 78        |

From the values in Table VIII it will be seen that the damping of the torsional oscillations is increased slightly by an increase in the load: by comparing the amplitudes of the 70th oscillation in each case. When the longitudinal load is increased four times, there is a decrease of about  $5\frac{1}{2}$  per cent. when a D. C. magnetic field is round the wire, and about  $6\frac{1}{2}$  per cent. for an A. C. magnetic field of frequency 250 per second. In Table IX, which gives the values for the wire in the softer state, there is a curious result when the light load is used, that is, there is less damping of the torsional oscillations with an A. C. magnetic field of frequency 250 than with an A. C. field of frequency 50 per second, which is the reverse of what occurs with the higher loads. In fact, a soft wire with a small load seems to behave in the same way as a hard wire under all loads. The damping of the torsional oscillations is much more pronounced when the wire is soft than when it is hard; and by taking the same range of loads as was taken above for the hard wire, that is, from  $1 \times 10^5$  to  $4 \times 10^5$  grammes per sq. cm., the amplitude of the 70th oscillation is decreased about 40 per cent. for a D. C. magnetic field and about 30 per cent. for an A. C. magnetic field of frequency 250 per second.

The effect of an increased longitudinal load in changing the subsidence of torsional oscillations is better seen from Table X, which gives in each case, for six different values of the load, the difference in the amplitude after 70 complete vibrations when a D. C. magnetic field was round the wire, and when A. C. magnetic fields of frequencies 50 and 250 per second respectively were applied.

TABLE X.

Rigidity  $\doteq 770 \times 10^5$  grammes per sq. cm.

| Differences.                     | Load in grammes per sq. cm. $\times 10^5$ . |     |     |    |    |   |
|----------------------------------|---|-----|-----|----|----|---|
|                                  | 0.5   | 1.0 | 1.5 | 2  | 3  | 4 |
| D. C. and A. C.<br>( $n = 50$ )  | 47  | 31  | 25  | 20 | 11 | 3 |
| D. C. and A. C.<br>( $n = 250$ ) | 40  | 33  | 29  | 25 | 17 | 9 |

These values are shown as curves in fig. 2 (p. 10), which shows that the D. C. and A. C. damping curves would be identical with a load of about

$4.3 \times 10^5$  grammes per sq. cm., when the A. C. magnetic field has a frequency of 50, and for a frequency of 250 per second, the load which should be on the wire to make the damping curves identical would be about  $5.1 \times 10^5$  grammes per sq. cm.

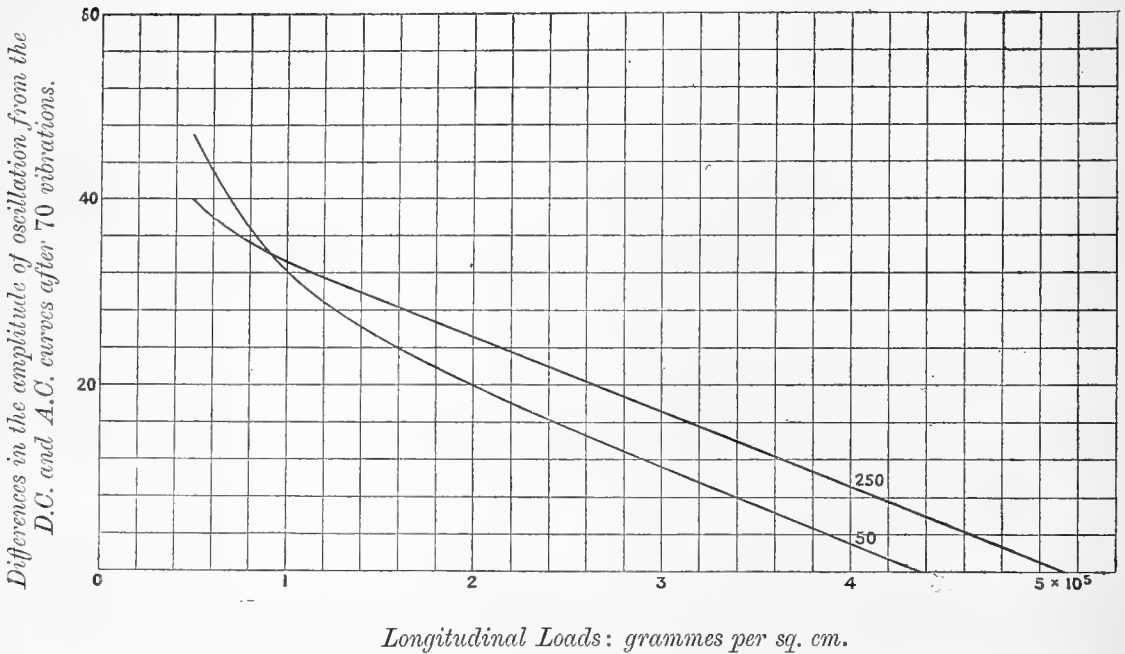


FIG. 2.

For the sake of comparison with the results given in Section I, and in order to show the behaviour of iron wire when oscillating in a high frequency alternating magnetic field, the whole of the observations obtained are here given in Table XI. The load on the wire was  $1.5 \times 10^5$  grammes per sq. cm. The values are shown as curves in fig. 3.

TABLE XI.

Rigidity  $\doteq 770 \times 10^6$  grammes per sq. cm.

| Number of Vibrations. | D. C. | A. C.    |           |
|-----------------------|-------|----------|-----------|
|                       |       | $n = 50$ | $n = 250$ |
| 0                     | 300   | 300      | 300       |
| 5                     | 281   | 277      | 275       |
| 10                    | 263   | 255      | 252       |
| 15                    | 246   | 235      | 232       |
| 20                    | 231   | 217      | 214       |
| 30                    | 203   | 185      | 183       |
| 40                    | 179   | 158      | 156       |
| 50                    | 159   | 135      | 133       |
| 60                    | 141   | 116      | 114       |
| 70                    | 125   | 100      | 96        |

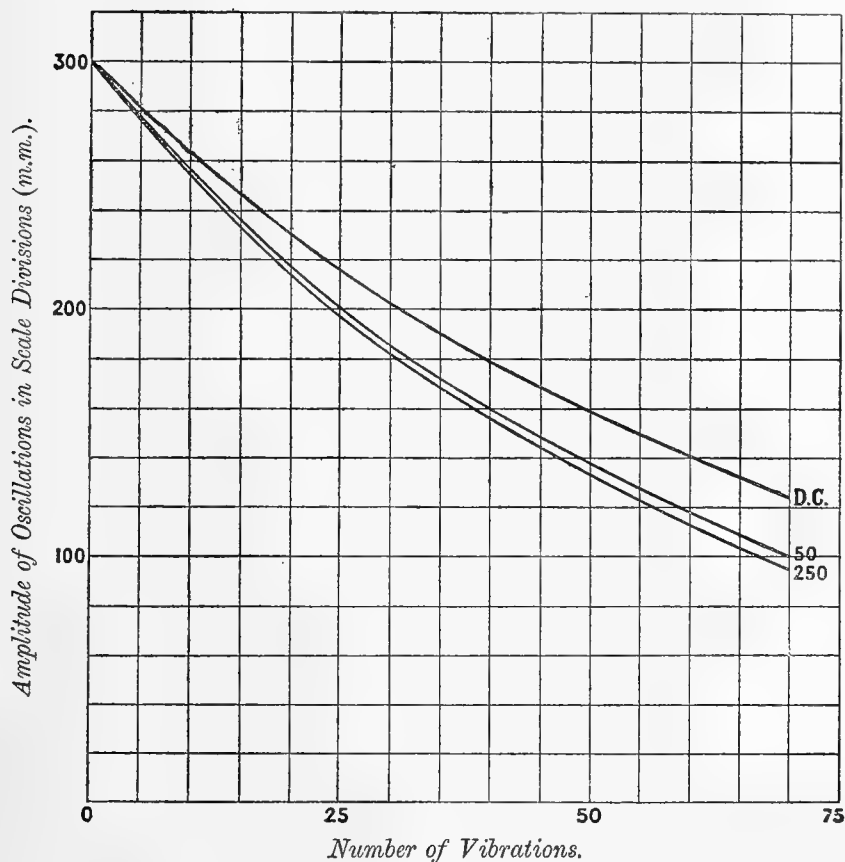


FIG. 3.



For assistance in making some of the observations I am indebted to Mr. F. O'Carroll, a Fourth-year Experimental Science Teacher, in training in this College.

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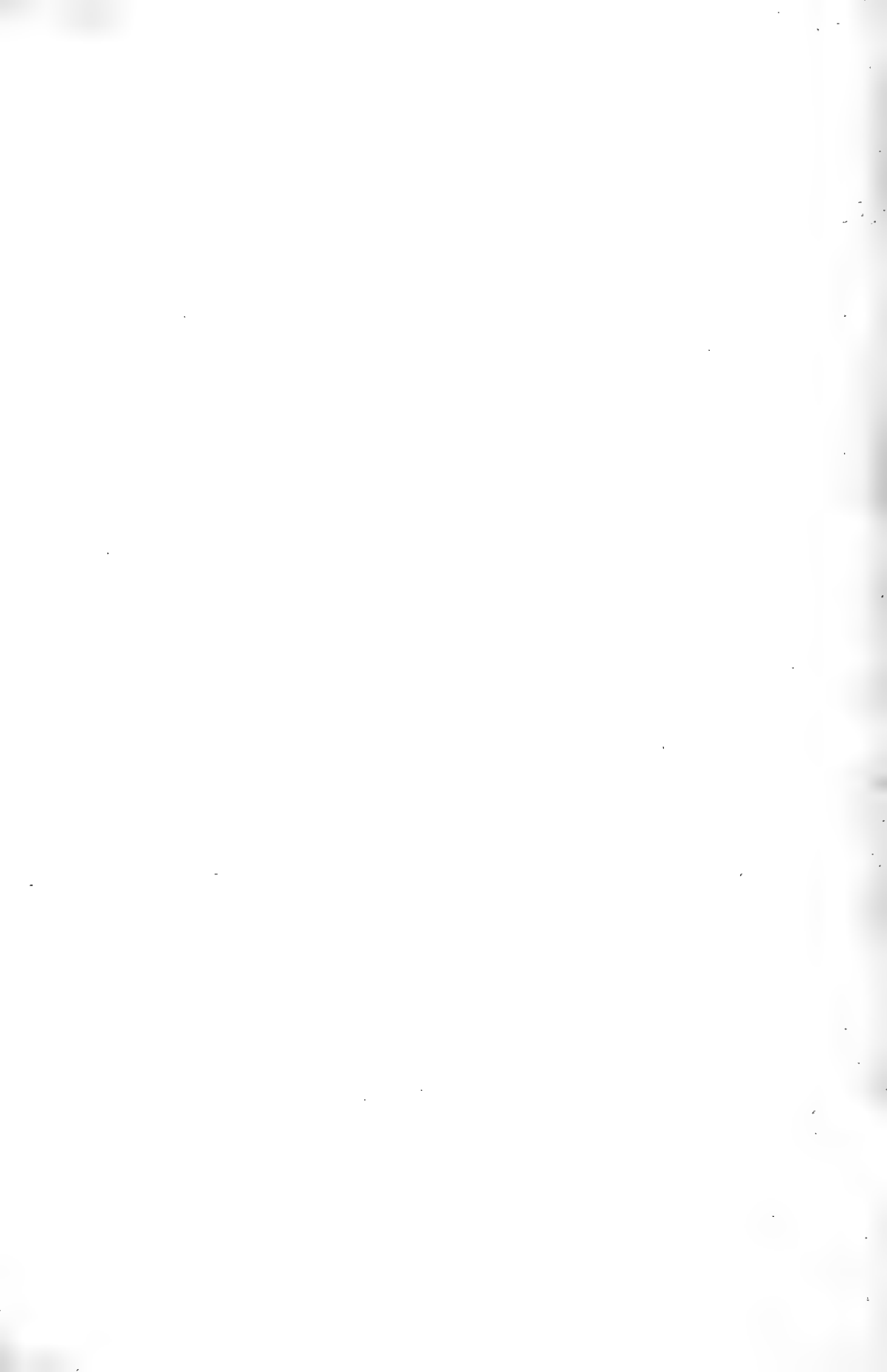
NOTE.—With respect to the internal friction of materials, I would draw attention to a very interesting paper on "The Internal Friction of Nickel in a Variable Magnetic Field," by Prof. Ernesto Drago of the R. University of Catania, Italy. (R. Accad. dei Lincei, vol. xxiv, serie 5<sup>a</sup>, 2<sup>o</sup> sem., fac. 1<sup>o</sup>, Roma, Luglio, 1915.)

## SCIENTIFIC PROCEEDINGS.

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### VOLUME XV.

1. The Subsidence of Torsional Oscillations and the Fatigue of Iron Wires when subjected to the Influence of Alternating Magnetic Fields of Frequencies up to 250 per second. By WILLIAM BROWN, B.SC. (January, 1916.) 6*d*.



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PRELIMINARY NOTES ON THE  
CARBOHYDRATES OF THE MUSCLES.



BY

THOMAS G. MASON, B.A., DIPLOM. AGRIC.

[COMMUNICATED BY PROFESSOR HENRY H. DIXON, SC.D., F.R.S.]

*[Authors alone are responsible for all opinions expressed in their Communications.]*

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## II.

PRELIMINARY NOTES ON THE CARBOHYDRATES OF THE  
MUSCI.

BY THOMAS G. MASON, B.A., DIPLOM. AGRIC., T.C.D.

[COMMUNICATED BY PROFESSOR HENRY H. DIXON, SC.D., F.R.S.]

[Read NOVEMBER 23, 1915. Published FEBRUARY 17, 1916.]

THE wide divergence of opinion that prevails concerning the carbohydrates of the angiosperms has suggested that an investigation conducted among the Musci would be of great interest, and might shed light on the subject of photosynthesis. The work was undertaken early in January, 1914; owing to the war, however, it was found necessary to discontinue it; yet, incomplete as it is, it seemed advisable to place on record the experiments which had been already completed.

The Musci chosen for investigation were—

*Polytrichum commune.*

*Thuidium tamariscinum.*

*Sphagnum cymbifolium.*

The material has been collected among the hills and woods of the counties Dublin and Wicklow, and the experiments have been carried out in the Botanical Laboratory, Trinity College, Dublin.

Brown and Morris (2), who worked on the leaves of *Tropaeolum*, arrived at the following conclusions:—

1. Cane-sugar is the first sugar synthesised by the assimilatory process, and is the starting-point of all the metabolic changes taking place in the leaf.
2. When the degree of concentration of the sucrose exceeds a certain amount, starch commences to be elaborated by the chloroplasts.
3. Sucrose is inverted, and starch converted into maltose before translocation.

It may be pointed out, however, that their experiments do not exclude

the possibility that levulose may be antecedent to the sucrose. They proved that levulose was a down-grade product from sucrose, but failed to show that it was not also an up-grade sugar.

Parkin (7), in his work on the carbohydrates of the foliage leaf of the Snow-drop, came to very similar conclusions, and further showed that:—

1. Only three carbohydrates are present in the Snow-drop leaf, viz., sucrose, glucose, and fructose.
2. The ratio of sucrose to hexoses in the leaf diminished from above downwards, so that the hexoses appear to be the sugars chiefly concerned in translocation.
3. During any single day of the spring the percentage of hexose sugars in the leaf remained fairly constant; that of the sucrose, however, increased during the day, and diminished during the night.

A. V. Campbell (3), who traced the diurnal fluctuations in each sugar of the mangold leaf, came to the following conclusions:—

1. Reducing sugars are the first carbohydrates to be found as soon as daylight begins.
2. When the reducing sugars have reached a certain concentration, the excess appears as sucrose.
3. Similarly starch begins to be formed as soon as the sucrose reaches its maximum.

Strakosch (10), who experimented on the leaves of *Beta vulgaris*, bases his conclusions chiefly on results obtained by microchemical work.

1. Dextrose is the first sugar to appear in the process of assimilation; in the small veins part of it is transformed into levulose.
2. In the larger veins the two hexoses combine to form sucrose.
3. Sucrose is the form in which the carbohydrates are translocated to the root.

Ruhland (9), who also worked on *Beta*, stated that the sugars wandered from the leaf chiefly as invert-sugar, especially as levulose, to the root, where they combined to form sucrose.

Thus, Brown and Morris, Parkin and Ruhland express the opinion that the sugars are translocated from the leaves as hexoses, while Strakosch, and apparently Campbell, hold that sucrose is the chief form in which the carbohydrates leave the leaves of angiosperms.

What follows is a summary of my preliminary experimental work with the Musci.

## (A) QUALITATIVE WORK.

## (1) IDENTIFICATION OF SUGARS.

An aqueous solution of the sugars, freed from tannin, gums, chlorophyll, &c., is prepared in the usual way.

A suitable quantity of the material to be examined is immersed in boiling alcohol for five minutes, in order to destroy the enzymes. The alcohol is decanted off and replaced by distilled water. After twelve hours' extraction the water is filtered off and added to the alcoholic extract. The alcohol is distilled off, and the chlorophyll thrown out of solution. Basic lead acetate is added to precipitate the tannin and gums, which are removed from the extract.

The excess of lead is neutralized by sodium carbonate; and the deleadied extract concentrated and placed aside for examination. For this the following tests have been employed.

*Reducing Sugar.*—For the detection of reducing sugars freshly made Fehling solution is quite satisfactory.

*Hexoses.*—A small quantity of the extract is added to a solution of two parts phenylhydrazine chloride and three parts sodium acetate in twenty parts of water. On heating for half-an-hour a yellow needle-shaped osazone separates from the mixture in the presence of certain hexose sugars, viz., *d*-glucose, *d*-fructose.

*Dextrose (d-glucose).*—A small quantity of the extract is added to an alcoholic solution of diphenylhydrazine. In the presence of glucose the colourless diphenylhydrazones separate from the mixture after several days.

*Levulose (d-fructose).*—A small quantity of the extract is added to an alcoholic solution of methylphenylhydrazine, to which a few drops of acetic acid have been added. The mixture is heated for ten minutes, and then placed aside. After a couple of weeks the red-yellow osazone appears in the mixture, if levulose is present. As a confirmatory test for levulose Pinoff's ammonium molybdate solution has been found quite satisfactory.

*Maltose.*—The greater solubility of the crystals of maltose phenylosazone in hot water offers a means of separating it from the less soluble osazones of other sugars, yet the influence of impurities modifies its character so greatly that this means of identification is often rendered inconclusive.

The increase in the amount of copper reduced after treatment with takadiastase is undoubtedly the most reliable means of identifying maltose.

*Sucrose.*—Sucrose is easily identified by means of the use of invertase. The study of the enzymes offers a means of checking the results derived by the above methods.

*Starch.*—In order to detect the presence of starch, the material which has been immersed in boiling alcohol for a few minutes is then placed aside till decolorized. After decolorization it is washed and placed in a 10 per cent. solution of chloral hydrate for six hours. Dilute iodine in glycerine was then used for the detection of starch granules.

*Polytrichum commune.*

*Hexoses.*—Both dextrose and levulose were detected.

*Disaccharides.*—The presence of sucrose is indicated by the increase in copper reduction on treatment with invertase under suitable conditions, details as to which are given with the quantitative work.

CuO reduced after 1·0182  
 „ „ before 0·6975.

The presence of maltose was demonstrated by the following experiment, 100 c.c. of previously inverted extract are treated with 0·2 g. of taka-diastase for 48 hrs. at 34°, and the copper reduction again noted.

CuO reduced before 1·032  
 „ „ after 1·143.

*P. commune* is probably one of the most highly specialized of the Musci; in its massiveness it approaches the vascular plants. The stem often reaches a length of more than twenty centimetres. The leaves, which are confined to the upper part of the stem, have a thick midrib. On the upper surface are a series of vertical lamellae. These lamellae are responsible for nearly the whole of the assimilation of the leaf, and, in fact, of the entire plant, for, with the exception of the very top, the stem is without chlorophyll. There is much starch in the cells of the lamellae, but the rest of the leaf is comparatively destitute of it. In the aerial stem is a thick-walled cylinder much of which is composed of starchless elements, which are apparently living. Outside of this lies a thin hydrom mantle (Tansley and Chick (11)). This hydrom mantle is surrounded by a layer of cells from one to two cells thick, which are densely filled with starch. Next to these cells a layer of thin-walled starch-free typical sieve-tubes occurs, rarely more than one cell thick. These leptoids are followed by a layer of very starchy cells, scarcely differentiated from the cortex, which also contains an abundance of starch.

The hydrom mantle and leptom are in communication with similar elements in the leaf trace.

*Thuidium tamariscinum.*

This plant is a small fern-like moss, growing in large mats in woods.

*Hexoses.*—Dextrose and levulose are present.

*Disaccharides.*—That sucrose is present is shown by the following figures :—

|                    |   |                            |
|--------------------|---|----------------------------|
| Grams CuO reduced, | { | after inversion = 0.9324.  |
|                    | { | before inversion = 0.3485. |

Typical lamellate crystals of maltosazone were entirely absent; on the other hand, a homogeneous yield of acicular crystals, insoluble in hot water, was produced on treatment with phenylhydrazine. On adding a trace of pure maltose to the extract, typical maltosazone could usually be detected after from three to five weeks. The presence of maltose, even in small quantities, is thus rendered improbable.

Starch was totally absent in both leaves and stem.

*Sphagnum cymbifolium.*

*Hexoses.*—Dextrose and levulose occur.

*Disaccharides.*—The presence of sucrose is demonstrated by the following :—

|                    |   |                            |
|--------------------|---|----------------------------|
| Grams CuO reduced, | { | before inversion = 0.3770. |
|                    | { | after inversion = 0.8454.  |

The presence of maltose was not brought to light by the use of phenylhydrazine.

Starch is absent from the leaves, but has been found in minute quantities in the stems of some of the material.

Thus dextrose, levulose, and sucrose have been found in all the material examined, and maltose in those containing any appreciable quantities of starch.

(2) IDENTIFICATION OF ENZYMES.

*General Method of Preparation.*—The material to be examined is immersed in 95 per cent. alcohol for thirty minutes; when freed as far as possible from the alcohol it is slowly dried at 30° C. The dried material is reduced to a fine powder, and placed aside for examination.

By means of the above treatment it was found that the plants were freed from much of their sugars.

The decanted alcohol contains an abundance of tannin.

*Invertase.*

Our knowledge of the invertase of the flowering plants is now fairly extensive. Special attention may be drawn to the works of Ruhland (8), and Kastle and Clarke (5).

The object that has been held in view here is not so much an examination of the enzyme under different conditions, or a comparison with the invertase



from other sources, as merely to demonstrate its presence and record its distribution.

A 1 per cent. sucrose solution has been employed, and to this the powdered leaf is added.

The following measures were adopted in order to minimize as far as possible all sources of error :—

1. The sucrose solution was tested for reducing substances before each experiment.
2. Toluol was used as an antiseptic.
3. All flasks were sterilized by heat.
4. The nature of the reducing sugars produced was determined by means of phenylhydrazine.

Two flasks were used in the following experiment :—

The first contained 50 c.c. of a 1 per cent. sucrose solution, to which 2 grams of the leaf-powder of *Polytrichum* had been added. It was boiled to destroy the enzymes, and furnished a means of making allowance for any sugars the leaf-powder might contain.

A second flask containing 50 c.c. of a 1 per cent. sucrose solution was boiled, thus ensuring against any active material that might exist in either the sucrose solution or in the flask. It was then cooled, and the 2 grams of leaf-powder were added.

After four days' incubation at 35° the sugar solution in each flask was filtered from the leaf-powder, which was thoroughly washed with distilled water, and made up to 100 c.c. The following figures show that the leaves of *Polytrichum commune* contain an active invertase :—

|   |         |
|---|---------|
| Grams CuO reduced before incubation by 100 c.c. of      |         |
| 1 per cent. sucrose . . . . .                           | = 0·00. |
| Grams CuO reduced after four days' incubation . . . . . | = 1·45. |

For the detection of the invertase in the various parts of the stem of *Polytrichum*, and in other mosses, two test-tubes are used : each is half-filled by a 1 per cent. sucrose solution ; to one a small quantity of the leaf-powder is added, and the whole is boiled for several minutes, cooled, toluol added, corked, and incubated at 34°. The other test-tube is boiled before the leaf-powder is added, and then treated in a similar manner to the first. After twenty-four hours' incubation, both test-tubes are examined for reducing sugars with freshly made Fehling solution and phenylhydrazine.

In *P. commune* invertase has been found both by day and night, and in all parts of the stem ; even after the plants had been subjected to four days' darkness its presence could be detected.

It is strange that in the juice squeezed from plants that had been frozen by means of liquid air, no invertive action could be detected. This may be due to the fact that the tannin had not been removed as it is in the alcoholic treatment.

Other Musci in which invertase has been detected are :—

- Sphagnum cymbifolium.*
- Brachythecium rivulare.*
- Dicranus majus.*
- Thuidium tamariscinum.*

In all these mosses there is no difficulty in detecting the enzyme; even after four hours appreciable quantities of reducing sugars can be detected; in *Sphagnum* this is not always the case.

*Diastase.*

The material under examination was treated in much the same way as that for invertase. A 0·2 per cent. solution of potato starch was used. The following measures were taken to eliminate errors:—

1. The starch solution was tested before use for reducing sugars.
2. Toluol was used as an antiseptic.
3. Freshly prepared Fehling solution was employed to detect the reducing sugar or sugars formed.
4. The same system of checking was used as for invertase, two flasks being employed, in one of which the leaf-powder was boiled.
5. The starch-paste after incubation was filtered off and tested with *liquor iodi* and Fehling solution.
6. Phenylhydrazine was employed in order to determine the nature of the sugar or sugars resulting from the hydrolysis.

In the following experiment 0·2 gram of leaf-powder was added to 50 c. c. of a 0·2 per cent. solution of starch, and incubated at 30° :—

|   | 16 hours.               |              | 48 hours.               |              |
|---|-------------------------|--------------|-------------------------|--------------|
|   | Iodine Colour Reaction. | Fehling ppt. | Iodine Colour Reaction. | Fehling ppt. |
| <i>P. commune</i> ,<br>after three days' darkness.  | purple                  | trace        | brown                   | marked       |
| <i>Sphagnum cymbifolium</i> ,<br>collected at dawn. | blue                    | none         | blue                    | none         |

The osazone crystals produced by the *Polytrichum* solution consisted of a very few typical hexose tufts, and a great number of hedgehog-like crystalline groups, which, it seems likely, are largely, if not altogether, composed of maltosazone; this view is supported by the fact that when pure maltose is added to the solution, there results a large addition of these crystals. They are fairly soluble in hot water, and have often been found thrown down from apparently pure maltose solutions, but in a mixed hexose-maltose solution it often seems as though the two types (viz., glucosazone and maltosazone) graded into one another. From the presence of hexose osazones in the incubated solution we may infer the presence of diastase and maltase in the leaves of *P. commune*.

*Maltase.*

In the detection of maltase the same precautionary measures were taken.

Two grams of the powdered leaf were added to 80 c.c. of a 0.38 per cent. solution of maltose. After forty-eight hours' incubation at 38°, both flasks were examined for reducing sugars.

50 c.c. of unboiled solution reduced, 0.35 g. Cu O.

50 c.c. of boiled solution reduced, 0.29 g. Cu O.

The above figures indicate the presence of an enzyme capable of converting maltose into glucose.

The presence of maltase in *P. commune* is most interesting; its distribution among the vascular plants has not yet been widely demonstrated. Brown and Morris' failure to find it in the leaves of *Tropaeolum* may be due to the fact that in that plant maltose is translocated from the leaves, so that maltase would not be required till the sugar has arrived at its destination.

## B. QUANTITATIVE WORK.

### METHOD OF ESTIMATION.

The fresh material is immediately immersed in alcohol, and boiled for ten minutes to destroy the enzymes.

A small quantity of calcium carbonate is added to prevent inversion by the acids of the plant.

After twenty-four hours' extraction the alcohol is decanted off, and to the moss is added cold distilled water.

After a further twenty-four hours' extraction this aqueous extract is added to the alcoholic extract. The residue is washed with warm alcohol, which in due course is added to the previous extracts.

A further extraction is found to contain neither sucrose nor reducing sugars.

On distillation of the alcohol the chlorophyll is precipitated, filtered off, and washed.

The extract is next treated with the minimum amount of basic lead acetate, and a little alumina cream. After the removal and washing of the precipitated gum and tannin, the excess of lead is removed by sodium carbonate. The deleaded filtrate is next concentrated, and made up to the required volume.

This concentration is a source of the greatest trouble, as it involves a browning of the levulose, which renders the use of the polarimeter out of the question. This concentration, however, is rendered inevitable, firstly by the paucity of the sugar present, and secondly by the necessity of using water for extraction in addition to alcohol.

Benedict's sodium-citrate method (S. R. Benedict (1)) has been used to make the following analysis of *P. commune*, collected at midday, August 15th. A weighed quantity of the fresh plant (both leaves and stem) was placed in alcohol, and treated as has been above indicated. The dry weight was obtained separately. The sugars extracted from 16.7 g. (dry wt.) were made up to 200 c.c. :—

|         |   |
|---------|---|
| 50 c.c. | were used in the estimation of the hexoses, |
| " "     | " " sucrose,                                |
| " "     | " " maltose,                                |

and 50 c.c. were placed aside to be used if required.

100 c.c. of the original solution were found to reduce 0.697 g. CuO.

To 50 c.c. made slightly acid to litmus paper, 6 c.c. of yeast invertase were added. At the end of twenty hours' incubation, the sugar solution was neutralized, filtered, and made up to 100 c.c.

100 c.c. (after correction for change in concentration) now reduced 1.0181 g. CuO.

The sucrose is calculated from the difference in the amount of CuO reduced before and after inversion.

$$1.0181 - 0.6971 = 0.321 \text{ g. CuO.}$$

As 1 gram of sucrose yields 1.052 grams invert sugar, which is capable of reducing 2.817 grams CuO, the amount of sucrose in 100 c.c. of the original solution is expressed by the fraction  $\frac{0.321}{2.817} = 0.1139 \text{ g.}$

For the estimation of maltose 50 c.c. of the inverted solution are treated with 3 c.c. of concentrated hydrochloric acid for three hours on a water-bath; it is then neutralized with sodium hydroxide, made up to 100 c.c., and the increase in reducing power noted.

100 c.c. (allowing for change in concentration) now reduces 1.1622 g. CuO.

$\therefore 1.1622 - 1.0181 = 0.1441$  g. CuO = 0.1138 g. maltose. Amount of CuO reduced by hexoses therefore is  $0.6970 - 0.1900 = 0.507$  g.

*P. Commune*, collected at noon, August 15.

|             | grms. CuO reduced<br>by sugar in<br>16.7 grms. moss. | grms. sugar in<br>16.7<br>grms. moss. | per cent. |
|-------------|--|---------------------------------------|-----------|
| Hexoses, .. | 1.014  | 0.3623                                | 2.17      |
| Sucrose, .. | 0.642  | 0.2278                                | 1.36      |
| Maltose, .. | 0.2882   | 0.2276                                | 1.36      |

The following is an analysis of *P. commune* after three days in darkness.

|             | grms. CuO reduced<br>by sugar in<br>15.5 grms. moss. | grms. sugar in<br>15.5<br>grms. moss. | per cent. |
|-------------|--|---------------------------------------|-----------|
| Hexoses, .. | 0.8655   | 0.3102                                | 2.00      |
| Sucrose, .. | 0.2578   | 0.0915                                | 0.59      |
| Maltose, .. | 0.3101   | 0.2450                                | 1.58      |

The great decrease in the total sugars, especially of the sucrose, is very noticeable. Experiments were also carried out to show the distribution of the sugars in leaf and stem. In order to bring into prominence the amounts of the various sugars that are present in the assimilating and non-assimilating parts of the plants, the tip of the stem, which contains a certain amount of green tissue, has been placed aside, and does not figure in the analysis of either leaf or stem. Owing to the time required to separate the leaves with their sheaths from the stem, it has been impossible to express the results as percentages, since inversion of sucrose would take place, if the separated parts were kept till ready for weighing. It has, therefore, been necessary to express the results of the analysis as ratios,

*P. commune.*

|      | Hexose.               |                         |        | Sucrose.              |                         |        | Maltose.              |                         |        | Place gathered. |
|------|-----------------------|-------------------------|--------|-----------------------|-------------------------|--------|-----------------------|-------------------------|--------|-----------------|
|      | grms. CuO in 100 c.c. | grms. Sugar in 100 c.c. | Ratio. | grms. CuO in 100 c.c. | grms. Sugar in 100 c.c. | Ratio. | grms. CuO in 100 c.c. | grms. Sugar in 100 c.c. | Ratio. |                 |
| Leaf | 0.4040                | 0.1448                  | 1      | 0.8731                | 0.3099                  | 2.14   | 0.0833                | 0.0658                  | 0.45   | Tibradden Wood  |
|      | 0.4855                | 0.1740                  | 1      | 1.0736                | 0.3811                  | 2.19   | 0.1123                | 0.0887                  | 0.51   | Kippure Woods.  |
| Stem | 0.4772                | 0.1711                  | 1      | 0.0914                | 0.0325                  | 0.19   | 0.1429                | 0.1129                  | 0.66   | Tibradden Wood. |
|      | 0.4968                | 0.1781                  | 1      | 0.1203                | 0.0427                  | 0.24   | 0.1622                | 0.1282                  | 0.72   | Kippure Woods.  |

In the above analysis the alteration in the hexose-sucrose ratio indicates an inversion of sucrose, as sugar passes from the leaves to the stem.

This inversion, which is rendered more probable by the presence of invertase in the leaf, points to the carbohydrates being translocated to a large extent in the hexose form.

In considering the conditions which prevail in the leaf, it is difficult to see how the hexoses can be responsible for synthesis of sucrose, as in the presence of invertase a very high concentration of hexose sugars would be needed to bring about its formation; such a high concentration is negated by the foregoing results.

The next experiment shows the way in which the sucrose in *Thuidium tamariscinum* diminishes when the plants are kept in darkness.

The difficulty of preparing the plants for analysis again renders it necessary to express the results as ratios.

|             | Prepared in the afternoon. |                         |        | After three days' darkness. |                        |        |
|-------------|----------------------------|-------------------------|--------|-----------------------------|------------------------|--------|
|             | grms. CuO in 100 c.c. sol. | grms. sugar in 100 c.c. | Ratio. | grms. CuO in 100 c.c. sol.  | grms. sugar in 100 cc. | Ratio. |
| Hexose, ..  | 0.3485                     | 0.1249                  | 1      | 0.3984                      | 0.1428                 | 1      |
| Sucrose, .. | 0.5839                     | 0.2072                  | 1.66   | 0.2129                      | 0.0756                 | 0.53   |

In dealing with *Sphagnum cymbifolium*, it has been necessary to bring up jars of alcohol to the bog for collection, as laboratory cultivation is out of the question. Once again, the results are expressed as ratios.

|             | Upper Green Part.     |                         |        | Lower Colourless Part. |                         |        |
|-------------|-----------------------|-------------------------|--------|------------------------|-------------------------|--------|
|             | grms. CuO in 100 c.c. | grms. sugar in 100 c.c. | Ratio. | grms. CuO in 100 c.c.  | grms. sugar in 100 c.c. | Ratio. |
| Hexose, ..  | 0.3770                | 0.1351                  | 1      | 0.4684                 | 0.1663                  | 1      |
| Sucrose, .. | 0.8206                | 0.2941                  | 2.18   | 0.4475                 | 0.1587                  | 0.95   |

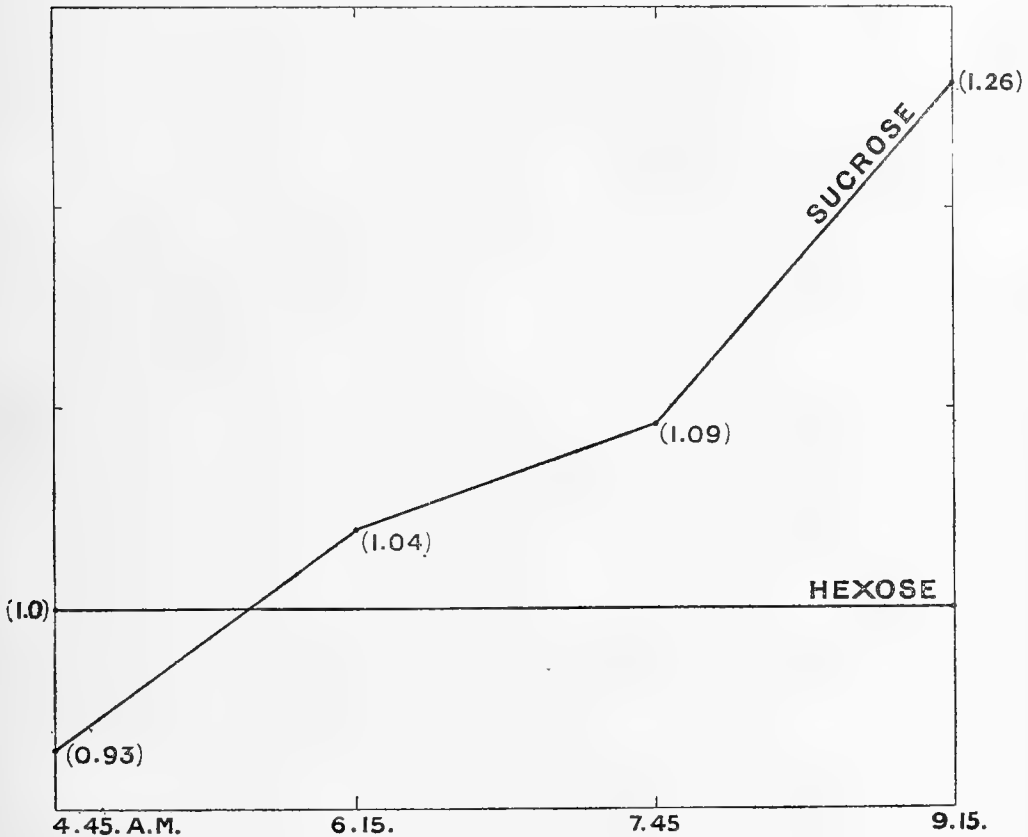
The above analysis renders it improbable that the hexoses are antecedent to the formation of sucrose, since here, also, that concentration of hexoses, necessary to bring about the synthesis of sucrose in the presence of invertase, is lacking. The next experiment was devised with the object of ascertaining, if possible, which was the first sugar to be formed after the application of light.

On August 22nd, four jars of moss were collected in alcohol from the mountains at intervals of one and a-half hours. The sun rose at 5.11 A.M., so the first sample was taken at 4.45 A.M. Only the green tops of the plants were employed, and each sample was taken from the same locality. The result of the analysis, expressed as ratios, is shown on the accompanying table and graph.

*Sphagnum cymbifolium.*

| Time at which collected. | 4.45 A.M.                               |                   |        | 6.15 A.M.             |                   |        | 7.45 A.M.             |                   |        | 9.15 A.M.             |                   |        |
|--------------------------|---|-------------------|--------|-----------------------|-------------------|--------|-----------------------|-------------------|--------|-----------------------|-------------------|--------|
|                          | grms. CuO reduced by 100 c.c. Solution. | Sugar in 100 c.c. | Ratio. | grms. CuO in 100 c.c. | Sugar in 100 c.c. | Ratio. | grms. CuO in 100 c.c. | Sugar in 100 c.c. | Ratio. | grms. CuO in 100 c.c. | Sugar in 100 c.c. | Ratio. |
| Hexoses,                 | 0.4785                                  | 0.1715            | 1      | 0.3671                | 0.1316            | 1      | 0.4793                | 0.1724            | 1      | 0.279                 | 0.1               | 1      |
| Sucrose,                 | 0.4515                                  | 0.16              | 0.933  | 0.3869                | 0.1373            | 1.043  | 0.5316                | 0.1887            | 1.094  | 0.3552                | 0.1261            | 1.261  |

The rise in the sucrose graph may be due either to an actual rise in the quantity of sucrose, or to a fall in the amount of hexoses owing to translocation, respiration, &c. A rise in the amount of sucrose is rendered almost certain, since a fall in the hexoses would involve an enormous diminution of total sugar.



The rather strange "hang" in the sucrose graph between 6.15 and 7.45 A.M. may be due to a more rapid inversion of sucrose than formerly; if such be the case, we must suppose that assimilation increased at a very great rate between 7.45 and 9.15 A.M., or else that translocation became more brisk; both factors may have been in operation. On the other hand, any slight unevenness in the third sample would be quite sufficient to explain the apparent hang.

It seems fairly clear, however, that sucrose is the first sugar to accumulate on illumination. If it is assumed that the hexoses are the first sugars to be formed in the plastid on exposure to light, it is difficult to see why, instead of accumulating, condensation to sucrose should be necessary.



## STARCH.

Marchal (6) has shown that *P. juniperum*, and, in fact, all the starch-building mosses examined, can build up starch, when artificially fed with solutions of varying concentration of sucrose, glucose, maltose, and lactose; but from the experiments it is impossible to come to any conclusion as to their relative efficiency. In his work he used percentages by weight, but it seems doubtful whether this does not put sucrose at a disadvantage in comparison with the hexoses. In discussing the starch of *P. commune*, the starch in the lamellae of the leaf and the starch in the stem must be distinguished. The question that naturally presents itself is whether the same sugar is concerned in the formation of both; probably the answer is in the affirmative. If it is so, we are faced with the following possibilities:—

*A.*—Sucrose is immediately concerned with the formation of the starch in the lamellae, and the quantities of sucrose that find their way into the stem are concerned *solely* with maintenance of the starch reserve there; in the last sentence the word “solely” must be emphasized, because the small quantities that occur in the stem would only be adequate provided they were entirely devoted to this work; but that this is not so is shown by the fact that invertase in large quantities occurs in the stem. It is further questionable whether the amount of sucrose which penetrates the rhizome would be adequate even if it was devoted exclusively to this work. It is reasonable therefore to conclude that either maltose or a hexose is responsible for the formation of starch. But maltose seems out of the question, since it is not known to arise, except from the hydrolysis of starch, whereas a constant supply from the leaves is necessary for this task. The only sugars that come down from the leaves in quantities anything like sufficient to maintain the starch supply are the hexoses.

*B.*—If it be granted that the same sugar is concerned in the formation of starch in both leaf and stem, then it follows that small quantities of sucrose in the plastids of the lamellae must be inverted, and that this invert sugar or one of its members must be responsible for the maintenance of starch in the leaf lamellae.

## SUMMARY.

1. Dextrose, levulose, and sucrose have been found in all the material examined, whereas maltose is dependent on the presence of starch.
2. Invertase is of wide distribution, whereas diastase and maltase have been found in *P. commune* alone. Thus their detection is dependent on the presence of appreciable quantities of starch.

3. In *P. commune* and *S. cymbifolium* the hexoses appear to be the chief form in which the carbohydrates descend the stem.

In reference to the remarks made above concerning the necessity of a high concentration of hexoses in order that sucrose be synthesised under the influence of invertase, it may be pointed out that though the experiments quoted in this work exclude the possibility of a high concentration for the whole leaf, yet they do not demonstrate the absence of a localized high concentration. This local concentration might exist in the chloroplasts, possibly as a film in contact with the chlorophyll. That this is not so is shown by the following considerations:—

1. The chloroplast would require a selectively semi-permeable membrane to permit the sucrose to diffuse and yet retain the hexose; experiments on starch-formation from hexose solutions negative this.
2. In the chloroplast, or that region of it where the hexose concentration is supposed to be present, there would be approximately 1 per cent. sucrose, and 99 per cent. hexose (the equilibrium percentages of these sugars in the presence of invertase (Visser 12)); this would involve (as analysis has shown) a diffusion of sucrose from the rest of the leaf into the chloroplast; since more than 1 per cent. of sucrose is present throughout the leaf.
3. In a lamella of *P. commune* composed of five tiers of cells, in order that sucrose may continue to diffuse away a high concentration is rendered inevitable in the uppermost cells, but a high concentration of sucrose in the cell prohibits the sugar formed in the chloroplast from diffusing out into the vacuole and cytoplasm; this banking up of sucrose involves a higher concentration in the region of hexose concentration than 1 per cent., and this would exclude further synthesis under the influence of invertase; but the energy entering the chloroplast would ensure a continuation of hexose-formation, and if this was unable to proceed to sucrose and so be removed, a banking up of hexose would occur, and so on through the different stages in the synthesis of the hexoses, till at length a stage would be reached where the energy entering the chloroplast would be unable to carry on the process.

If we substitute a high concentration of sucrose for hexose in the chloroplast, we escape all the above difficulties. It should be noted that though invertase has been shown to be present in the leaf, yet it has not yet been demonstrated that it is present in the plastid.

In conclusion it must be pointed out that the factors that operate in bringing about the synthesis of sucrose in the plant cell are still very obscure. (Robertson, Irvine, and Dobson (8).)

Hudson's (4) work has rendered it improbable that invertase in aqueous solution possesses this property.

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## SCIENTIFIC PROCEEDINGS.

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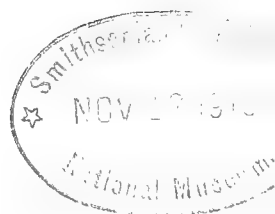
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A NEW FORM OF VERY HIGH RESISTANCE  
FOR USE WITH ELECTROMETERS.

BY

JOHN J. DOWLING, M.A., M.R.I.A.,

LECTURER IN PHYSICS, UNIVERSITY COLLEGE, DUBLIN.



*[Authors alone are responsible for all opinions expressed in their Communications.]*

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## III.

A NEW FORM OF VERY HIGH RESISTANCE FOR USE  
WITH ELECTROMETERS.

By JOHN J. DOWLING, M.A., M.R.I.A.,  
Lecturer in Physics, University College, Dublin.

[Read NOVEMBER 23, 1915. Published FEBRUARY 2, 1916.]

§ 1. THE minute currents met with in many modern lines of research have usually been measured by observing the rate of charging of a system of known capacity with an electrometer or electroscope. There are certain disadvantages in this procedure, and some efforts have been made to devise a "steady deflection" method, notably by Bronson<sup>1</sup> and by Campbell.<sup>2</sup> To effect this it is simply necessary to use the electrometer to measure the potential drop across a suitable high resistance, through which the current to be measured passes to earth.

§ 2. There is, however, one serious obstacle to be overcome, namely, that the resistance required for this purpose is usually very large indeed. Thus, if the electrometer gives a full-scale deflection for about  $\frac{1}{10}$  volt, and if a current of  $10^{-9}$  ampere is to be measured, we require a resistance of the order of 100 megohms.

Moreover, this resistance must not vary with the current, so that the electrometer deflections may be proportional to the currents being measured. It is also very desirable that the resistance should possess no appreciable temperature coefficient, and that it should be free from polarisation effects. These requirements we may regard as essential; but the utility of the resistance method would be greatly enhanced were it possible to vary the resistance according to the strength of the current to be measured. Thus it would be very useful if the resistance could be constructed to have a definite value, such as 100, 500, 1000, or 5000 megohms: but it would be still more serviceable if it could be altered, while in use, from one to another of these values.

I believe the apparatus now to be described meets these requirements.

§ 3. The method of attaining such high resistances suggested itself in connection with Siemens' method of measuring a small capacity. In this method

<sup>1</sup> Bronson, Amer. Journ. Sc., 1905, 4th Ser., vol. xix., p. 185.

<sup>2</sup> Campbell, Phil. Mag., 1911, vol. xxii., p. 301—and later papers.

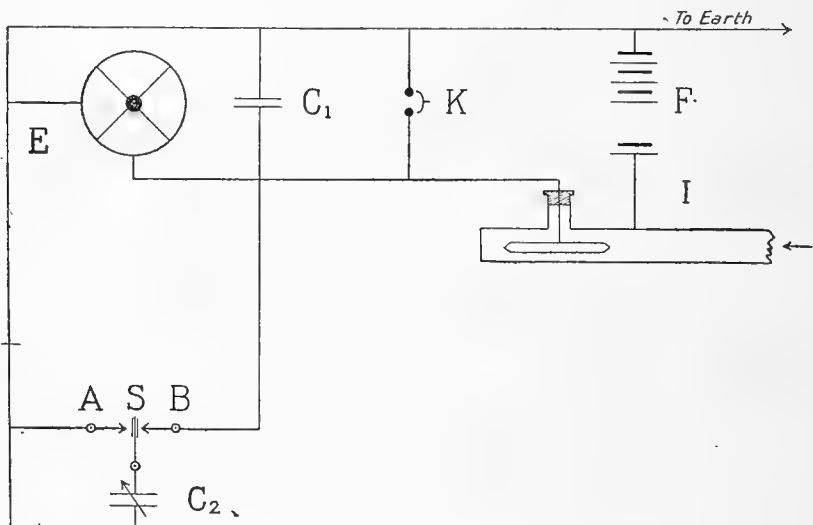


a current is passed through a circuit by the alternate charging and discharging of a condenser. If the capacity of the condenser is  $c$  farads, and if it be charged and discharged  $n$  times per second, the charging potential being  $V$  volts, it is clear that the current passing is  $ncV$  amperes. This arrangement is obviously equivalent to a resistance  $R = \frac{1}{nc}$  ohms.

This equivalent resistance will usually be very large. Thus, if  $c = \cdot 001$  microfarad =  $10^{-9}$  farad, and if  $n = 10$  per second, we obtain:—

$$R = \frac{1}{nc} = 10^8 \text{ ohms} = 100 \text{ megohms.}$$

This is, therefore, of the order required, as we have seen, for the measurement of currents in the neighbourhood of  $10^{-9}$  ampere, by a steady deflection method. By varying  $n$  and  $c$ , it is possible to obtain equivalent resistances from  $10^7$  to  $10^{10}$  ohms. Indeed, wider ranges may be covered, but the author has not yet tried the method outside these limits.



§ 4. The apparatus is very simple. In the figure a quadrant electrometer  $E$  is shown as ordinarily used with an extra capacity  $c_1$ , connected up to an ionisation chamber  $I$  in order to measure the current therein. To this system is further connected the arrangement shown in the lower part of the figure.  $A$  and  $B$  are two platinum-tipped contact screws, mounted on insulating pillars. Between these is mounted a steel spring,  $S$ , also supported on an insulating pillar, and having platinum contact pieces facing those on the screws  $A$  and  $B$ . The screws are adjusted so as to allow the spring to vibrate with just sufficient amplitude to make alternate contacts with them. To the spring  $S$  is connected one terminal of the condenser  $c_2$ , which may con-

veniently have a capacity of one-thousandth of a microfarad and be subdivided into smaller fractions.

The vibration of the spring  $S$  is controlled by an electromagnet, which is excited by an intermittent current from a tuning-fork or other automatic interrupting device.

§ 5. The action of the apparatus is obvious. On opening the earthing key  $K$ , the electrometer system ( $EC_1$ ) charges up to a steady potential  $V$ , such that the intermittent current  $nc_2 V$  drawn off by the vibrating contact is equal to the current  $i$  being measured, which passes into the electrometer system from the ionisation vessel  $I$  (or other source of current). This is, of course, correct only if the potential to which  $c_2$  is charged at each contact is approximately the same as the electrometer potential. For this to be the case, it is simply necessary that  $c_2$  should be small compared with  $c_1$ . This condition is readily fulfilled in practice, since  $c_2$  rarely exceeds  $\cdot 001$  microfarad.

If the above condition is not fulfilled, we sacrifice the simplicity of the relation between the electrometer deflection and the current. As against this drawback we would have the advantage that the electrometer would take up its deflections the more rapidly the smaller we made  $c_1$ . On putting this to a practical trial, however, in the case where  $c_1$  and  $c_2$  were equal, it was found that another difficulty was met with. Owing to slight variations in the times of contact of  $S$  with  $A$  and  $B$  respectively, the electrometer deflection was unsteady. As it was not found easy to remedy this, further trials of the apparatus in this way were abandoned.

§ 6. The writer has tested the method over a considerable range, using it to measure ionisation currents in gases drawn from a flame. Each measurement was repeated immediately afterwards by the old "rate of charge" method. In all cases a very good agreement was found, provided that the condition mentioned in the previous paragraph was fulfilled. There was one difficulty met with. The electrometer was somewhat unsteady at first. This was found to be due to the faulty action of the contact-breaker; but on approaching the screws  $A$  and  $B$  very near together, so as to limit the vibration of  $S$  to a very small amplitude, the trouble disappeared.

The largest "equivalent resistance" tried was limited by the apparatus used by the writer, namely: (1) the smallest condenser ( $c_2$ ); (2) the slowest interrupting device. The smallest condenser was about  $10^{-4}$  microfarad, and the clockwork interrupter gave two interruptions per second. The equivalent resistance was, therefore,  $\frac{1}{2 \times 10^{-10}}$  ohms, that is 5000 megohms.

The lowest equivalent resistance tried was  $10^7$  ohms, or 10 megohms. This was obtained by using a capacity  $c_2 = \cdot 002$  microfarad and a tuning-fork

interrupter giving 50 interruptions per second. Several intermediate values were also tried.

With this range of resistances, and an electrometer having a sensibility of about 2000 per volt, it was possible to measure accurately currents between  $5 \times 10^{-12}$  ampere and  $1.5 \times 10^{-8}$  ampere. By using even smaller capacities ( $c_2$ ) and a slower interrupter it should be possible to measure currents less than  $10^{-13}$  amperes. In consequence of the long period of the electrometer needle, it would appear possible that an interrupter which made contact only once every two or three seconds might be employed.

§ 7. An obvious modification is to convert the method into a "zero" or a "compensation" method. This may readily be done by connecting the contact screw  $A$ , not to earth, but to a potential dividing device, of which one terminal is earthed. The condenser,  $c_2$ , then feeds in an inverse "compensating" current ( $= -n c_2 v$ ), which tends to prevent the electrometer system charging up under the influence of the current  $i$ . This compensating current may be varied by changing either  $n$ , or  $c_2$ , but preferably by changing  $v$  by means of the potential divider. The electrometer readings  $V_E$  are now proportional to the difference between the current  $i$  being measured and the "compensation" current. The *total* value of  $i$  is obviously

$$i = n c_2 (V_E + v).$$

The advantages of a method of compensation have frequently been recognized in cases where small variations of a comparatively large current, say in an ionised gas, have to be examined; but the method here described appears to the writer to be more satisfactory than any yet tried.

In the practice of the compensation method small values of  $c_2$  and  $n$  are chosen, and a comparatively high potential is applied at  $A$  by means of the potential divider. A large electrometer deflection may, therefore, be obtained even when the current  $i$  is almost balanced by the "compensation" current.

§ 8. It is hoped that the method outlined above may be found of use by other workers. An important advantage found in practice was the economy of time during a set of observations. This was due to the fact that it was generally unnecessary to earth the electrometer between consecutive observations. Any induction effect, for instance, produced on changing the potential of the ionisation vessel  $I$  by a moderate amount died away in a few seconds; and the electrometer seldom required more than half a minute to reach its new position of rest. In certain classes of work this rapidity should be very advantageous.

I have pleasure in thanking Professor M'Clelland for the interest he has shown in this work.

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ON THE PATH OF A SMALL PERMEABLE BODY  
MOVING WITH NEGLIGIBLE ACCELERATION  
IN A BIPOLAR FIELD.

BY

PHILIP E. BELAS, B.A., A.R.C.Sc.I.,

AND

MARCUS HARTOG, M.A., D.Sc. (N.U.I.)

UNIVERSITY COLLEGE, CORK.

[COMMUNICATED BY PROFESSOR WILLIAM BROWN, B.SC.]

(PLATE I.)

[*Authors alone are responsible for all opinions expressed in their Communications.*]

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## IV.

ON THE PATH OF A SMALL PERMEABLE BODY MOVING WITH  
NEGLIGIBLE ACCELERATION IN A BIPOLAR FIELD.

By PHILIP E. BELAS, B.A., A.R.C.Sc.I.,

AND

MARCUS HARTOG, M.A., D.Sc. (N.U.I.),

University College, Cork.

(COMMUNICATED BY PROFESSOR WILLIAM BROWN, B.Sc.)

(PLATE I.)

[Read NOVEMBER 23, 1915. Published FEBRUARY 28, 1916.]

*Historical.*

THIS investigation originated in the researches of one of us (Dr. Hartog) upon the "Mechanism of Mitosis in the dividing cell." Struck by the similarity of the spindle form which is assumed by the achromatin fibres of a cell undergoing division with that of inductive dust, when scattered on a flat surface, or suspended in a liquid of lower permeability, between two poles of opposite sign, he was led to develop a theory that at a particular stage in its life-history the cell was the seat of a dual force, like electrostatic, centring on two bodies—the centrosomes—whose field was bounded by the cell wall. The chromosomes were to be considered as portions of matter more permeable (in the broad Kelvin sense) than the medium in which they moved and their orientations in the equatorial plane, discessions and migration to the centrosomes were to be accounted for by the differential action about the two force centres on these and on the surrounding medium.

This theory we consider to be fully established by the experiments described in a series of papers by Dr. Hartog, and in this our joint paper.

When we were attempting to model the phenomena of mitosis by means of a bipolar magnetic field, we had to consider what would be the path of a small disc of very soft iron if floated in a viscid liquid between the poles of an electromagnet—the disc at no time acquiring observable acceleration.

A more accurate model of the field of the living cell would be obtained by using charged electric spheres; but since climatic and other conditions made electrostatic force inadmissible in practice, the plane section of the magnetic field through the poles, having the same general distribution of energy, was utilized by us. On looking up the literature of fields of force, electrostatic and magnetic, we noticed a remarkable paucity of information.

A single North Pole—that useful abstraction—would of course move along



the lines of force to the opposite pole, which statement is equivalent to defining a line of force; but beyond the general statement that a permeable body would always move so as include the greatest number of lines of induction, there was no indication of the actual trajectory. We therefore determined to investigate the problem for ourselves as follows:—

*Descriptive.*

Our first experiments were made with circular discs of thin charcoal iron, cemented by paraffin to the lower faces of discs of cork or linoleum to float them. The liquid used was water, and the method of observation was to powder the surface with starch or flour so as to increase the frictional resistance and, at the same time, to define the passage of the floating disc by its wake.

Among our preliminary experiments we wish to note three that are well suited for demonstration purposes. A Gillette razor-blade floating on the surface film of water, or gum-water, shows very clearly the relation of our curves to the lines of force of the field, whether homo-polar or hetero-polar. Still better is a light compass needle<sup>1</sup> pivoted on a pin, attached to a cork float; the compass-needle is at all points tangential to a line of force, while the float bearing it of course follows such a curve as we have described.

A magnetic shell formed by punching a disk from an annealed Gillette blade, hardening it and magnetizing it in a coil traversed by a strong current, and then attached to a disk of cork, follows the lines of force of the field; this was devised to model the behaviour of a *charged body* in an electrostatic field, as contrasted with the path of a body more permeable than the medium.

This was unsuited to give accurate records of the path followed. We replaced the water by various viscid liquids, of which glycerine soon showed its superiority, though it has the disadvantage of becoming hydrated during the time of experiment. The disturbing effects of currents and of surface tension were reduced very greatly with this liquid, the latter being noticeable only towards the extreme edge of the trough.

We soon had to replace the floating discs, since, owing to their form, they gave a lurch whenever the exciting current was put on or increased. This was avoided by using a spherical float. Paraffin softened by gentle heat was compressed in a bullet-mould; the part adjoining the channel for pouring in lead was melted with a hot needle, and reduced iron pushed in. The sphere measured  $\frac{3}{8}$  inch in diameter, and contained about 0.13 gms. of iron.

We attempted to record the path by covering the trough, through which the magnet poles projected, with a sheet of ground glass, rendered transparent

<sup>1</sup> A more permeable body and a magnet of course follow similar paths, since the lines of induction in the former make it a magnet for the time being.

by wetting with glycerine, and tracing the path with a pencil; but apart from other difficulties, the error of parallax was so great and unequal that we abandoned it.

*Final Method.*

Ultimately the following method of record gave us results freer from error than the experimental conditions to be recorded.

A strongly built  $\frac{1}{2}$ -plate camera (see Plate I.) was bedded on its side in a teak board, excavated to hold it firmly, and provided with a backward extension carrying leaden weights to prevent overbalancing. Attached to the lens is a right-angled prism, looking directly over the centre of the field, so that it is reflected and focussed on the ground-glass screen of the camera, which is reversed. This permits dots to be made by the "recorder" with a pencil at the successive portions of the screen occupied by the image of the zenith of the spherical float (which is spotted with black); and it is these dots that are reproduced in our figures.

Needless to say, the camera and prism must be so adjusted that the horizontal face of the latter is parallel to that of the fluid, and that the axes of the camera are parallel to those of the trough, so that all perspective distortion is avoided. The prism used was a first-class one by Beck, as was also the objective, a 6" Unifocal Anastigmat, used at full aperture. Both performed admirably.

A second observer, or rather "controller," is in charge of the exciting current, which must be carefully regulated, since too strong a field would so increase the speed as the float approaches a pole that the observer could not dot in the positions fast enough, and there would also be the danger that acceleration would not be taken up by the friction of the medium. The plate, after completion of the records for a given arrangement of poles (which may take up to eight hours), is now removed, and the dots gone over with water-proof Indian ink. A negative is now made by contact on a backed Imperial Process plate.

The variation of the intensity of the exciting current is controlled by an electrolytic resistance; a long china dish containing a sheet of absorbent cotton wool, and well wetted with a dilute solution of sodium phosphate or copper sulphate. The movable electrode is a small block of lead with a short string hanging down, which serves to reduce the current to a minimum without breaking it when the block is raised off the wet cotton.

An ammeter reading to 1/100ths is interposed, for though the motions of the float are the main guide to the controller of the current, the indications of the ammeter enable him after a little while to prevent instead of correcting variations of speed. The source of energy is from the town supply, D.C., 230 v.; the maximum current used about .6 amps., the minimum about .02.

It soon became evident that the method was susceptible of great accuracy, and is yet capable of further improvement; but we content ourselves with indicating the lines along which we worked, as the results obtained were sufficient for our purpose, leaving other refinements to those who may be induced to pursue the matter further with a view to obtain quantitative results.

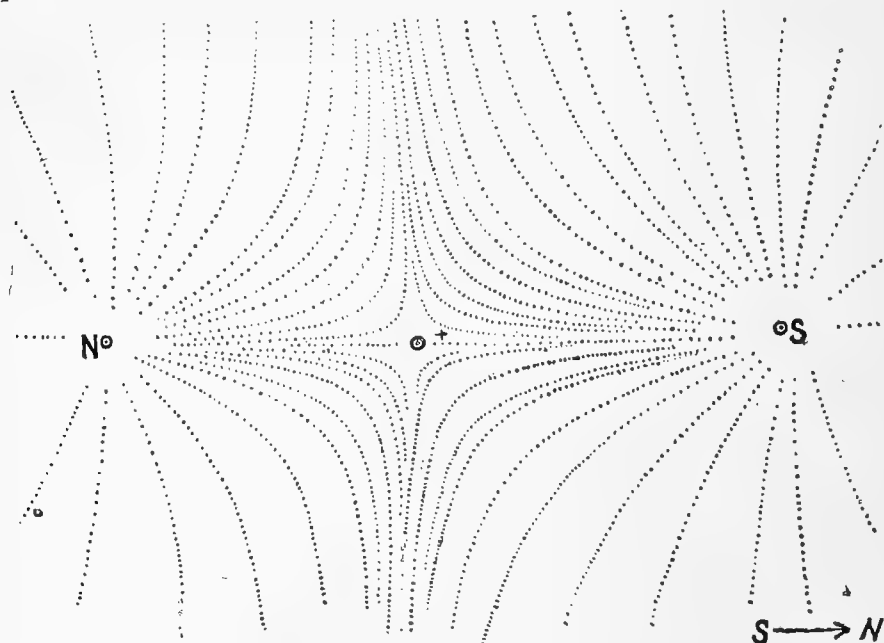


FIG. 1.

*Errors of the Method.*

We have already referred to surface-tension and its practical elimination. However, floating dust, bubbles, &c., deviate the path of the float, and must be avoided. Their effect is easily seen by the recorder, and when observed he effaces the curve commenced, and repeats the record after the controller has skimmed the peccant particle away.

Fig. 1 shows the trajectories of the paraffin sphere, when started from various points in the field of two unlike magnetic poles, which were reversed with respect to the horizontal field of the earth's magnetism. The figure bears a striking similarity to the well-known distribution of lines of force for *like* poles.

The cross + marks the point equidistant from either pole-piece, and will be referred to as the Centre of the Field or C.F. The ⊙ marks the spot where the sphere remains at rest. For a small displacement along the diameter this is a position of stable equilibrium, but for a displacement

along the axis it is a position of unstable equilibrium, the sphere moving to the nearer pole.

We refer to this spot as the Resting point or R. P. The two poles are, of course, also R. P.'s; stable for all displacements. The most noteworthy feature in this diagram is that while the curves are symmetrical about the axis, the R. P. does not coincide with the C. F., and the diameter is curved.

Fig. 2 shows the path of the same sphere in the field between two South Poles. Here there is not such a lack of symmetry. The C. F. and R. P. are practically coincident, but there are in addition two other

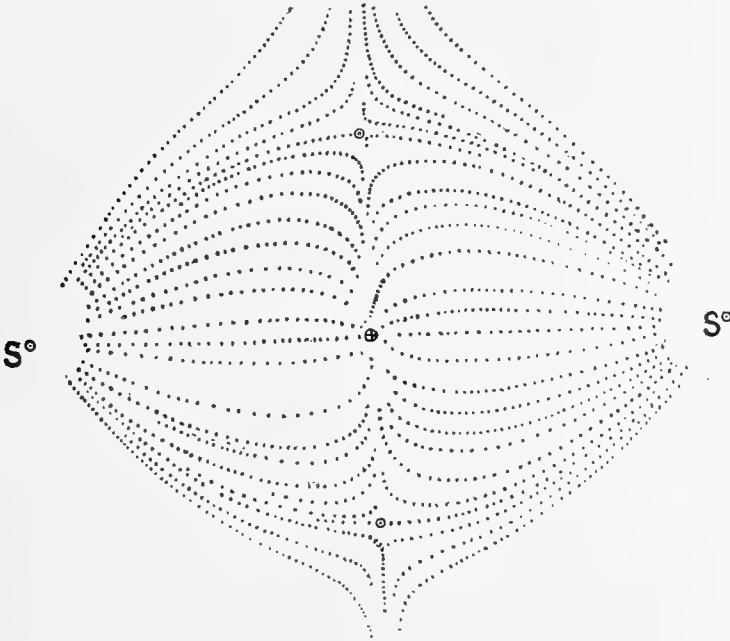


FIG. 2.

“diametral” R. P.'s with a change in the sign of the curvature of the trajectories on either side. Thus there are in this field five R. P.'s, viz. the two poles stable for all displacements, the C. F. unstable for all displacements, and the two new ones which are stable for displacements along the diameter only, but unstable for all others, the particle moving along a curve to one or other pole. The actual position of the diametral Resting Points of an inductor depends on the theory of greatest diameters.

Fig. 3 shows the trajectories of the same sphere in the extra-polar regions of the fields shown in fig. 1, and fig. 4 a similar region corresponding to fig. 2.

The lines are practically radial near the poles, and, beyond indicating some changes of curvature in the outer regions, show little of interest. We

include them merely to show that the extra-polar field was not overlooked; but we concern ourselves at present with the inter-polar space.

*Want of Symmetry.*

In our earlier investigation we were much troubled by a lack of symmetry in our diagrams. To facilitate observation, we had erected our apparatus without reference to its magnetic bearing, judging that the earth's field would not appreciably interfere with the strong electro-magnetic field. We were speedily undeceived, however, as in the outer and weak parts of the field distortion was considerable. On swinging the magnet so that its axis lay north and south, matters were improved, but distortion was still present.

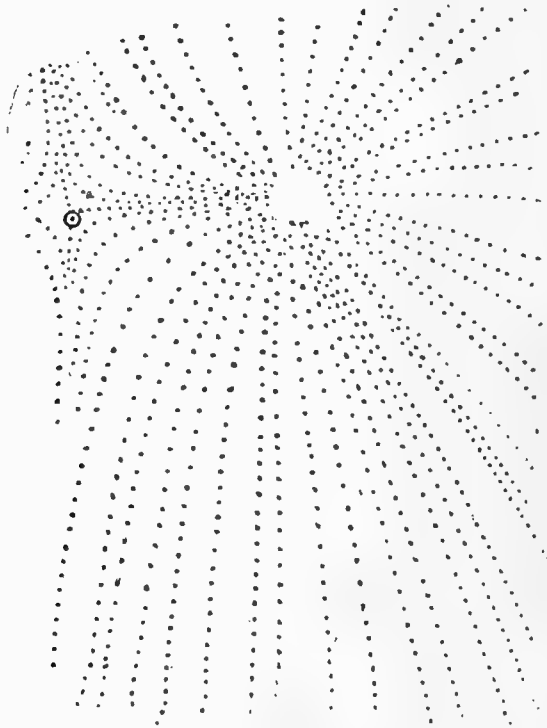


FIG. 3.

We found that the base-plate of our magnet was of rough cast-iron considerably harder than the wrought-iron cores, and having been once magnetized retained that magnetism with remarkable tenacity. Reversing the current in the coils of the magnet only produced a temporary reversal of the lines in the sole, which assumed its original magnetic state when the current was broken. It was evident then that a certain minimum of current was required to magnetize the sole in a contrary direction to its permanent magnetism. Now, as we were accustomed to regulate the strength of our field by varying the current between  $\cdot 6$  and  $\cdot 02$  amps., at a

certain stage the sole, freed from this coercive force, would suddenly reverse, and we would now be working in a highly complex field, viz., (i) the earth's horizontal component; (ii) the field of the electro-magnet parallel indeed to this; (iii) the sub-permanent field of the sole, whose poles might be anywhere in it. We took off the sole, had it heated red-hot and cooled all night in cinders lying east and west; but even this failed to quite remove the permanent magnetism, although the curves were somewhat amended. We now abandoned the base-plate, supported the magnet poles on a wooden base, and removed then to a small room set apart for magnet work, being free from iron fixtures.

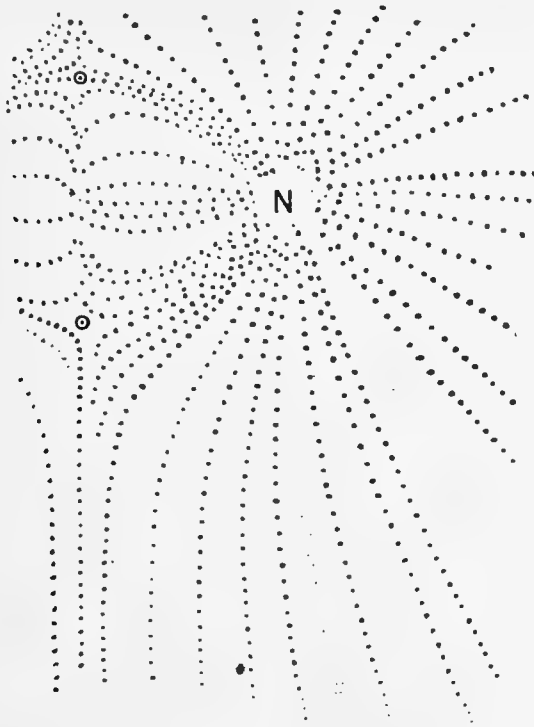


FIG. 4.

On repeating our work, there seemed at first to be a marked improvement, but sooner or later a curve would be traced which would *cross* some of the previous ones, and the stage at which this interesting event would take place could not be foretold.

It seemed to us that though we had no permanent magnetism cropping up as before, yet as the two cores of the magnet were unlikely to be exactly alike in hardness, we were dealing with two separate magnets of unequal strength, and moreover, the ampere-turns on each were not likely to be exactly the same; the case was even worse than before; so we returned to the base-plate, taking care that its permanent magnetism was in the same

direction as the electro-magnetism of the cores, and not reversing the current at any time during the taking of a set of records.

Thus we obtained curves which, though possessing but a bi-lateral symmetry about the interpolar axis, are not otherwise distorted.

The curvature of the diameter and non-coincidence of the R. P. and C.F. are due to the combined effects of the magnetism of the sole, and the earth's horizontal field—but it is beyond the scope of this paper to analyse these effects singly.

The latter might be eliminated entirely by working in a closed chamber with thick walls of soft iron. Effects due to permanent magnetism of the iron might be eliminated by making the electro-magnet of laminated Swedish charcoal iron throughout.

In presenting our results we lay stress on the following points:—

(i) The path of the body depends upon its size.

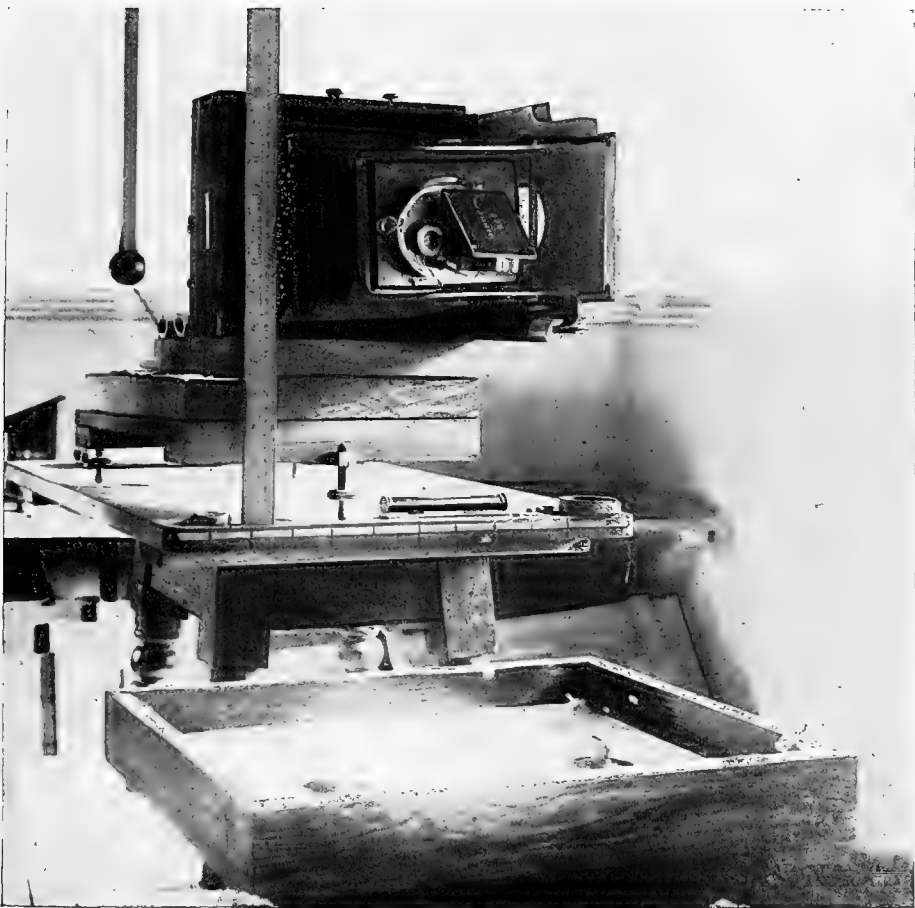
(ii) The field in which it moves is not constant. It is, in fact, the resultant of the earth's field and a parallel field, which is varied in intensity for reasons already shown.

(iii) The presence of the body modifies the geometrical configuration of the field.

We realize that there are serious objections to be overcome in order to obtain quantitative results, and that the curves we show are the paths of *one* particular body moving in *one* particular resultant field; but we consider that such results are a first approximation to the experimental solution of a difficult problem.

This investigation was made to supply the approximate physical data demanded for biological phenomena by one of the authors; and has supplied to him what was needed. As his collaboration now ends, we must apologize for presenting a research in a state which may be criticized as inchoate by the professed physicist.

NOTE.—During the interval that elapsed between the reading of this paper and its publication, Dr. Felix E. Hackett (Royal College of Science, Dublin) has pointed out from theory that in the horizontal plane through the poles  $NN'$  there is a maximum for the magnetic force along the perpendicular bisecting  $NN'$  at  $O$ , at a point  $P$ , such that  $OP = ON \times .708$ , and hence  $P$  is a rest point. This is not in accordance with the results of our experiments, and I hope shortly to investigate the discrepancy. Professor Bergin, M.A. (University College, Cork), also mentioned this, and showed that there are other maxima along lines parallel to  $OP$ . These would not be found by our method of experiment; but might be shown if the particle were constrained to move (say) in perfectly smooth glass tubes. These maxima soon disappear as either pole is approached.—P. E. B.



CAMERA AND OTHER APPARATUS USED IN THE EXPERIMENTS (*vide* p. 35).





## SCIENTIFIC PROCEEDINGS.

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1. The Subsidence of Torsional Oscillations and the Fatigue of Iron Wires when subjected to the Influence of Alternating Magnetic Fields of Frequencies up to 250 per second. By WILLIAM BROWN, B.SC. (January, 1916.) 6*d*.
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3. A New Form of very High Resistance for use with Electrometers. By JOHN J. DOWLING, M.A., M.R.I.A. (February, 1916.) 6*d*.
4. On the Path of a small Permeable Body moving with Negligible Acceleration in a Bipolar Field. By PHILIP E. BELAS, B.A., A.R.C.SCI., and MARCUS HARTOG, M.A., D.SC. (N.U.I.) (Plate I.) (February, 1916.) 6*d*.



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THE CHANGE OF LENGTH IN NICKEL WIRES  
OF DIFFERENT RIGIDITIES, DUE TO ALTER-  
NATING MAGNETIC FIELDS OF FREQUENCIES  
UP TO 150 PER SECOND.

BY

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*[Authors alone are responsible for all opinions expressed in their Communications.]*

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## V.

THE CHANGE OF LENGTH IN NICKEL WIRES OF DIFFERENT RIGIDITIES, DUE TO ALTERNATING MAGNETIC FIELDS OF FREQUENCIES UP TO 150 PER SECOND.

BY WILLIAM BROWN, B.Sc.,

Professor of Applied Physics, Royal College of Science for Ireland, Dublin.

[Read DECEMBER 21, 1915. Published FEBRUARY 28, 1916.]

EARLY in the year 1914 the present writer brought before this society the results of some experiments on the change in the length of a soft nickel wire when it was subjected to the influence of alternating magnetic fields of frequency 50 per second.<sup>1</sup>

The present communication gives results obtained with nickel wires in *five* different states of rigidity, when they were subjected to the influence of longitudinal magnetic fields, direct and alternating up to a frequency of 150 per second.

The rigidity of each wire was measured by means of a slightly modified form of Searle's torsion apparatus already explained in a previous paper by the writer.<sup>2</sup> In the case of each wire employed the length was 226 cms. and the diameter 0.169 cm., and the magnetic field was in every case uniform throughout the entire length of the wire. The longitudinal loads used were in the ratio 1, 4, 16, the greatest load being  $2 \times 10^5$  grammes per sq. cm.

The change in the length of the wire when the magnetic field was applied was read off directly by means of a microscope reading to  $9.2 \times 10^{-7}$  per unit length of the wire, as already explained in the author's former paper.<sup>3</sup>

The temperature of the room during the experiments was kept as nearly as possible at 17°C.

It was found that when a direct magnetic field was started round the wire, and during the application of an alternating magnetic field, that the wire became slightly heated, as shown by the slight elongation observed by

<sup>1</sup> Scient. Proc. Roy. Dub. Soc., vol. xiv, No. 21.

<sup>2</sup> Scient. Proc. Roy. Dub. Soc., vol. xii, No. 36, p. 481.

<sup>3</sup> Scient. Proc. Roy. Dub. Soc., vol. xiv, No. 21, p. 298.

means of the microscope; and in order to avoid as much as possible any error due to this heating of the wire, the following method of taking the readings was adopted:—The magnetic field was put on the solenoid—and kept on as short a time as possible—and the hair in the eye-piece of the microscope set after a few trials on the given mark on the wire, then, before the *second or zero reading* was taken, an interval of from 2 to 12 minutes was allowed to elapse, so that the expansion by heat due to the magnetic field was avoided.

This heating of the wire by an alternating magnetic field of frequency 250 per second was so great that experiments with this magnetic field were not continued. Moreover, it was considered that the results obtained with an alternating magnetic field of frequency 150 per second indicated what might be expected from applying the higher frequency magnetic field.

In order to compare the results obtained in the case of alternating magnetic fields, with those obtained with direct magnetic fields, observations were made up to a maximum value of 200 c.g.s. units in both cases; the alternating magnetic fields are expressed as root-mean-square values.

The results obtained with the wire having a simple rigidity of about  $810 \times 10^6$  grammes per sq. cm. are shown in Tables I, II, and III, when here, as well as throughout the paper, H stands for the strength of the applied magnetic field, whether longitudinal (D.C.) or alternating (A.C.), and  $n$  for the frequency of the alternating field.

TABLE I.

Rigidity  $\doteq 810 \times 10^6$  grammes per sq. cm.

Load =  $0.125 \times 10^5$            "           "           "           "

| H   | $\frac{dl}{l} \times 10^{-6}$ cms. |          |          |           |
|-----|------------------------------------|----------|----------|-----------|
|     | D.C.                               | A.C.     |          |           |
|     |                                    | $n = 25$ | $n = 50$ | $n = 150$ |
| 20  | 4                                  | 5.5      | 7.5      | 10.5      |
| 40  | 8                                  | 10.8     | 13.8     | 18        |
| 60  | 11.5                               | 15.5     | 19       | 23.8      |
| 80  | 14.5                               | 19.5     | 24       | 28.5      |
| 120 | 20.5                               | 25.8     | 31.5     | 35        |
| 160 | 25                                 | 30.5     | 36.8     | 39.5      |
| 200 | 29                                 | 34       | 40       | 42        |

TABLE II.

Rigidity  $\doteq 810 \times 10^6$  grammes per sq. cm.

Load =  $0.5 \times 10^5$  „ „ „ „

| H.  | $\frac{dl}{l} \times 10^{-6}$ cms. |          |          |           |
|-----|------------------------------------|----------|----------|-----------|
|     | D.C.                               | A.C.     |          |           |
|     |                                    | $n = 25$ | $n = 50$ | $n = 150$ |
| 20  | 4                                  | 5        | 5.5      | 8         |
| 40  | 8                                  | 10       | 11       | 14.5      |
| 60  | 12                                 | 14       | 15.5     | 19        |
| 80  | 15.5                               | 17.5     | 19.5     | 23        |
| 120 | 21                                 | 23       | 27.5     | 28        |
| 160 | 25                                 | 27       | 30       | 32        |
| 200 | 27.5                               | 30       | 33       | 34        |

TABLE III.

Rigidity  $\doteq 810 \times 10^6$  grammes per sq. cm.

Load =  $2 \times 10^5$  „ „ „ „

| H.  | $\frac{dl}{l} \times 10^{-6}$ cms. |          |           |
|-----|------------------------------------|----------|-----------|
|     | D.C.                               | A.C.     |           |
|     |                                    | $n = 25$ | $n = 150$ |
| 20  | 4                                  | 4.5      | 6.5       |
| 40  | 7.5                                | 8.5      | 12        |
| 60  | 11                                 | 12.5     | 16.5      |
| 80  | 14                                 | 16       | 20        |
| 120 | 19                                 | 21.5     | 25        |
| 160 | 23                                 | 25       | 28        |
| 200 | 26                                 | 27.5     | 30        |

In this last Table the values corresponding to  $n = 50$  are omitted because



for this frequency of an applied A.C. field it was found that the wire with this load on was thrown into such a state of vibration that it was impossible to take readings. The natural vibration frequency of the wire in this case was probably some harmonic of that of the applied field.

Taking the values of the contraction in Tables I, II, and III for the magnetic fields of 200 units, we find generally that, as the load on the wire is increased the contraction is decreased. When the load is *increased* 16 times the contraction is decreased about 10 per cent. for the longitudinal magnetic field, and about 30 per cent. for an alternating magnetic field of frequency 150 per second. For the same magnetic field of 200 units, when the frequency of the applied alternating magnetic field is *increased* 6 times the contraction of the wire is increased by about 24 per cent. for the light load, 13 per cent. for the middle load, and 9 per cent. for the highest load used.

In Tables IV and V are given the results obtained with a wire having a rigidity of about  $708 \times 10^6$  grammes per sq. cm. When the alternating magnetic fields were applied to the wire when it had the light load on, the vibrations were such that the readings on the microscope could not be taken. The values of the contraction obtained with this load, ( $0.125 \times 10^6$ ) grammes per sq. cm. in the direct longitudinal magnetic field, are given in Table IV in the column marked *d.c.*

TABLE IV.

Rigidity  $\doteq 708 \times 10^6$  grammes per sq. cm.

Load =  $0.5 \times 10^5$  grammes per sq. cm.

| H.  | $\frac{dl}{l} \times 10^{-6}$ cms. |      |               |               |                |
|-----|------------------------------------|------|---------------|---------------|----------------|
|     | <i>d.c.</i>                        | D.C. | A.C.          |               |                |
|     |                                    |      | <i>n</i> = 25 | <i>n</i> = 50 | <i>n</i> = 150 |
| 20  | 10.5                               | 10   | 11.5          | 14            | 15             |
| 40  | 19                                 | 18   | 20            | 24            | 26             |
| 60  | 26                                 | 24   | 26.5          | 31            | 34             |
| 80  | 31.5                               | 28.5 | 31.5          | 36.5          | 39.5           |
| 120 | 40                                 | 35.5 | 38.5          | 45.5          | 48             |
| 160 | 45.5                               | 40.5 | 43.5          | 52.5          | 55             |
| 200 | 49.5                               | 44   | 48            | 58            | 61             |

TABLE V.

Rigidity =  $708 \times 10^6$  grammes per sq. cm.Load =  $2 \times 10^5$  grammes per sq. cm.

| H.  | $\frac{dl}{l} \times 10^{-6}$ cms. |          |          |           |
|-----|------------------------------------|----------|----------|-----------|
|     | D.C.                               | A.C.     |          |           |
|     |                                    | $n = 25$ | $n = 50$ | $n = 150$ |
| 20  | 11                                 | 11.5     | 12       | 14        |
| 40  | 19                                 | 20       | 21       | 24        |
| 60  | 25                                 | 27       | 28       | 31.5      |
| 80  | 30                                 | 32       | 34       | 37        |
| 120 | 36                                 | 39       | 41.5     | 45        |
| 160 | 40                                 | 43.5     | 47       | 51        |
| 200 | 42                                 | 47       | 52       | 56        |

From Tables IV and V, by considering the values of the contraction obtained with the wire in this soft state, when in the magnetic field of 200 units, we find, for a longitudinal magnetic field, that when the load is *increased* 16 times the contraction is *decreased* about 15 per cent., that is half as much again as when the wire was harder.

For the same magnetic field of 200 units, when the frequency of the applied alternating magnetic field is *increased* 6 times, the contraction is *increased* about 27 per cent. for the middle load and 19 per cent. for the high load, which is about double that obtained with the hard wire, that is for a difference in the rigidity of about  $12\frac{1}{2}$  per cent.

Three other wires having rigidities intermediate to the two already mentioned were tested in a similar manner, when they were under *two* different longitudinal loads, and when they were subjected to the influence of longitudinal magnetic fields, and alternating magnetic fields of frequency 150 per second only. The results so obtained are given in Tables VI, VII, and VIII, the numbers in the tables being as before the values of  $\frac{dl}{l} \times 10^{-6}$  cms.

TABLE VI.

Rigidity  $\doteq 790 \times 10^6$  grammes per sq. cm.

| H.  | Load = $0.5 \times 10^5$ grams.<br>per sq. cm. |           | Load = $2 \times 10^5$ grams.<br>per sq. cm. |           |
|-----|--|-----------|--|-----------|
|     | D.C.   | A.C.      | D.C.   | A.C.      |
|     |  | $n = 150$ |  | $n = 150$ |
| 20  | 6  | 9.5       | 5  | 8         |
| 40  | 11   | 17        | 9.5  | 15        |
| 60  | 15.5   | 23        | 13.5   | 20        |
| 80  | 19   | 27        | 17   | 24        |
| 120 | 25   | 33        | 22.5   | 29.5      |
| 160 | 28.5   | 37        | 26.5   | 33        |
| 200 | 31   | 39        | 29   | 35        |

TABLE VII.

Rigidity  $\doteq 750 \times 10^6$  grammes per sq. cm.

| H.  | Load = $0.5 \times 10^5$ grams.<br>per sq. c.m. |           | Load = $2 \times 10^5$ grams.<br>per sq. c.m. |           |
|-----|---|-----------|---|-----------|
|     | D.C.  | A.C.      | D.C.  | A.C.      |
|     |   | $n = 150$ |   | $n = 150$ |
| 20  | 7   | 15        | 7   | 9         |
| 40  | 13.5  | 26        | 13  | 17        |
| 60  | 19  | 33        | 17.5  | 23        |
| 80  | 23.5  | 38        | 21.5  | 28        |
| 120 | 30.5  | 44.5      | 28  | 36        |
| 160 | 34.5  | 48        | 32  | 41        |
| 200 | 37  | 50        | 35  | 45        |

TABLE VIII.

Rigidity  $\doteq 715 \times 10^6$  grammes per sq. cm.

| H.  | Load = $0.5 \times 10^5$ grams.<br>per sq. cm. |           | Load = $2 \times 10^5$ grams.<br>per sq. cm. |           |
|-----|--|-----------|--|-----------|
|     | D.C.   | A.C.      | D.C.   | A.C.      |
|     |  | $n = 150$ |  | $n = 150$ |
| 20  | 11   | 20        | 9  | 11        |
| 40  | 19.5   | 32        | 16.5   | 20        |
| 60  | 26   | 39        | 22.5   | 28        |
| 80  | 30   | 44        | 27   | 34        |
| 120 | 36.5   | 51        | 34   | 42.5      |
| 160 | 40.5   | 56        | 38   | 49        |
| 200 | 43   | 59        | 41   | 54        |

The values of the contraction as affected by the rigidity, load, and magnetic field in the three wires last mentioned, will be found to lie intermediate to the values obtained with the wires when in the hardest and softest states.

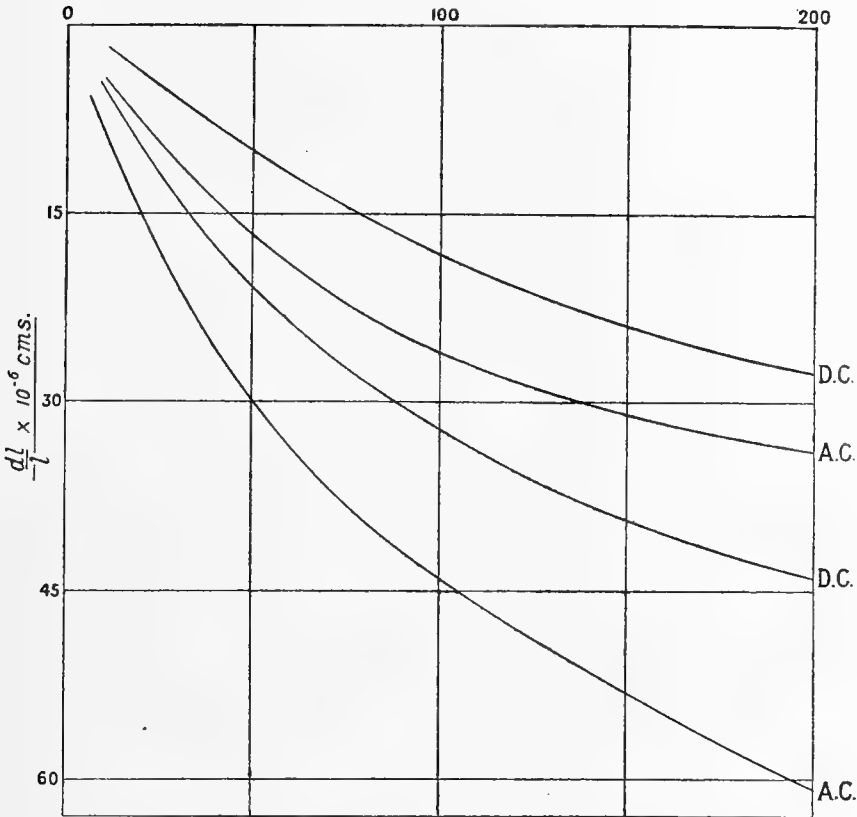
In Table IX are collected the values of the rigidity and the values of the contraction obtained with longitudinal magnetic fields of 200 units produced by direct current and alternating current of frequency 150 per second, when the wires were under the influence of two different loads.

TABLE IX.

| Rigidity<br>grammes<br>per sq. cm. | Load = $0.5 \times 10^5$ grams.<br>per sq. cm. |           | Load = $2 \times 10^5$ grams.<br>per sq. cm. |           |
|------------------------------------|--|-----------|--|-----------|
|                                    | D.C.   | A.C.      | D.C.   | A.C.      |
|                                    |  | $n = 150$ |  | $n = 150$ |
| $810 \times 10^6$                  | 27.5   | 34        | 26   | 30        |
| 790 „                              | 31   | 39        | 29   | 35        |
| 750 „                              | 37   | 50        | 35   | 45        |
| 715 „                              | 43   | 59        | 41   | 54        |
| 708 „                              | 44   | 61        | 42   | 56        |

These values in Table IX lead to a very interesting result, for if we plot the values of the rigidity of the wire as abscissae, and as ordinates, the corresponding values of the contraction produced by a magnetic field of 200 c.g.s. units, we find that the points for both the direct and alternating magnetic fields lie very approximately on two straight converging lines. When the load of  $0.5 \times 10^5$  grammes per sq. cm. is on the wire these two lines when produced meet at the point marked  $870 \times 10^6$  on the scale of rigidity, which means that, if it were possible to have a nickel wire of rigidity  $870 \times 10^6$  grammes per sq. cm., the contraction due to the action of the direct and the alternating magnetic fields of 200 units would be of the same amount. When the longitudinal load on the wire is  $2 \times 10^5$  grammes per sq. cm. in the same way, the plotted results give two straight lines which when produced meet at the point marked  $850 \times 10^6$  on the scale of rigidity. These values are, of course, imaginary, as it is not likely that the material nickel could be put into such a physical state that its rigidity would be either of the values mentioned above.

*Magnetic Field.*



The figure shows in the form of curves the results obtained with the wires having the *highest* and the *lowest* rigidity of those used in the experiments when the longitudinal load of  $0.5 \times 10^5$  grammes per sq. cm. was on the wires, and when the wires were under the influence of magnetic fields D.C. and A.C. of frequency 150 per second.

The two higher curves are those obtained with the wire having rigidity  $810 \times 10^6$  grammes per sq. cm., and the two lower curves those obtained with the wire of rigidity  $708 \times 10^6$  grammes per sq. cm.

From these curves, as well as from Tables II and IV, above, it will be seen that for a *decrease* in the rigidity of about  $12\frac{1}{2}$  per cent. the contraction of the

nickel wire in a magnetic field of 200 c.g.s. units is *increased* by about 60 per cent. for a direct field and about 80 per cent. for an alternating field of frequency 150 per second.

For assistance in reading the microscope I am indebted to Mr. A. V. Henry, a third-year Experimental Science Teacher-in-Training in this College.

## SCIENTIFIC PROCEEDINGS.

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OSMOTIC PRESSURES IN PLANTS.

VI.—ON THE COMPOSITION OF THE SAP IN THE CONDUCTING  
TRACTS OF TREES AT DIFFERENT LEVELS AND AT  
DIFFERENT SEASONS OF THE YEAR.

BY

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[*Authors alone are responsible for all opinions expressed in their Communications.*]

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## VI.

## OSMOTIC PRESSURES IN PLANTS.

VI.—ON THE COMPOSITION OF THE SAP IN THE CONDUCTING TRACTS OF TREES AT DIFFERENT LEVELS AND AT DIFFERENT SEASONS OF THE YEAR.

BY HENRY H. DIXON, Sc.D. (DUBL.), F.R.S.,  
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[Read DECEMBER 21, 1915. Published MARCH 21, 1916.]

IN a previous paper of this series (1) it was shown that the sap centrifuged from the wood of trees always contains sugars and salts, the former being in preponderating quantities as a rule. Furthermore, it was proved that the sugars are present during early spring in larger amounts than at other times. Certain views were also put forward regarding the functions of the living elements of the wood, and root-pressure was explained with due regard to the quantitative measurements of the osmotic pressure of the wood-sap.

In the above-mentioned research attention was mainly focussed on the constituents of the sap at constant levels in the various trees investigated. The aim of the present paper is to study the composition of the sap at different levels in the same tree, and to repeat the examination during the seasons of the year upon closely similar trees.

With this object nine trees were investigated—three of *Acer macrophyllum* growing out of one old stump, and very much alike in their dimensions; two each of *Ilex aquifolium* and *Cotoneaster frigida*; and one each of *Arbutus unedo* and *Ulmus campestris*. Thus the list includes the evergreens *Ilex* and *Arbutus*, the sub-evergreen *Cotoneaster frigida*, and two typical deciduous trees, *Acer* and *Ulmus*. It would be preferable to include a larger variety of trees, and a greater number of each species; but up to the present we have had opportunities of investigating only a limited number.

As in former papers,  $\Delta$  denotes the depression of freezing-point of the sap as ascertained by the thermo-electric method of cryoscopy, and P the osmotic pressure in atmospheres, calculated from  $\Delta$ . Under  $C \times 10^5$  are given

the values of electrical conductivity measurements, expressed in mhos, upon the same sap.  $\Delta_e$  represents the depression of freezing-point occasioned by the electrolytes; this is calculated by finding the value of  $\Delta$  for a solution of some standard substance, such as potassium chloride, which has an electrical conductivity equal to that of the sap. As explained in an earlier paper (1), this is an approximate value, but it is sufficiently accurate for dilute solutions. Accordingly,  $\Delta - \Delta_e$  is a fairly reliable measure of the non-electrolytes, which are almost entirely sugars, dissolved in the saps under examination.

In the two columns at the right are shown the percentages of reducing sugars (R) and of sucrose (S) found. The reducing sugars include the mono-saccharides, glucose, (dextrose) and *d*-fructose (laevulose) and the disaccharide maltose. The latter was found only in a few instances. Its presence was detected by means of its phenylosazone, and a rough idea of the relative amounts of the two hexoses and maltose was obtained by microscopic examination of the osazone crystals. It must be remembered that these hexoses yield the same osazone. The percentages shown are only rough estimations carried out upon the sap by Fehling's solution. The figures for sucrose were obtained by treating sap, inverted with hydrochloric acid, in the same manner. Allowance was of course made for the reducing sugars previously found. The figures under R are calculated as if only glucose were present; thus when maltose is present the value will be too low, as the reducing power of maltose is only about half that of glucose, weight for weight.

*Deciduous Trees.*

Below are recorded the results afforded by the examination of portions of the stem of a large elm, felled on March 3rd. The sap was extracted by centrifuging small cylinders of wood, as previously described (1).

TABLE I.

*Ulmus campestris.* Wood-sap from tree, March 4th.

| Expt. | Source of Sample      | $\Delta$ | $\Delta_e$ | $\Delta - \Delta_e$ | P.   | C $\times 10^5$ | Percentage of Sugar                  |         |
|-------|-----------------------|----------|------------|---------------------|------|-----------------|--------------------------------------|---------|
|       |                       |          |            |                     |      |                 | Reducing sugar calculated as glucose | Sucrose |
| 805   | Stem, 0.6 metre level | 0.094°   | 0.044°     | 0.050°              | 1.13 | 95.5            | 0.5, m.                              | 0.5     |
| 806   | Stem, 16       ,,     | 0.174°   | 0.059°     | 0.115°              | 2.09 | 127.2           | 0.5, m.                              | 0.5     |
| 807   | Stem, 20       ,,     | 0.293°   | 0.047°     | 0.246°              | 3.52 | 101.8           | 2.0, m.                              | 1.0     |

It may be mentioned here for the sake of comparison that a—

1 per cent. solution of glucose gives a depression of  $0.106^{\circ}$ , and a  
 1 per cent. „ „ sucrose „ „ „  $0.054^{\circ}$ .

These figures indicate the values  $0.08^{\circ}$ ,  $0.08^{\circ}$ , and  $0.266^{\circ}$  respectively for  $\Delta - \Delta_e$  in the above three experiments. As may be seen from the table, the values of  $\Delta - \Delta_e$  show that the sugar determinations are over- and under-estimates in the first two respectively, and the error in each is much the same. The third is an under-estimate, but the agreement is good. The occurrence of maltose, as well as of hexoses, is denoted by *m*. Microscopic examination of the osazones showed that in the first maltose and hexoses were present in roughly equal quantities; in the second the hexoses predominated, and the same was true of the third.

The table shows that the fraction of the osmotic pressure of the sap attributable to non-electrolytes is greater than that due to electrolytes, but the preponderance becomes more marked at the higher levels. As noted in the first paper (1), this demonstrates that the percentage by weight of the non-electrolytes far exceeds that of the electrolytes, for osmotic pressures are proportional to molecular concentrations, and the sugars have much higher molecular weights than have the salts of the sap. The latter, moreover, are ionised, so as to yield two or more ions, each of which functions as a molecule as far as osmotic pressure is concerned.

Furthermore, it is seen that the rise in osmotic pressure as the higher levels are reached is entirely brought about by the increase in the quantities of sugar present, not by the electrolytes. This must not be taken to mean that no other non-electrolytes are present, but only that the agreement between the values of  $\Delta - \Delta_e$  and the results of the rough sugar estimations are such as to justify one in speaking of the sugars as the controlling factor in the total of non-electrolytes.

Comparison of the figures given by *Ulmus* with those of *Acer* recorded in this and the first paper shows that the relatively high values for the osmotic pressure and sugar content of the sap are due to the vernal mobilization of carbohydrate reserves. The presence of maltose also points to this, as it is usually absent from wood-sap at other times of the year, being probably hydrolysed to glucose in the living elements of the wood when secretion of sugar takes place at a slower rate. With regard to this secretion, or diffusion as it appears to be in reality, it may be recalled that Osterhout (2) has shown how greatly the presence of certain sugars may increase the permeability of protoplasm. In this sucrose has a more marked action than have other sugars.

A particularly favourable opportunity for studying the variation in the composition of the sap, both with respect to the height above ground and to the season, was afforded by three tall stems from a large old stump of *Acer macrophyllum* growing in the Botanic Gardens of Trinity College, Dublin. Two of these, felled in October and February, were as similar as two trees could possibly be, and sap was obtained from them at intervals up to 10 metres. The third, felled in April, was slightly smaller, but afforded material for examination up to 9.5 metres. The results are given in Tables II-IV.

TABLE II.

*Acer macrophyllum*, October 13th.

| —                 | $\Delta$ | P    | $C \times 10^5$ | $\Delta_e$ | $\Delta - \Delta_e$ | R percent.      | S percent. |
|-------------------|----------|------|-----------------|------------|---------------------|-----------------|------------|
| Root . . .        | 0.060°   | 0.72 | 76.4            | 0.035°     | 0.025°              | 0               | 0.6        |
| Stem 0 m. level . | 0.053°   | 0.63 | 84.6            | 0.039°     | 0.014°              | 0               | 0.35       |
| „ 2 m. „ .        | 0.046°   | 0.56 | 61.0            | 0.028°     | 0.018°              | 0               | 0.25       |
| „ 4 m. „ .        | 0.035°   | 0.42 | 54.2            | 0.025°     | 0.010°              | 0               | 0          |
| „ 6 m. „ .        | 0.040°   | 0.49 | 64.8            | 0.030°     | 0.010°              | 0               | 0          |
| „ 8 m. „ .        | 0.048°   | 0.57 | 70.9            | 0.033°     | 0.015°              | Trace<br>minute | 0.5        |
| „ 10 m. „ .       | 0.068°   | 0.81 | 79.0            | 0.037°     | 0.031°              | Trace<br>minute | 0.5        |

TABLE III.

*Acer macrophyllum*, February 25th.

| —                 | $\Delta$ | P    | $C \times 10^5$ | $\Delta_e$ | $\Delta - \Delta_e$ | R percent.      | S percent. |
|-------------------|----------|------|-----------------|------------|---------------------|-----------------|------------|
| Root . . .        | 0.089°   | 1.07 | 84.8            | 0.039°     | 0.050°              | Trace<br>minute | 1.0        |
| Stem 0 m. level . | 0.146°   | 1.76 | 111.4           | 0.052°     | 0.094°              | Trace           | 1.5        |
| „ 2 m. „ .        | 0.146°   | 1.76 | 92.4            | 0.043°     | 0.103°              | Trace           | 2.5        |
| „ 4 m. „ .        | 0.178°   | 2.14 | 85.0            | 0.039°     | 0.139°              | Trace<br>minute | 3.0        |
| „ 6 m. „ .        | 0.179°   | 2.15 | 94.4            | 0.044°     | 0.135°              | 0               | 3.0        |
| „ 8 m. „ .        | 0.224°   | 2.70 | 71.2            | 0.033°     | 0.191°              | 0               | 4.0        |
| „ 10 m. „ .       | 0.307°   | 3.71 | 142.6           | 0.067°     | 0.240°              | 0               | 5.5        |

TABLE IV.  
*Acer macrophyllum*, April 14th.

| —                 | $\Delta$ | P    | $C \times 10^5$ | $\Delta_e$ | $\Delta - \Delta_e$ | R percent.      | S percent. |
|-------------------|----------|------|-----------------|------------|---------------------|-----------------|------------|
| Root . . .        | 0·111°   | 1·34 | 140·6           | 0·066°     | 0·045°              | Trace           | 0·4        |
| Stem 0 m. level . | 0·109°   | 1·31 | 110·9           | 0·051°     | 0·058°              | Trace<br>minute | 0·4        |
| „ 2 m. „ .        | 0·108°   | 1·30 | 108·6           | 0·050°     | 0·058°              | 0               | 0·4        |
| „ 4 m. „ .        | 0·108°   | 1·30 | 97·1            | 0·045°     | 0·065°              | 0               | 0·5        |
| „ 6 m. „ .        | 0·144°   | 1·73 | 117·8           | 0·055°     | 0·089°              | 0               | 0·7        |
| „ 8 m. „ .        | 0·165°   | 1·98 | 121·9           | 0·057°     | 0·108°              | 0               | 0·7        |
| „ 9·5 m. „ .      | 0·180°   | 2·16 | 139·3           | 0·065°     | 0·115°              | Trace<br>minute | 0·7        |

As the chief interest attaches to the values of  $\Delta - \Delta_e$ , R, and S, they have been recorded in Table V, the figures for the three trees at different levels being placed side by side for the sake of comparison. Graphs of the concentrations of the non-electrolytes at different levels, and at different dates, are given in the figure on the next page.

TABLE V.  
*Acer macrophyllum*.

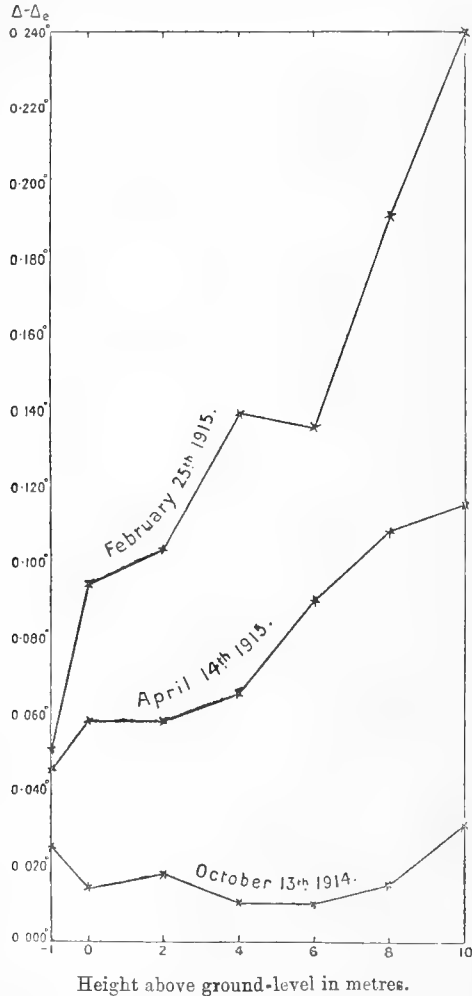
| —               | $\Delta - \Delta_e$ (total sugars) |         |         | R percentage    |                 |                 | S percentage |         |         |
|-----------------|------------------------------------|---------|---------|-----------------|-----------------|-----------------|--------------|---------|---------|
|                 | Oct. 13                            | Feb. 25 | Apr. 14 | Oct. 13         | Feb. 25         | Apr. 14         | Oct. 13      | Feb. 25 | Apr. 14 |
| Root . . .      | 0·025°                             | 0·050°  | 0·045°  | 0               | Trace<br>minute | Trace           | 0·6          | 1·0     | 0·4     |
| Stem 0 m. level | 0·014°                             | 0·094°  | 0·058°  | 0               | Trace           | Trace<br>minute | 0·35         | 1·5     | 0·4     |
| „ 2 m. „        | 0·018°                             | 0·103°  | 0·058°  | 0               | Trace           | 0               | 0·25         | 2·5     | 0·4     |
| „ 4 m. „        | 0·010°                             | 0·139°  | 0·065°  | 0               | Trace<br>minute | 0               | 0            | 3·0     | 0·5     |
| „ 6 m. „        | 0·010°                             | 0·135°  | 0·089°  | 0               | 0               | 0               | 0            | 3·0     | 0·7     |
| „ 8 m. „        | 0·015°                             | 0·191°  | 0·108°  | Trace<br>minute | 0               | 0               | 0·5          | 4·0     | 0·7     |
| „ 10 m. „       | 0·031°                             | 0·240°  | 0·115°  | Trace<br>minute | 0               | Trace<br>minute | 0·5          | 5·5     | 0·7     |

From Tables II, III, and IV it may be seen that the osmotic pressure of the transpiration stream is greatest at the top of the stem in each case. While this is so the gradient and the absolute value vary greatly at different seasons. In the autumn the root possesses higher osmotic



pressure than the lower portions of the stem, the minimum lying at the 4-metre level. In the early spring the gradient from root to summit is unbroken, and the same is true in the late spring. The greatest pressures are found in early spring.

The electrical conductivity measurements do not show such a degree of



regularity as the osmotic pressures, but in a general way they follow the latter in autumn, inasmuch as the root and summit are higher than the 4-metre level, which is a minimum value. In early and late spring there is a marked rise in conductivity, the April measurements being on the whole considerably higher than those of February.

The key to the whole series of changes is, however, obtained by examining the values of  $\Delta - \Delta_e$ , which indicate the depressions of freezing-point due to

the total sugars. The sugar present in preponderating quantities is sucrose, as only traces of reducing sugars were found or none at all. For the sake of comparison these figures are recorded in columns side by side in Table V. It must be remembered that while the values of  $\Delta$ ,  $\Delta_e$  and  $\Delta - \Delta_e$  are accurate determinations, the percentages of sugar recorded are only rough measurements.

It is at once evident that there is an enormous influx of sucrose in the spring, the amount being from five to fourteen times as great in February as in October at various levels in the stem. By April the quantity of sucrose has fallen to about half what it was in February.

The explanation of the rise in the sugar content, and to a lesser degree in the content of electrolytes, appears to be that the storage cells of the wood parenchyma and medullary rays are actively secreting sugar into the transpiration stream as it passes them. Consequently the latter becomes richer and richer as it ascends. It is quite possible that the *secretion* is really a simple diffusion of the sugar from the cell in which it is stored and formed anew by the hydrolysis of polysaccharides, into the dilute stream which is passing by.

The fact that sucrose is the most important sugar in the transpiration stream in this and many other trees cannot be passed over lightly. It is not stored as such to any very considerable extent. But starch and hemicelluloses disappear and sucrose is found. Now it is well known that diastase produces maltose from starch, and on further hydrolysis glucose results. How then does the sucrose arise? One is forced to postulate either a peculiar type of starch hydrolysis, or that the cell synthesizes sucrose from glucose as fast as the latter is formed. The subject is one for further investigation, and is allied to the production of sucrose from polysaccharides in many fruits in the last stages of ripening.

TABLE VI.  
*Ulmus campestris*, March 3rd.

| —                   | $\Delta$ | P    | $C \times 10^5$ | $\Delta_e$ | $\Delta - \Delta_e$ | R<br>percent. | S<br>percent. |
|---------------------|----------|------|-----------------|------------|---------------------|---------------|---------------|
| Stem 0.6 m. level . | 0.094°   | 1.13 | 95.5            | 0.044°     | 0.050°              | 0.5 m.        | 0.5           |
| „ 16 m. „ .         | 0.174°   | 2.09 | 127.2           | 0.059°     | 0.115°              | 0.5 m.        | 0.5           |
| „ 20 m. „ .         | 0.293°   | 3.52 | 101.8           | 0.047°     | 0.246°              | 2.0 m.        | 1.0           |

In this experiment a tall tree was examined when at the stage of vernal mobilization of carbohydrates. The osmotic pressure rises very markedly

towards the upper end of the stem. Unlike *Acer*, *Ulmus* possesses noticeable quantities of reducing sugars. From inspection of the phenylosazones it was seen that in the lowest portion maltose and hexoses were present in roughly equal quantities. At the 16-metre level the hexoses were in slight excess, and this excess became greater in the highest portion.

*Sub-Evergreens.*

Two similar specimens of *Cotoneaster*, grown in a very sheltered, over-shadowed position, were examined in February and June, from the root up to the 6-metre level. In addition two others were examined in October and December, but in these latter measurements on the intervening tracts of the stem were not made.

TABLE VII.

*Cotoneaster frigida*, osmotic pressure in atmospheres.

| —                  | Oct. 1914. | Dec. 1914. | Feb. 9th, 1915. | June 21st, 1915. |
|--------------------|------------|------------|-----------------|------------------|
| Root . . . . .     | 0.78       | 0.48       | 0.63            | 1.34             |
| Stem 6 m. level, . | 1.04       | 0.64       | 0.64            | 0.76             |

From these it is seen that the pressures are higher in October and in June than in the winter or spring, for in evergreens there is no marked mobilization of reserves in the spring. The values of the conductivity, etc., for the 1914 experiments have been published already (1). Below are given the full set of measurements for the two 1915 experiments.

TABLE VIII.

*Cotoneaster frigida*, February 9th, 1915.

| —                 | $\Delta$ | P.   | $C \times 10^5$ | $\Delta_e$ | $\Delta - \Delta_e$ | R<br>percent.    | S<br>percent. |
|-------------------|----------|------|-----------------|------------|---------------------|------------------|---------------|
| Root . . . . .    | 0.052°   | 0.63 | 48.4            | 0.022°     | 0.030°              | 0                | 0.25          |
| Stem 0 m. level . | 0.056°   | 0.67 | 37.1            | 0.017°     | 0.039°              | 0.5              | 0.5           |
| „ 1 m. „ .        | 0.042°   | 0.51 | 34.9            | 0.016°     | 0.026°              | 0.5              | 0.5           |
| „ 2 m. „ .        | 0.044°   | 0.53 | 30.0            | 0.014°     | 0.030°              | 0.5              | 0.5           |
| „ 3 m. „ .        | 0.034°   | 0.41 | 30.5            | 0.014°     | 0.020°              | 0                | 0.5           |
| „ 4 m. „ .        | 0.032°   | 0.38 | 27.6            | 0.013°     | 0.019°              | 0                | 0.5           |
| „ 5 m. „ .        | 0.050°   | 0.60 | 30.7            | 0.014°     | 0.036°              | Trace<br>minute. | 0.5           |
| „ 6 m. „ .        | 0.053°   | 0.64 | 31.3            | 0.014°     | 0.039°              | 0                | 0.5           |

TABLE IX.

*Cotoneaster frigida*, June 21st, 1915.

| —                         | $\Delta$ | P.   | $C \times 10^5$ | $\Delta_e$ | $\Delta - \Delta_e$ | R<br>per cent.   | S<br>per cent. |
|---------------------------|----------|------|-----------------|------------|---------------------|------------------|----------------|
| Root . . . . .            | 0·111°   | 1·34 | 108·9           | 0·051°     | 0·060°              | 0                | 0·75           |
| Stem 0 m. level . . . . . | 0·069°   | 0·83 | 57·1            | 0·026°     | 0·043°              | 0·75             | 0·25           |
| „ 1 m. „ . . . . .        | 0·049°   | 0·59 | 50·9            | 0·024°     | 0·025°              | 0·5              | 0·25           |
| „ 2 m. „ . . . . .        | 0·058°   | 0·71 | 53·8            | 0·025°     | 0·033°              | 0·5              | 0·5            |
| „ 3 m. „ . . . . .        | 0·051°   | 0·61 | 48·7            | 0·023°     | 0·028°              | 0                | 0·75           |
| „ 4 m. „ . . . . .        | 0·051°   | 0·61 | 48·1            | 0·022°     | 0·029°              | 0                | 0·5            |
| „ 5 m. „ . . . . .        | 0·052°   | 0·63 | 48·4            | 0·022°     | 0·030°              | 0                | 0·75           |
| „ 6 m. „ . . . . .        | 0·063°   | 0·76 | 58·0            | 0·027°     | 0·036°              | Trace<br>minute. | 0·75           |

Perhaps the most striking fact brought out by Tables VIII and IX is the peculiar distribution of sugars in the stem-sap. Sucrose is invariably present, the quantities found in June being on the whole decidedly greater than in February. Reducing sugars, hexoses, on the other hand, are in each case absent from the root and higher portions of the stem except for traces in two instances. Yet from the ground-level up to a height of two metres about one-half per cent. is found both in spring and summer. Why a sugar should be present in quantity in one part of an ascending stream and absent in the parts below and above is a subject pressing for investigation.

As compared with *Acer* and *Ulmus* the electrolyte content of *Cotoneaster* is low throughout the whole year. Possibly the vernal rise in electrolytes which occurs in deciduous trees is connected with the escape of organic acids and salts from the cells along with sugar.

Variations in the electrolyte concentration at different levels may be more or less explained by the action of cells adjoining the transpiration stream in abstracting materials for the growth of the cambium, &c., and by the concentration effected by evaporation taking place in the leaves. In several instances there appears a greater concentration of electrolytes at the base of the stem than in the roots. This seems to necessitate a passage of electrolytes from the cells of the wood into the transpiration stream.

*Evergreens.*

A specimen of *Arbutus* was examined in December, the root, stem, and leaves being all tested. The high sugar content of the root is noticeable. Comparison of the transpiration sap with that from the leaf tissues pressed after treatment with liquid air shows how relatively enormous are the concentrations of both sugars and electrolytes in the latter. The values are given in Table X.

TABLE X.

*Arbutus unedo*, December 11th.

| —            | $\Delta$ | P.    | $C \times 10^5$ | $\Delta_e$ | $\Delta - \Delta_e$ | R<br>percent. | S<br>percent. |
|--------------|----------|-------|-----------------|------------|---------------------|---------------|---------------|
| Root . . .   | 0.041°   | 0.50  | 34.2            | 0.016°     | 0.025°              | 0.25          | 1.0           |
| Stem . . .   | 0.038°   | 0.46  | 27.8            | 0.013°     | 0.025°              | 0.25          | 0.25          |
| Leaves . . . | 1.228°   | 14.78 | 643.0           | 0.310°     | 0.918°              | —             | —             |

Two specimens of *Ilex* were cut down, one in the end of January after a fall of snow, and the other in March. As in *Cotoneaster* and *Arbutus*, the conductivity of the sap is low. Again, the sugar content of the root is high. Moreover in *Ilex* reducing sugars are of importance throughout the whole of the conducting tracts, and are present in greater quantities than sucrose in all levels above that of the ground. The results are shown in Tables XI and XII. As in other evergreens, no vernal mobilization of reserves is to be found. The top of the stem may have a higher osmotic pressure than the lower portions and root, though in one case (as in *Arbutus*) that of the root was slightly greater than that of the stem.

TABLE XI.

*Ilex aquifolium*, January 23rd.

| —           | $\Delta$ | P.   | $C \times 10^5$ | $\Delta_e$ | $\Delta - \Delta_e$ | R<br>percent. | S<br>percent. |
|-------------|----------|------|-----------------|------------|---------------------|---------------|---------------|
| Roots . . . | 0.070°   | 0.84 | 84.7            | 0.039°     | 0.031°              | —             | —             |
| Stem . . .  | 0.056°   | 0.67 | 55.4            | 0.026°     | 0.030°              | —             | —             |

TABLE XII.

*Ilex aquifolium*, March 22nd.

| —                     | $\Delta$ | P.   | $C \times 10^5$ | $\Delta_e$ | $\Delta - \Delta_e$ | R<br>percent. | S<br>percent. |
|-----------------------|----------|------|-----------------|------------|---------------------|---------------|---------------|
| Roots . . .           | 0·048°   | 0·58 | 46·5            | 0·022°     | 0·026°              | 0·25          | 0·6           |
| Stem 0 m. level . . . | 0·074°   | 0·89 | 96·6            | 0·045°     | 0·029°              | 0·25          | 0·6           |
| „ 1 m. „ . . .        | 0·062°   | 0·75 | 71·3            | 0·033°     | 0·029°              | 0·25          | 0·25          |
| „ 2 m. „ . . .        | 0·066°   | 0·79 | 66·9            | 0·031°     | 0·035°              | 0·25          | 0·25          |
| „ 3 m. „ . . .        | 0·067°   | 0·81 | 74·6            | 0·035°     | 0·032°              | 0·25          | 0·25          |
| „ 4 m. „ . . .        | 0·105°   | 1·26 | 59·7            | 0·028°     | 0·077°              | 0·25          | 0·0           |

While obtaining the sap for these determinations one could not help being struck by the surprising amount which may often be extracted from fresh wood by centrifuging; thus the wood of *Salix babylonica* cut in December gave as much as 4 c.c. from a cylinder about 2 cm. diam. and 10 cm. long; and a similar piece of the root of *Cotoneaster frigida* yielded almost as much in the month of February. A yield of 1 – 2·5 c.c. was the usual quantity from pieces of wood of this size. Similar cylinders (viz. 2 cm. diam., 10 cm. long) of *Ilex aquifolium* seldom yielded as much as 1 c.c.

The differences in the colour of the sap are also remarkable; some are pale brown, e.g. that from *Acer macrophyllum*, *A. pseudoplatanus*, *Populus alba*, *Cotoneaster frigida*, and *Ilex aquifolium* (the last often inclines to grey); others, e.g. from *Fagus silvatica* and *Salix babylonica*, are of a wonderfully beautiful amethystine hue. The presence of oxidases is often indicated by the darkening of the sap on exposure to air. It is open to question how far these pigments and oxidases are derived from the injured cells of the wood centrifuged, and how far they are to be regarded as part of the constituents of the transpiration stream in the uninjured stems.

## SUMMARY.

1. Large quantities of sap may, as a rule, be centrifuged from the conducting wood of trees. This sap varies in colour and in electrolyte and non-electrolyte content.

2. When in a condition of physiological rest during the late autumn and winter, the osmotic pressure of the wood-sap of deciduous trees is small and approximately constant throughout; the stems, the roots, and upper portions

of the stem have, however, slightly greater pressure than the intervening portions.

3. During the early spring the sap is enriched by the addition of large quantities of sugars from the storage cells of the wood-parenchyma and of the medullary rays. Accordingly the osmotic pressure rises in a very marked degree from root to summit, the increase being particularly great in the upper regions.

4. During the late spring the concentration of sugars is still considerable, being roughly half of the earlier value. The electrolytes of the sap are, however, present in much greater concentration than in the early spring.

5. In *Acer macrophyllum* reducing sugars are never found in the wood-sap, except in traces, whereas sucrose is present in quantity. In the other trees examined both reducing sugars and sucrose are present, the latter predominating as a rule. During the vernal mobilization of reserves the reducing sugars consist of the hexoses and maltose; at other times the latter is absent.

6. In evergreens and sub-evergreens the seasonal changes are not very striking, nor are the gradients of osmotic pressures from root to summit as regular as in deciduous trees. The osmotic pressure of the transpiration sap in the root exceeds that in the stem at certain seasons.

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THE VERTICILLIUM DISEASE OF THE  
POTATO.

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(PLATES II-III.)



[*Authors alone are responsible for all opinions expressed in their Communications.*]

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## VII.

## THE VERTICILLIUM DISEASE OF THE POTATO.

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[Read DECEMBER 21, 1915. Published MARCH 22, 1916.]

## I. INTRODUCTORY.

DURING the past seven summers special investigations dealing with various diseases of the potato have been pursued in Ireland, where the potato crop is such an important one. Some of the diseases dealt with have been new, while others, although not new, were more or less obscure and had previously been insufficiently studied, so that it was possible to throw new light on them.

The results of these investigations have been published annually in the form of general summaries or reports, and in certain cases the diseases have formed the subjects of special scientific papers.<sup>1</sup>

The disease with which the present paper deals has been referred to briefly in these reports from 1910 onwards, but no detailed account of it has yet been given. It is not really a new disease, although up to the time of starting the present investigations comparatively little was known about it, and definite record of its presence in the British Isles had apparently not been made. It has, in fact, long remained incompletely studied and concealed amongst the congeries of diseases passing under the names of Curl and Leaf-Roll, from which, however, it must now be removed and be recognized as a distinct disease of a definite type caused by a specific parasitic organism, as will be clear from the discussion in Section VIII of this paper.

The reason why the present study of the disease has been a somewhat protracted one is partly because the disease was only one of several which

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<sup>1</sup>These reports will be found in the Journal of the Department of Agriculture and Technical Instruction for Ireland, vols. x, xi, xii, xiii, xiv, and xv, 1910 to 1915. References to the special scientific papers mentioned will be found in these reports.

were being studied simultaneously, but more especially because it was found that in order to obtain accurate information upon the extent and mode of transmission of the disease by affected plants to their progeny it was necessary to extend the observations over several successive seasons. Failure to do this by earlier workers has resulted in somewhat incorrect notions regarding the disease.

## II. SYMPTOMS AND CAUSE OF THE DISEASE.

The case of the disease which formed the starting-point of the present investigations was met with on a farm in Co. Dublin in the first week of August, 1909. The plants were of the variety Duchess of Cornwall (a type of Up to Date), and were being grown in a small plot.

The affected plants, which were distributed promiscuously through the plot, were of fair size, certainly not dwarfs, but not so large as their healthy neighbours. They were clearly distinguished from the healthy plants by the fact that their lower leaves were brown, shrivelled, and practically dead. The upper, younger internodes of the stalks had failed to elongate normally, and the leaves borne on them were more or less crowded together, forming a kind of rosette. The individual leaflets of these upper leaves were folded upwards and inwards on their midribs, consequently exposing their lighter-coloured under-surfaces to view.

On cutting the stalks transversely, the wood of three principal vascular bundles was seen to be discoloured, being of a yellowish brown tint and not so dark as is usually the case in attacks of Black Stalk Rot due to *Bacillus melanogenes*. On pulling the stalks from the ground, it was at once clear that the disease was not Black Stalk Rot, because the portions of them near the surface of the ground and below it were not black and rotten, but, externally at any rate, apparently quite healthy.

The parent tubers from which the diseased plants had sprung were, in the cases examined in detail, already rotten; but it may be stated here that such tubers do not always decay in this manner, for very often they may be found, at the close of the season, hard and apparently sound.

Amongst the newly formed tubers rather small-sized ones predominated, although a few quite large ones were sometimes also present. The total yield from the diseased plants was considerably less than that from the neighbouring healthy ones. The tubers produced by the affected plants showed no external signs of any disease. When, however, these tubers were cut across at their heel (proximal) ends, most of them showed a brown, discoloured vascular ring, due, as subsequent microscopical examination showed, to the browning of the walls of the elements of the wood, and, in the region

quite close to the point of attachment of the rhizome, to discolouration of the walls of other cells also. (See fig. 7, Plate III.) This browning of the vascular ring could be seen with the naked eye, extending in some cases for quite a considerable distance towards the rose (distal) end of the tuber, and, with the microscope, it was still to be seen in sections of the vascular tissue made at the extreme rose end.

Transverse sections of the stalks of affected plants, made both in their over- and underground portions, and examined with the microscope, showed that the wood vessels were more or less thoroughly choked with branched, septate fungus mycelium which, in a rare instance or two, bore single-celled oval conidia within the cavities of the vessels. Similar mycelium was found in abundance in the wood vessels of the leaves, roots, and rhizomes of affected plants. From the rhizomes the mycelium was definitely traced into the wood vessels of the new tubers, and in one case, which will be described in detail later, it was followed by means of hand sections to a distance of four centimetres from the heel end of the tuber.

When cut portions of the affected plants (including tubers) were kept moist for a few days in covered dishes, the fungus grew out from the wood vessels and formed aerial, verticillately branched conidiophores, on the tip of each of which a glistening, spherical globule, containing a number of conidia, was borne. (See figs. 5 and 6, Plate III.)

When portions of affected stalks were allowed to remain for about twelve days under such conditions, they began to rot; and microscopical examination showed that the mycelium had spread from the vessels to the surrounding tissues, was turning black, and assuming a resting condition. (See fig. 4, Plate III.)

The fungus, which infection experiments have proved to be the cause of the disease, was identified as *Verticillium albo-atrum*, a species first described by Reinke and Berthold<sup>1</sup> in 1879, and assigned by them as the cause of a potato disease, which they regarded as Curl (Kräuselkrankheit).

The appearances described above are quite characteristic of the *Verticillium* disease. A study of it, however, over several seasons has shown that its external symptoms are subject to considerable variation in intensity. For instance, the curling or rolling of the leaflets has been found to be not an absolutely constant feature of the disease, and thus the terms "Curl" and "Leaf Roll" are to be avoided in speaking of this disease, the more so since they have been used in the past in a somewhat indiscriminate way, as will be seen from the discussion in a later section of this paper.

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<sup>1</sup> Reinke, J., and G. Berthold, *Die Zersetzung der Kartoffel durch Pilze.* (Dritter Abschnitt. Die Kräuselkrankheit der Kartoffel.) Berlin, 1879, p. 67.

The view of the nature of the disease which has resulted from a study of it during several seasons is that it consists primarily of a more or less premature death of the plant owing to a gradual process of desiccation, proceeding from below upwards. It is to be regarded as a type of wilt-disease, although actual wilting of the foliage—*i.e.* a condition of flaccidity, limpness, or loss of turgor in the leaves while still green—is extremely rare in this country, and has only been seen in cases where healthy plants have been artificially inoculated through wounds with pure cultures of the fungus.

In cases of severe attack the affected plants may attain the height of only a few inches, and they may be killed off comparatively early and without developing any curl or roll in the foliage. On the other hand, in cases of very slight attack the plants may attain practically their normal size, and may not begin to die off much before the usual time. Rolling or curling of the foliage may here also be absent, and such cases of the disease are easily overlooked, particularly if the plants are at the same time attacked by blight (*Phytophthora infestans*) or by the Botrytis disease. Of course, the greater number of cases of the disease lie between these two extremes.

In many cases after the death of the plants black streaks are noticeable on the dead stalks. These are due to the production of the black form of mycelium by the fungus and must not be confounded with the black, adherent, flattened sclerotia of Botrytis so often seen on dead potato stalks.

The only certain means of diagnosing the disease is by finding the mycelium of *Verticillium albo-atrum* in the wood vessels of the plant or of the tuber from which it is derived. Even the absence of the mycelium from the wood vessels of the stem, root, &c., of a plant at a given moment is not necessarily proof that such plant is not diseased, or at any rate that it will not become so. For in many cases it has been found that the mycelium passes from the parent tuber into the stalk rather slowly, and the foliage may be just beginning to show typical symptoms of the disease before the mycelium has reached the stem. The non-realization of this possibility has doubtless been the cause of some at least of the contradictory statements made with regard to this disease.

Finally, it may be stated that no case of the disease has been met with in which the affected plant has failed to bear some new tubers; and since a large proportion of these tubers contain the fungus within them, the disease will spread to the next generation. The disease, therefore, is not extinguished automatically in any given generation of affected plants, as has been supposed.

### III. PREVIOUS INVESTIGATION OF THE DISEASE.

As mentioned above, Reinke and Berthold in 1879 described the disease due to *Verticillium albo-atrum* under the name of Curl-Disease

(Kräuselkrankheit). When the present investigation was started, the account given by these authors was practically the only one dealing in detail with the *Verticillium* disease; and although during its progress some additional information concerning it has been published, such as that by Spieckermann and by Orton, which will be considered later on, yet Reinke and Berthold's work still remains the fundamental one on this disease. Before proceeding further, therefore, it will be necessary to give a brief résumé of the account of the disease as given by these authors, laying stress on those points which seemed to require further investigation before being accepted as conclusively established.

Reinke and Berthold describe the disease as making its appearance under three distinct forms or types (A, B, and C). Type A is seen towards the beginning of July, and is characterized by the wilting, drying up, and yellowing of the lower leaves, not accompanied, at least to any extent, by curling of the leaflets, or by brown spotting of the foliage. Fungus mycelium is present in the wood vessels situated in all parts of the plant. It is found in the new tubers, but is said never to proceed far into them, a distance of fifteen millimetres from the heel being the maximum observed. It is stated to pass the winter at the point of detachment of the tuber from its rhizome and partially within the tuber.

Type B of the disease is seen at the same time as type A. Some time after the middle of July, potato-stalks, which up to that time had appeared perfectly healthy, begin to show a curling of the leaflets at their edges, and brown spots begin to appear on the foliage. At length such spotted leaves become completely dried up. The tissues of all the overground portions of the affected stalks are completely free from fungus mycelium, but *in the cortex* of those portions of them situated below ground and in that of the roots it is stated that *Verticillium albo-atrum* is present. The fungus in this case also reaches the new tubers, but by exactly what route is not clear from the description. It is said to pass the winter as in the previous type at the very heel-end of the tuber, and it could never be traced any distance into the interior of the tuber.

Although the two types mentioned are generally well marked and were described separately, the authors admit that they occur not infrequently on different stalks of one and the same plant, and even sometimes on one and the same stalk. It is also admitted that in certain cases of type B of the disease, mycelium was found after a time in the vessels of the stalks. It may be stated at once that in the present author's opinion mycelium would probably always have been found in the wood vessels of all parts of plants affected with type B of the disease had the search for it not been made too early. Types A and B



of the disease then would appear to be essentially similar, the principal difference being that in type B the mycelium of the fungus takes somewhat longer to reach the plant from the parent tuber than is the case with type A.

Type C is stated to arise exclusively when tubers derived from plants affected with either type A or type B of the disease are planted, although such tubers may also give rise to "misses," *i.e.*, may produce no plants at all. Plants affected with type C of the disease come above ground late, develop slowly, and remain small. The leaves do not expand fully; and are not of the normal green colour. The leaflets are curled and wavy, the petioles being bent backwards. Death and desiccation of the plants take place from above downwards, and after the death of one stalk others may subsequently develop from the same tuber, but only to die away in their turn. The stalks are exceedingly brittle, and the plants are said to die without producing any new tubers, so that the disease exhausts itself in this, the second, generation.<sup>1</sup> No fungus mycelium is present in the vessels of plants of type C at any time; but the mycelium of *V. albo-atrum* is stated to be present in the cortical tissues of the subterranean portion of the stalks. The seed-tubers producing this type of the disease, when they have not already rotted in the ground, contain no mycelium in their internal tissues; but *Verticillium* is stated to be present in the cells of the skin, although it does not penetrate into the subepidermal tissues.

What strikes one as rather remarkable in Reinke and Berthold's account of the disease is the absence of the fungus from the wood vessels in types B and C, and, as has already been surmised, this may possibly be due to the fact that a long enough period was not allowed to elapse before the examination was made.

Much stress is laid on the point that the fungus is only present at the very heel-end of the tubers derived from plants affected with the A and B types of the disease, and that even at the end of the season when such tubers had produced plants of the C type mycelium could not be found in their interiors.

The mode of transmission of the fungus from the first generation (A and B types) to the second (C type) is, as described, a most peculiar one. It is stated that when the tubers having the mycelium strictly limited in location to their heel-ends are planted in the spring the mycelium grows *around the outside of the tuber* in the cork layers of the skin, and without penetrating the interior. Having in this way reached the bases of the young sprouts, it

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<sup>1</sup> In a postscript it is stated that in a few cases tubers from plants affected with the A type of the disease gave rise to plants of the B and not of the C type; hence it is assumed that in such cases the disease would become exhausted in the third generation.

finds its way into them, probably through the cortical portions of the young roots. It was certainly to be expected that since the fungus was located primarily in the vessels of the affected stalks and entered the new tubers, it would pass in through the vessels, remain in them during the winter, and pass out from them into the vessels of the new stalks in the spring; but it is quite clear that Reinke and Berthold did not admit this view.

It was particularly with a view of throwing light on this point that the present investigation was started, although it was also desired to obtain information on other phases of the disease and on the behaviour of the fungus in pure culture. The account of the fresh investigations on the disease will, therefore, now be proceeded with; and the small amount of further literature on it, published while the investigations were proceeding, will be dealt with where necessary.

#### IV. LOCALIZATION OF THE MYCELIUM IN AFFECTED TUBERS.

It is a matter of no difficulty to trace by means of suitable sections the passage of the mycelium from affected stalks through the rhizomes and into the heel-ends of the new tubers. It passes exclusively through the wood vessels. This has been studied, not merely by sections, but by suitable incubation of portions of rhizomes as well as of tubers, proving that the fungus involved was the species of *Verticillium* in question.

All the tubers borne by an infected plant, however, do not necessarily become infected. As a rule the fungus only reaches the older and larger tubers, while the smaller and younger ones often remain free from invasion. Here it may be stated that the tubers which do not become infected with the mycelium of the fungus produce, when planted, absolutely healthy plants, and their progeny continues to do likewise. Hence, by separating out the non-infected tubers (by the method to be described subsequently) from a mixed stock of seed-tubers derived from affected plants, and by employing them as seed-tubers, it has been possible to raise a new stock free from the disease.

As has already been pointed out, Reinke and Berthold maintain that when the fungus reaches the heel-end of a new tuber it remains strictly localized there. Spieckermann<sup>1</sup> also states that at the time of digging, the mycelium is chiefly confined to the heel-end of the tuber, and seldom proceeds further or reaches the rose-end. He believes that during the winter resting period of the tuber the mycelium does not make any further progress, since even in spring its growth has not advanced, and the sprouts are, therefore, all viable.

<sup>1</sup> Spieckermann, A., Beiträge zur Kenntniss der Bakterien- ring- und Blattrollkrankheiten der Kartoffelpflanze. Jahresber. d. Ver. f. angew. Bot., viii, 1911, p. 1.

This author, however, does not provide any experimental evidence in favour of his contention ; and the observations and experiments now to be described show that these views do not hold good.

In 1909 a large tuber, nearly thirteen centimetres long, borne by an affected plant, was subjected to microscopic examination by means of sections of the vascular tissues removed from it, at intervals, in such a way that the use of the tuber, or rather portions of it, as "seed" for the following season would not be interfered with. By this means the mycelium was traced definitely in the vessels of the tuber to a distance of 4 cm. from its heel-end, and the browning of the woody tissue was visible to the naked eye for a distance of about 1.5 cm. beyond this point. Owing to the comparatively small size of the vessels, and the difficulty of cutting hand-sections accurately transverse to their long axis in the rose-end region, it was not possible to demonstrate with certainty the presence of mycelium in them by this method ; but it was noted that the walls of these vessels appeared, under the microscope, distinctly browned, although this was not evident to the naked eye.

This tuber was, in the autumn, cut transversely into two portions, the cut being made some distance nearer to the rose-end than the point to which the mycelium had definitely been traced. The heel-end portion had two eyes on it, while the rose had three. In the spring of 1910 the two halves were so cut that five sets were available, each containing one eye. These sets were planted in sterilised soil, each in a separate pot. Sets 1 and 2 were from the heel-half of the tuber in which the mycelium was known to be present, while Sets 3, 4, and 5 were from the rose-half in which the presence or absence of mycelium was doubtful in the autumn. It could not, at any rate, have reached them during the winter from the heel-portion of the tuber because this had already been cut off in the autumn.

The five sets were planted towards the end of April, and all of them except No. 3 produced small plants which up to the middle of July showed no symptoms of any disease. Set No. 3 was totally destroyed by a soft-rot apparently of bacterial origin, while the plant derived from Set No. 4 was practically destroyed by an attack of caterpillars. As time progressed little or no signs of rolling were observable in the leaflets of the plants ; but the lower leaves began to wither and dry up ; and before the end of August all three plants were practically dead, having succumbed to a progressive desiccation proceeding from below upwards. Microscopical and cultural examination showed that the vessels of these plants were completely choked with the mycelium of *Verticillium albo-atrum*, which was also present in the roots of the plant derived from set No. 4. In two cases (Nos. 1 and 5), in

which the old sets had not rotted, but were fairly well preserved, the fungus was found to be present in their now strongly browned woody tissues.

From this experiment it seems safe to conclude that the fungus was present in the autumn in the original tuber, not merely localized at the heel-end, but also at a distance from it at least greater than one-half of the length of the tuber.

The question of the exact location of the fungus within the tuber is an important one from the practical point of view. For, if it is strictly confined to a small area near the heel-end of the tuber in the autumn, and does not progress further during the winter, it should be possible to get rid of the disease by merely cutting off the comparatively small portions of the heel-ends of affected tubers before using them for seed. This point was, therefore, gone into in further detail.

A preliminary experiment was carried out in 1910 with tubers derived from affected plants. Small portions of the heel-ends were first cut off, in order to see whether the vascular ring was browned or not. The tubers were then divided into two groups: (*a*) those with no browning, hence apparently healthy; and (*b*) those showing browning, hence presumably diseased. The tubers in group (*b*) were then further subdivided. From the heel-ends of one half of them the tissues were cut away until the browning of the vascular ring was no longer visible to the naked eye, while to those of the other half nothing further was done. By this means the attempt was made to divide the tubers into the following three classes:—(1) healthy; (2) primarily diseased, but rendered healthy by cutting away the diseased tissue; (3) diseased.

The tubers were planted under field conditions at a time when it was unfortunately impossible, owing to the pressure of other work, to devote as much attention to the behaviour of the resulting plants individually as was desirable. Further, a severe attack of blight, combined with another of the sclerotium disease, seriously interfered with the success of the experiment. Nevertheless, taking as a criterion the amount of rolling in the leaflets exhibited before these diseases gained the upper hand, it was possible to see that the plants derived from the tubers of Class 3 (diseased) were decidedly the worst, while there was not any clear difference between those derived from the tubers of Classes 1 and 2. Plants with *Verticillium* in the vessels of their stems were found, however, in all three classes, but such plants did not appear to predominate in one class more than in the others.

The experiment, although leaving much to be desired, showed at least that no reliance could be placed on naked-eye examination of the cut ends of tubers as a means of discriminating between those containing the fungus and

those free from it, and proved that the cutting away of the heel-ends of the tubers was not sufficient to eliminate the disease with certainty.

It was clear that in any further experiments on these lines it would be necessary to test individually each tuber before using it to ascertain whether it contained the fungus or not, and the method of testing was as follows:—

The tubers were first thoroughly cleaned by careful scrubbing in plenty of running water, and then dried in a clean linen towel. They were purposely not treated with any disinfectant, lest some of it should be absorbed into the wound at the heel-end of the tuber caused by its severance from the rhizome, which might prevent the development of the fungus if present.

A small portion of the heel-end of the tuber, about a millimetre or so thick, was then cut in such a way that it remained hanging from the tuber by a small bit of skin, the two cut surfaces being of course exposed. Tubers prepared in this way were put into clean covered glass dishes the bottoms of which were lined with moist filter paper. After standing for two or three days at room temperature microscopic examination of the tubers was made.

*Verticillium* when present in the wood vessels of a tuber does not produce aerial growth and conidiophores at the cut surfaces with the luxuriance generally observed when pieces of affected stalks, rhizomes, or roots are suitably incubated. Nevertheless it does grow out in varying degrees, if present, and by microscopical examination one can decide whether a tuber possesses it or is free from it, although cases do arise occasionally where definite decision is not possible.

Examination was always carried out at three places—(1) the natural wound at the heel-end; (2) the cut ends of the vascular tissue of the small portion of the tuber nearly severed; (3) the cut ends of the vascular tissue of the remaining part of the tuber. Only when the fungus was present or absent at all of these three places simultaneously was the tuber regarded as infected or free from infection respectively for the purpose in view.

It may be stated that the mycelium can be traced definitely growing out of the browned xylem portions of the vascular ring of the tuber, and, indeed, the exit of an individual hypha from the cavity of a particular wood vessel has in many cases been traced, so that there can be no doubt as to the source from which the fungus comes. Occasionally the growth of other fungi makes certain determination practically impossible, and this is especially the case when *Hypochneus Solani* is present on the surface of the tuber under examination, for it rapidly produces a luxuriant growth at the expense of the cells killed by the process of cutting. Even in such cases, however, with some experience it is sometimes possible to discriminate between the growth of

Verticillium emanating from the wood vessels and the coarse mycelium of Hypochnus covering the cut surface.

In the autumn of 1914 twenty-five tubers which were proved conclusively to contain the fungus, by testing as above described, were selected. In the third week of October, i.e. soon after they were dug, these tubers were each cut into two portions, a heel portion and a rose portion, each possessing eyes, the heel portions being as a rule larger than the corresponding rose portions. The fifty sets thus obtained were then indelibly marked with Indian ink, so that they could not possibly become mixed. They were placed in a sprouting box and allowed to remain there over winter. In the spring all of them had produced normal sprouts from the various eyes.

In January, 1915, a further set of twenty-five tubers was selected which were found on testing as before to contain the fungus. These were also allowed to sprout in a box, which they did in normal fashion. In April, a day or two before planting, these tubers were each cut into two portions, roses and heels respectively. The tubers cut in the autumn and in the spring were all selected from the same lot, and were the produce of affected plants grown in 1914.

At planting time in 1915, therefore, there were sets from twenty-five autumn-cut tubers, and a similar number from spring-cut ones. Five pairs of each were grown in pots in Dublin in a cool greenhouse, while the remainder were planted at Clifden. No farmyard manure was used in either case. The resulting plants, some of which were diseased and some healthy, were carefully examined for the presence or absence of mycelium in their stalks. In the cases of the healthy plants, where no mycelium was found, they were allowed to grow until the close of the season, when they were dying naturally, so that the absence of mycelium was not due to the plants having been examined too early.

A summary of the results is given in the following table :—

| No. and description of sets planted. | No. of plants developed. | No. of misses. | Diseased plants with Verticillium. | Healthy plants without Verticillium. | % diseased of those developed. |
|--------------------------------------|--------------------------|----------------|------------------------------------|--------------------------------------|--------------------------------|
| 25 Autumn-cut. Heels.                | 23                       | 2              | 21                                 | 2                                    | 91                             |
| 25 do. Roses.                        | 24                       | 1              | 15                                 | 9                                    | 63                             |
| 25 Spring-cut. Heels.                | 23                       | 2              | 22                                 | 1                                    | 96                             |
| 25 do. Roses.                        | 25                       | 0              | 19                                 | 6                                    | 76                             |

With regard to the "misses," these were due in the two cases of autumn-cut heels to the sets succumbing apparently to a soft bacterial rot. In the spring-cut heels the miss in one case was evidently due to the attacks of slugs, and in the other a weak shoot had developed from the small set, which, however, had also been attacked and was not strong enough to reach above ground. *Verticillium* was found to be present in the vascular tissues of the remaining more or less sound portions of these sets in July. The miss in the case of the autumn-cut roses was due to the removal of the set, probably by a rat or a jackdaw, as both of these animals were observed at various times to be active in this manner on neighbouring plots. It is not believed that the presence of *Verticillium albo-atrum* in the sets was the cause of any of these misses. This point will be referred to again later in this paper.

It is scarcely necessary to go into the details of the development of the plants from these various sets; suffice it to say that many of them, from roses as well as heels, were small from the start and soon showed signs of the disease, dying away soon after the middle of July. Others were larger and lasted longer, while comparatively few lasted out the season. In all cases in the table where the plants are described as containing *Verticillium*, it should be understood that this was determined both by microscopic examination and by cultural methods. The same methods were applied and gave negative results in the cases of the plants described as being without *Verticillium*.

It will be seen, as was to be expected, that a very high percentage of the heel-end sets, both autumn-, and spring-cut, gave diseased plants; nevertheless a few of them gave healthy plants, from which it follows that an affected set or tuber, although it generally gives rise to a diseased plant, does not necessarily do so. Further evidence of this will be adduced presently. It may also fairly be concluded that even in the autumn the fungus must have reached in very many cases (sixty-three per cent. in this particular experiment) the rose-end half of the tuber, and that consequently it is not correct to regard the fungus as generally hibernating in a more or less strictly localized position at the very heel-end.

Further, since the percentage of diseased plants arising from the spring-cut rose sets is considerably higher than that of the corresponding autumn-cut ones, it may be concluded that the mycelium does make some progress from the heel towards the rose-end of an affected tuber during storage over winter.

The fungus has been isolated from the vascular tissues of various regions in tubers both before planting and also at the close of the season when they have produced diseased plants. (See fig. 1, Plate III.) It has never been observed to spread from the wood vessels to the surrounding tissues in the

tubers as it does in the stalks, and the black sclerotial form of the mycelium has not been found in the tubers. It is true that affected tubers, when kept unplanted till the late summer, often show, when cut across, a strong blackening in the region of the vascular ring; but microscopic examination shows that this blackening is not due to the presence of mycelium, but to some colouring matter produced in the cells in this region.

From what has been said, it seems clear that the mycelium of the fungus which is present in the tubers produced by affected plants—and very few of the tubers produced by such plants are free from it—is located in the wood vessels of the vascular tissues and is confined to them. But it is by no means necessarily localized at the heel-end of the tuber, and may probably spread slowly in the vessels of the tuber during winter storage. Judging from the varying amount of aerial growth produced at the cut surfaces of the vessels of affected tubers when suitably incubated, it seems likely that the amount of mycelium present in such tubers may vary considerably, and that thus one tuber may be more strongly infected than another.

It is quite conceivable—although it has not definitely been proved—that the strongly infected tubers give rise to plants which show the disease early and soon die off, and that the less strongly infected ones produce plants which attain more normal size, and which do not show symptoms of the disease until considerably later. Finally, the fact that affected tubers occasionally produce healthy plants may be explained by the original infection of the tuber being so slight that the fungus was unable to reach the plant developing from such a tuber before the conclusion of its growth.

#### V. PRODUCTION OF DISEASED PLANTS FROM AFFECTED TUBERS.

According to Reinke and Berthold, when affected tubers are planted, the fungus grows over the outside of the tuber in the cork cells, and so reaches the young sprouts through the cortical portions of the young roots. This idea was based chiefly on the fact that *Verticillium* was found growing on the skin of the tubers as well as in the cortical portions of roots and young stems. It does not follow, however, that the *Verticillium* found in such situations was in reality *V. albo-atrum*, and I am of opinion that Reinke and Berthold were misled by an assumption of this kind. I have found two apparently new species of *Verticillium* (which will be described in detail in another paper) which occur on potato tubers, and which in the conidial form might easily be mistaken for *V. albo-atrum*, but which, when grown in pure culture, are clearly quite different from it and from each other. Neither of these species is capable of producing a disease of any kind in the potato; they are both pure saprophytes.



It is much more reasonable to suppose that the fungus present in the wood vessels of the tuber passes from them at some time or other directly into those of the developing sprouts; and although this passage has not been definitely traced while it is taking place, yet there is every reason to suppose that it does occur.

There would be considerable difficulty in following the course of the mycelium from tuber to developing stalk while this is actually taking place, particularly because the passage does not appear to occur until after the sprouted tuber has been planted, and the young shoots have made considerable growth.

During the several seasons over which this disease has been studied, no evidence has been obtained that the presence of the fungus in the tuber interferes with the production of sprouts; on the other hand, affected tubers have always been found to sprout normally, and to be indistinguishable from healthy ones in this respect.

According to Miss Dale<sup>1</sup> *Verticillium albo-atrum* is a cause of "blindness" (non-development of sprouts) in potatoes. It seems clear, however, from her description that this author was not really dealing with this species of *Verticillium* at all, for it never forms "small rounded segments containing numerous drops of oil," although one of the two new species referred to above does this. The species associated with "blindness" was found in the epidermal and cortical tissues, and not, apparently, in the wood vessels. Further, no infection experiments were made, and it is quite possible that the "blindness" was due to some other cause, while the *Verticillium* present was simply living saprophytically on the dead tissues.

The following observations show that the fungus in the wood vessels of the tuber does not pass at once into the developing sprouts. Seven tubers from affected plants were tested in September, 1914, and were found to contain mycelium of *V. albo-atrum*. They were allowed to sprout in a box during the winter—which they did normally—and remained unplanted till the third week in July, 1915. At this time the tubers were somewhat shrivelled owing to loss of water, and each had produced several sprouts of varying lengths from the eyes situated both near the rose and heel ends of the tubers. A further test was then made of the tubers, and it was found that the mycelium in their vessels was still living. All the sprouts of each tuber

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<sup>1</sup> Dale, E., On the Cause of "Blindness" in Potato Tubers. *Ann. Bot.*, vol. xxvi, 1912, p. 129. I cannot, however, follow Wollenweber, who says (*Phytopathology*, iii, 1913, p. 40) that Miss Dale's *Verticillium* is probably "*Periola tomentosa* (Fr.), Reinke and Berthold (1879) [*sic*] . . . only resembling *Verticillium* macroscopically." As far as I have seen it, *Periola* does not resemble a *Verticillium* even macroscopically.

were then subjected to careful microscopical and cultural examination, but in no single instance could the fungus be found present in a sprout. In one case it was found in the wood vessels of a tuber close to the point of origin of the sprouts, but even here the sprouts themselves were free from it.

The young shoots produced by affected tubers always appear healthy (although they may be small) when first they come above ground; and if they are examined microscopically at this stage, mycelium may not be found in their wood vessels. But if they are allowed to remain longer, sooner or later symptoms of disease will begin to develop in their foliage, such as rolling of the leaflets, or dying off of the lower leaves. When this occurs, or at any rate very soon afterwards, mycelium will be found in the wood vessels of the lower portions of the stalks at least, while often it has not yet reached the upper parts. This mycelium has been traced down the stalk, back to the point of insertion of the latter on the parent tuber, and finally into the wood vessels of the tuber itself at this point, thus permitting of no reasonable doubt but that it has grown from the wood vessels of the tuber into those of the stalk. No evidence was found of the presence of the fungus in the cortical tissues of these stalks, and consequently it could not have reached the wood vessels from this source. Hence it is believed that the mycelium reaches the young stalks, not by growth over the outside of the tuber, as Reinke and Berthold supposed, but by direct growth through the xylem system common to tuber and stalk.

There is, however, a distinct pause of longer or shorter duration before the mycelium proceeds from the tuber to the stalk, during which temporarily healthy stalks are developed from affected tubers. If this pause is sufficiently prolonged, either because the amount of mycelium in the tuber was originally very small, or its location was removed so far from the developing shoot that the latter could not be reached in time, then it is possible to understand how an affected tuber may give rise to a plant which remains healthy throughout the season, and which produces healthy progeny.

Statistics compiled for the seasons 1912–1915 show that when affected tubers are planted 96 per cent. of them give rise to diseased plants bearing further affected progeny, while the remaining 4 per cent. produce healthy plants with healthy progeny.

## VI. THE FUNGUS IN PURE CULTURES.

Since when placed under suitable conditions of moisture and temperature, the fungus present in infected tissue grows out into the surrounding air, and produces a plentiful crop of conidiophores and conidia, it is a com-

paratively easy matter to obtain it in pure culture. This has been done in several instances by planting out the conidia in gelatine media either directly or after a first transference to suitable slants in test-tubes, or to media previously allowed to set in Petri dishes. In this last-named way it is possible to exercise microscopic control over the growth which develops from the inoculating material; and platings of conidia from growths of this kind, which are found to be free from bacterial or other contamination, have always given pure cultures. In some instances the additional precaution was taken of making successive platings before arriving at the particular culture destined to serve as a stock from which cultural and other studies were to be made.

The fungus has also been isolated from the vascular tissue of affected tubers both before planting and after they have been planted and have given rise to diseased plants. It frequently happens that the parent tubers from which diseased plants are developed are to be found at the close of the season more or less completely hard, sound, and not fully depleted of their reserve food materials. In such tubers the woody tissues containing the fungus are strongly browned, as shown in fig. 3, Plate III. Cultures from tubers were obtained by transferring—under conditions of asepsis—portions of the affected woody tissue direct to suitable media in slants or on set plates. Some of these direct transfers proved to be pure from the start, while others of course were contaminated by the presence of other organisms, especially in the case of old tubers; but even in these latter instances *Verticillium alboatrum* was always present, and by further work could be obtained in pure culture.

The fungus grows well as a saprophyte on a variety of media such as Quaker Oat agar, oat-extract agar, wort gelatine, cooked potato agar, potato-stalk agar, cooked potatoes, cooked potato-stalks, and beef extract agar and gelatine.

It produces both aerial mycelium bearing conidiophores with conidia and submerged mycelium. There has been a tendency during the period of over two years through which the cultures have continuously been propagated for the relative proportion of aerial mycelium developed to diminish. Both the aerial and the submerged mycelium is at first pure white in diffused light, but in the course of time black submerged mycelium is produced just in the same way as occurs in the stalks of affected plants, and the medium therefore becomes blackened. This blackening is due solely and entirely to the blackening of the mycelium, and not to the production of dark chlamydo-spores, as occurs in the two other species of *Verticillium* already alluded to.

On certain media, viz., beef extract agar and gelatine and potato-stalk extract gelatine, this blackening of the submerged mycelium does not occur at all. Further, although the fungus readily develops this black submerged mycelium (except on the media just mentioned) when cultivated soon after its isolation from the potato, yet in the course of time, after prolonged cultivation on these media, its power of producing black submerged mycelium gradually diminishes until it becomes entirely lost.

Most of the cultures were kept in the diffused light of the laboratory, but a special comparative series was made to see whether light exercised any influence on the behaviour of the fungus. Parallel cultures were for this purpose (*a*) kept in total darkness, and (*b*) exposed directly to daylight in a window facing north but protected from direct sunlight. No very striking differences were observed in the cultures, but in the dark the aerial growth was pure white, while in the light it took on a faint pink fringe, and the blackening of the submerged mycelium which occurred both in the dark and in the light began to be perceptible in the cultures kept in the dark slightly sooner than in those exposed to light. On all the gelatine media used liquefaction of the gelatine invariably occurred. This took place perhaps somewhat slowly; but in slants in test-tubes the medium was usually completely liquefied in cultures at room-temperature one week old.

Many attempts were made to cultivate the fungus on living potato tubers and on cut portions of living green potato-stalks, but without success. A limited amount of development occurred in the cells injured by cutting or making the inoculation. In the case of the cut stalks further growth took place only when they had been standing for such a long time that they had begun to die. In the case of the tubers or cut portions of them no further growth took place, and a layer of cork was developed beneath the wounded surface. Hence, although the fungus is a vascular parasite of the potato, it is quite incapable of causing a rot of the living tubers or stalks.<sup>1</sup>

The morphological characters of the fungus were accurately described and figured by Reinke and Berthold, and its growth in pure culture has not resulted in the necessity of altering or adding to the description given by them. It is believed, however, that the species which these authors met with living on the skin of the tuber and in the cortex of the stalks below ground was not the same as that inhabiting the wood-vessels, but probably one of the two already referred to, which develop dark-coloured chlamydospores on their submerged mycelium.

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<sup>1</sup> The opposite results obtained by Carpenter (*Journ. Agric. Research* V, No. 5, 1915, p. 203) are, as he himself points out, doubtful, and were probably due to imperfect experimental methods.

In spite of prolonged culture on varied media, *Verticillium albo-atrum* has not been found to produce any other reproductive bodies such as perithecia, nor has it ever produced chlamydospores of any kind.

#### VII. INFECTION EXPERIMENTS.

The first attempt at producing the disease by suitable inoculation of a healthy plant was made at Clifden in the summer of 1909. The inoculation was made by inserting a portion of the woody tissue containing the fungus, obtained from a diseased plant, into a freshly prepared wound made to the depth of the wood just above ground-level in the stalk of a healthy plant, taking precautions to avoid, as far as possible, contamination with other micro-organisms. After nineteen days there were no distinct outward signs that infection had occurred; but as the foliage of the plant was beginning to be destroyed with the ordinary blight, it was decided to break off the experiment at this point. Sections of the inoculated stem showed the presence of fungus mycelium in the wood vessels to a distance up the stem of twenty centimetres from the wound; and on suitable incubation it proved to be that of *Verticillium*. Hence it appeared probable that there would be no difficulty in transferring the disease by inoculation.

In the foregoing case of course a pure culture was not employed, but in 1914 several series of infection experiments were made with pure cultures. Those of the first series were carried out on plants in pots in the greenhouse of the Seeds and Plant Disease Division of the Department of Agriculture in Dublin, and were as follows:—

The plants for the experiments were grown from previously sprouted healthy tubers from which all the eyes except the strong terminal one were excised. This was done in order that each plant might have but one substantial sprout or stalk suitable for inoculation. Inoculation was made in all cases by introducing portion of a pure culture into wounds carefully made in the sprouts or stems at a node, precautions being taken to prevent contamination by other micro-organisms. After inoculation the wounds were carefully covered with tinfoil, and were thus not allowed to come into direct contact with the soil. In every case where an inoculation was made a similar sprouted tuber or plant was treated in the same way, except that no portion of a culture was introduced into the wound; and this served as a control. In this particular series there were eight plants inoculated at four different periods, together with their eight controls. Some of them were inoculated in the sprouts before planting, others when the shoots were only about two inches above the soil, and the remainder at correspondingly later dates. Symptoms

of disease began to appear in the earlier inoculated plants about one month after inoculation ; but in those inoculated later, when the plants were much larger, the symptoms first appeared within about seven days. The symptoms were the appearance on the older leaves of pale green or yellow areas with rather ill-defined margins. After a time these areas dried up and became brown and dead. Gradually these symptoms repeated themselves in the successively younger leaves, often but not always accompanied by an inrolling of the margins of their leaflets. In some cases the leaves while still green showed a true wilting due to loss of turgor in their cells ; and by degrees the foliage of the inoculated plants died off by a process of desiccation proceeding from below upwards. When the foliage was dead, a similar process of desiccation took place in the stalks proceeding from above downwards. When the inoculations were made while the plants were still young, the inoculated plants remained much smaller than the corresponding controls ; but this difference, although present, was not so marked in the case of plants inoculated when already fairly advanced in growth. A good idea of the kind of result obtained in this series of inoculation experiments is afforded by figs. 3 and 4, Plate II.

When the discolouring leaves showing the first symptoms of disease in the plant were removed and placed in a moist atmosphere, they quickly became covered externally with an aerial development of conidiophores of *Verticillium*, thus proving that the fungus had already reached them. Sections of the veins and petioles of such leaves showed the abundant presence of the mycelium in the wood vessels. The same mycelium was also found to be present in the stems, roots, and some of the new tubers of the inoculated plants at the conclusion of the experiment. It was an easy matter to obtain the fungus in culture from dead or dying plants, and to prove by the character of the black submerged mycelium developed in due time that it was *Verticillium alboatrum*.

The control plants were just as carefully watched and examined for the presence of the fungus as the inoculated ones, but they showed no signs whatever of disease, and no mycelium could be found in their vessels ; in short, they remained perfectly sound, and produced sound tubers.

The second series of inoculation experiments was carried out in one of the gardens at the Albert Agricultural College, Glasnevin, in the open ground. Six previously sprouted healthy tubers were inoculated in the sprouts before planting, and six plants from healthy tubers were inoculated in their stalks below ground in the manner previously described, when they were about 30 cm. high. There were twelve controls. All of the inoculated plants remained smaller than the corresponding controls. They soon began to show

the characteristic symptoms of the disease, and they died off prematurely, whereas the controls behaved normally. Microscopic examination of the inoculated plants showed the fungus present in all their organs, including some of the new tubers. Similar examination of the controls showed that ten of them were quite free from the fungus. In the case of one of the remaining two, it was found in the vessels of a single rhizome, but in no other portion of the plant, and in the case of the other it was present in the vessels of some of the roots. These two plants were growing in close proximity to two of the inoculated plants, and it is quite possible that the rhizome and the roots may have become infected by coming into contact with the diseased roots or rhizomes of these neighbouring plants; it would have been better if the controls had been planted at a greater distance from the inoculated plants.

A further series of inoculation experiments was carried out in the field at Clifden, there being four inoculated plants and four controls. Two of these and the corresponding controls were on plants of the variety Up-to-Date, which was the one used in the previously described series. The controls remained perfectly sound, while the inoculated plants became diseased, and were found to contain the fungus in all their parts, as in the cases already described.

The other two inoculated plants and the corresponding controls at Clifden were, however, of the varieties Shamrock and Northern Invincible respectively. Both of these varieties have proved themselves to be resistant to the attacks of blight (*Phytophthora infestans*), the former very highly so and the latter slightly less highly. The method of inoculation was the same as that employed in the previous experiments. The plant of Northern Invincible became diseased, and invaded in all its parts by the fungus, just as had been the case with the Up-to-Dates, while some of the tubers also contained it. On the other hand, the symptoms of disease in the inoculated plant of Shamrock were less pronounced, and the invasion by mycelium was much less extensive. The fungus was found in the vessels of the upper portions of the inoculated stem; but just below the inoculating wound it stopped, and it did not proceed further downwards. The roots, rhizomes, and tubers were found to be free from it. Hence it would appear probable that this variety is somewhat resistant to this disease, as well as to the blight. The controls in this case also remained sound, and were found to be free from mycelium.

Still further inoculation experiments were carried out on cut stalks placed in Tollens' nutrient solution, and kept under observation in the laboratory. It is not necessary to deal with these in detail; suffice it to say that the fungus spread from the inoculating wound in the vessels, both up and

down the stalk, but in a somewhat less vigorous fashion than where the stalks remained on the plant.

Some of the tubers produced by inoculated plants in 1914, which investigation showed contained the mycelium of the fungus in their vascular tissues, were planted in 1915, and gave rise to diseased plants, which could not be distinguished from similar plants arising from infected tubers produced in the previous season by naturally diseased plants.

Berthold and Reinke carried out infection experiments with the fungus, but, of course, not in pure culture. A considerable number of them gave negative results, particularly when the inoculations were made only into the parenchymatous tissue of tubers, or that of the cortex of stems. Positive results were, however, obtained, when the inoculation wound included a portion of the woody tissue, and the inoculated plants showed their type A of the disease.

The experiments described conclusively show that *Verticillium albo-atrum* is an active parasite capable of luxuriant growth and development in the larger vessels of the woody tissue of the potato, and that it is the direct cause of the disease described.

In the cases of the disease studied by the present author the source of the infection of the plant has generally been due to the planting of affected seed-potatoes, and no experiments have yet been carried out to ascertain the way in which primary infection of plants derived from healthy tubers might occur under natural conditions. Reinke and Berthold showed that when a young root was brought into contact with the mycelium of the fungus, the latter penetrated into the superficial tissues of the root, but apparently it did not reach the vascular tissues. Infection experiments with conidia placed on the surfaces of young roots did not succeed, as the conidia did not germinate. It seems probable that primary infection may occur directly from the fungus living as a saprophyte in the soil; but further experiments in this direction with pure cultures of the fungus are necessary before a definite conclusion can be drawn. Miss Dale<sup>1</sup> claims to have isolated *Verticillium albo-atrum* from a sandy soil, and cultivated it on various media. Since it is stated that the fungus in all its stages is a pure white, it might seem improbable that it was in reality *V. albo-atrum*. Nevertheless, in view of the fact that the fungus when grown for a long period as a saprophyte gradually loses its power of producing black mycelium, it is possible that the same loss had occurred owing to a prolonged period of saprophytic growth in the soil. In a case of

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<sup>1</sup> Dale, E., On the Fungi of the Soil. I. Sandy Soil. *Annales Mycologici*, x. No. 5, 1912, p. 465.



this kind, suitable inoculation experiments with potato plants would enable a definite decision to be made.

#### VIII. RELATION OF THE VERTICILLIUM DISEASE TO "CURL" AND "LEAF ROLL."

The term "Curl" has long been in use for certain potato troubles. A disease known by this name is said to have been seen first in England so long ago as 1764; and towards the end of the eighteenth and during the early part of the nineteenth centuries it was the subject of much discussion by agricultural writers of the day. The literature on the subject is very extensive, but, unfortunately, in the main it is most unprofitable reading. From a study of this literature it is impossible to obtain an accurate idea of what the Curl really was, for most of the writers on the subject preferred exercising their imaginations in speculations as to the probable causes of the disease and in formulating remedies for it, rather than attempting to give a careful description of the symptoms which characterized it. It is quite possible, and indeed probable, that the term "Curl" was applied to more than one distinct disease of the potato; and this supposition, if correct, would serve to explain the conflicting opinions often published concerning it. Anyone who wishes to get an insight into the complexity of the views concerning "Curl" which prevailed during the early part of last century cannot do better than consult such a summary of them as that published in 1804 by Forsyth.<sup>1</sup>

Apparently as time went on the trouble known as "Curl" became less serious, and in the middle of the nineteenth century it was for a time quite overshadowed in importance by the epidemics of blight from which the potato crop then suffered. Nevertheless, it is clear from Hallier's<sup>2</sup> account that the disease (Kräuselkrankheit) was still prevalent in the early seventies of last century in many districts in Germany. Hallier's description of it would lead one to believe that it was one caused by a specific fungus inhabiting the vessels of the wood, and perhaps identical with the Verticillium disease described in the present paper. He himself certainly adopted this view, and named the supposed fungus *Rhizoctonia tabifica*. It is clear, however, that Hallier applied this name not to a single fungus, but to more

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<sup>1</sup> "The Principles and Practice of Agriculture," systematically explained, in two volumes; being a treatise compiled for the fourth edition of the *Encyclopædia Britannica*, and revised and enlarged by Robert Forsyth, Esq. Edinburgh: Constable & Co., 1804. See particularly p. 174 et seq.

<sup>2</sup> Hallier, E., "Die Ursache der Kräuselkrankheit." *Zeitsch. f. Parasitenkunde*, iv, 1875, p. 97.

than one of those which are frequently found growing together on dead or dying potato-stalks.<sup>1</sup> The principal literature on Curl (Kräuselkrankheit), from Kühn's time onward, is dealt with by Reinke and Berthold in their paper already referred to, so that it is not necessary to go further into the matter here. It seems fairly clear that what is in the present paper called the Verticillium disease was sometimes included in what was called Curl (Kräuselkrankheit) in the seventies of the nineteenth century. Whether, however, the disease called Curl in the previous century applied solely to the Verticillium disease is another question. On the whole, it seems likely that it was only one of the diseases covered by this term.

There is another form of "Curl" to which I called attention in 1912,<sup>2</sup> which cannot well be confounded with the Verticillium disease, and the cause of which is quite unknown. Affected plants are small, and their foliage is very much crumpled and curled. No fungus is present in the plants; they produce few and only small tubers, which reproduce the disease when planted. In the cases studied by me the tubers produced in successive seasons became smaller and smaller until, finally, they were not large enough to remain alive until the spring, so that the race of abnormal plants died out completely. This form of Curl has also been recognized in Germany and in America, the term "curly dwarf" having recently been applied to it in the latter country.

Again, in England the term "leaf-curl" has recently been applied<sup>3</sup> to a potato disease said to be due to *Macrosporium solani* (Cooke), but which still lacks proper scientific study and investigation. Further, Vañha,<sup>4</sup> in 1910, regarded a new fungus (*Solanella rosea*) as being responsible for a potato disease, which he designated "curl" or "roll" disease (Kräusel- oder Rollkrankheit), without, however, bringing forward really convincing evidence.

Without going any further into the matter, it is quite clear that the term "Curl" (or "Leaf-Curl") has been applied to several probably distinct diseases of the potato, and it would therefore be well to refrain from the use of it in future.

In 1907 Appel<sup>5</sup> published a leaflet describing a disease of the potato which

<sup>1</sup> The sclerotium, with appendages, described and figured by Hallier as a resting stage of his *R. tabifica*, is, I have discovered, an early stage in the formation of its fructification by a species of Colletotrichum, which I hope to describe elsewhere.

<sup>2</sup> "Jour. Dep. Agric. and Tech. Instr. Ireland," xii, 1912, p. 354.

<sup>3</sup> "Journal Board of Agric.," vol. xii, 1905-1906, p. 476. *Ib.*, vol. xiii, 1907-1908, p. 466.

<sup>4</sup> Vañha, J., "Die Kräusel- oder Rollkrankheit der Kartoffel, ihre Ursache und Bekämpfung." Monatshefte f. Landwirtschaft, iii, 1910, p. 268.

<sup>5</sup> Appel, O., "Die Blattrollkrankheit der Kartoffel." Kais. Biol. Anst. f. Land- u. Forstwirtschaft. Flugblatt 42, 1907.

was then prevalent in Germany and some of the neighbouring countries. The disease was stated to be by no means a new one, but rather one which had hitherto been included amongst that congeries of diseases known as "Curl" (Kräuselkrankheit). To this particular form of disease the name Blattrollkrankheit ("Leaf-Roll" disease) was given, and one or more fungi (not specifically named) belonging to the genus *Fusarium* were said to be the cause of it.

This publication may be looked upon as the first of a long series of others which followed dealing with "Leaf-Roll." In some of these Appel's results are confirmed, and to some extent amplified. Thus, not only was a *Fusarium* found to be the cause of the disease, but in many cases the parasite was found to be *Verticillium albo-atrum*.<sup>1</sup> On the other hand, many students of the "Leaf-Roll" disease stoutly maintained that it was not due to a fungus at all, for the simple reason that the presence of a fungus in the vessels (as described by Appel) was by no means a constant or, in some cases, even frequent symptom of the disease. Thus arose a controversy between those who regarded this disease as of parasitic origin and those who maintained the contrary, and who explained it as being due perhaps to the upsetting of enzymic equilibrium, or some other such occult cause. It is not necessary to deal here with the literature which this controversy brought into existence; suffice it to say that had the upholders of the non-fungus theory of the cause of "Leaf-Roll" been acute enough to realize that the disease with which they were dealing was not the "Blattrollkrankheit" as first defined by Appel at all, but something quite different, the controversy would probably never have arisen. However, the development of this controversy need not be regarded as having served no useful purpose, for it has certainly been the means of stimulating research into some of the more obscure diseases of the potato, from which good results have followed.

It will be seen then that just as the term "Curl" is not applicable strictly to any one specific disease, so the term "Leaf-Roll," although introduced to apply to the specific disease caused by species of *Fusarium* invading the wood vessels, came to connote not only this disease, but also a similar one due to *Verticillium albo-atrum*, and, further, another (or possibly others, for the matter cannot yet be regarded as definitely settled), the cause of which is still not sufficiently well understood.

A distinct step forward in the direction of a clearing up of the prevalent confused ideas concerning Leaf-Roll was the publication in 1914 of a

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<sup>1</sup> Appel, O., "Einiges über die Blattrollkrankheit der Kartoffel." Jahresber. Ver. Angew. Bot., vi, 1909, p. 259.

Bulletin compiled by Orton.<sup>1</sup> Here for the first time, apparently, the disease due to *Verticillium* is distinctly dissociated from Curl and Leaf-Roll diseases, and placed in the group of Wilt diseases along with one previously known in America from the work of Smith and Swingle, and stated to be caused by *Fusarium oxysporum*. It follows that Appel's Blattrollkrankheit as originally described by him would also logically find a place in this group, although the actual species of *Fusarium* causing it may not be identical with that found in America, and even although the external symptoms of wilting, &c., were not absolutely identical in the two continents. All these diseases have this in common, viz., that more or less premature death by desiccation of the plant occurs owing to the choking of the wood vessels with fungus mycelium. It has been proposed to apply the term *vascular-mycosis* to diseases of this type; but the term is not above criticism. Since the fungus mycelium is, at any rate in the early stages of the disease, confined to the wood vessels, and since these form only a part of the vascular system of a plant, it would seem much more desirable to use a still more precise term, and I, therefore, suggest the word "*hadromycosis*" for use in this connexion. It must be remembered that the vascular system of a plant does not consist of xylem alone; and, in view of the fact that another disease, which will be referred to in a moment, has been designated "*phloem-necrosis*," it seems eminently desirable to employ the term "*hadromycosis*" instead of the more clumsy one "*vascular-mycosis*."

It is interesting to note that Appel in one of his most recent publications<sup>2</sup> proposes to follow Orton, and says, "I wish to eliminate the name leaf-roll disease for the parasitic troubles, and substitute the name vascular-mycosis."

The term "Leaf-Roll" or "Blattrollkrankheit" should, therefore, now be applied only to certain diseases of the potato showing rolling of the foliage in which parasitic organisms are, as far as is known at present, not the causative agents. Whether there is only one such disease, or whether the term may still, for the present at any rate include several diseases, cannot be decided until further research throws the necessary light on the matter.

Very important work on Leaf-Roll (using the term in its restricted sense as above described) has recently been done by Quanjer.<sup>3</sup> This author

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<sup>1</sup> Orton, W. A., Potato Wilt, Leaf Roll, and related Diseases. Bull. 64. U. S. Dept. of Agric. Feb. 1914. [To this Bulletin is appended a very useful Bibliography of the subject under discussion.]

<sup>2</sup> Appel, O., Leaf Roll Diseases of the Potato. *Phytopathology*, vol. v., No. 3, 1915, p. 139.

<sup>3</sup> Quanjer, H. M., Die Nekrose des Phloëms der Kartoffelflanze, die Ursache der Blattrollkrankheit. *Med. v. d. Rijks Hoogere Land-, Tuin-, en Boschbouwschool*, vi, 1913.

shows that the disease is characterized by the degeneration of the phloem elements in the vascular tissue of affected plants, and he, therefore, uses the term "phloem-necrosis" to describe it. What the exact cause of this leptonecrosis (as it might also possibly be termed) may be is not yet understood; but further investigation will, no doubt, yield interesting and possibly far-reaching results.

The conclusion as regards the *Verticillium* disease is, however, a clear one, viz., that it is a specific disease caused by a definite parasitic fungus, and, as such, it is not for the future to be classed under either of the somewhat indefinite terms "Curl" or "Leaf-Roll," but rather to be regarded as a specific type of hadromycosis.

#### IX. DISTRIBUTION OF THE DISEASE, LOSSES CAUSED BY IT, AND SUGGESTED PREVENTIVE MEASURES.

The *Verticillium* disease of the potato seems to be fairly widespread on the continent of Europe, and is present in the United States of America. It is probably more or less prevalent in Great Britain, although, so far as I am aware, no British mycologist has reported its presence there.<sup>1</sup> Marshall Ward<sup>2</sup> published many years ago a preliminary description of a disease which very possibly may have been this particular one; but apparently the matter was never thoroughly investigated. Orton,<sup>3</sup> however, definitely states that he obtained specimens of the disease in England from Ormskirk and Reading.

Until the season of 1915, when two other cases of it came under my notice, both of them in early potatoes of the variety Beauty of Hebron, the only case of this disease which I had observed was the one found in 1909 and propagated ever since then at the Clifden Investigation Station for purposes of study. It should be stated that no special means have been taken to ascertain to what extent exactly it may be prevalent in Ireland, and it may possibly be commoner than one supposes. On the other hand, if it were really common, and if it caused appreciable losses, it is most unlikely that its presence in this country would have escaped the attention of the very numerous agricultural Inspectors, Instructors, and Overseers who are in such constant and close touch with our farmers.

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<sup>1</sup> As has already been pointed out, the species mentioned in Miss Dale's paper was probably not *Verticillium albo-atrum*, but some allied species.

<sup>2</sup> Ward, H. M., A Potato Disease. Rep. British Assoc. for Adv. of Science, 1898, p. 1046.

<sup>3</sup> *loc. cit.*, p. 87.

As regards losses, these are not easy to estimate, but for the whole country they cannot at present be considered serious. Weighings were made in 1914 of the yields of diseased and healthy plants growing under similar conditions of cultivation on one and the same type of soil. The average yield per plant of forty-seven healthy plants was thirty-six ounces, while that of forty-two diseased plants was only twenty-seven ounces, so that there was a loss of one-quarter of the crop owing to the disease. The plants were growing in both cases in very poor soil, and in the absence of the usual dressing of farm-yard manure; and it is quite possible that in a rich and well-manured soil the difference in the yields between healthy and diseased plants might be still more pronounced. Hence if the disease by any means became widespread throughout the country, the losses might be very considerable.

Since the disease is in all probability primarily contracted from the soil, a proper course of rotation of crops should be followed, and potatoes should not be cultivated for successive seasons on the same land. Where a diseased crop has been grown the soil is almost certain to be contaminated thereby, owing to the decayed and infected portions of the roots, rhizomes, and stalks remaining in it after the crop is lifted. These portions of the plant contain the fungus in them in its resting form ready to develop when the conditions are favourable for it. It is a sound practice to burn potato-stalks when the crop is lifted, as they may harbour not only the *Verticillium* disease, but also other pests.

The chief danger of introducing the disease into a new locality lies in the use of infected seed-tubers. Growers of potatoes for seed purposes should be particularly on the alert with regard to this disease. Should any affected plants be observed in the crop, it would be best that the crop in such a case should not be used for seed at all. If the affected plants are but few and far between, each one should be dug out lock, stock, and barrel as soon as possible. The tubers might be cooked and fed to pigs, but the foliage, stalks, and roots should be destroyed, as far as possible, by burning. Should growers have any difficulty in recognizing the disease, they should avail themselves of the advice of technical experts, which is now so easily obtainable. Farmers should scrutinize their seed-potatoes closely, and should look with suspicion on any tubers which show a brown discolouration of the vascular ring when cut across near the heel-end. Tubers showing this brown ring are not necessarily diseased, but very frequently they are, and they should be submitted for examination by a competent authority before being purchased or used for seed purposes.

It has been shown that all of the tubers produced by a diseased plant are

not necessarily infected, although the great majority of them certainly are. It has also been found that a small percentage of affected tubers may produce healthy plants with sound progeny, so that with proper care it would be possible in the course of a couple of seasons or so to raise a fresh stock of healthy seed-tubers from a previously diseased one.

It might be possible also to heat affected seed-tubers to a temperature high enough to kill the fungus in the wood vessels without injuring the vitality of the tubers themselves, as can be done with tubers attacked with *Phytophthora infestans*; experiments on this point are now being carried out, but the results will not be known for some time.

#### X. SUMMARY.

The *Verticillium* disease of the potato is one which results in the more or less premature death of the plant, the general symptoms exhibited being those of a process of gradual desiccation.

The mycelium of the fungus *Verticillium albo-atrum* R. and B. is found in the wood vessels of all parts of affected plants. It passes into the wood vessels of the new tubers, and from these again, in the great majority of cases, into the plants which develop from them. Hence the disease is transmitted by means of infected tubers. The fungus in the tuber is not necessarily strictly localized at or near the heel-end, as previous authors have supposed.

The fungus grows well in pure culture as a saprophyte, and infection experiments on healthy plants carried out with pure cultures were successful in reproducing the disease.

The disease was, to some extent at least, formerly covered by the terms "Curl" and "Leaf-Roll," but it is now to be removed from this category, and to be regarded as a specific type of those diseases in which the wood vessels become infested with fungus mycelium and for which the general term *hadromycosis* is suggested.

The disease does not appear to be very common in the British Isles, and the losses due to it are at present probably not large; but should it become prevalent, the losses might be severe. The most satisfactory preventive measures are to maintain a proper rotation of crops, and to take steps to ensure that the potatoes used for seed purposes are healthy.

XI. EXPLANATION OF PLATES.

PLATE II.

Fig.

1. A potato plant derived from a tuber naturally infected with *Verticillium albo-atrum*, and showing in the upper leaves of the central stalk the first external symptoms of the disease. Photographed August 12th, 1913.
2. The same plant completely killed as a result of the attack. Photographed September 17th, 1913.
3. The plant on the left (*a*) was inoculated in a sprout on May 11th, 1914, before planting, with a pure culture of *V. albo-atrum*. The photograph was taken on July 14th, 1914. The gradual and premature death of the foliage proceeding from below upwards will be observed. The control plant (*b*) was not inoculated, and was perfectly healthy.
4. The same two plants photographed six days later when the inoculated plant was quite dead, but the control still healthy.

PLATE III.

1. The mycelium of *V. albo-atrum* developing at the cut surfaces of wood vessels in the vascular ring of an old tuber which had produced a diseased plant.  $\times 50$ .
2. The black mycelium of *V. albo-atrum* developed in pure culture. No chlamydospores are present.  $\times 220$ .
3. Portion of a tuber which had produced a diseased plant, with the cortical tissues removed and showing the strongly browned network of woody tissue which still contained the mycelium of the fungus.  $\times 1\frac{1}{2}$ .
4. Longitudinal section through the xylem of an affected potato-stalk showing the blackened resting mycelium in the vessels and adjacent elements of the wood.  $\times 224$ .



5. Conidiophores of *V. albo-atrum* showing the spheres of conidia on the tips of the verticillate branches.    × 60.
6. Cut portions of affected potato-stalks which had been kept moist for a few days, showing the tufts of mycelium of *V. albo-atrum* growing out at the cut ends of the wood vessels.
- 7 An affected tuber with a thin slice of its heel-end removed, showing the discolouration of the tissues due to the presence of *V. albo-atrum*.



1.



2.



*a*

*b*

3.

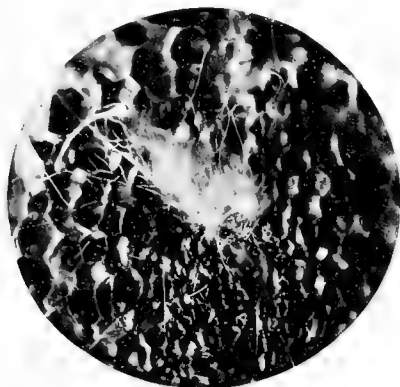


*a*

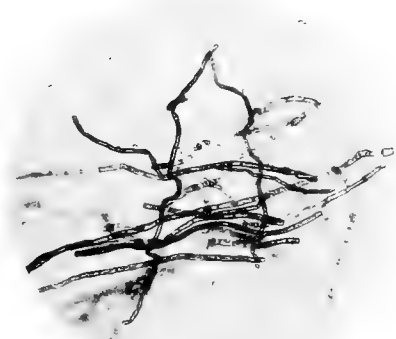
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4.

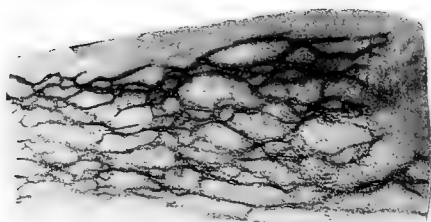




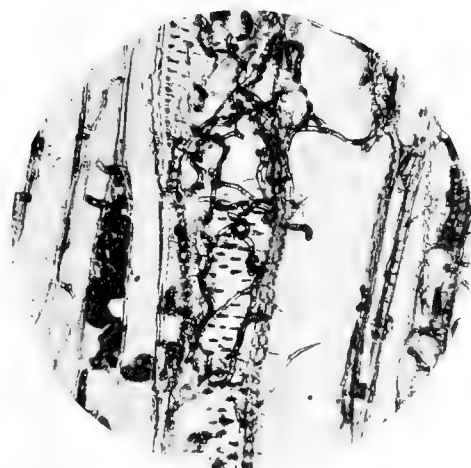
1.



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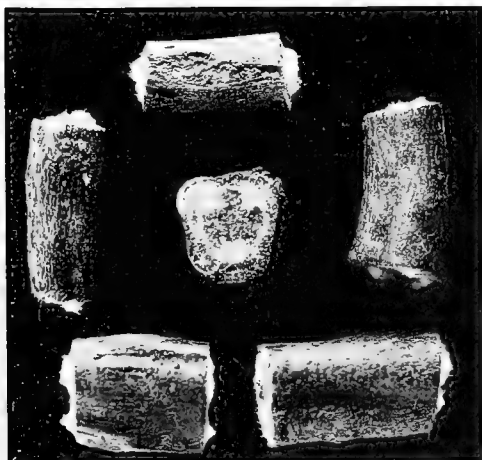
3.



4.



5.



6.



7.



## SCIENTIFIC PROCEEDINGS.

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1. The Subsidence of Torsional Oscillations and the Fatigue of Iron Wires when subjected to the Influence of Alternating Magnetic Fields of Frequencies up to 250 per second. By WILLIAM BROWN, B.SC. (January, 1916.) 6*d*.
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7. The Verticillium Disease of the Potato. By GEORGE H. PETHYBRIDGE, PH.D., B.SC. (Plates II-III.) (March, 1916.) 1*s*. 6*d*.



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ON THE BOILING-POINTS AND CRITICAL  
TEMPERATURES OF HOMOLOGOUS  
COMPOUNDS.

BY

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TRINITY COLLEGE, DUBLIN.



[*Authors alone are responsible for all opinions expressed in their Communications.*]

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## VIII.

ON THE BOILING-POINTS AND CRITICAL TEMPERATURES  
OF HOMOLOGOUS COMPOUNDS.BY SYDNEY YOUNG, D.Sc., F.R.S.,  
Trinity College, Dublin.

[Read MARCH 28. Published APRIL 3, 1916.]

IN the year 1842 Kopp made the statement that in every homologous series of organic compounds the boiling-point rises eighteen degrees for each addition of  $\text{CH}_2$ ; and although he afterwards modified his views to the extent that he adopted different constants for different homologous series, he still adhered to the conclusion that for each series the rise of boiling-point for each additional  $\text{CH}_2$  group was constant.

The error into which Kopp fell was due partly to the limited number and the uncertainty of the data available, but chiefly to the fact that the very numerous compounds—alcohols and acids—which contain a hydroxyl group exhibit abnormal physical properties. The same remark applies also, although in lesser degree, to the esters derived from the aliphatic alcohols and acids, and to certain other series of organic compounds. In all such series the abnormality diminishes with rise of molecular weight.

It is quite obvious that the paraffins and many of their derivatives are very far indeed from following Kopp's rule; and many attempts have been made to find a formula applicable to the boiling-points of these compounds.

In the earlier formulae it was sought to find a relation between the boiling-points and the number of atoms in the molecule, but none of these formulae gave satisfactory results, and it may be sufficient to mention that references to the original papers are given in Smiles's "Relations between Chemical Constitution and some Physical Properties," 1910, p. 222.

In 1894, Walker ("Journ. Chem. Soc." lxx., 193) proposed the formula  $T = aM^b$ , where  $T$  is the absolute boiling-point,  $M$  the molecular weight, and  $a$  and  $b$  are constants depending on the series; and in 1899 E. Boggio-Lera (Gazzetta, xxix., 1, 441) brought forward the formula  $T = a\sqrt{M} + c$ . Each author gave values of the constants for a number of homologous series; but it may be noted that when, as in most cases, the number of members of a series is small, and different constants are used for each series, it should not be difficult to get good agreement between the calculated and observed results if accurate data are available. The normal paraffins afford an excellent test of the utility of a formula, for the series is complete to  $C_{19}H_{40}$ , and there is no fear of complications due to molecular association.

For the normal paraffins the best results appear to be obtained by taking  $b = 0.5$  in Walker's formula and  $c = 0$  in Boggio-Lera's; the two formulae, therefore, become identical, and for  $a$  the value 37.38 may be adopted.

The calculated and observed values are given in Table I, and it will be seen that while the agreement is satisfactory from  $C_6H_{14}$  to  $C_{14}H_{30}$ , or perhaps  $C_{15}H_{32}$ , the deviations increase rapidly at lower and higher temperatures, and are very large for the lowest members of the series.

Ramage, in 1904 ("Cambridge Phil. Soc. Proc.," xii., 445), proposed a new formula,  $T = \alpha[M(1 - 2^{-n})]^2$ , in which  $\alpha = 37.3775$ , and has therefore the same value as the  $a$  in Walker's formula, and  $n$  is the number of carbon atoms in the molecule. This formula gives much better results at the lower temperatures, as will be seen from Table I, but for the highest members of the series  $2^{-n}$  is negligible, and the formula becomes identical with Walker's.

Last year a new formula,  $\log \theta = K(\log M)^s$ , was proposed by Ferguson ("Phil. Mag.," xxix., 599). This formula is of the same form as Walker's, but, in place of the absolute temperatures and the molecular weights, the logarithms of these values are taken. For the normal paraffins, Ferguson takes  $K = 1.929$  and  $s = 0.4134$ . The agreement between the calculated and observed temperatures is generally satisfactory from  $C_6H_{14}$  to  $C_{17}H_{36}$ , and the formula gives better results than those of Walker and Boggio-Lera or of Ramage, but the deviations become considerable below  $C_6H_{14}$  and above  $C_{17}H_{36}$  (*vide* Table I).

[TABLE I.]

TABLE I.  
*Boiling-points of Normal Paraffins.*

| Paraffin.                       | B.P.<br>(Abs.)<br>observed. | WALKER AND<br>BOGGIO-LERA. |                  | RAMAGE.          |                  | FERGUSON.        |                  | YOUNG.           |                  |
|---------------------------------|-----------------------------|----------------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|
|                                 |                             | Calcu-<br>lated.           | Differ-<br>ence. | Calcu-<br>lated. | Differ-<br>ence. | Calcu-<br>lated. | Differ-<br>ence. | Calcu-<br>lated. | Differ-<br>ence. |
| CH <sub>4</sub>                 | 108.3                       | 149.5                      | + 41.2           | 105.7            | - 2.6            | 121.05           | + 12.75          | 106.75           | - 1.55           |
| C <sub>2</sub> H <sub>6</sub>   | 180.0                       | 204.75                     | + 24.75          | 177.3            | - 2.7            | 184.75           | + 4.75           | 177.7            | - 2.3            |
| C <sub>3</sub> H <sub>8</sub>   | 229.0                       | 247.95                     | + 18.95          | 231.9            | + 2.9            | 233.75           | + 4.75           | 229.85           | + 0.85           |
| C <sub>4</sub> H <sub>10</sub>  | 272.8                       | 284.7                      | + 11.9           | 275.6            | + 2.8            | 274.7            | + 1.9            | 272.6            | - 0.2            |
| C <sub>5</sub> H <sub>12</sub>  | 309.2                       | 317.2                      | + 8.0            | 312.2            | + 3.0            | 310.2            | + 1.0            | 309.4            | + 0.2            |
| C <sub>6</sub> H <sub>14</sub>  | 341.95                      | 346.65                     | + 4.7            | 345.9            | + 1.95           | 341.9            | - 0.05           | 341.95           | 0                |
| C <sub>7</sub> H <sub>16</sub>  | 371.4                       | 373.8                      | + 2.4            | 372.3            | + 0.9            | 370.7            | - 0.7            | 371.3            | - 0.1            |
| C <sub>8</sub> H <sub>18</sub>  | 398.6                       | 399.1                      | + 0.5            | 398.3            | - 0.3            | 397.2            | - 1.4            | 398.1            | - 0.5            |
| C <sub>9</sub> H <sub>20</sub>  | 423.5                       | 422.9                      | - 0.6            | 422.5            | - 1.0            | 421.8            | - 1.7            | 422.85           | - 0.65           |
| C <sub>10</sub> H <sub>22</sub> | 446.0                       | 445.45                     | - 0.55           | 445.2            | - 0.8            | 444.8            | - 1.2            | 445.85           | - 0.15           |
| C <sub>11</sub> H <sub>24</sub> | 467.0                       | 466.9                      | - 0.1            | 466.8            | - 0.2            | 466.5            | - 0.5            | 467.35           | + 0.35           |
| C <sub>12</sub> H <sub>26</sub> | 487.5                       | 487.4                      | - 0.1            | 487.3            | - 0.2            | 487.0            | - 0.5            | 487.65           | + 0.15           |
| C <sub>13</sub> H <sub>28</sub> | 507.0                       | 507.05                     | + 0.05           | 507.0            | 0                | 506.4            | - 0.6            | 506.8            | - 0.2            |
| C <sub>14</sub> H <sub>30</sub> | 525.5                       | 526.0                      | + 0.5            | 526.0            | + 0.5            | 525.1            | - 0.4            | 525.0            | - 0.5            |
| C <sub>15</sub> H <sub>32</sub> | 543.5                       | 544.25                     | + 0.75           | 544.2            | + 0.7            | 542.9            | - 0.6            | 542.3            | - 1.2            |
| C <sub>16</sub> H <sub>34</sub> | 560.5                       | 561.95                     | + 1.45           | 561.9            | + 1.4            | 560.2            | - 0.3            | 558.85           | - 1.65           |
| C <sub>17</sub> H <sub>36</sub> | 576.0                       | 579.1                      | + 3.1            | 579.0            | + 3.0            | 576.4            | + 0.4            | 574.7            | - 1.3            |
| C <sub>18</sub> H <sub>38</sub> | 590.0                       | 595.75                     | + 5.75           | 595.7            | + 5.7            | 592.25           | + 2.25           | 589.9            | - 0.1            |
| C <sub>19</sub> H <sub>40</sub> | 603.0                       | 611.95                     | + 8.95           | 611.9            | + 8.9            | 607.55           | + 4.55           | 604.5            | + 1.5            |

In the year 1905 I pointed out ("Journ. de Chimie physique," iii., 245, and "Phil. Mag.," series 6, ix., 1) that the rise of boiling-point due to a CH<sub>2</sub> group may be regarded as a function of the absolute temperature, and I showed that the formula

$$\Delta = \frac{144.86}{T^{0.0148\sqrt{T}}}$$

(where  $\Delta$  is the difference between the boiling-point  $T$  of any normal paraffin and that of its next higher homologue) is applicable, not only to the series of normal paraffins, but to other series of organic compounds, with the exception of the lower members of such series. It is, of course, not applicable to substances the molecules of which are associated; but in any series of

associated compounds the deviations diminish with rise of molecular weight and eventually become small.

In Table I the values given were obtained by taking the absolute boiling-point of methane to be 106.75, and calculating the boiling-points of the succeeding paraffins from the values of  $\Delta$  given by the formula.

During the last few months a series of papers has been published in the *Journal of the American Chemical Society*, on the boiling-points and critical temperatures of some carefully prepared and purified paraffins. The data are tabulated below:—

*Absolute Boiling-points.*

|                 |         |                           |               |      |        |
|-----------------|---------|---------------------------|---------------|------|--------|
| Normal propane, | 229.0°, | Burrell and Robinson,     | . . . xxxvii, | 2188 | (1915) |
| Normal butane,  | 272.8°, | Burrell and Robinson,     | . . . " "     | " "  | " "    |
| Normal nonane,  | 423.5°, | Latham Clarke, and Adams, | . . . " "     | 2536 | " "    |
| Isobutane,      | 259.7°, | Burrell and Robinson,     | . . . " "     | 2482 | " "    |

*Absolute Critical Temperatures.*

|                |         |                      |               |      |        |
|----------------|---------|----------------------|---------------|------|--------|
| Normal butane, | 426.2°, | Siebert and Burrell, | . . . xxxvii, | 2683 | (1915) |
| Isobutane,     | 406.7°, | Siebert and Burrell, | . . . " "     | " "  | " "    |

The observed boiling-points of these paraffins differ somewhat from those given by previous authors; they are probably more accurate, and are adopted in Table I instead of the values given in earlier tables.

Taking the whole series from  $\text{CH}_4$  to  $\text{C}_{19}\text{H}_{40}$ , it is clear that the best results are given by the formula

$$\Delta = \frac{144.86}{T^{0.0148\sqrt{T}}},$$

and that, of the other formulae, Ferguson's is available over a wider range than either of the others. The relative availability of the formulae is shown by the following comparison:—

|   | Walker and<br>Boggio-Lera. | Ramage. | Ferguson. | Young. |
|---|----------------------------|---------|-----------|--------|
| Number of differences smaller than 1°                   | 8                          | 8       | 9         | 13     |
| Number of differences greater than 2°                   | 10                         | 8       | 5         | 1      |
| Greatest difference, . . . . .                          | 41.2°                      | 8.9°    | 12.75°    | 2.3°   |
| Greatest difference, omitting $\text{CH}_4$ , . . . . . | 24.75°                     | 8.9°    | 4.75°     | 2.3°   |

The boiling-points of only four members of the series of isoparaffins have been determined. These are given in Table II, together with the values of  $\Delta$  derived from the observed boiling-points, those calculated from the formula

$$\Delta = \frac{144.86}{T^{0.0148\sqrt{T}}},$$

and the differences between the calculated and observed

values of  $\Delta$ .

TABLE II.

*Boiling-points of Isoparaffins.*

| Formula.                       | Abs. B.P. | Δ.        |             |             |
|--------------------------------|-----------|-----------|-------------|-------------|
|                                |           | Observed. | Calculated. | Difference. |
| C <sub>4</sub> H <sub>10</sub> | 259·7°    | 41·25°    | 38·45°      | - 2·8°      |
| C <sub>5</sub> H <sub>12</sub> | 300·95°   | 34·05°    | 33·5°       | - 0·55°     |
| C <sub>6</sub> H <sub>14</sub> | 335·0°    | 28·3°     | 30·0°       | + 1·7°      |
| C <sub>7</sub> H <sub>16</sub> | 363·3°    |           |             |             |

The agreement is not so satisfactory as with the normal paraffins, and it may be noted that whereas in most homologous series the calculated values of Δ are higher than the observed in the case of the lowest members of the series, they are lower in this series.

*On the Relation between the Critical Temperatures and Boiling-points of Homologous Compounds.*

It was first suggested by Pawlewski [Berichte, xv., 460 and 2460 (1882); xvi., 2633 (1883)] that the difference between the critical temperature and the boiling-point was the same for all substances; but the compounds examined by him were of too similar character, and the rule is not really even roughly applicable to all substances. For example, the difference for hydrogen is 15°, and for benzene 208·3°.

In 1890 Guldberg (Zeitschr. phys. Chem., v., 374) pointed out that the absolute critical temperatures are roughly proportional to the absolute boiling-points; thus for hydrogen and benzene the ratios are 1·75 and 1·63.

I have shown (Stoichiometry, p. 183) that—

- (1) In any homologous series the ratios  $\frac{T_c}{T_b}$  diminish, though usually at a decreasing rate, with rise of molecular weight.
- (2) The ratios are generally nearly the same for the members of closely related (not homologous) substances.
- (3) In the case of isomeric substances the ratios for iso-compounds are higher than for normal, and for di-iso-compounds they are still higher.

It is now possible to add normal and iso-butane to the list of paraffins available for comparison, and as regards rules (1) and (3) we have the data given in Table III.

TABLE III.

*Ratios of absolute Critical Temperatures to absolute Boiling-points.*

## HOMOLOGOUS SERIES.

| Normal Paraffins.               | $\frac{T_c}{T_b}$ | Isoparaffins.                  | $\frac{T_c}{T_b}$ |
|---------------------------------|-------------------|--------------------------------|-------------------|
| CH <sub>4</sub>                 | 1.764             |                                |                   |
| C <sub>2</sub> H <sub>6</sub>   | 1.694             |                                |                   |
| C <sub>3</sub> H <sub>8</sub>   | 1.616             |                                |                   |
| C <sub>4</sub> H <sub>10</sub>  | 1.555             | C <sub>4</sub> H <sub>10</sub> | 1.566             |
| C <sub>5</sub> H <sub>12</sub>  | 1.520             | C <sub>5</sub> H <sub>12</sub> | 1.531             |
| C <sub>6</sub> H <sub>14</sub>  | 1.485             |                                |                   |
| C <sub>7</sub> H <sub>16</sub>  | 1.454             |                                |                   |
| C <sub>8</sub> H <sub>18</sub>  | 1.427             |                                |                   |
| C <sub>9</sub> H <sub>20</sub>  | —                 |                                |                   |
| C <sub>10</sub> H <sub>22</sub> | 1.402             |                                |                   |

## ISOMERS.

|               | $\frac{T_c}{T_b}$ |                | $\frac{T_c}{T_b}$ |
|---------------|-------------------|----------------|-------------------|
| Isobutane     | 1.566             | Isopentane     | 1.531             |
| Normal butane | 1.555             | Normal pentane | 1.520             |

## SCIENTIFIC PROCEEDINGS.

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7. The Verticillium Disease of the Potato. By GEORGE H. PETHYBRIDGE, PH.D., B.SC. (Plates II–III.) (March, 1916.) 1*s*. 6*d*.
8. On the Boiling-points and Critical Temperatures of Homologous Compounds. By SYDNEY YOUNG, D.SC., F.R.S. (April, 1916.) 6*d*.





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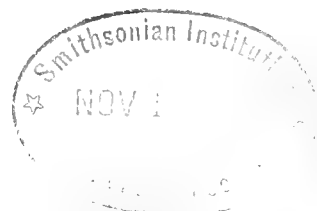
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THE SUBSIDENCE OF TORSIONAL OSCILLA-  
TIONS OF NICKEL WIRES WHEN SUBJECTED  
TO THE INFLUENCE OF TRANSVERSE  
MAGNETIC FIELDS UP TO 200 C.G.S. UNITS.

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[*Authors alone are responsible for all opinions expressed in their Communications.*]

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## IX.

THE SUBSIDENCE OF TORSIONAL OSCILLATIONS OF NICKEL WIRES WHEN SUBJECTED TO THE INFLUENCE OF TRANSVERSE MAGNETIC FIELDS UP TO 200 C.G.S. UNITS.

By WILLIAM BROWN, B.Sc.

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[Read FEBRUARY 22. Published APRIL 3, 1916.]

FOR some considerable time past I have, on various occasions, brought before this Society the results of experiments on the behaviour of iron and nickel wires when they were subjected to the influence of *longitudinal* magnetic fields, both continuous and alternating.

The present communication contains the results of some preliminary experiments with nickel wires when they were subjected to the influence of *transverse* magnetic fields. The transverse magnetic fields employed in the experiments were produced in a soft iron tube 220 cms. long, 2·54 cms. external diameter, and 1·6 cms. internal diameter, with a slot 0·5 cm. wide cut right through the wall over the whole length of the tube, the faces of the slot being 0·47 cm. wide. A bare copper wire 0·4 cm. diameter, painted with insulating varnish, was fixed in the central axis of the iron tube by means of a vulcanite bush at each end, and in order to keep the wire central throughout the length of the tube, thin vulcanite discs were placed at intervals. When an electric current is sent through the copper wire, a transverse magnetic field is produced in the slot; and when a nickel wire is placed in the slot, it will be subjected to the action of the transverse field, that is, to a steady continuous magnetic field or to an alternating magnetic field according as a direct current or an alternating current is sent through the copper wire.

The relation between the strength of the transverse magnetic field in the  
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gap or slot, and the strength of the current through the central copper wire, was found in the usual way, by means of an exploring coil, earth inductor, and ballistic galvanometer. The galvanometer employed was a moving-coil bifilar suspension ballistic galvanometer with a period of *eleven* seconds.

The strength of the magnetic field in the gap was found to be proportional to the current strength in the copper wire, in such a way that if we plot as abscissae the values of the current in the copper wire and as ordinates the corresponding values of the magnetic field strength in the slot, the points will lie on a straight line passing through the origin. Thus, if a line be drawn from the origin to a point corresponding to current = 80 amperes and magnetic field = 300 units, all the intermediate values will lie on that line.

The iron tube and copper wire were fixed vertically against the wall with suitable adjusting supports, and the nickel wire to be tested was suspended separately so as to hang in the middle of the slot in the iron tube. The free length of the nickel wire was 225 cms., thus leaving 2·5 cms. free from the iron tube at the top and bottom, the vibrating load on the lower end of the nickel wire had a small mirror attached, the distance of this mirror from the scale on which the amplitudes of the torsional oscillations were read, by means of a light-spot, was 167 cms. The maximum amplitude used was at the mark 300 on the millimetre scale, which corresponded to an angular twist of the lower end of the wire of about  $5^{\circ} 10'$  on each side of the zero on the scale.

The vibrating load was a non-magnetic cylinder composed of lead and brass, and the torsional oscillations were set up by the application of two properly timed simultaneous puffs of air which strike tangentially on the sides of the vibrator. A great many preliminary experiments were performed in order to find out the best method of procedure and also the most suitable load to use on the wire. With a given load on the wire, the subsidence of torsional oscillation was observed when *no* transverse magnetic field was on the wire, that is, when the wire was under the influence of the field due to the earth's magnetic force only; then a given electric current was sent through the central copper wire which gave a transverse magnetic field in the gap or through the nickel wire, and a series of observations of the torsional oscillations were again taken. This was done for magnetic fields of various values both direct and alternating. It was found that when the strength of the magnetic field approached 120 units, the nickel wire was inclined to be attracted to one or other face of the slot. In order to get over this tendency of the wire to move towards the side of the slot, the following plan was adopted:—One end of a *string of torsionless floss silk* was fixed by means of a small three-jaw

clutch, to the lower side of the vibrator in the axis of rotation, and after passing over two frictionless pulleys the other end had a scale pan attached on which weights could be placed.—In this way a longitudinal pull was produced (in addition to that due to the vibrator) along the axis of the nickel wire under test, and the string was carefully arranged so that there was no torsion. Though this extra pull does not *measurably* change the period of oscillation of the vibrator, it changes slightly the damping of the torsional oscillations as shown below in Table I in the column marked (d.c.).

In order, therefore (with the present arrangement of one copper wire down the middle of the iron tube), to be able to take the observations when magnetic fields up to 200 c.g.s. units were on the nickel wire, it was arranged to use throughout (1) a vibrating load on the end of the wire equivalent to  $2 \times 10^5$  grammes per sq. cm.; and (2) a load of 1670 grammes on the scale-pan end of the silk string, making in all a longitudinal pull on the wire under test equivalent to  $2.3 \times 10^5$  grammes per sq. cm.

The wire first tested was a No. 16 soft nickel wire of simple rigidity about  $708 \times 10^6$  grammes per sq. cm.

Observations on the subsidence of torsional oscillations were taken for *twelve* different values of transverse magnetic fields up to 200 c.g.s. units, both continuous and alternating, of frequency 50 per second, that is *twenty-four* sets of observations in all. When the values are plotted with the number of vibrations as abscissae and the corresponding values of the amplitude of oscillation as ordinates, we get the curve of subsidence of torsional oscillations referred to here as the damping curve.

It was found that the application of a continuous transverse magnetic field had no effect whatever on the damping of torsional oscillations, that is, the damping curves were identical for no field and for a continuous field of 200 c.g.s. units; but that a transverse alternating magnetic field had an effect on the damping curve, that is, for a magnetic field of the 200 units the amplitude of the 70th vibration was *decreased* about  $10\frac{1}{2}$  per cent. from its value with no field.

In Table I are given the values for no field, or the earth's magnetic field only, and for an alternating transverse magnetic field of 200 units; the values for the lower alternating transverse fields are not given in the table, but they all lie between the values given in the columns marked D.C. and A.C. The column marked (D.C.) gives the values of the amplitude of oscillation when the weight of 1670 grammes was on the scale-pan end of the torsionless silk string, that is, when the extra longitudinal pull through the string was on the wire, and the column marked (d.c.) gives the values when the silk string was off, there being no transverse magnetic field or a direct transverse field of

200 units in each case. The column marked (A.C.) gives the values when a transverse alternating magnetic field of 200 units, and frequency 50 per cent. per second, was on the wire; and with the full longitudinal load on, that is, the same load as was on when the values in column marked (D.C.) were observed.

TABLE I.

Rigidity  $\doteq 708 \times 10^6$  grammes per sq. cm.

| Number of Vibrations. | H = 200 |       |       |
|-----------------------|---------|-------|-------|
|                       | d. c.   | D. C. | A. C. |
| 0                     | 300     | 300   | 300   |
| 5                     | 282     | 283   | 281   |
| 10                    | 265     | 267   | 264   |
| 15                    | 250     | 253   | 248   |
| 20                    | 235     | 239   | 233   |
| 30                    | 210     | 215   | 206   |
| 40                    | 188     | 195   | 184   |
| 50                    | 170     | 178   | 166   |
| 60                    | 155     | 164   | 150   |
| 70                    | 143     | 153   | 137   |

From the values in the *third* and *fourth* columns in Table I, we find that the alternating field *decreases* the amplitude of the 70th vibration by  $10\frac{1}{2}$  per cent.; and from those in the *second* and *third* columns we see that the extra longitudinal pull on the wire, due to 1670 grammes, raises the damping curve, the amplitude of the 70th vibration being *increased* about 7 per cent. This extra weight being always on in the further experiments, comparison can be made on the effects of direct and alternating magnetic fields, and also when alternating fields of different frequencies are employed.

In order to find the effect of transverse magnetic fields of different frequencies on soft nickel wire, arrangements were made to obtain the same value of current from *three* different alternators, and it was found that the current most suitable was that which gave a transverse magnetic field of 65 units. Observations were made of the torsional subsidence when the wire was subjected to magnetic fields of frequencies 25, 50, 100, and 200 per second; and the results are given in Table II, where, for

comparison, the results for no field, or a direct field of 200 units are also given in column marked (D.C).

TABLE II.

Rigidity  $\doteq 708 \times 10^6$  grammes per sq. cm.

| Number of Vibrations | D. C. | A. C. H = 65 |        |         |         |
|----------------------|-------|--------------|--------|---------|---------|
|                      |       | n = 25       | n = 50 | n = 100 | n = 200 |
| 0                    | 300   | 300          | 300    | 300     | 300     |
| 5                    | 283   | 280          | 281    | 282     | 283     |
| 10                   | 267   | 263          | 264    | 265     | 266     |
| 15                   | 253   | 247          | 248    | 251     | 252     |
| 20                   | 239   | 233          | 235    | 237     | 238     |
| 30                   | 215   | 208          | 210    | 212     | 214     |
| 40                   | 195   | 187          | 190    | 192     | 194     |
| 50                   | 178   | 170          | 172    | 174     | 177     |
| 60                   | 164   | 155          | 158    | 160     | 162     |
| 70                   | 153   | 143          | 146    | 148     | 150     |

From the values in Table II it will be seen that there is slightly less damping of the torsional oscillations when the frequency of the magnetic field is increased ; thus, when the frequency is *increased* eight times, the amplitude of the 70th vibration is *increased* about  $4\frac{1}{2}$  per cent.

The soft nickel wire was then taken down from the apparatus, and a hard nickel wire put in its place. This new wire had a rigidity of about  $810 \times 10^6$  grammes per sq. cm., and it was put through exactly the same series of tests as the soft wire. In this case also it was found that the torsional subsidence curves were identical for all direct transverse magnetic fields from 0 to 200 c.g.s. units ; and that when an alternating transverse magnetic field of 200 units and frequency 50 per second was round the wire, the damping curve was below the curve obtained with the direct field. The results are given in Table III, and the values—not given—which were obtained with alternating magnetic fields up to 150 units were intermediate between the values given in the columns marked D.C. and A.C. in the table.

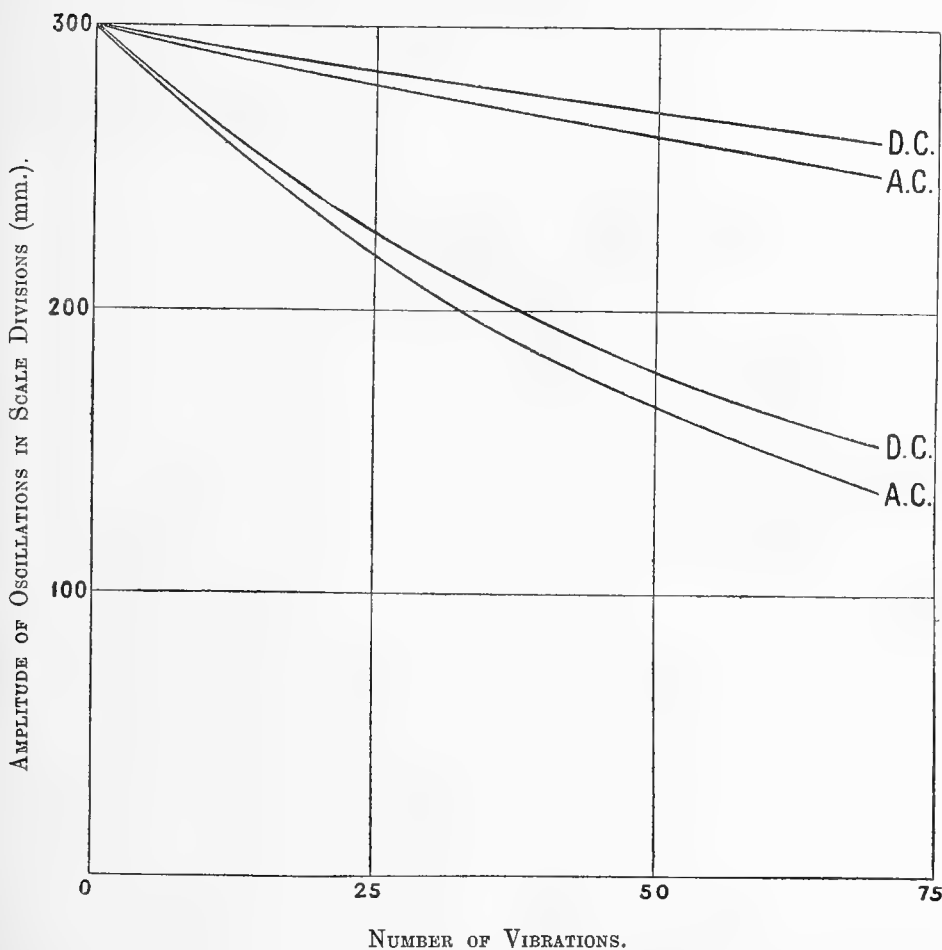


TABLE III.

Rapiditv  $\doteq 810 \times 10^6$  grammes per sq. cm.

| Number of<br>Vibrations. | H = 0 | H = 200            |
|--------------------------|-------|--------------------|
|                          | D. C. | A. C. ( $n = 50$ ) |
| 0                        | 300   | 300                |
| 5                        | 297   | 296                |
| 10                       | 294   | 292                |
| 15                       | 291   | 288                |
| 20                       | 288   | 284                |
| 30                       | 282   | 276                |
| 40                       | 276   | 269                |
| 50                       | 270   | 262                |
| 60                       | 264   | 255                |
| 70                       | 259   | 249                |

From the values in Table III it would seem that the application of a transverse alternating magnetic field of 200 units *decreases* the amplitude of oscillation of the 70th vibration by less than 4 per cent. as compared with  $10\frac{1}{2}$  per cent. when the wire was softer (Table I)—that is, for a difference of about  $12\frac{1}{2}$  per cent. in the rigidity. From Tables I and III we see that for the same difference in the rigidity the amplitude of the 70th vibration is *increased* nearly 70 per cent. for a direct magnetic field and about 81 per cent. for an alternating field of 200 units and frequency 50 per second. The results with the wires in the soft and hard state are shown in the form of curves in the figure (p. 105), when the two upper curves refer to the hard wire and the two lower to the wire in the soft state.



When the hard nickel wire was tested in a transverse alternating magnetic field of 65 units at frequencies 25, 50, 100, and 200 per second, the numbers obtained in each of the four cases were precisely the same as those in the column marked D. C. in Table III.—that is, alternating magnetic fields with the above frequencies and of value 65 units have no effect on the damping of the torsional oscillations of a hard nickel wire. This, of course, may not be true when stronger magnetic fields are applied, which will be subsequently tested when the apparatus now being prepared is in operation. The diminution of the amplitude of the 70th vibration by about  $10\frac{1}{2}$  per cent. with a transverse alternating magnetic field of 200 units and frequency 50 per second, when the nickel wire is soft, may be partly due to eddy currents set up in the wire itself. In order to test this, a non-magnetic soft No. 16 copper wire was

taken and put through the same series of tests as was the nickel wire, and though the presence of the nickel wire in the gap of the iron tube will increase the magnetic field, whereas the presence of the copper wire will slightly diminish it, still, the specific resistance of copper compared with nickel being in the ratio of 1:7.7, a comparison is possible. For strict comparison the magnetic field in which the copper is tested should be stronger than the field round the nickel when tested; this will be done when stronger fields are available. The copper wire had on a longitudinal load of  $2 \times 10^5$  grammes per sq. cm., and the subsidence of torsional oscillations was observed in transverse magnetic fields of values  $H = 0$ ,  $H = 200$  D.C.,  $H = 200$  A.C. ( $n = 50$ ) and  $H = 65$  A.C. ( $n = 50$ ) and ( $n = 200$ ), and the curves obtained in the five cases were precisely identical. It may be concluded therefore (for transverse magnetic fields up to 200 units) that eddy currents in the wire have little or no effect on the damping of the torsional oscillations.

For assistance in wiring up the apparatus, and in making some of the observations, I am indebted to Mr. R. Macaulay, the Electrician at the Royal College of Science.

## SCIENTIFIC PROCEEDINGS.

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THE  
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ON THE HYDROCARBONS OF BEESWAX.

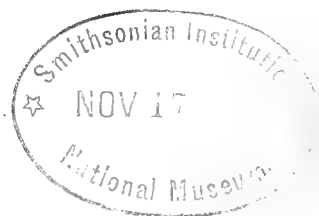
BY

HUGH RYAN, D.Sc.,

AND

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UNIVERSITY COLLEGE, DUBLIN.



[*Authors alone are responsible for all opinions expressed in their Communications.*]

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## X.

## ON THE HYDROCARBONS OF BEESWAX.

BY HUGH RYAN, D.Sc., AND THOMAS DILLON, D.Sc.,  
University College, Dublin.

[Read JANUARY 25. Published MAY 26, 1916.]

THIS research was undertaken with a view to throwing some light on certain anomalies with regard to the composition of beeswax, which have been observed in the results obtained by various investigators.

In 1812, J. F. John<sup>1</sup> discovered that beeswax could be divided into two parts—the one part, soluble in alcohol, he called “cerin,” and the other, which was sparingly soluble in that solvent, he named “myricin.”

John, Buchold, and Brandes,<sup>2</sup> and Boudet and Boissenot<sup>3</sup> were of opinion that beeswax consisted mainly “of cerin,” while B. C. Brodie,<sup>4</sup> to whom we are most largely indebted for our knowledge of the constituents of the wax, showed on the other hand that the major constituent of the wax is “myricin.”

Various conceptions of the chemical nature of “cerin” and “myricin” were formed during the first half of the nineteenth century. Thus Gerhardt,<sup>5</sup> starting from the hypothesis of Ettl<sup>6</sup> that “cerin” and “myricin” are isomeric substances, put forward the view that “myricin” is the “metaldehyde” of stearic acid, and in this way sought to explain the fact, noticed by Ettl, that beeswax, on distillation, forms a hydrocarbon melene ( $C_{30}H_{60}$ ).

These conceptions were, however, untenable, and it remained for the brilliant investigations of Brodie, in 1849, to establish the character of the two chief constituents of the wax.

<sup>1</sup> *Chemische Schriften*, 1812, iv., p. 38.

<sup>2</sup> *Repert.* iv., p. 145.

<sup>3</sup> *Journ. de Pharm.*, 1848, xiii., p. 42.

<sup>4</sup> *Phil. Trans.* 1848, p. 147; 1849, p. 91. *Liebig's Annalen der Chemie u. Pharm.*, 1849, lxxi., p. 144. *Journ. f. prakt. Chemie*, 1849, xlvi., p. 391.

<sup>5</sup> *Annales de Chimie* [3], 1845, xv., p. 236.

<sup>6</sup> *Liebig's Annalen der Chemie u. Pharm.*, 1832, ii., p. 253.



Brodie showed that the main constituent of "cerin" is cerotic acid, to which he gave the formula  $C_{27}H_{54}O_2$ . Many years afterwards R. Henriques<sup>1</sup> proved that the formula for cerotic acid is  $C_{26}H_{52}O_2$ .

According to Brodie myricin, on distillation, gave a mixture of fatty acids, the chief of which was palmitic, and hydrocarbons, such as melene; and on hydrolysis by means of alcoholic potash, it was converted into melissyl alcohol and potassium palmitate—reactions which prove that myricin is the melissyl ester of palmitic acid. He also found that when melissyl alcohol is heated with potash-lime it forms melissic acid ( $C_{30}H_{60}O_2$ ), and as he made no mention of the occurrence in the wax of any other alcohol, ceryl alcohol excepted, the conclusion to be drawn from his results is that the chief unsaponifiable constituent of beeswax is melissyl alcohol (with some ceryl alcohol).

After Brodie had established the general chemical character of the wax, the first to undertake a detailed examination of its non-acid constituents was Schwalb.<sup>2</sup>

Schwalb showed that beeswax contains about 7 per cent. of hydrocarbons, and that the melissyl alcohol described by Brodie is really a mixture of three alcohols, namely, melissyl alcohol ( $C_{31}H_{64}O$  ?), ceryl alcohol ( $C_{27}H_{56}O$ , or  $C_{26}H_{54}O$ ), and an alcohol having either the formula  $C_{25}H_{52}O$ , or  $C_{24}H_{50}O$ . He isolated from myricin two hydrocarbons which had nearly the same melting-points and percentage-compositions as normal heptacosane ( $C_{27}H_{56}$ ), and normal hentriacontane ( $C_{31}H_{64}$ ).

In 1890, A. and P. Buisine<sup>3</sup> undertook a complete quantitative examination of beeswax, determining the percentages of cerotic acid, combined palmitic acid, combined alcohols and hydrocarbons in several samples of wax.

The method they used for the estimation of the alcohols was similar to that which Hell<sup>4</sup> had previously described for the determination of the molecular weights of the higher primary alcohols. It consisted of measuring the volume of the hydrogen which was evolved when a weighed quantity of the wax was heated with a mixture of powdered potash and potash-lime to a temperature of 250° C. for two hours. The hydrocarbons were estimated in the same operation as that which served for the determination of the alcohols. When all the hydrogen had been evolved, the alcohols had presumably been converted into acids, and been fixed by the potash. The substances

<sup>1</sup> Ber. Deutsch. Chem. Gesell. 1897, xxx., p. 1418.

<sup>2</sup> Liebig's Annalen der Chemie u. Pharm., 1886, ccxxv., p. 106.

<sup>3</sup> Bull. Soc. Chim., 1890 [3], iii., p. 867.

<sup>4</sup> Liebig's Annalen der Chem. u. Pharm., 1884, ccxxiii., p. 264.

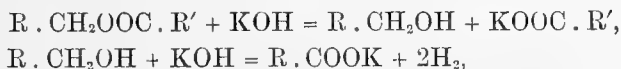
extracted by petroleum ether from the residue were assumed to consist entirely of hydrocarbons.

The results obtained by this method present, however, discrepancies, which become apparent on examining the figures for any one of the many samples analysed. Thus in a wax from the department of Somme they found:—

|                                       |                 |
|---------------------------------------|-----------------|
| Ester number . . . . .                | 72.22           |
| Cerotic acid . . . . .                | 14.87 per cent. |
| Palmitic acid . . . . .               | 32.95 „ „       |
| “Melissyl alcohol” . . . . .          | 52.64 „ „       |
| Hydrocarbons . . . . .                | 13.39 „ „       |
| Volume of hydrogen from 1 gram of wax | 53.5 c.c.s.     |

Now, the ester number of a wax, that is the number of milligrams of potash required to hydrolyse the esters in 1 gram of the wax, is very simply related to the volume of hydrogen evolved, when 1 gram of the wax is heated to 250° C. with potash lime.

The equations for the reactions being:—



it follows that one gram-molecule of the ester  $R \cdot CH_2OOC \cdot R'$ , or of the alcohol  $R \cdot CH_2OH$  will evolve 44.52 litres of hydrogen, at normal temperature and pressure, when heated with potash-lime. If  $M$  is the molecular weight of the ester or alcohol, then the number of cubic centimetres of hydrogen evolved from 1 gram of the ester or alcohol is  $\frac{44520}{M}$ , and since 56.15 grams of potash are required to hydrolyse 1 gram-molecule of the ester, we have  $\frac{Me}{1000} = 56.15$ , where “e” is the ester number, and finally

$$N = \frac{e \times 44520}{1000 \times 56.15} \text{ c.c.}$$

The volume of hydrogen theoretically obtainable from 1 gram of the wax, the analysis of which is given above, is 57.25 c.c., and the volume actually found by A. and P. Buisine was 53.5 c.c. Since the volume of the hydrogen evolved was only 93.45 per cent. of the theoretical, it follows that 6.55 per cent. of the alcohols from which the esters are derived evolved no hydrogen. This may have been due to incompleteness of the reaction, or to the presence of alcohols other than primary in the esters, or to both these causes.

Direct experiments with melissyl alcohol, which we carried out, showed that the reaction, although nearly, is not quite complete—the alcohol evolving 95·9 per cent. of the quantity of hydrogen theoretically obtainable from it by interaction with potash-lime.

In the experiment of A. & P. Buisine the amount of combined primary alcohols in 100 grams of the wax, which, owing to incompleteness of the reaction, does not evolve hydrogen, may be taken as 2·16 grams; and as the total amount of combined alcohols which evolved no hydrogen was 3·45, it is possible that a very small portion, about 1·3 per cent., may consist of combined alcohols other than primary. We, therefore, examined the behaviour of some synthetical higher tertiary and secondary alcohols towards potash-lime, and found that they did not evolve hydrogen, so that if esters derived from alcohols similar to these were present in the wax, the volume of hydrogen evolved would be less than that calculated from the ester number of the wax.

Our experiments also indicate that the so-called hydrocarbons extracted by petroleum ether from the product of the interaction of the wax with potash-lime contain on an average about 0·8 per cent. of oxygen.

With regard to the percentage of hydrocarbons in beeswax, Schwalb stated that it is about 7, and A. and P. Buisine that it is about 14, of which, however, we have shown above that a portion is due either to incompleteness of the reaction or to incompleteness of the reaction and the presence of higher alcohols other than primary. It is difficult to explain the difference, 3·5 per cent., between the figure of A. and P. Buisine as corrected by us and that of Schwalb, unless we assume that a slight further action of potash-lime on the acids leads to the formation of hydrocarbons.

#### EXPERIMENTAL PART.

##### I. ACTION OF POTASH-LIME ON ALCOHOLS.

1. *Melissyl alcohol*.—Melissyl alcohol (0·5061 gram) was melted with an equal weight of finely powdered potash in a porcelain capsule on the water-bath. The solid mass obtained on cooling was powdered in a mortar, intimately mixed with about ten times its weight of dry powdered potash-lime, and transferred completely to the hard glass tube of Buisine's apparatus, in which it was heated to 250° C. for three hours. The volume of hydrogen obtained was 53·5 c.c. at 21·5° C. at 748 mmp., which, when reduced to standard temperature and pressure, became 48·83 c.c. Hence the volume from one gram of the alcohol was 97·35 c.c., whereas that theoretically obtainable is 101·53 c.c.

It is possible, therefore, that of the 6·55 per cent. of alcohols, which in the

case of beeswax give no hydrogen, 4.1 per cent. may be due to incompleteness of the reaction, and, if the evolution of hydrogen from the alcohols is not interfered with by the other constituents of the wax, about 2.45 per cent. of the wax, although capable of combining with acids to form esters, does not give hydrogen when heated with potash-lime.

Such alcohols may be secondary or tertiary, and in order to test this view higher tertiary<sup>1</sup> and secondary<sup>2</sup> alcohols were synthesized, and their behaviour towards potash-lime was investigated.

2. *Dimethyl-Heptadecyl Carbinol.*—The tertiary alcohol dimethyl-heptadecyl carbinol,  $C_{17}H_{35} \cdot C(CH_3)_2 \cdot OH$ , was melted on the water-bath and mixed with an equal weight of powdered potash. When cold the mass was well mixed in a mortar with ten parts of finely powdered potash-lime and then transferred completely to a hard glass tube. The latter was connected to a Toepler pump, exhausted of air, and then heated in a mercury-bath. On raising the temperature slowly to 220° C. water came over, but no hydrogen was evolved.

Most of the dimethyl-heptadecyl carbinol was recovered unchanged from the product. At higher temperatures water was given off, but there was still no evolution of hydrogen.

3. *Diphenyl-Heptadecyl Carbinol and Pentadecyl-p. Tolylyl Carbinol.*—Similarly, at temperatures not exceeding 250° C., the tertiary alcohol diphenyl-heptadecyl carbinol,  $C_{17}H_{35} \cdot C(C_6H_5)_2 \cdot OH$ , and the secondary alcohol pentadecyl-p. tolylyl carbinol,  $C_{15}H_{31} \cdot CHOH \cdot C_6H_4CH_3$ , did not evolve hydrogen when heated with potash-lime.

4. *Glucose.*—By interaction with potash-lime at 250° C. glucose gave a volume of hydrogen slightly smaller than that which corresponds to the one primary alcoholic group which the substance contains. The secondary alcoholic groups did not contribute to the evolution of hydrogen under these conditions.

## II. THE HYDROCARBONS.

The hypothesis formed by us that alcohols are contained in the so-called hydrocarbons extracted by Buisine's method was subjected to a direct test by determining the percentages of carbon and hydrogen in the extract.

Myricin, prepared from Irish beeswax by extraction in the manner described by one of us,<sup>3</sup> was hydrolysed with potash, and the unsaponifiable

<sup>1</sup> Proc. Royal Irish Acad., 1912, xxix., B, p. 235.

<sup>2</sup> Proc. Royal Irish Acad., 1912, xxx., B, p. 1.

<sup>3</sup> Proc. Royal Dublin Soc., 1909, xii. (N.S.), p. 212.

matter was extracted from the dry residue by means of petroleum ether. The unsaponifiable matter was melted on the water-bath in a porcelain capsule, and an equal weight of finely powdered potash was stirred into the mixture. Powdered, dry potash-lime was next added, the wax and the alkali were intimately mixed by rubbing in a mortar, and the mixture was introduced into the hard glass tube of Buisine's apparatus. The tube was heated to 230°–250° C. until evolution of hydrogen ceased; its contents were then transferred to a Soxhlet apparatus and extracted with petroleum ether. The product was again heated with potash and potash-lime as before, and, if on the second heating no gas was evolved, the percentages of carbon and hydrogen in the extract obtained at this stage were determined.

Four different specimens prepared in this manner gave on analysis the following results:—

- I. 0·1124 substance gave 0·3512 CO<sub>2</sub> and 0·1429 H<sub>2</sub>O
- II. 0·1237 substance gave 0·3874 CO<sub>2</sub> and 0·1529 H<sub>2</sub>O
- III. 0·1020 substance gave 0·3178 CO<sub>2</sub> and 0·1274 H<sub>2</sub>O
- IV. 0·0705 substance gave 0·2206 CO<sub>2</sub> and 0·0867 H<sub>2</sub>O

corresponding to

|          | I.    | II.   | III.  | IV.   |
|----------|-------|-------|-------|-------|
| C, . . . | 85·21 | 85·41 | 84·97 | 85·34 |
| H, . . . | 14·22 | 13·83 | 13·98 | 13·76 |
| O, . . . | 0·57  | 0·76  | 1·05  | 0·9   |

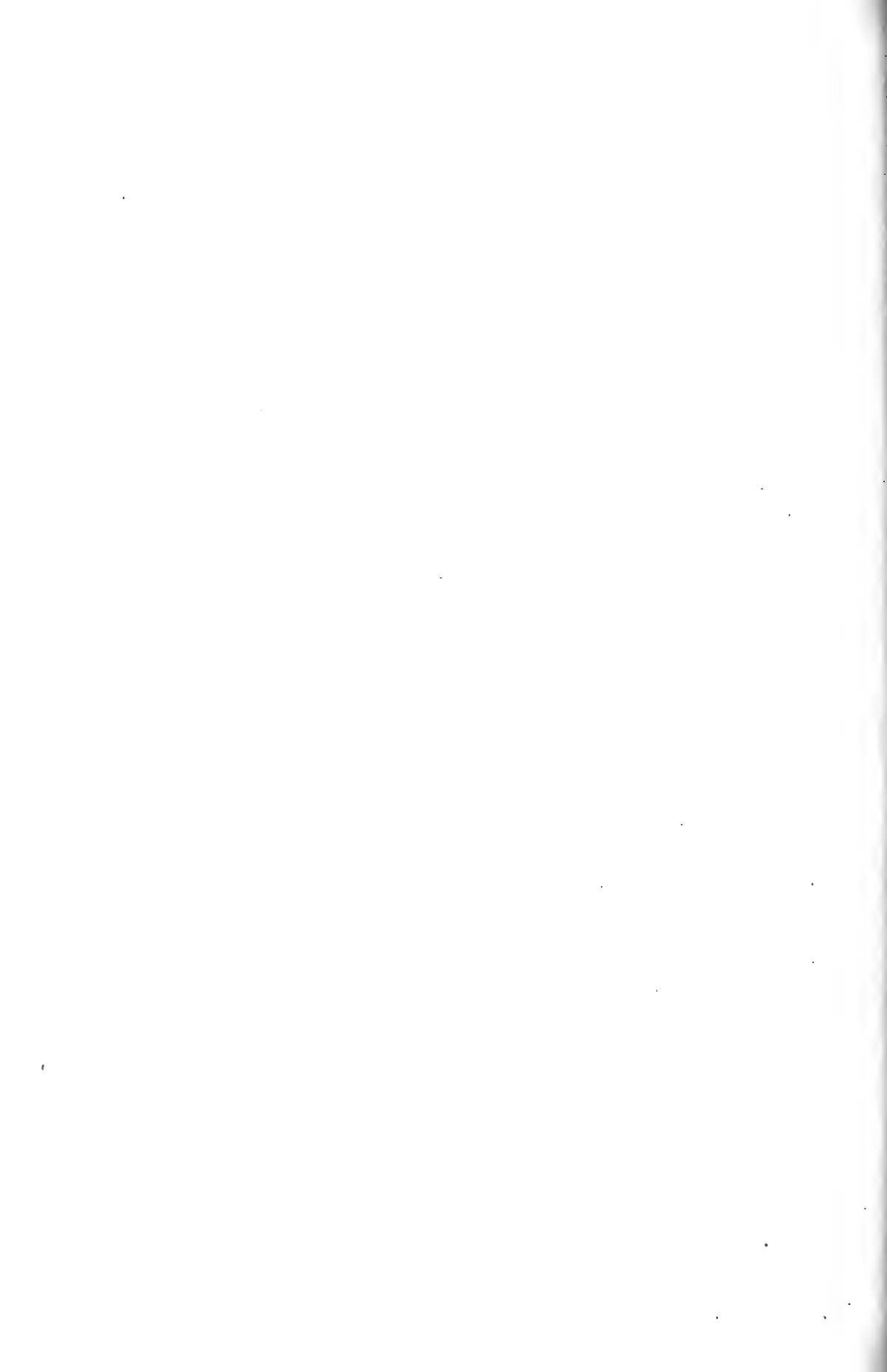
As all the specimens contained oxygen, the so-called hydrocarbons must contain a small quantity of an oxygenated substance or substances. We also determined the percentage of these so-called hydrocarbons in a sample of Irish beeswax, using apparatus similar to that designed by A. and P. Buisine, working in the manner they recommend, and confirmed the results which they obtained.

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ON DESOXY-HYDROCATECHIN-TETRAMETHYL-  
ETHER.

BY

HUGH RYAN, D.Sc.,

AND

MICHAEL J. WALSH, M.Sc.,

UNIVERSITY COLLEGE, DUBLIN.



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## XI.

## ON DESOXY-HYDROCATECHIN-TETRAMETHYL-ETHER.

[PRELIMINARY COMMUNICATION.]

BY HUGH RYAN, D.Sc., AND MICHAEL J. WALSH, M.Sc.,

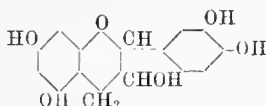
University College, Dublin.

[Read JANUARY 25. Published MAY 26, 1916.]

GAMBIR CATECHU, an extract from the twigs of *Uncaria catechu* and *Uncaria acida*, is used for the tanning of skins and the dyeing of cotton or wool. Catechin, the main constituent of the extract, was isolated by van Eisenbeck in 1832.<sup>1</sup>

In 1902, A. G. Perkin and E. Yoshitake<sup>2</sup> showed that *Gambir catechu* contains two different catechins, one melting at 175° C., and the other at 235° C., and that catechu—an extract from *Acacia catechu*—contains another catechin which melts at 204° C. Since these catechins, on decomposition, are resolved into catechol and phloroglucinol, they must be very closely related.

The formula



proposed by Perkin and Yoshitake for catechin formed the first real attempt to represent graphically the chemical behaviour of catechin.

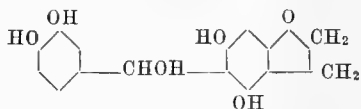
This formula is in agreement with the formation of catechin-tetramethyl-ether, catechin-pentacetate, with the decomposition of the substance into catechol and phloroglucinol, with the formation of catechone-trimethylether, and with the possibility of resolving catechin, or its monocarboxyl derivative, into optically active components, as M. Nierenstein<sup>3</sup> has succeeded in doing in the case of the latter substance.

<sup>1</sup> Liebig's *Annalen der Chemie u. Pharm.*, 1832, i., p. 243.

<sup>2</sup> *Journ. Chem. Soc.*, 1902, lxxxi., p. 1169.

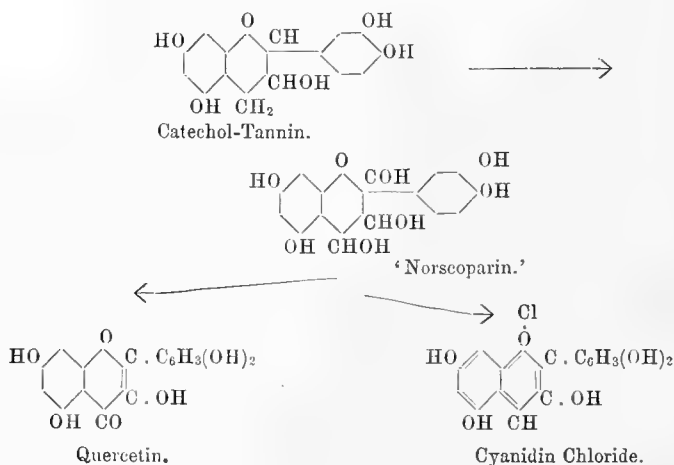
<sup>3</sup> Liebig's *Annalen der Chemie*, 1913, cccxcvi., p. 194.

St. von Kostanecki and V. Lampe,<sup>1</sup> assuming that a compound which contains the grouping  $\begin{array}{c} \diagup \text{C}-\text{C} \diagdown \\ \text{H} \quad \text{OH} \end{array}$  would split off water more easily than catechin does, replaced the chromane formula of Perkin and Yoshitake by the coumarane formula



The chromane formula has nevertheless some advantages which are not possessed by that of von Kostanecki and Lampe.

It has been pointed out by A. G. Perkin,<sup>2</sup> that there is a very close relationship between the nuclear groups of tannins and those of the flavone dyes which occur associated with the tannins in many plants. Thus catechin and quercetin, which occur in catechu, both contain the catechol and the phloroglucinol nuclei. Facts such as these, which can scarcely be regarded as casual coincidences, suggest the probability that the flavone dyes—and the same may be said of the members of the anthocyan group, the chemical nature of which has recently been elucidated by Willstaetter and his pupils—are formed in the plants from the more widely distributed phloba-tannins. Thus it is easy to see that catechol-tannin, if it has the formula given to it by Perkin and Yoshitake, may pass by the relatively simple processes of oxidation and dehydration into either cyanidin or quercetin:—



In support of the view here put forward we may mention that the substance known to botanists as “soluble starch,” which occurs in the epidermis of the

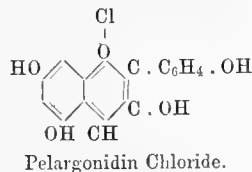
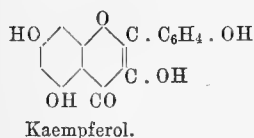
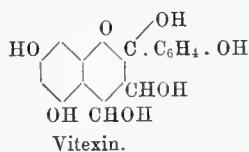
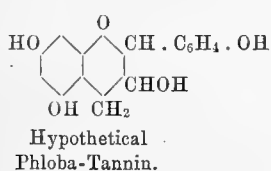
<sup>1</sup> Ber. d. Deutsch. Chem. Ges., 1906, xxxix., p. 4007.

<sup>2</sup> Journ. Chem. Soc., 1897, lxxi., p. 1138.

leaves of many plants, and which was isolated from *Saponaria officinalis* by G. Barger,<sup>1</sup> was shown to be a glycoside of vitexin; a substance previously obtained by A. G. Perkin,<sup>2</sup> and which is closely related to the hypothetical dihydroxy-catechol-tannin mentioned above.

Moreover, as A. G. Perkin has shown that scoparin is probably monomethoxy-vitexin, the former substance should on this hypothesis be the monomethylether of dihydroxy-catechol-tannin.

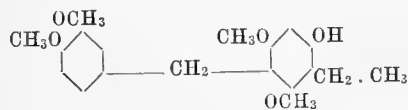
Just as demethylated scoparin (norscoparin) may be regarded as the intermediate compound between catechol-tannin and the anthocyan cyanidin or the flavonol quercetin, so vitexin may fulfil the same role for a phloba-tannin on the one hand, and the anthocyan pelargonidin or the flavonol kaempferol on the other hand.



The main objection to the formula of Perkin and Yoshitake is the fact that catechin-tetramethylether forms with ease only a monobromo derivative, and that although catechin-tetramethylether can be oxidised to the quinone, catechone-trimethylether, monobromo-catechin-tetramethylether cannot be oxidised to a quinone. These reactions, which are difficult to interpret from the chromane formula, are quite in accordance with the coumarane formula.

Since the two formulae have been developed by analytical methods, which are in themselves not conclusive, we deemed it of interest to try to discriminate between them by a synthetical process.

By energetical reduction of catechin-tetramethylether, von Kostanecki and Lampe<sup>3</sup> obtained an oily product which they termed desoxy-hydrocatechin-tetramethylether, and to which they assigned the formula



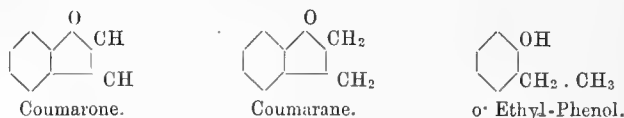
<sup>1</sup> Journ. Chem. Soc., 1906, lxxxix., p. 1210.

<sup>2</sup> Journ. Chem. Soc., 1900, lxxvii., p. 416.

<sup>3</sup> Ber. d. Deutsch. Chem. Ges., 1907, xl., p. 720.

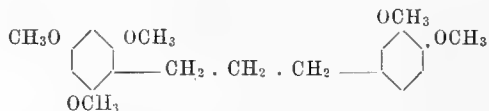
which is based on their formula for catechin, and on the analogy between their experiment and that by which Hans Alexander<sup>1</sup> converted coumarane into *o*. ethylphenol.

By the action of sodium and alcohol on coumarone, Alexander obtained coumarane as primary product, and the phenol as secondary product.



Desoxy-hydrocatechin-tetramethylether, which is soluble in alkali, was further methylated by von Kostanecki and Lampe, forming a well-crystallized pentamethylether, which melted at 83°–84° C.

If, however, the chromane formula be assumed correct, the desoxy-hydrocatechin-pentamethylether will be represented by



As the synthesis of dimethoxy- $\gamma$ -phenylpropyl-phloroglucinol-trimethylether seemed more difficult to realize than that of 3-ethyl-2.4.6.3'.4'-pentamethoxy-diphenyl-methane, we attempted the synthesis of the latter in preference to that of the former substance.

Vanillin was converted by means of potash and dimethyl sulphate into veratric aldehyde, and the latter was oxidised by potassium hypobromite to veratric acid. Veratroyl chloride was prepared from the acid by means of thionyl chloride.

Since Coto bark residues were not available, we were obliged to prepare phloroglucinol-trimethylether directly from phloroglucinol, and after several experiments we found that the best method of effecting this operation was by a slight modification of that described by J. Herzig and Br. Erthal.<sup>2</sup>

Following the procedure previously employed by von Kostanecki and Tambor<sup>3</sup> for the preparation of phloracetophenone-trimethylether, the latter substance was obtained, and this on reduction with amalgamated zinc and hydrochloric acid was converted into the ethyl homologue of phloroglucinol-trimethylether:—



<sup>1</sup> Ber. d. Deutsch. Chem. Ges., 1892, xxv., p. 2409.

<sup>2</sup> Monatsh. f. Chemie, 1911, xxxii., p. 481.

<sup>3</sup> Ber. d. Deutsch. Chem. Ges., 1899, xxxii., p. 2262.



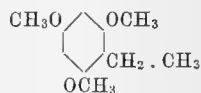
solution, which was kept constantly stirred during the operation. When all the dimethyl sulphate had been run in, potash and dimethyl sulphate were again added in the same manner as before. The mixture was cooled, made slightly alkaline, and distilled in a current of steam. The oily distillate was reserved, and the residue in the distillation flask was acidified and extracted with ether. On evaporating the ether an oily residue was obtained, which was again methylated, and distilled with steam as before. The phloroglucinol-trimethylether, which distilled with the steam as a colourless oil crystallizing on standing, was filtered and dried in a vacuum desiccator. It melted at 52°-53° C. The yield was 3 grams.

### 2. *Phloracetophenone-Trimethylether.*

Phloracetophenone-trimethylether was obtained from phloroglucinol-trimethylether by the method described by von Kostanecki and Tambor.<sup>1</sup>

Phloroglucinol-trimethylether (4 grams) was added to a solution of 5 grams of acetyl chloride in 20 c.c. of dry carbon disulphide contained in a round flask of 200 c.c. capacity. Anhydrous ferric chloride (6.5 grams) was then added, and the mixture was heated on the water-bath under a reflux condenser, protected from atmospheric moisture by a calcium chloride tube until the evolution of hydrochloric acid ceased. The carbon disulphide was distilled, and the residue was washed with ice-cold, acidulated water. Hot water was added to a solution of the substance in boiling alcohol until the mixture became turbid. The solid, which was deposited on cooling, after recrystallization from dilute alcohol, melted at 99-100° C. The yield of the ketone was nearly quantitative.

### 3. *Ethylphloroglucinol-Trimethylether.*



In a round flask of about 300 c.c. capacity, 15 grams of ordinary granulated zinc were covered with a cold 5-per cent. solution of mercuric chloride, and the mixture was allowed to stand for a few hours at the temperature of the laboratory. The solution was poured off from the amalgamated zinc, and the latter was used for the reduction without further washing or drying. Phloracetophenone-trimethylether (3 grams), water (30 c.c.), and concentrated hydrochloric acid (15 c.c.), were added to the flask, and the contents were heated to gentle boiling under a reflux condenser for six hours. At intervals during the process a mixture of equal parts of concentrated hydrochloric acid and water was added to the contents of the flask. The oily product of the reaction was extracted with ether, the solvent was evaporated, and the residual oil was distilled in a current of

<sup>1</sup> Ber. d. Deutsch. Chem. Ges., 1899, xxxii., p. 2262.

steam. The oil contained in the distillate was converted, on standing, into a colourless, crystalline solid, which, when dried in a vacuum desiccator, melted at 29°–30° C., and gave on analysis the following results:—

0.1771 substance gave 0.4353 CO<sub>2</sub> and 0.1404 H<sub>2</sub>O,  
 corresponding to C 67.02, H 7.92,  
 C<sub>11</sub>H<sub>16</sub>O<sub>3</sub> requires C 67.35, H 8.16.

Ethylphloroglucinol-trimethylether in appearance resembles phloroglucinol-trimethylether. It dissolves readily in the ordinary organic solvents, such as alcohol and ether. It is insoluble in water or dilute aqueous potash.

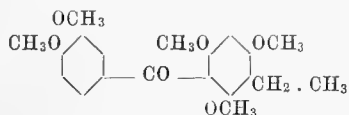
4. *Veratroyl-Chloride.*

Vanillin (25 grams) was converted into veratric aldehyde by dissolving it in 32 c.c. of 25 per cent. aqueous potash, heating to boiling on a sand-bath, and adding 45 grams of dimethyl sulphate in two instalments. The product of the reaction was cooled, diluted with water, and extracted with ether. On evaporation of the ether the aldehyde was deposited in the form of colourless crystals.

The aldehyde was oxidized to veratric acid by means of bromine and potash. Veratric aldehyde (10 grams) was added to a solution of bromine (10 grams) and potash (14 grams) in 200 c.c. of water. The mixture was heated to boiling on a sand-bath, and kept constantly agitated by a current of air which was aspirated through it. The heating was continued until the oil had all dissolved. The solution was cooled, and after addition of 1 gram of sodium bisulphite the veratric acid was precipitated by acidifying the solution with hydrochloric acid. When recrystallized from boiling alcohol it melted at 178°–180° C.

The veratric acid (5 grams) was converted into veratroyl chloride by heating with thionyl chloride (7 grams) until the reaction was finished. On fractional distillation of the product the veratroyl chloride came over in the neighbourhood of 290° C. as an oil, which quickly changed to a colourless crystalline solid, melting at 68°–69° C.

5. *Veratroyl-Ethylphloroglucinol-Trimethylether.*



An intimate mixture of 2.5 grams of ethyl-phloroglucinol-trimethylether and 4 grams of veratroyl chloride was placed in a dry round flask, and covered with a layer of dry carbon disulphide. About 4 grams of powdered, anhydrous, resublimed aluminium chloride were added, and the mixture was



heated on the water-bath, under a reflux condenser, until the evolution of hydrochloric acid had ceased. The flask was allowed to stand over-night, and its contents were then added to ice-cold, acidulated water. The unchanged phloroglucinol-trimethylether was distilled in a current of steam; the residue left in the distillation flask was filtered, washed with a little warm aqueous alkali, and recrystallized a few times from alcohol. It melted at  $123^{\circ}$ – $124^{\circ}$  C., and gave on analysis the following results :—

0.1097 substance gave 0.2680  $\text{CO}_2$  and 0.0660  $\text{H}_2\text{O}$ ,  
 corresponding to C 66.63, H 6.68,  
 $\text{C}_{20}\text{H}_{24}\text{O}_6$  requires C 66.66, H 6.66.

Veratroyl-ethylphloroglucinol-trimethylether crystallizes from alcohol in colourless plates, which are insoluble in water or dilute alkali, and soluble in chloroform, alcohol, ether, or benzene.

#### 6. *Reduction of Veratroyl-Ethylphloroglucinol-Trimethylether.*

(a) *Sodium and Alcohol.*—A solution of 0.55 grams of veratroyl-ethylphloroglucinol-trimethylether in 50 c.c. of absolute alcohol was heated to boiling under a reflux condenser, and 2 grams of sodium were added rapidly in small portions, through the tube of the condenser. When all the sodium had dissolved the excess of alcohol was removed by distillation in a current of steam. The oily residue in the distillation flask was extracted with ether, the ethereal layer was washed with dilute alkali, dried, and allowed to evaporate. The oil, which remained, was very soluble in the usual organic solvents, such as ether and alcohol. On prolonged standing in the air or in a vacuum desiccator, with or without addition of solvents, it did not crystallize.

(b) *Amalgamated Zinc and Hydrochloric Acid.*—Veratroyl-ethylphloroglucinol-trimethylether (0.85 gram) was reduced by means of amalgamated zinc and hydrochloric acid by a method similar to that by which phloracetophenone-trimethylether was converted into ethylphloroglucinol-trimethylether. The oily reaction-product was extracted with ether, the ethereal solution was washed with dilute aqueous potash, dried, and allowed to evaporate. As in the case of the reduction with sodium and alcohol the small quantity of oil which was obtained was readily soluble in the ordinary organic solvents, and could not be converted into a crystalline form.

When a solution of the oil in the least possible quantity of absolute alcohol was inoculated with one or two crystals of desoxy-hydrocatechin-pentamethylether, which was prepared from catechin by the method described by Von Kostanecki and Lampe,<sup>1</sup> and allowed to stand in a vacuum desiccator, the substance did not crystallize.

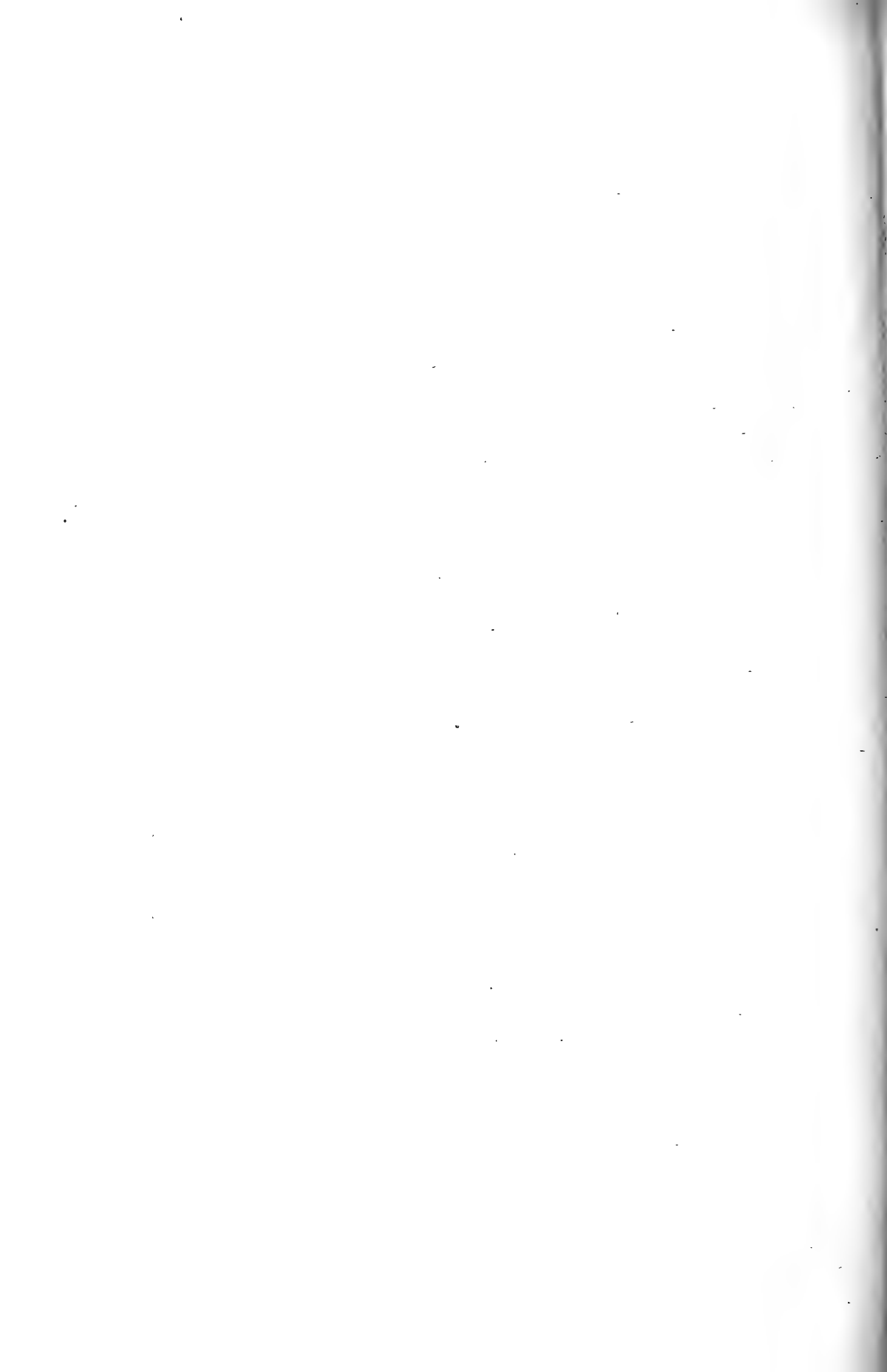
<sup>1</sup> Ber. d. Deutsch. Chem. Ges., 1907, xl., p. 720.

## SCIENTIFIC PROCEEDINGS.

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THE CHANGE OF LENGTH IN NICKEL WIRES  
DUE TO TRANSVERSE MAGNETIC FIELDS  
DIRECT AND ALTERNATING.

BY

WILLIAM BROWN, B.Sc.,

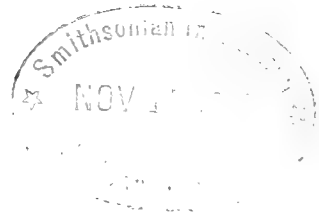
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[*Authors alone are responsible for all opinions expressed in their Communications.*]

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## XII.

THE CHANGE OF LENGTH IN NICKEL WIRES DUE TO  
TRANSVERSE MAGNETIC FIELDS DIRECT AND  
ALTERNATING.

BY WILLIAM BROWN, B.Sc.,

Professor of Applied Physics, Royal College of Science for Ireland.

Read MARCH 28. Published MAY 26, 1916.

A CONSIDERABLE amount of work has been done on the change in the length of iron and nickel wires and rods when they were subjected to the influence of magnetic fields, and an excellent list of papers on the subject, ranging from 1847 to 1908, is given by Dorsey.<sup>1</sup> Subsequent investigations, bringing the work up to 1916, have been made by Williams,<sup>2</sup> Heaps,<sup>3</sup> and the present writer,<sup>4</sup> the latter working with alternating as well as direct longitudinal magnetic fields.

Several workers have tried the effect of transverse magnetic fields on iron, but, with the exception of Williams in 1914, and of Heaps in 1915, whose results were more of a qualitative than quantitative nature, no one—as far as the present writer knows—has obtained definite quantitative results on the effect of direct and alternating transverse magnetic fields on nickel.

The present communication gives some results obtained with soft nickel wire when it was subjected to the influence of transverse magnetic fields, both direct and alternating. The transverse magnetic fields employed in the experiments were produced in a gap of a soft iron tube by means of *five* insulated copper wires inside the tube, the return wires of the circuit being 200 cms. distant. The iron tube had a slot cut right through the wall along its whole length of 215 cms., the other dimensions of the tube being 2.54 cms. external diameter, 1.6 cm. internal diameter, breadth of face of slot 0.47 cm., and width of slot 0.8 cm. The copper wires in the tube were each 0.4 cm. diameter, and were each insulated by being painted with two coatings of anti-sulphuric enamel, then with one layer of silk ribbon; and when they

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<sup>1</sup> Phys. Rev., vol. xxx, p. 718.

<sup>2</sup> Phys. Rev., vol. iv, p. 498, 2nd Series.

<sup>3</sup> Phys. Rev., vol. vi, p. 34, 2nd Series.

<sup>4</sup> Scient. Proc. Roy. Dub. Soc., vol. xiv, p. 297, and vol. xv, p. 41.

were assembled, that is, four wires grouped round one in the centre of the tube, they were firmly bound together and given a coating of shellac varnish. The assembled wires were then firmly fixed in the tube, and the circuit arranged so that the electric current went through the five wires in the *same direction*, producing a transverse magnetic field in the gap or slot. The strength of the magnetic field in the gap was proportional to the total current through the wires, and, by plotting the values of the current as abscissæ and the corresponding values of the field as ordinates, if a straight line be drawn from the origin to the point corresponding to current = 360 amperes (72 amperes in each wire), and magnetic field = 1000 units, all the intermediate points will lie on that line. The tube, with the wires inside, was fixed vertically against the wall with adjustable supports, and the nickel wire under test was suspended in the middle of the gap from a separate support. The nickel wire was kept in the middle of the gap by means of thin strips of wood along each side throughout its whole length, so that, when the transverse fields were applied there was no motion of the wire to either face of the slot. The total length of the nickel wire was 225 cms., and the length of the iron tube 215 cms., thus leaving 5 cms. of the nickel wire at top and bottom free from the influence of the field in the gap of the iron tube.

The load on the lower end of the wire was applied by means of a brass cylinder 1.2 cms. diameter, having at one end a three-jaw clutch for attaching to the wire, and at the other a hook to which a cord was fixed, and then passed over two frictionless pulleys to a scale-pan for holding the required weights.

On account of the great length of the wire under test, the change in the length on the application of the magnetic fields could be read off directly by means of a microscope having a fine hair in the eye-piece, one of a number of fine lines on the brass cylinder serving as an index mark. The movement of the hair was made by means of a micrometer screw with graduated head or cap, one division of which was equivalent to a change of  $9.2 \times 10^{-7}$  per unit length of the wire.

The nickel wire tested was 0.169 cm. in diameter, having rigidity =  $708 \times 10^6$  grammes per sq. cm., and was loaded with a weight equivalent to  $2 \times 10^5$  grammes per sq. cm. The wire was subjected to direct transverse magnetic fields up to a maximum value of 1000 units, and to alternating transverse magnetic fields of maximum value 200 units; but, for the sake of comparison with previous work with longitudinal fields, the values of the expansion here given in the table lie within a maximum of 200 units for both direct and alternating fields.

In the table the values in column marked H are the strengths of the applied magnetic fields, D.C. representing direct or continuous fields, and

A.C. alternating fields of frequency 50 per second. The values in columns marked L are for longitudinal magnetic fields, and are taken from Table V, p. 45, of a previous paper by the author.<sup>1</sup> The values in columns marked T were obtained with transverse magnetic fields direct and alternating, the latter of frequency 50 per second.

The previous tests with *longitudinal* fields direct and alternating, and the present tests with *transverse* fields direct and alternating, were performed on the same nickel wire when it had on the same longitudinal load of  $2 \times 10^5$  grammes per sq. cm.

Rigidity  $\doteq 708 \times 10^6$  grammes per sq. cm.

Load =  $2 \times 10^5$  " " " "

| H   | $\frac{dl}{l} \times 10^{-6}$ cms. |      |      |      |
|-----|------------------------------------|------|------|------|
|     | D.C.                               |      | A.C. |      |
|     | L                                  | T    | L    | T    |
| 20  | 11                                 | 3.0  | 12   | 5.0  |
| 30  |                                    | 5.5  |      | 7.5  |
| 40  | 19                                 | 9.5  | 21   | 11.5 |
| 50  |                                    | 12.0 |      | 15   |
| 60  | 25                                 | 11.0 | 28   | 13.5 |
| 80  | 30                                 | 8.0  | 34   | 10.5 |
| 100 |                                    | 6.5  |      | 8.5  |
| 120 | 36                                 |      | 41.5 |      |
| 150 |                                    | 4.2  |      | 5.8  |
| 160 | 40                                 |      | 47   |      |
| 200 | 42                                 | 3.5  | 52   | 5.0  |

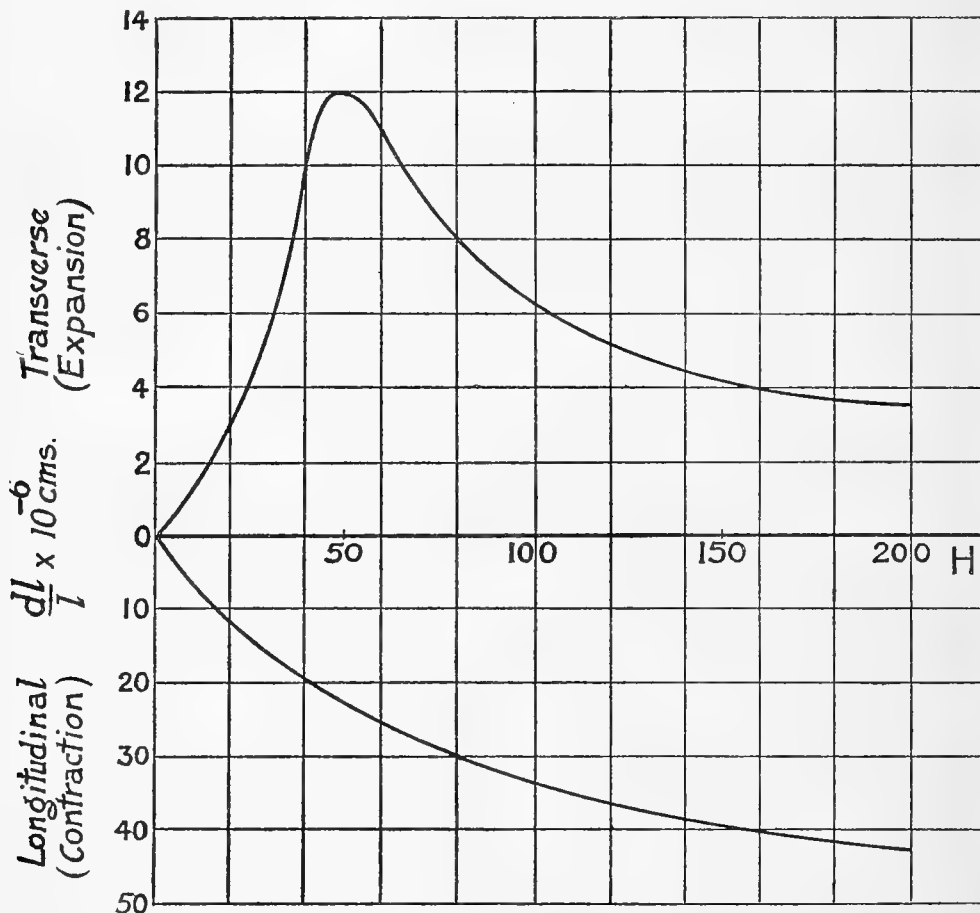
The action of the two *direct* magnetic fields *longitudinal* and *transverse* on nickel wire is better seen from the curves in the Figure (p. 124), where the strengths of the fields are plotted as abscissæ, and as ordinates the corresponding values of the *expansions*, above the axis of abscissæ; and the values of the *contraction*, below the axis.

The upper curve, or curve of expansion, when produced comes gradually towards the axis of abscissæ, and appears to touch the axis somewhere in the region of magnetic field 1000 units; at least, when a magnetic field of 1000 units was put on and off the apparatus employed, there was no change in the

<sup>1</sup> *Scient. Proc. Roy. Dub. Soc.*, vol. xv. Feb. 1916.



length visible in the microscope. The maximum expansion, it will be seen, takes place in a field of about 50 units, that is, in a field of about double the value of the longitudinal magnetic field which gives the maximum twist (Weidemann effect) with the same load on the wire,<sup>1</sup> this twist depending on the load but independent of the current density in the wire.<sup>2</sup>



In conclusion it may be said that:—

1. For both direct and alternating transverse magnetic fields a nickel wire expands to a maximum, and then diminishes gradually for high fields.
2. The maximum expansion for both direct and alternating transverse fields takes place in the same field-strength of about 50 units.

I am again indebted to the College Electrician, Mr. R. Macaulay, for assistance in this work.

<sup>1</sup> *Scient. Proc. Roy. Dub. Soc.*, vol. xiii, p. 31. April, 1911.

<sup>2</sup> *Scient. Proc. Roy. Dub. Soc.*, vol. xii, p. 511. December, 1910.

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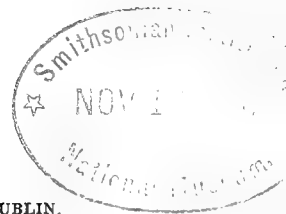
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THE SUBSIDENCE OF TORSIONAL OSCILLA-  
TIONS OF NICKEL AND IRON WIRES WHEN  
SUBJECTED TO THE INFLUENCE OF TRANS-  
VERSE MAGNETIC FIELDS UP TO 800 C.G.S.  
UNITS.

BY

WILLIAM BROWN, B.Sc.,

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*[Authors alone are responsible for all opinions expressed in their Communications.]*

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# Royal Dublin Society.

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## XIII.

THE SUBSIDENCE OF TORSIONAL OSCILLATIONS OF NICKEL  
AND IRON WIRES WHEN SUBJECTED TO THE INFLUENCE  
OF TRANSVERSE MAGNETIC FIELDS UP TO 800 C.G.S. UNITS.

By WILLIAM BROWN, B.Sc.,

Professor of Applied Physics, Royal College of Science for Ireland, Dublin.

Read MARCH 28. Published MAY 29, 1916.

IN a recent communication<sup>1</sup> there was brought before the Royal Dublin Society the results of some experiments on the behaviour of nickel wires when they were made to oscillate in transverse magnetic fields, both direct and alternating, the maximum value of the field used being 200 c.g.s. units. The present communication is in continuation of the above-mentioned work, and gives results obtained with nickel and iron wires when magnetic fields up to maximum value of 800 c.g.s. units were employed. In this case the transverse magnetic fields used in the experiments were produced in a soft iron tube by means of *five* insulated copper wires arranged in series inside the tube, the return wires of the circuit being two metres away from the iron tube.

For these experiments a new iron tube with a slot down its whole length was obtained, the tube being 215 cms. long, 2.54 cms. external diameter, 1.6 cms. internal diameter; breadth of face of slot, 0.47 cms.; and width of slot, 0.8 cm.—that is, 3 mm. wider than the slot in the tube previously used. The copper wires in the tube were each 0.4 cm. diameter, and were each insulated by being painted with two coatings of anti-sulphuric enamel, then one layer of thin silk ribbon, and when they were finally assembled—that is, grouped four wires round one in the centre of the tube—they were bound firmly together, and given a coating of shellac varnish. The wires were then firmly fixed in the tube, and the circuit arranged so that the current went through the five wires in the *same direction*, and produced a transverse magnetic field in the gap of the iron tube. The relation between the current in the copper wires and the magnetic field in the gap was found as before

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<sup>1</sup> Scient. Proc. Royal Dublin Soc., 1916, vol. xv, No. 9, p. 99.

by means of an exploring coil, earth inductor, and ballistic galvanometer, and by plotting the total current in the wires as abscissæ and the corresponding values of the field as ordinates, the points were found to lie on a straight line passing through the origin. Thus, if a line be drawn from the origin to a point corresponding to current = 360 amperes (72 amperes in each wire) and magnetic field = 1000 c.g.s. units, all the intermediate points will lie on that line.

For a detailed account of the arrangements and method of experiment I would refer to my previous paper.<sup>1</sup> I may just say that, as before, the distance from the mirror on the vibrator to the millimetre scale was 167 cms.; and though the wire in some cases in the present experiments was only *one-third* the length of the wire formerly used, the maximum amplitude of oscillation was the same, namely, from zero to the mark 300 on the scale, giving a twist of the lower end of the wire equal to about  $5^{\circ} 10'$ .

On account of the strong magnetic fields used, the whole length of the wire, 225 cms., could not be employed, because the wires were attracted to the face of the slot; so after some preliminary tests it was arranged for high fields to use throughout the experiments a length of 75 cms. of the wire, with an oscillating load on the end of the wire equivalent to  $2 \times 10^5$  grammes per sq. cm., and 2670 grammes on the scale-pan end of the torsionless silk string previously explained.<sup>2</sup>

## SECTION I.

### *Nickel Wires.*

The wire first tested was a No. 16 soft nickel wire of simple rigidity, about  $708 \times 10^6$  grammes per sq. cm. Observations on the subsidence of torsional oscillations were taken for many values of transverse magnetic fields up to a maximum value of 800 c.g.s. units, both direct and alternating of frequency 50 per second; and, as before, the shape of the subsidence curve was obtained in any case by plotting the number of vibrations as abscissæ, and as ordinates the corresponding values of the amplitude of oscillations.

The more important of the values obtained are given in Table I, where the numbers in columns 2 and 3 under the mark D.C., were obtained when the nickel wire was subjected to no field or to a direct transverse magnetic field, and those under the mark A.C., when it was under the influence of alternating transverse magnetic fields of frequency 50 per second.<sup>3</sup> The value opposite

<sup>1</sup> *Loc. cit.*

<sup>2</sup> *Loc. cit.*

<sup>3</sup> The alternating transverse magnetic fields are reckoned in root-mean-square values.

the letter H represents the strength of the magnetic field applied in each case, and the letter  $n$  refers to the frequency of the alternating field.

TABLE I.

Rigidity  $\doteq 708 \times 10^6$  grammes per sq. cm.

| Number of Vibrations. | D.C.  |         | A.C. ( $n = 50$ ) |         |         |
|-----------------------|-------|---------|-------------------|---------|---------|
|                       | H = 0 | H = 800 | H = 300           | H = 500 | H = 800 |
| 0                     | 300   | 300     | 300               | 300     | 300     |
| 5                     | 261   | 260     | 261               | 261     | 261     |
| 10                    | 231   | 227     | 230               | 229     | 228     |
| 15                    | 206   | 200     | 205               | 203     | 202     |
| 20                    | 183   | 178     | 182               | 180     | 179     |
| 30                    | 149   | 143     | 146               | 143     | 142     |
| 40                    | 124   | 115     | 119               | 116     | 114     |
| 50                    | 104   | 94      | 99                | 94      | 92      |
| 60                    | 89    | 72      | 82                | 77      | 75      |
| 70                    | 77    | 66      | 69                | 63      | 60      |

From Table I by comparing the values in columns 2, 3, and 6, it will be seen that with a soft nickel wire, both the direct and alternating magnetic fields *increase* the damping of torsional oscillation, that is, the amplitude of the 70th oscillation is *decreased* by about 14 per cent. by the application of a direct transverse magnetic field of strength 800 units, and by about 22 per cent. by applying an alternating transverse magnetic field of the same strength, and of frequency 50 per second. The values—not given in the Table—obtained with direct transverse fields of lower strength than 800 units, showed that the change in the damping of the torsional oscillations began to be noticeable when a field of about 300 units was applied, and it gradually increased till the values given in column 3 were attained. In the previous work, when the wire was three times longer (225 cms.), and with the same oscillating load on, there was no difference in the damping of the oscillations for no field, and for a field of 200 units.<sup>1</sup>

In order to find the effect of transverse magnetic fields of different frequencies on a soft nickel wire, arrangements were made as before to

<sup>1</sup> *Loc. cit.*, p. 99.



obtain the same current strength from different alternators, and it was found that the current most suitable was that which gave a transverse field of 250 units. Observations were made of the torsional subsidence of the wire when it was subjected to the influence of transverse magnetic fields of strength 250 units, and of frequencies 25, 50, 100, and 200 per second respectively. A few of the results are given in Table II, where for comparison there are also given in column 2 the values obtained when there was no transverse field on the wire. The length of the wire was 75 cms., and the oscillating load  $2 \times 10^5$  grammes per sq. cm. with 2670 grammes on the scale-pan end of the torsionless floss-silk string.

TABLE II.

Rigidity  $\doteq 708 \times 10^6$  grammes per sq. cm.

H = 250 units.

| Number of Vibrations. | H = 0 | A.C.   |        |         |         |
|-----------------------|-------|--------|--------|---------|---------|
|                       |       | n = 25 | n = 50 | n = 100 | n = 200 |
| 0                     | 300   | 300    | 300    | 300     | 300     |
| 10                    | 231   | 226    | 230    | 232     | 234     |
| 20                    | 183   | 177    | 183    | 186     | 188     |
| 30                    | 149   | 141    | 148    | 151     | 154     |
| 50                    | 104   | 94     | 100    | 104     | 108     |
| 70                    | 77    | 65     | 70     | 75      | 80      |

From the values in Table II it will be seen—when transverse magnetic fields of 250 units at different frequencies are applied—that as the frequency is *increased*, the damping of the torsional oscillations is *decreased*. For a frequency of 200 per second the amplitude of the 70th oscillation is increased by about 4 per cent. as compared with the amplitude when there was no field round the wire; also, when the frequency is increased *eight* times, the amplitude of the 70th oscillation is increased about 23 per cent.

The soft nickel wire was replaced in the apparatus by a hard nickel wire of rigidity about  $810 \times 10^6$  grammes per sq. cm. This wire was of the same length, had on it the same load, and was put through exactly the same series of tests as was the soft wire. The more important of the results obtained are given in Table III, the observed values of the torsional subsidence were

the same when no field, and when a direct transverse magnetic field of 800 units was round the wire, the values being those given in column 2 of the Table.

TABLE III.

Rigidity  $\doteq 810 \times 10^6$  grammes per sq. cm.

| Number<br>of<br>Vibrations. | D.C.      | A.C.      |           |
|-----------------------------|-----------|-----------|-----------|
|                             | $H = 800$ | $H = 300$ | $H = 800$ |
| 0                           | 300       | 300       | 300       |
| 5                           | 288       | 285       | 279       |
| 10                          | 275       | 271       | 261       |
| 15                          | 264       | 258       | 243       |
| 20                          | 254       | 246       | 227       |
| 30                          | 234       | 223       | 199       |
| 40                          | 216       | 203       | 174       |
| 50                          | 199       | 186       | 153       |
| 60                          | 185       | 171       | 135       |
| 70                          | 172       | 158       | 120       |

From the values in Table III, by comparing columns 2 and 4 it will be seen that the application of an alternating transverse magnetic field of 800 units and frequency 50 per second *decreases* the amplitude of the 70th oscillation by about 30 per cent., as compared with 22 per cent. when the wire was soft (Table I). From a comparison of Tables I and III it will be seen that when a direct magnetic field of 800 units was acting on the wire, a change in the rigidity from  $708 \times 10^6$  to  $810 \times 10^6$  grammes per sq. cm. showed in the amplitude of the 70th oscillation an increase of 160 per cent., but in the case of an alternating field of the same strength and frequency 50 per second, the amplitude of the 70th oscillation was increased 100 per cent.

The results for the *soft* wire and for the *hard* wire for no field (O) and for an alternating field of 800 units (A. C.) are shown in the form of curves in figure 1 (p. 130), where the *two upper* curves refer to the hard wire and the *two lower* curves to the wire in the soft state.

When this hard nickel wire was tested in transverse magnetic fields of strength 250 units and of frequencies 25, 50, 100, and 200 per second respectively, it was found that the damping of the torsional oscillations was increased as compared with the effect of no field or of a direct field of 800 units; but when the frequency of the applied field was increased, the damping was decreased.

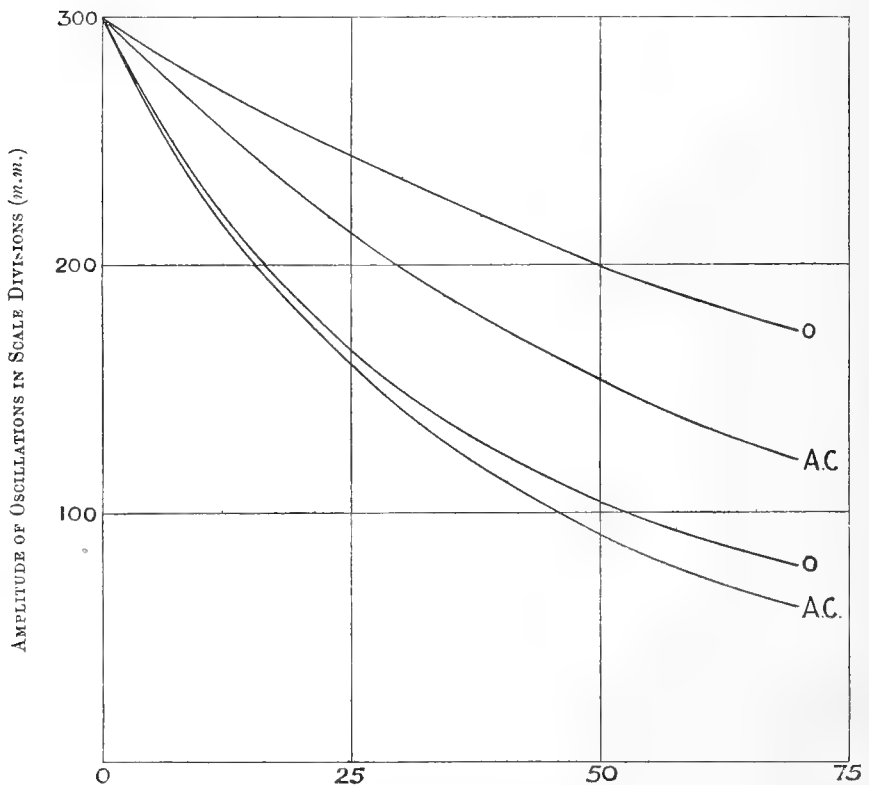


FIG. 1.—NUMBER OF VIBRATIONS.

A few of the values—enough to enable the curve to be drawn if required—are given in Table IV, and also in column marked D.C., for the sake of comparison, some of the values obtained when no field or a direct field of 800 units was round the wire.

TABLE IV.

Rigidity  $\doteq 810 \times 10^6$  grammes per sq. cm.

H = 250 units.

| Number of Vibrations. | D.C. | A.C.     |          |           |           |
|-----------------------|------|----------|----------|-----------|-----------|
|                       |      | $n = 25$ | $n = 50$ | $n = 100$ | $n = 200$ |
| 0                     | 300  | 300      | 300      | 300       | 300       |
| 10                    | 275  | 278      | 278      | 279       | 280       |
| 20                    | 254  | 247      | 248      | 249       | 250       |
| 30                    | 234  | 225      | 227      | 228       | 230       |
| 50                    | 199  | 188      | 191      | 193       | 195       |
| 70                    | 172  | 157      | 161      | 164       | 167       |

From Table IV, by comparing columns 2 and 3, it will be seen that when an alternating transverse magnetic field of 250 units and frequency 25 per second is applied to the hard nickel wire, the damping of the torsional oscillations is increased, that is, the amplitude of the 70th oscillation is *decreased* by nearly 9 per cent. as compared with nearly 16 per cent. when the wire was soft (Table II); also, from columns 3 and 6, when the frequency of the field is increased *eight* times, the damping of the oscillations is decreased about 6 per cent. as compared with 23 per cent. when the wire was soft (Table II).

## SECTION II.

*Iron Wires.*

A No. 16 iron wire of rigidity  $780 \times 10^6$  grammes per sq. cm. was put into the apparatus in place of the hard nickel wire, and it was put through the same series of tests as were the nickel wires, that is, for the whole length of the wire, 225 cms., the tests were made in magnetic fields up to a maximum value of 200 c. g. s. units, and for the length of 75 cms. in magnetic fields of maximum value 800 units. For the wire 225 cms. long the load used was the same as that employed for the nickel wire of the same length, namely, an oscillating load on the end of the wire equivalent to  $2 \times 10^5$  grammes per sq. cm. and a weight of 1670 grammes on the scale-pan end of the torsionless silk string.<sup>1</sup> For the wire 75 cms. long the oscillating load was the same, but the weight

<sup>1</sup> *Loc. cit.*

on the scale-pan end of the silk string was 2670 grammes, that is, the same as was used with the corresponding length of the nickel wire.

The more important of the results obtained in the subsidence of torsional oscillations are given in Table V; the values—not given in the Table—obtained with transverse magnetic fields of lower strength than 200 units, both direct and alternating, were proportionately lower than those in the Table.

TABLE V.

Rigidity  $\doteq 780 \times 10^6$  grammes per sq. cm.

| Number of Vibrations. | H = 0 | H = 200 |      |
|-----------------------|-------|---------|------|
|                       |       | D.C.    | A.C. |
| 0                     | 300   | 300     | 300  |
| 5                     | 277   | 278     | 274  |
| 10                    | 256   | 257     | 252  |
| 15                    | 238   | 238     | 232  |
| 20                    | 220   | 220     | 213  |
| 30                    | 190   | 189     | 181  |
| 40                    | 165   | 163     | 153  |
| 50                    | 142   | 140     | 130  |
| 60                    | 123   | 120     | 110  |
| 70                    | 105   | 103     | 93   |

From the Table it will be seen, from inspection of columns 2 and 3, that the application of a direct transverse magnetic field of 200 units has slightly increased the damping of the torsional oscillations, and from columns 2 and 4 that an alternating field has decreased the amplitude of the 70th oscillation by over 11 per cent., that is, by about the same amount as was obtained for a soft nickel wire when tested under the same conditions.

The iron wire was tested in alternating transverse magnetic fields of strength 65 units, and of frequencies 25, 50, 100, and 200 per second respectively, and some of the values obtained are given in Table VI; and for comparison the values obtained with no field are also given.

TABLE VI.

Rigidity  $\doteq 780 \times 10^6$  grammes per sq. cm.

H = 65 units.

| Number of Vibrations. | H = 0 | A.C.   |        |         |         |
|-----------------------|-------|--------|--------|---------|---------|
|                       |       | n = 25 | n = 50 | n = 100 | n = 200 |
| 0                     | 300   | 300    | 300    | 300     | 300     |
| 20                    | 220   | 220    | 220    | 219     | 219     |
| 50                    | 142   | 140    | 139    | 138     | 137     |
| 70                    | 105   | 104    | 103    | 102     | 100     |

By comparing the values in Table VI, above, with those in Table II, page 128, in the former paper,<sup>1</sup> it will be seen that, unlike nickel wire, the damping of torsional oscillations in iron wire is slightly *increased* as the frequency is *increased*. When the frequency is increased *eight* times, the amplitude of the 70th oscillation is *decreased* about 4 per cent., whereas with nickel wire tested under similar conditions the amplitude of the 70th oscillation is increased  $4\frac{1}{2}$  per cent.

The iron wire was then tested when of length 75 cms. with the oscillating load on the end of the wire equal to  $2 \times 10^5$  grammes per sq. cm. and a weight of 2670 grammes on the scale-pan end of the silk string, the transverse magnetic fields used being up to a maximum of 800 units both direct and alternating.

The more important of the values obtained are given in Table VII, and those values—not given in the table—which were obtained with direct transverse magnetic fields of strengths from 100 to 700 units were intermediate to the values given in columns 2 and 3 in Table VII.

<sup>1</sup> *Loc. cit.*, p. 103.

TABLE VII.

Rigidity  $\doteq 780 \times 10^6$  grammes per sq. cm.

| Number of<br>Vibrations. | D.C.  |         | A.C. ( $n = 50$ ). |         |         |
|--------------------------|-------|---------|--------------------|---------|---------|
|                          | H = 0 | H = 800 | H = 200            | H = 500 | H = 800 |
| 0                        | 300   | 300     | 300                | 300     | 300     |
| 5                        | 281   | 273     | 275                | 270     | 267     |
| 10                       | 264   | 250     | 252                | 244     | 239     |
| 15                       | 249   | 229     | 233                | 221     | 215     |
| 20                       | 235   | 209     | 215                | 201     | 194     |
| 30                       | 209   | 176     | 185                | 167     | 158     |
| 40                       | 187   | 148     | 160                | 140     | 130     |
| 50                       | 168   | 125     | 141                | 119     | 107     |
| 60                       | 161   | 104     | 125                | 101     | 87      |
| 70                       | 136   | 87      | 111                | 87      | 71      |

From Table VII it will be seen that the application of transverse magnetic fields, both direct and alternating, have a pronounced effect on the damping of the torsional oscillations when the iron wire is of comparatively short length.

The amplitude of the 70th oscillation is decreased by about 36 per cent. by the application of a direct field of strength 800 units, as is seen from columns 2 and 3; from columns 4 and 6 for an increase of the alternating field of four times, the amplitude is decreased also about 36 per cent.; and from columns 2 and 6 it is decreased 47 per cent. by the application of an alternating field of 800 units.

The results obtained, with no field (0), for a field of 800 units direct (D.C.), and with alternating (A.C.), are shown in the form of curves in fig. 2 (p. 135).

The results obtained with the short wire when alternating magnetic fields of strength of 250 units at the four different frequencies were employed are given in Table VIII, and also, for comparison, the values when there was no field on the wire.

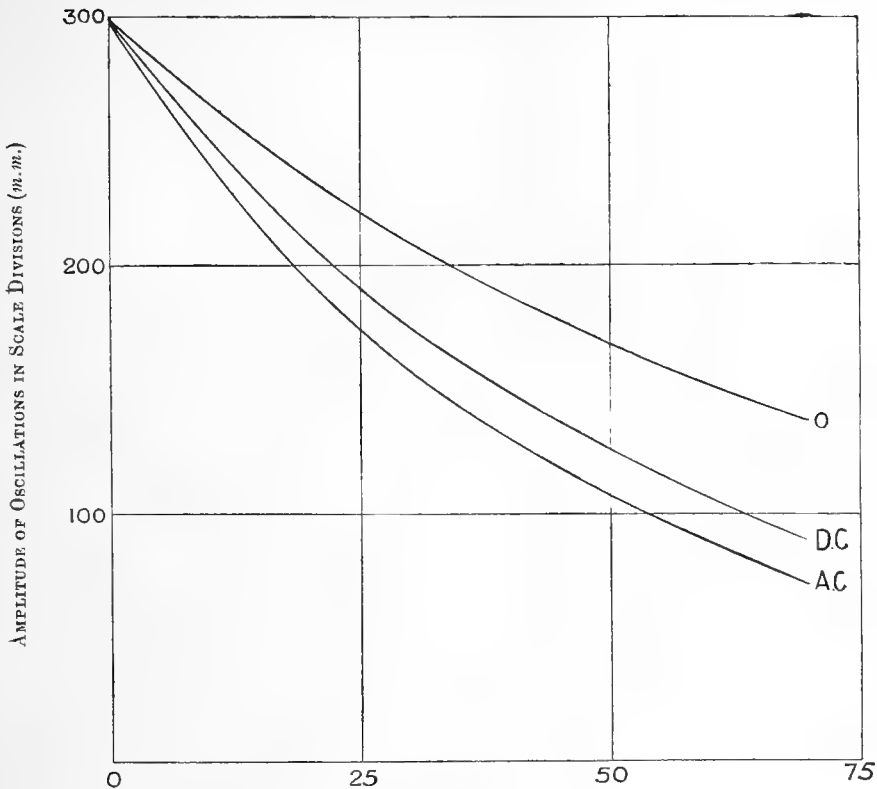


FIG. 2.—NUMBER OF VIBRATIONS.

TABLE VIII.

Rigidity  $\doteq 780 \times 10^6$  grammes per sq. cm.

H = 250 units.

| Number of Vibrations. | H = 0 | A.C.   |        |         |         |
|-----------------------|-------|--------|--------|---------|---------|
|                       |       | n = 25 | n = 50 | n = 100 | n = 200 |
| 0                     | 300   | 300    | 300    | 300     | 300     |
| 15                    | 249   | 231    | 229    | 228     | 226     |
| 30                    | 209   | 183    | 181    | 178     | 175     |
| 50                    | 168   | 139    | 135    | 132     | 129     |
| 70                    | 136   | 110    | 104    | 100     | 96      |

The values in Table VIII show that when the frequency of the applied transverse alternating magnetic field is increased, the damping of the torsional



oscillations is increased. By comparing columns 3 and 6 it will be seen that when the frequency of the field is increased *eight* times, the amplitude of the 70th oscillation is decreased by nearly 13 per cent., and by comparing columns 2 and 6 the amplitude is decreased nearly 30 per cent. in a field of strength 250 units and of frequency 200 per second.

As a test for the presence of eddy currents in a wire due to high transverse magnetic fields, and their action on the damping of the torsional oscillations, a soft No. 16 copper wire, 75 cms. long, and loaded the same as were the nickel and iron wires, was put into the apparatus, and a series of tests made. Observations of torsional subsidence were made with magnetic fields of  $H = 0$ ,  $H = 800$  D.C., and  $H = 800$  A.C. of frequency 50 per second, and the values obtained in the three cases were identical.

For assistance in preparing the apparatus and in making some of the observations I am indebted to Mr. R. Macaulay, the Electrician at the Royal College of Science.

## SCIENTIFIC PROCEEDINGS.

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1. The Subsidence of Torsional Oscillations and the Fatigue of Iron Wires when subjected to the Influence of Alternating Magnetic Fields of Frequencies up to 250 per second. By WILLIAM BROWN, B.SC. (January, 1916.) 6*d*.
2. Preliminary Notes on the Carbohydrates of the Musci. By THOMAS G. MASON, B.A., DIPLOM. AGRIC. (February, 1916.) 6*d*.
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NOTE ON LAMINATED MAGNETS.

BY

WILLIAM BROWN, B.Sc.,

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[*Authors alone are responsible for all opinions expressed in their Communications.*]

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## XIV.

## NOTE ON LAMINATED MAGNETS.

BY WILLIAM BROWN, B.Sc.,

Professor of Applied Physics, Royal College of Science for Ireland, Dublin.

[Read MAY 23. Published JUNE 19, 1916.]

IN his "Magnetical Investigations," 1839, Scoresby gives some results obtained with laminated magnets when the laminations were in contact, and when they were separated by pieces of wood varying in thickness from 0·14 of an inch to 1 inch; and he shows that when the plates or laminations are separated there results a stronger magnet than when they are in contact. Jamin<sup>1</sup> also worked with laminated magnets with respect to the carrying power and distribution of magnetism. The present writer has not been able to find any past or recent work which gives experimental data on how the apparent distance between the poles of a straight magnet varies with the number of laminations composing the magnet, and this note gives the results of some experiments on this subject. The laminations were made out of a piece of clock-spring steel, cut into strips 10 cms. long, 0·5 cm. wide, and 0·06 cm. thick. They were made glass-hard by being raised to a bright red heat in a muffle furnace, and then dropped end on into a vessel of cold water three feet deep; and in order to keep them as straight as possible in the hardening process they were fixed between two pieces of square-section steel rod. When cleaned up and polished each strip weighed very approximately 2·33 grammes.

These laminations were taken in sets consisting of 1, 2, 3, 5, 7, 10, 15, and 20 strips respectively, each set was magnetised, as explained below, in the same magnetic field, and the magnetic moment and apparent distance between the poles measured. The tests were made (1) when the laminations were all in actual contact; (2) when the laminations were separated by pieces of paper of the same length and width as the lamination, and of thickness 0·015 cm., 0·03 cm., and 0·06 cm. respectively, that is, there were four sets of experiments made in all.

The magnets when being tested were fixed in a non-magnetic brass holder, which clamped the combination at each end and also at the middle. The

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<sup>1</sup> Compt. Rend., Tome lxxv, lxxvi, lxxvii, lxxx. 1872-75.

magnetic moment was measured by the usual end-on magnetometric method, and the distance between the poles measured in each case as follows:—The brass frame containing the laminations was placed on a horizontal table in a magnetically east and west direction, and a small compass needle, 1 centimetre long, mounted on a horizontal axis and encased in a brass and glass frame, was moved along the magnet until it stood vertically. This operation was done for each end of the magnet, and the distance between the two marks was taken off by means of a pair of drawing compasses made entirely of brass and measured on a millimetre scale. In this way a difference of one-quarter of a millimetre in the distance could be read. Each time a lamination was added, the bundle was re-magnetised in the same direction in a magnetic field of about 1200 units.

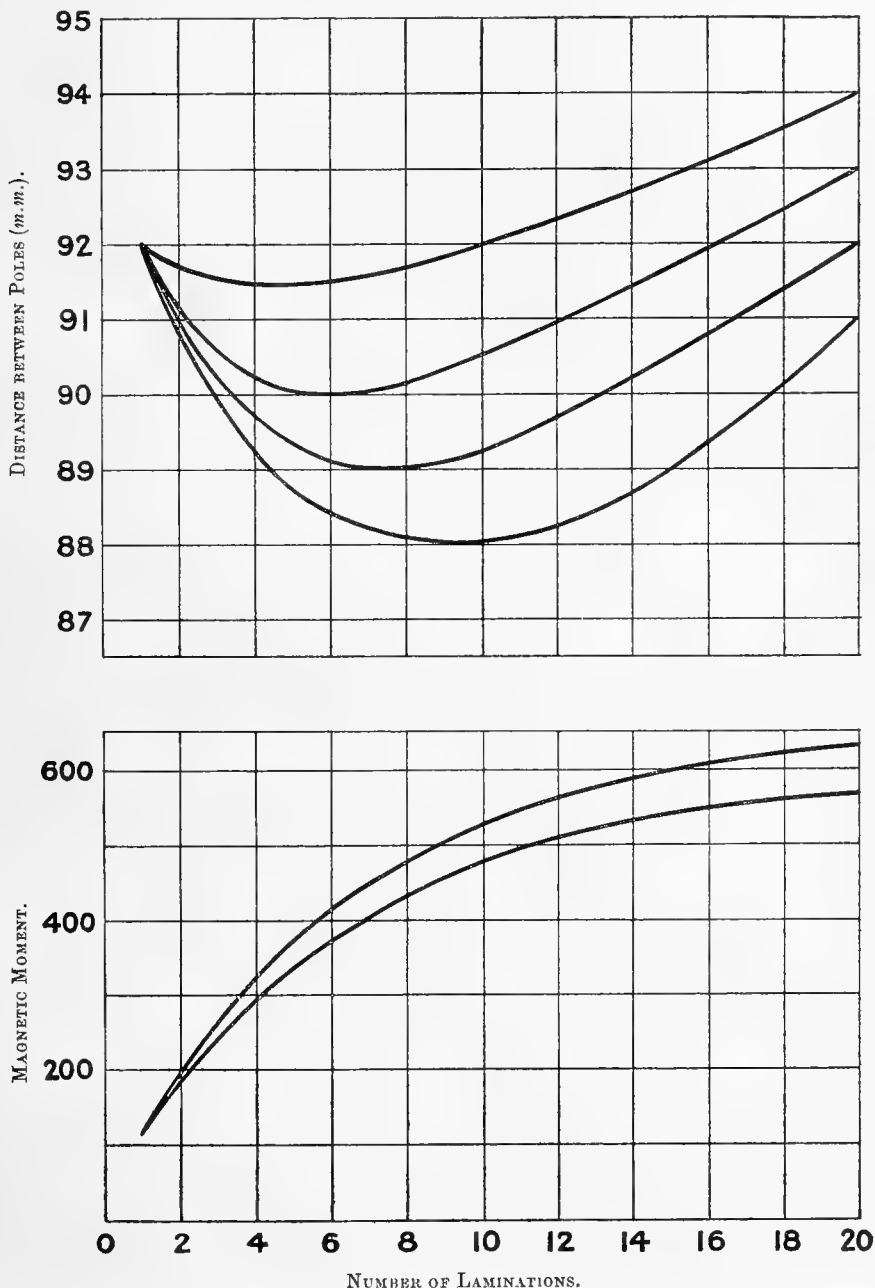
TABLE I.

| Number of Laminations | Distance between the Poles (m.m.) |             |            |            |
|-----------------------|-----------------------------------|-------------|------------|------------|
|                       | $d = 0$                           | $d = 0.015$ | $d = 0.03$ | $d = 0.06$ |
| 1                     | 92                                | 92          | 92         | 92         |
| 2                     | 90.7                              | 91          | 91.2       | 91.7       |
| 3                     | 90                                | 90.3        | 90.5       | 91.6       |
| 5                     | 88.8                              | 89.4        | 90.0       | 91.6       |
| 7                     | 88.2                              | 89.0        | 90.0       | 91.7       |
| 10                    | 88.0                              | 89.3        | 90.5       | 92.0       |
| 15                    | 89.0                              | 90.5        | 91.2       | 93         |
| 20                    | 91                                | 92          | 93         | 94         |

TABLE II.

| Number of Laminations | Magnetic Moment |             |            |            |
|-----------------------|-----------------|-------------|------------|------------|
|                       | $d = 0$         | $d = 0.015$ | $d = 0.03$ | $d = 0.06$ |
| 1                     | 110             | 110         | 110        | 110        |
| 2                     | 185             | 190         | 195        | 200        |
| 3                     | 250             | 255         | 260        | 265        |
| 5                     | 340             | 350         | 360        | 370        |
| 7                     | 405             | 420         | 430        | 445        |
| 10                    | 475             | 490         | 500        | 525        |
| 15                    | 540             | 555         | 570        | 600        |
| 20                    | 570             | 580         | 600        | 635        |

The results are given in Tables I and II, and some of them shown in the form of curves in the figure, where the upper curves are the graphs of the



values in Table I, and the lower curves those of the values in columns 1, 2, 5 in Table II. The values opposite the symbol  $d$  give the thickness in fractions of a centimetre of the paper which separated the laminations of steel.



In the upper set of curves, the lowest one gives the graph of the values in column 2, Table I, that is when the steel laminations were in contact, and the highest curve the values in column 5, Table I, that is when the laminations were separated by a piece of paper 0·06 cm. thick, or of the same thickness as the steel plates; and the two intermediate curves give the graphs of the values in columns 3 and 4 of Table I when the thickness of the separating paper was 0·015 cm. and 0·03 cm. respectively. Each one of these curves seems to be a parabola; the equation of the lower curve is  $x^2 = 25y$ , and its axis of figure when produced meets the axis of abscissæ at the point corresponding to 5 laminations instead of at 9, that is at an angle of 85 degrees instead of 90 degrees. It will be seen that as the cross-section of the compound magnet grows from a rectangle to a square the distance between the poles *decreases*, and as the section further grows from a square to a rectangle the distance between the poles again *increases*, that is, the poles are at the least distance apart when the cross-section of the compound magnet is very approximately a square, whether the magnet is built up of *steel* or *steel and paper* combined.

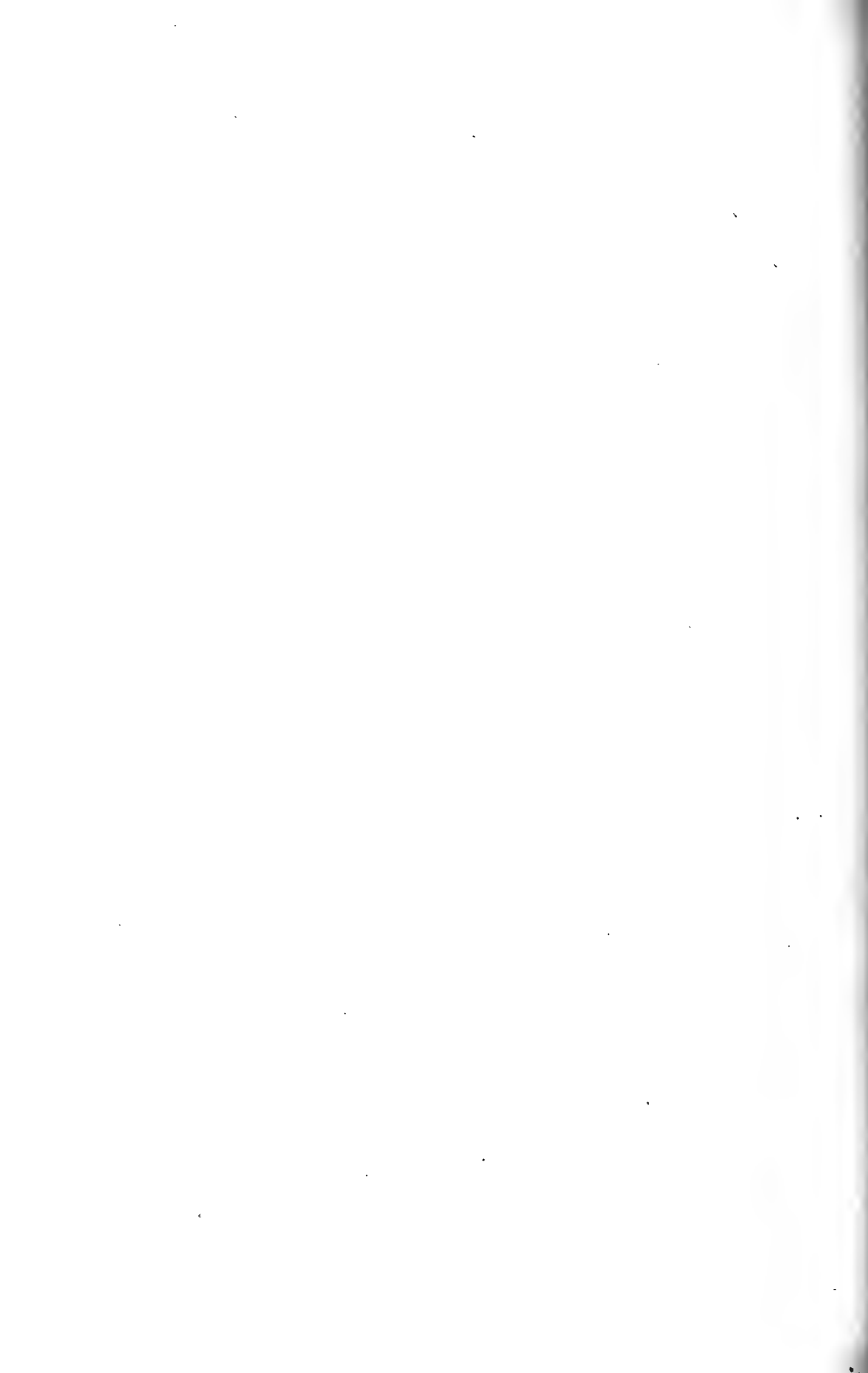
From the lower curve of magnetic moments, it will be seen that when there are *nine* laminations the magnetic moment is 455 units, and when the number of laminations is *eighteen* the moment is 560 units, or an increase of only 23 per cent. From the upper curve, when there are *five* laminations each separated by paper of thickness 0·06 cm. the moment is 370 units, and with *ten* laminations the moment is 525 units, an increase of 42 per cent., whilst with *twenty* laminations the moment is 635 units, a further increase of about 21 per cent. It would appear, therefore, that the best magnet to use, with the given steel plates, would be one made up of *nine* laminations in contact, that is, when the cross-section of the magnet is practically a square and the poles at the minimum distance apart.

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ON THE MODE OF OCCURRENCE AND ORIGIN  
OF THE ORBICULAR GRANITE OF  
MULLAGHERG, CO. DONEGAL.

BY

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(PLATES IV-V.)

[*Authors alone are responsible for all opinions expressed in their Communications.*]

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## XV.

ON THE MODE OF OCCURRENCE AND ORIGIN OF THE  
ORBICULAR GRANITE OF MULLAGHERG, CO. DONEGAL.

BY GRENVILLE A. J. COLE, M.R.I.A., F.G.S.,

Professor of Geology in the Royal College of Science for Ireland.

(Plates IV-V.)

Read FEBRUARY 23, 1915. Published, with additions, OCTOBER 26, 1916.

## I. THE OCCURRENCE IN THE FIELD.

ABOUT 1887, Mr. J. R. Kilroe, of the Geological Survey of Ireland, observed "concretionary balls" in the granite of the townland of Mullagherg, west of Crolly Bridge, in the county of Donegal. The locality lies on an inlet of Inishfree Bay, close to where the name Glendowan appears on Sheet 9 of the 1-inch map of the Ordnance Survey, published in 1858, and in revised form in 1905. Mr. Kilroe's specimens were examined petrographically by Dr. F. H. Hatch,<sup>1</sup> and the occurrence is described by the finder, with comments by Dr. J. S. Hyland, in the Memoir of the Geological Survey of Ireland to Sheets 3, 4, &c., issued in 1891.<sup>2</sup>

Since that time, the somewhat remote locality has been visited by Miss M. K. Andrews of Belfast, who has very kindly allowed me to use the whole of the material collected by her, and her fine series of thin slices cut from the spherulites and the associated rocks; by Mr. R. Bell, at the instance of Mr. F. N. Ashcroft, who wished to present a specimen of the rock to the British Museum; by Mr. R. Welch, one of whose excellent photographs is reproduced in the present paper; and by Mr. T. Hallissy and myself, during a recent official mapping of the district on the scale of six inches to one mile. The Geological Survey obtained, as the result of this re-examination, a number of large blocks from the orbicular mass, some of which have been sawn and polished, so as to display the relations and structures of the spherulites (Plates IV and V).

In the field, this orbicular mass is seen to be a specialised and comparatively small portion of the typical red granite of the district. This granite

<sup>1</sup> "On the Spheroid-bearing Granite of Mullagherg," *Quart. Journ. Geol. Soc. London*, vol. xlv (1888), p. 548.

<sup>2</sup> *Mem. to Sheets 3, 4, &c.*, pp. 80 and 137.

is intrusive in the Dalradian (pre-Cambrian) sedimentary series; like them, it may be of pre-Cambrian age, and at the latest it may have been associated

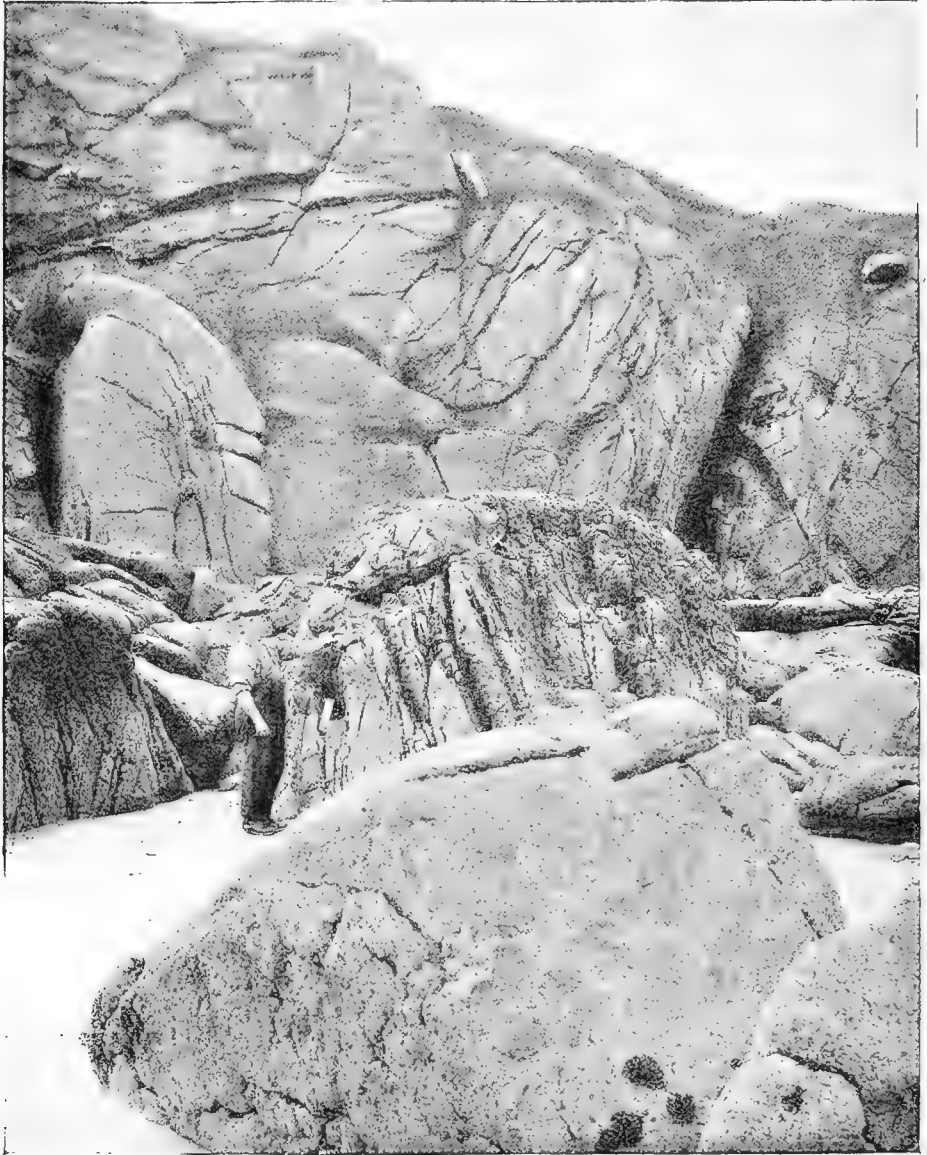


FIG. 1.—Orbicular granite in normal biotite-granite of Mullaghderg, Inishfree Bay, Co. Donegal. A large boulder of the orbicular rock lies in the foreground. Photographed by Mr. R. Welch.

with the Caledonian earth-folding of early Devonian times. At Mullaghderg a small patch of the granite, merging on all sides into the normal type

(fig. 1), is crowded with the crystalline spheroids described by Hatch. A block in the foreground of the photograph shows the character of the sea-worn surfaces, and it is possible that some extension of the rock-type occurs under the sand towards the bay.

The joints break cleanly through the spherulites,<sup>3</sup> which give the impression of a charge of round shot fired into the granite cauldron while its contents were in a molten state. They lie close to one another in a crowded group, divided by thin films of granite. Subsequent veins, also of red granite, cut the mass, and occasionally cross the spherulites.

The grey outer zone of most of the spherulites, composed of felspathic matter arranged radially, together with associated grains of magnetite, has been well described by Hatch. The nucleus within it, often consisting of coarse-grained red granite, weathers away more easily than the radial zone. Since the granite matrix surrounding the spherulites is similar in composition to many of the cores, it also becomes worn down, and the grey zone stands out on joint-surfaces as a raised ring. Here and there the radial zone consists of red felspar, side by side with the more frequent grey examples.

In many cases concentric shells of granitoid matter lie between the grey zone and the nucleus, the latter exhibiting merely a granitic structure without zoning. The most important point to be recorded in this paper is that some of the cores consist of elongated, irregular, and ragged schistose matter, with no resemblance to segregations. The foreign nature of these cores can be still more clearly recognised in the polished slabs that are now placed in the Geological Survey Collection in the National Museum, Dublin (fig. 3). A few small inclusions of foreign rocks occur near a grey dyke referred to by Hatch.<sup>4</sup> One on the east side of the dyke is somewhat granitised. I have little doubt that these were derived from the Dalradian series invaded by the granite; but they are not surrounded by spherulitic matter.

Here, and there a group of the large spherulites, together with the interstitial and environing granite, is surrounded by a grey zone with radial structure, precisely similar to that round individual spherulites. The whole group seems to have become so far differentiated in the cooling granite as to promote a deposition of andesine and magnetite at its outer surface.

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<sup>3</sup>The term spherulite was logically used by Vogelsang ("Études sur les cristallites," *Archives néerlandaises*, vol. vii) for such forms, as well as for the more familiar small examples in dykes and lava-flows, and it conveys no assumption as to mode of origin. *Variolite*, though employed by von Chrustschoff in a general sense, properly refers to spherulites in variolites. A. C. Lawson (*Univ. Calif., Bull. Depart. Geol.*, vol. iii, p. 396) uses the word orbule.

<sup>4</sup>*Op. cit.* (1), p. 548.



Beyond this surface, spherulites have arisen independently, like those in the surrounded group.

The impression made upon me in the field was that a portion of the roof covering the granite cauldron, to which possibly some already chilled granite adhered, had fallen in upon unconsolidated material below, and that the blocks had promoted a rapid cooling, with consequent spherulitic crystallisation round them. It was left for subsequent examination of polished surfaces and thin slices to show how far interaction had gone on between the included materials and the granite magma in which they had become immersed.

Hatch quotes observations by Kilroe to the effect that the occurrence at Mullaghderg lies at a considerable distance from the margin of the granite. This point is of importance if the spherulites are held to have originated in undigested inclusions. Mica-schist forms the eastern boundary of the granite cauldron four miles away at Crolly Bridge; but it is clear that we have to consider in such cases the possible nearness of the roof. Mica-schist and limestone occur as part of the roof, or a roof-pendant, at Annagarry Bridge, and limestone and quartzite are associated as a patch in the granite at Lough Ibby, still nearer to Mullaghderg.

## II. THE NATURE AND ORIGIN OF THE NUCLEI OF THE SPHERULITES OF MULLAGHDERG.

K. von Chrustschoff (Khrushchov),<sup>5</sup> in 1891, classed the rock of Mullaghderg among those in which orbicular structure originated around "inclusions," which might be more acid or more basic products of segregation from the magma, or which might be, on the other hand, foreign bodies. His point is that something that was already cooled before the individualisation of the main crystalline mass has served in such cases as a nucleus for spherulitic growth. He places in the same group the orbicular rocks of Wirvik (Finland), Kortfors (Karlskoga, Örebro, Sweden), and Slättmossa (Sweden) in distinction from those of Corsica and Romsås, in which he believes the spherulites to be "endomorphe Kontaktbildungen." All these, like the rock of Mullaghderg, show radial structure in their spherulitic growths; and von Chrustschoff connects this<sup>6</sup> with the close packing of the nuclei.

N. O. Holst and F. Eichstädt<sup>7</sup> described the spherulites in the Slättmossa

<sup>5</sup> "Über holokrystalline makrovoriolitische Gesteine"; sub-title, "Über einige neue und weniger bekannte holokrystalline Kugelgesteine"; *Mém. Acad. Imp. Sci., St. Pétersbourg*, vii<sup>e</sup> sér., tome xlii (1891-4), p. 231.

<sup>6</sup> *Ibid.*, p. 232.

<sup>7</sup> "Klotdiorit från Slättmossa, Kalmar län," *Geol. Fören. i Stockholm Förhandl.*, vol. vii. (1884), p. 134.

rock as products of crystallisation from the granite magma, and Dr. Holst informs me that his opinion is still unchanged. Von Chrustschoff<sup>8</sup> believes that in this case basic products of segregation have served as nuclei, and have reacted on the magma like foreign inclusions, a zone of intermediate composition arising on their surfaces. Personal experience over wide areas has made me very sceptical as to these so-called basic segregations, which prove in so many cases to be ill-digested foreign bodies. Von Chrustschoff<sup>9</sup> holds that the magnificent spherulites of the granite of Ghistorrai, near Fonni in Sardinia, which happen to show concentric structure only, originated in fragments of various foreign rocks. These are closely packed, as is the case at Mullaghderg, and it is pointed out that in such conditions the zones of mixture during a process of absorption remain longer in stationary contact with regard to the material of the inclusions. Interaction is thus favoured, while complete absorption by diffusion outwards is prevented. Von Chrustschoff remarks that orbicular structure is unlikely to occur in a deep-seated (intratelluric) reservoir, where total destruction of a foreign body will take place. Observations in recent years, however, on blocks removed by "stoping" from the roofs or margins of such reservoirs show that all stages of alteration may be traced in connexion with "batholites" of vast extent. Stress may, however, be laid on von Chrustschoff's suggestion that close packing is an important factor in the production of orbicular spherulites from inclusions, and Carl Benedicks and Olof Tenow<sup>10</sup> show in their experiments that melting is checked by the near approach of nuclei.

Von Chrustschoff was not in a position to determine the presence of foreign nuclei in the granite of Mullaghderg; field-observation, however, as we have seen, at once reveals them. In this and other respects the rock closely resembles that occurring in boulders at Kangasniemi in Finland. The admirable description of the latter example by B. Frosterus<sup>11</sup> leaves, indeed, little to be said as to the main characters revealed at Mullaghderg. The nuclei at Kangasniemi are inclusions of gneiss with dark mica; and Frosterus<sup>12</sup> urges that magmatic action has changed some of these inclusions into rocks with granitic structure. While the mother-rock contains biotite, plagioclase (albite or oligoclase), orthoclase, microcline, and quartz, the

<sup>8</sup> *Op. cit.* (5), p. 229.

<sup>9</sup> *Op. cit.* (5), pp. 128 and 239.

<sup>10</sup> "Künstliche Nachbildung von Schmelz-und Kugelstrukturen in Gesteinen," Geol. Fören. i Stockholm Förhandl., vol. xxxiii (1912), p. 108.

<sup>11</sup> "Ueber einen neuen Kugelgranit von Kangasniemi in Finland," Bull. Comm. géol. de Finlande, No. 4 (1896). Compare his account of the rock of Wirvik, Tscherm. Mitt., vol. xiii (1893), p. 177.

<sup>12</sup> *Ibid.* (1896), p. 9.

felspar of the granitic kernel, where alteration has gone so far, is oligoclase,<sup>13</sup> with some andesine posterior to it, and a very little orthoclase and microcline. Frosterus concludes that a fluid zone formed round the inclusions, as a mixture of their material and the granite magma, and that plagioclase-constituents moved from this towards the centre, while more acid matter (potassium felspar) moved outwards. By diffusion, the molten material of the mixed zone became divided into concentric layers, the acidity of which increases outwards. Analyses show that the chemical composition of the mixed zone is intermediate between that of a schistose inclusion and of the granite.<sup>14</sup>

Frosterus observes that at Kangasniemi potassium felspar is more prominent in the felspathic zone round about the kernel of the spherulites when this kernel has undergone the greatest alteration, and he looks on this as a replacement of plagioclase by resorption. Nuclei of granitic structure occur both at Kangasniemi and Mullaghderg, side by side with less modified nuclei of schist. If the replacement suggested by Frosterus can go on within the kernel as well as in the mixed zone immediately round it, *we have the possibility of a pseudomorphic replacement by granite of the original included block of biotite-gneiss, schist, or amphibolite.*

The evidence at Mullaghderg is very strong in this direction. Hatch,<sup>15</sup> working on very limited material, described the nucleus of the spherulite examined by him as consisting principally of triclinic felspar, together with a little quartz and possibly orthoclase. He observed that it was not so basic as the marginal portions. In the field or on our polished slabs, a fragment of schist is often seen within the felspathic nucleus (Plate IV, E and F). The foreign schistose rock is thus the original nucleus. Where it has been preserved, it is surrounded by a granite zone, rich in quartz and felspar. The concentric and radial zones in turn surround this granitic region, and beyond them lies the general granite of the cauldron (fig. 3).

Not only has the zone around the schistose nucleus an essentially granitic structure, but it is rich in potassium felspar. The felspars of this zone, moreover, occasionally penetrate the schistose nucleus, and indicate the commencement of pseudomorphosis. In a thin section cut from a highly granitic nucleus (fig. 2), a cluster of biotite crystals, separated from one another, but sufficiently grouped and concentrated to suggest their former association, remains as the last trace of the inclusion. The biotite crystals are associated with magnetite and with a little sphene. They are arranged round crystals of felspar, as if their constituents had separated out to form

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<sup>13</sup> *Ibid.*, pp. 18 and 7.

<sup>14</sup> *Ibid.*, p. 31.

<sup>15</sup> *Op. cit.* (1), p. 555.

dark mica after an episode of melting. They represent the reconsolidation of basic matter that was unable to diffuse away completely from the central region of attack. The resemblance of this patch to the recrystallised relics of schist-layers in composite gneisses is suggestive, and, indeed, convincing. Where the nucleus of a spherulite consists of granite, this nucleus often contains more biotite than is common in the granite of the cauldron, a feature that is, of course, explicable if the granitic matter has entered the spherulite as a replacement of an originally basic nucleus.

More than this, the grey concentric zones of oligoclase and magnetite have been attacked by resorption, and they have been penetrated here and there, like those of Kangasniemi,<sup>16</sup> by films from the still fluid magma. They



FIG. 2.—Thin section of central portion of spherulite from granite of Mullaghderg, showing arrangement of biotite, which represents the residue of an inclusion, around crystals of felspar.  $\times 14$ . Geological Survey specimen.

have also suffered from stoping and solution at their inner surfaces (Plate IV, D, and Plate, V, I). A molten and highly siliceous (undersaturated) zone has worked against them, as well as against the relics of the basic nucleus. In so doing, its temperature has been raised,<sup>17</sup> and it no doubt remained liquid after the consolidation of the magma in the cauldron. Its primary efficiency, however, depended on the supply of material from without, and on the possibility of the diffusion of absorbed material in a reverse direction

<sup>16</sup> *Op. cit.* (11), p. 20.

<sup>17</sup> See S. J. Shand, "On Saturated and Unsaturated Igneous Rocks," *Geol. Mag.*, 1913, p. 510.

outwards. In many cases a granitic nucleus has finally resulted, with no trace at the centre of the former basic core. The material of this core must now be sought in the outer shells of the spherulite. Continued action has threatened even these outer zones; and in some cases the original inclusions have left merely dark fluidal bands, which impart to the granite here and there the aspect of a gneiss (compare p. 157).

The granite nuclei are thus localised instances of a process of pseudomorphosis that has become familiar to us on a large scale in the field. The cleanness of the contact-zone which is seen in many instances where a granite magma has invaded superincumbent or surrounding rocks has been explained by the draining off of the absorbed matter to other portions of the cauldron,<sup>18</sup> The bands of granite that often predominate in the material of a composite gneiss, such as that on the south side of the Gweebarra River in the county of Donegal, are not merely injections between layers of schist, but take the place of bodies of schist or associated rocks that have disappeared by interchange with the advancing granite. Such a pseudomorphosis obviously implies removal of material. Professor Schwarz<sup>19</sup> speaks of a replacement of the slate at Sea Point, near Cape Town, by granite, and of felspathic matter as dissolving out the slate and crystallising "in the cavity it had eaten out for itself." He urges that, "of the various substances in solution, felspar is the most mobile, and gains admittance to the slates first." Though he does not specify an opposite process of diffusion, he no doubt contemplates the passing out of aluminous and ferromagnesian matter from the slates. I have seen reason<sup>20</sup> to differ from his views as to the production of the porphyritic orthoclase, which is accompanied in the slate by more fine-grained and diffused material from the granite, and which may have been floated into the softening slate in an already formed condition; but my own examination of the historic Sea Point section enables me thoroughly to agree with Professor Schwarz's well-expressed proposition that it reveals "a pseudomorph in granite of the sedimentary rocks." Whatever view is taken in such cases as to the origin of large crystals of felspar within the attacked rock, their resemblance to those in the adjacent granite furnishes evidence of the introduction of matter from the invader. The softening of the rock that is attacked, whether it is a bounding mass or an inclusion, allows of its ready

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<sup>18</sup> G. A. J. Cole, "Geology of Slieve Gallion," *Sci. Trans. R. Dublin Soc.*, vol. vi (1897), p. 242.

<sup>19</sup> E. H. L. Schwarz, "The Sea-Point Granite-Slate contact," *Trans. Geol. Soc. S. Africa*, vol. xvi (1914), pp. 37, 35, and 36.

<sup>20</sup> G. A. J. Cole, "A Composite Gneiss near Barna (County Galway)," *Quart. Journ. Geol. Soc. London*, vol. lxxi (1916), p. 186.

penetration. In an example described from the county of Down,<sup>21</sup> there can be no doubt whatever that the porphyritic crystals of orthoclase and quartz now found in the inclusions existed already as such in the granite that melted these inclusions. The porphyritic crystals of orthoclase that distinguish the granite of Shap Fell, in Westmorland, may similarly have become imported into the included blocks, in which they are often conspicuous. At the same time, something has passed out from these blocks, if only to make way for these crystals, and for the permeating and unconsolidated granite magma, which is now represented by quartz and smaller felspar crystals. The inclusions have become granitised, because the surrounding matrix has become enriched by basic matter. J. A. Phillips<sup>22</sup> figures crystals of orthoclase extending from the Shap granite into the dark inclusions as evidence that the two types of rock developed contemporaneously; but the range of subsequent observation prevents us from accepting this as a necessary conclusion. A. Harker and J. E. Marr,<sup>23</sup> who also regard the included blocks at Shap as segregations, none the less point out that the orthoclase within them has suffered from corrosion. While interaction took place between the invading and the invaded matter, the surfaces of the inclusions became rounded by solution and by outward diffusion of their substance, just as the artificial angular inclusions of paraffin used by Benedicks and Tenow (*op. cit.*, 10, p. 108) became rounded in molten paraffin, when the addition of resin to the latter allowed a sufficiently high temperature to be employed. J. A. Phillips,<sup>24</sup> more than thirty years ago, recognised that a rounded form might be imparted to an inclusion of foreign origin.

Schwarz considers the case of felspathic molecules moving as such into the invaded rock. Where, however, the inclusion resists permeation by the molten magma as a whole, the transference of material probably occurs by a still more subtle process of selection. Kurd Endell<sup>25</sup> has experimented with a lump of limestone immersed in molten microcline, the inclusion being ultimately converted into a yellow glass. He concludes from an analysis of this glass that silica and soda may diffuse more rapidly than potash into a nucleus rich in calcium. Where the softening is less, and even where the solid state is maintained by an inclusion, a transference of matter from the surrounding

<sup>21</sup> G. A. J. Cole, "On Derived Crystals in the Basaltic Andesite of Glasdrumman Port," *Sci. Trans. R. Dublin Soc.*, vol. v (1804), p. 244.

<sup>22</sup> "Additional Note on Certain Inclusions in Granites," *Quart. Journ. Geol. Soc. London*, vol. xxxviii (1882), p. 216.

<sup>23</sup> "The Shap Granite," *ibid.*, vol. xlvii (1891), pp. 280 and 282.

<sup>24</sup> "On Concretionary Patches and Fragments of other Rocks contained in Granite," *Quart. Journ. Geol. Soc. London*, vol. xxxvi (1880), p. 1.

<sup>25</sup> "Über Diffusionserscheinungen in Silikatschmelzen bei höheren Temperaturen," *Neues Jahrb. für Min. &c.*, 1913 (2), p. 152.

granite may go on by ionic rather than by magmatic penetration.<sup>26</sup> Though the transference is selective, it seems probable that continued interaction wholly destroys the original nucleus, by the opposite diffusion of its materials into the great mass of molten highly siliceous matter round about. Such matter, as Shand points out, rises in temperature until solution of the more basic substance is complete. While oligoclase and andesine are formed during the earlier stages, which are recorded in the spherulites of orbicular rocks, the presence of potassium felspar in an inclusion, where this mineral also exists in the surrounding rock, marks an advanced stage of destruction.

C. W. Drysdale<sup>27</sup> has recently recorded a remarkable instance of the replacement of invaded material by an igneous rock. Further details would seem desirable; but it appears that "the more permeable pebbles and matrix" of a conglomerate of Eocene or Oligocene age are now represented by pseudomorphs of syenitic constitution. The syenite penetrated the conglomerate in Miocene times, before the stratum was consolidated, so that the completeness of the interaction, rivalling that in composite gneisses, cannot be ascribed to exceptional conditions of metamorphism in the lower layers of the crust.

These considerations render it less difficult to regard the granite nuclei in the rock of Mullaghderg as of external and pseudomorphic origin, whether they include a residue of schist or not. Similarly, the "granulite" nuclei in the orbicular rock of Walkraal, described by W. J. Gau,<sup>28</sup> may represent the almost complete assimilation of more basic inclusions. They are closely set, and are surrounded by pegmatitic shells, and they differ from the medium-grained hornblende-granite or granulite that surrounds them in containing rather more biotite than hornblende. F. D. Adams and A. E. Barlow<sup>29</sup> have critically considered the sheets of spherulites that occur in the granite of Pine Lake, and have well compared them with axiolitic bands in lavafloes. They are mainly composed of quartz, muscovite, and sillimanite, but contain a small amount of orthoclase. The wall-rock is "a basic gabbro-like amphibolite," from which, as the authors point out, the spherulites are not likely to have been derived. They regard the nodules as segregations of more acid material from the magma, but suggest, however, that "schlieren" may have been brought from another part of the igneous reservoir. May we not see, then, in these spherulites the result of the enrichment in silica of

<sup>26</sup> *Ibid.*, p. 131.

<sup>27</sup> "Geology of Franklin Mining Camp," Geol. Surv. Canada, Mem. 56 (1915), p. 82.

<sup>28</sup> "Notes on the Bushveld in the Neighbourhood of the Junction of the Elands and Oliphants Rivers," Trans. Geol. Soc. S. Africa, vol. ix (1906), p. 70.

<sup>29</sup> "Geology of the Haliburton and Bancroft Areas, Ontario," Geol. Survey Canada, Mem. 6 (1910), p. 127.

foreign inclusions, which were possibly sheets of sedimentary rock? In that case the change has been partly pseudomorphic, and the spherulitic form has arisen, as at Mullaghderg, by the outward diffusion of material from the original inclusions.

The most interesting nucleus among those observed in the granite of Mullaghderg is that shown below the letter F, on Plate IV, and, from another section, in fig. 3. A long flake of biotite-schist, perhaps originally an amphibolite,<sup>30</sup> includes crystals of pink felspar, which in places seem, like those of Barna, to be passing in from the similarly pink granite zone around. Outside this granite-zone grey concentric zones of radially grouped soda-lime felspar and magnetite occur, as in the ordinary spherulites; but the external form has been controlled by the elongated nucleus. In the same

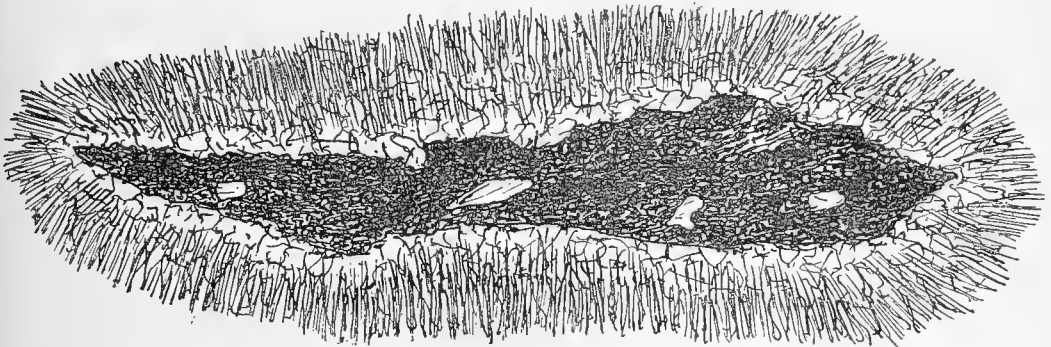


FIG. 3.—Sketch of a partially granitised inclusion of schist in an elongated spherulite in the granite of Mullaghderg, showing penetration by the zone of granite round it. The inner edge of the radial region of the spherulite is indicated by the shading surrounding the granitic zone. Drawn from polished surface. Natural size.

plate a granitic nucleus is seen in the spherulite D, and this nucleus has caused foundering and partial absorption of the concentric outer zones.

It is not clear that the resorption of the spherulites, or the introduction of the matter that has attacked and ultimately replaced many of their original cores, is connected with the second intrusion of granite that formed the subsequent veins. Such veins of pink aplite are well seen at H in Plate V, and thin representatives of them traverse the main rock, the grey radial zones, and the granitic nuclei of the spherulites. The formation of the miniature cauldrons within the grey concentric and radial zones seems, however, to have been contemporaneous with that of the grey zones. Their contents were, however, reinforced from the still fluid magma round about the spherulites after these zones had reached a fairly rigid state, and the molten

<sup>30</sup> Compare *op. cit.* (20), p. 185.



granite that here and there penetrates and parts the concentric shells sends off feeders through these shells into the central miniature cauldrons.

### III. THE ZONAL STRUCTURE OF THE SPHERULITES.

Zones, lighter or darker than the central core, have often been observed round bodies included in igneous rocks. The zoning of ordinary crystals through changes in the condition of the magma round about them is familiar enough, and von Chrustschoff<sup>31</sup> observes that in the rock of Fonni felspars which have been melted out as relics from porphyritic inclusions become zoned by additions as they float away into their new surroundings. Von Chrustschoff also cites zones of hornblende round nuclei in a rock in the Svartdal as due to the attraction of concentrated ore-masses in these nuclei. But the outer zone in the case of most inclusions is not to be ascribed to deposition from without, but to interaction between the inclusion and the enclosing magma. Hence it frequently represents a loss, rather than an addition, of material.

Benedicks and Tenow emphasised the relict character of such zones in a paper somewhat earlier than that already quoted.<sup>32</sup> In their considerations the enveloping magma is supposed, for the sake of simplicity, to be of the same composition as the inclusions, while the inclusions consist of two minerals, say hornblende and felspar. It is suggested that such an inclusion, as the temperature rises, loses by melting at its outer zone material which will form, at that particular temperature, a eutectic layer. Material more acid or basic than the eutectic remains behind nearer to the nucleus of foreign rock. If the temperature continues to rise, the eutectic zone approaches the original composition of the nucleus, by absorption of the relict zone, and at last the inclusion may disappear altogether into the general melt. Cooling at a particular stage, however, may preserve a distinctly zonal structure. The authors urge that there is every passage in the granite of Upsala from dark zones formed round fragments of mica-gneiss or diorite into the lumps that Högbom styles basic segregations. Two years later<sup>33</sup> they mixed paraffin with graphite, and plunged angular blocks of this mixture, heated to near their melting-point, into already molten paraffin. The paraffin streamed out of the surface-layers of the block, leaving behind a dark zone of concentrated

<sup>31</sup> *Op. cit.* (5), pp. 233 and 239.

<sup>32</sup> "Om de s. k. basiska utsöndringarna i Upsalagraniten och om klotgranitens bildningssätt ur fysikalisk-kemisk synpunkt," *Geol. Fören. i Stockholm Förhandl.*, vol. xxxii (1910), p. 1506. On the formation of a eutectic zone in an orbicular hornblende-gabbro, compare J. A. Bancroft, "Geology between Strait of Georgia, &c.," *Geol. Surv. Canada, Mem.* 23 (1913), p. 101.

<sup>33</sup> *Op. cit.* (10), p. 105.

graphite. This serves to illustrate their proposition that, as a rock-inclusion melts, a zone of molten products forms about it, in which relics of the solid nucleus survive. These particles gather towards one another and towards the still unmelted core. When melting has gone on up to the centre of the inclusion, the origin of the structure becomes unrecognisable, as is usually the case in orbicular granites.

J. A. Phillips,<sup>34</sup> who was one of the first to study concretionary patches and inclusions in granite in thin slices with the microscope, also made good use of polished surfaces. In this he followed A. Delesse,<sup>35</sup> who drew with a camera lucida from such surfaces of spherulitic rocks. Phillips notices that in the granite of Dyce Quarry, near Aberdeen, a thin layer of mica envelops a large mass of more finely grained granite, and that the quartzose sedimentary rocks included in the granite of Goraghtwood in Co. Down are "darkened by the presence of a disseminated material of a nearly black colour, to a depth of about an inch only." This altered portion is more hornblendic than the central mass, and contains less lime; the other chemical differences pointed out by J. A. Phillips seem unimportant.

At Swan Mount, Portnoo, in the county of Donegal, the granite contains abundant closely set inclusions of the local Dalradian rocks. More prolonged heating might have converted these into spherulites, like those of Slättmossa, Kangasniemi, or Mullaghderg. When a polished surface is examined, dark reaction-rims are seen round the aphanitic inclusions. The first step has been taken towards zone-formation, by the diffusion outwards of certain constituents, and the concentration of others in the relict zone.

The resorption-zones so often seen round amphiboles that are included porphyritically in andesitic lavas are familiar illustrations of the same selective process. Magnetite is developed in these zones, and resists solution. In some cases the original crystal is represented merely by an assemblage of black grains. Since magnetite is the dark mineral in the concentric zones at Mullaghderg, it is of interest to quote another case of its development in a relict zone. R. A. Daly<sup>36</sup> has observed nodules of granular olivine in a peridotite dyke, which probably developed at some place other than that to which they have now been carried. These inclusions, as we may call them, are 3 to 6 cm. in diameter, and are surrounded by kelyphitic shells up to 15 mm. thick. The photographs given show a darker zone between the nodules and

<sup>34</sup> *Op. cit.* (24), pp. 12 and 17.

<sup>35</sup> "Recherches sur les roches globuleuses," *Mém. Soc. géol. de France*, 2me sér., vol. iv (1851), p. 301.

<sup>36</sup> "Geology of the N. American Cordillera at the 49th Parallel," *Geol. Surv. Canada*, Mem. 38 (1912), p. 43, and plate 37.

these lighter shells. While the olivine in the nodules is associated with a chrome-spinellid and a little pyroxene, the kelyphitic zone consists of tremolite and magnetite.

Schrauf's "kelyphite" is now generally regarded as a product of interaction, and we may probably cite its formation round garnet in peridotite as evidence of a zonal replacement of the garnet. Sir T. H. Holland,<sup>37</sup> on the other hand, considers the micropegmatitic zone round garnets in certain diorites, charnockites, and pyroxenites as a phase in garnet growth, rather than as a siliceous interchange with the more basic matter of the garnet.

As an example of how zones of interaction may become relict zones, we may cite the concentration of pyroxene and garnet by a process of selective absorption, which has been pointed out in connexion with igneous contacts in Ireland.<sup>38</sup> In both the cases studied, the minerals have arisen as the result of metamorphism in the rock attacked, and have then proved more resistant to absorption than their companions in the altered mass.

This leads us to enquire whether the production of minerals by contact-metamorphism, which may, of course, work upon a regional scale, does not commonly imply a transference of material to the altered rock, accompanied by a removal of other material into the invader. This outward streaming as the concomitant of an inward streaming clearly concerns the formation of concentric shells round about the nuclei in orbicular rocks. The range of density in the common rock-forming minerals is not sufficient to allow of the utilisation of much imported material within the limits of the block attacked. In a large number of observed cases, moreover, basic inclusions become replaced in part by quartz and felspar. Just as carbon dioxide passes out during the production of silicates in a limestone, so magnesium and iron, at any rate, disappear from a basic inclusion by diffusion outwards. H. J. Johnston-Lavis<sup>39</sup> in 1894 pointed out this exchange of constituents as a cause of variation in igneous rocks, and styled his hypothesis, perhaps somewhat vaguely, "osmotic." Endell,<sup>40</sup> when urging the ionic nature of such diffusion, gives very just recognition to Johnston-Lavis as the pioneer. A. C. Lawson<sup>41</sup> connected zoned orbicular structure with osmotic diffusion in

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<sup>37</sup> "On the Origin and Growth of Garnets, and of their Micropegmatitic Intergrowths in Pyroxenic Rocks," *Rec. Geol. Surv. India*, vol. xxxix (1896), p. 20.

<sup>38</sup> G. A. J. Cole, "On Contact-phenomena at the Junction of Lias and Dolerite at Portrush," *Proc. R. Irish Acad.*, vol. xxvi, Sect. B. (1906), p. 62.

<sup>39</sup> "The Causes of Variation in the Composition of Igneous Rocks," *Natural Science*, vol. iv (1894), p. 139.

<sup>40</sup> *Op. cit.* (25), p. 131.

<sup>41</sup> "The Orbicular Gabbro at Debesa, San Diego County, California," *Univ. Calif., Bull. Depart. Geol.*, vol. iii (1904), p. 396.

1904, when he stated that the distance between the centres of "orbules" may be determined by the rather short distances through which osmotic diffusion operates in limited time. The radial structure in the spherulites of the rock described by Lawson depends on the grouping of olivine, which controls the associated felspar; and Lawson observes that this arrangement may be due to radial movement of the diffusion currents. No definite suggestion is made, however, as to the nature of the bodies from which the diffusion took place. Diffusion implies the presence of something capable of spreading through a medium. The spacing of the centres must surely be due, not to the distances reached by the solute, but to the original distribution of crystal-segregations or inclusions in the gabbro magma. Seeing that the centre of the spherulites now consists of a granular basic felspar, probably anorthite, with olivine and a little hypersthene, it is of interest to enquire whether a concentration of calcium and a loss of iron and magnesium has not resulted from the process of diffusion.

Johnston-Lavis in 1894 postulated the presence of a liquid, which might consist of molten silicates, as the agent of diffusion, and as a necessary factor in segregation. In his still more important paper published in collaboration with J. W. Gregory<sup>42</sup> later in the same year, it is shown how a banded or zonal structure may be a consequence of diffusion. Nothing can be clearer than the few lines in which the authors anticipate, in explaining the layers of olivine in limestone, the principle so admirably developed and illustrated experimentally by Raphael E. Liesegang<sup>43</sup> in recent years.

Von Chrustschoff,<sup>44</sup> as far back as 1891, realised that the absorption of inclusions in igneous rocks implies a diffusion of matter in opposite directions. He attributes the radial structure at Ghistorrai, Sardinia, to the slowness with which the magma was able "von aussen nachzudringen und nach aussen zu diffundiren." Johnston-Lavis<sup>45</sup> held that diffusion was responsible for the development of concretions of calcium carbonate in marl. Liesegang<sup>46</sup> states, somewhat more definitely, that in the case of such concretions, "Da der Kalk von auszen kommt, musz etwas, was den Kalk fällt, von den Zentren

<sup>42</sup> "Eozoöнал Structure of the Ejected Blocks of Monte Somma," *Sci. Trans. R. Dublin Soc.*, vol. v (1894), p. 264.

<sup>43</sup> "Über die Schichtungen bei Diffusionen" (Leipzig, 1907), and especially "Geologische Diffusionen" (Dresden, 1913).

<sup>44</sup> *Op. cit.* (5), p. 129.

<sup>45</sup> *Op. cit.* (39), p. 137.

<sup>46</sup> "Geol. Diffusionen," pp. 159 and 171. S. Taber, "The Growth of Crystals under External Pressure," *Amer. Journ. Sci.*, vol. xli (1916), p. 555, points out how concretions, such as flints in limestone, may replace the pre-existing rock by exerting pressure during crystal growth, and hence promoting the solution of the material where this is more soluble under pressure.

ausgehen." He points out in a later passage the analogy between concretions in sedimentary rocks and orbicular spherulites. The features shown by the spherulites of Mullaghderg certainly demand a movement in opposite directions, which continued to act even after the formation of well-marked zonal envelopes.

The grey zone of radially arranged soda-lime felspar round about the granitic and schistose nuclei at Mullaghderg corresponds with the zone of mixture described by Frosterus and other authors.<sup>47</sup> It lies at some distance from the relics of the original nucleus, on account of the inward flow of the granite magma and the outward flow of basic matter through it. At a certain distance from the original nucleus of amphibolite or biotite-schist, the ferromagnesian compounds have decomposed, and iron has separated in the form of magnetite, which was immiscible with its molten surroundings at the temperature attained.<sup>48</sup> From the close association of biotite with the magnetite, and especially its occurrence in one of Miss Andrews's specimens as a zonal deposit along with the magnetite grains, it appears that biotite separated from the mixture, and was then decomposed and in large part re-absorbed. The withdrawal of iron oxide from the molten mixture, impoverishing the zone immediately outside that along which the magnetite was deposited, appears to have allowed of further diffusion, without more than a scattered crystallisation of magnetite. But soon a second deposition occurred, and the process was repeated rhythmically, until in some cases four light-coloured zones and four more rich in magnetite were formed.

Ultimately the mixed silicates in which the magnetite granules made their appearance crystallised radially as andesine, or oligoclase verging upon andesine. The radial structure of the felspar probably accounts for the arrangement of much of the magnetite, which developed as a number of accreting nuclei between the main concentric zones of deposition. A small amount of biotite occurs in the felspathic envelopes, showing that some of the material of the nucleus escaped complete decomposition. The great bulk of the magnesium, however, and perhaps part of the lime, passed out from the destroyed portion of the inclusion into the general magma of the cauldron.

In many cases, as we have seen, the process of zone-building ceased, on account of the complete destruction of the basic inclusion. In other cases, a relic still remained when the urgent attack of a fresh unsaturated magma,

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<sup>47</sup> On the influence of temperature in freeing this zone from ferromagnesian constituents, compare J. A. Bancroft, *op. cit.* (32), p. 101.

<sup>48</sup> For numerous examples of the production of magnetite by the interaction of molten minerals, see F. W. Clarke, "Data of Geochemistry," U. S. Geol. Surv., Bull. 616 (1916), p. 345.

accompanied, in all probability, by a rise of temperature, threatened the spherulites with resorption. The streaks and swirls of granite rich in biotite that appear in the more normal granite of Mullaghderg probably represent flakes detached from the bounding walls of schist, which were carried about in the magma under normal conditions, such as favour irregular diffusion. They are too rich in basic magnesian matter to have been produced by the resorption of the oligoclase-magnetite zones of the spherulites.

The grey zones that occasionally occur, as described in Section I of this paper, about a whole group of spherulites and their interstitial granite may, however, be ascribed to the resorption stage. The included region has served as a compound nucleus, from which matter has streamed out, until it was precipitated along a saturated zone in the quiescent magma round about. The closely packed spherulites have probably, as von Chrustschoff suggests, prevented free flow and rapid interaction in a magma that was otherwise still effective as regards temperature and possibilities of diffusion.

The plasticity of the zonal portion of the spherulites during the resorption stage is evidenced at Mullaghderg, as at Wirvik and Kangasniemi, by the moulding of the spherulites against one another. Like the closely set rock-inclusions at Portnoo, the spherulites are separated by thin sheets of the encasing granite; but none the less their outer surfaces have influenced one another. The convex bulge of a spherulite produces a concavity in a neighbour squeezed against it (Plate IV, C, D, and F).

#### IV. SUMMARY.

From examination of the orbicular granite of Mullaghderg in the field, and in polished surfaces prepared for the Geological Survey of Ireland, a close resemblance is noted between this rock and that described by B. Frosterus from boulders at Kangasniemi in Finland. The orbicular structure has developed round a number of close-set foreign inclusions of biotite-schist, which may have been originally amphibolites. By diffusion, basic material has spread from these inclusions outwards, and has in part been precipitated as a zone of soda-lime felspar and magnetite. The granite magma has been substituted for the dissolved portions of the inclusions, and complete destruction of the inclusions has thus given rise to spherulites with granitic cores. Where a relic of the schist remains, it is surrounded by granite, outside which lie the radial and concentric zones described by Dr. Hatch in 1888. Resorption-effects are noticeable, acting from without, and also from within the spherulites, on the radial and concentric envelopes.

## DESCRIPTION OF PLATES.

## PLATE IV.

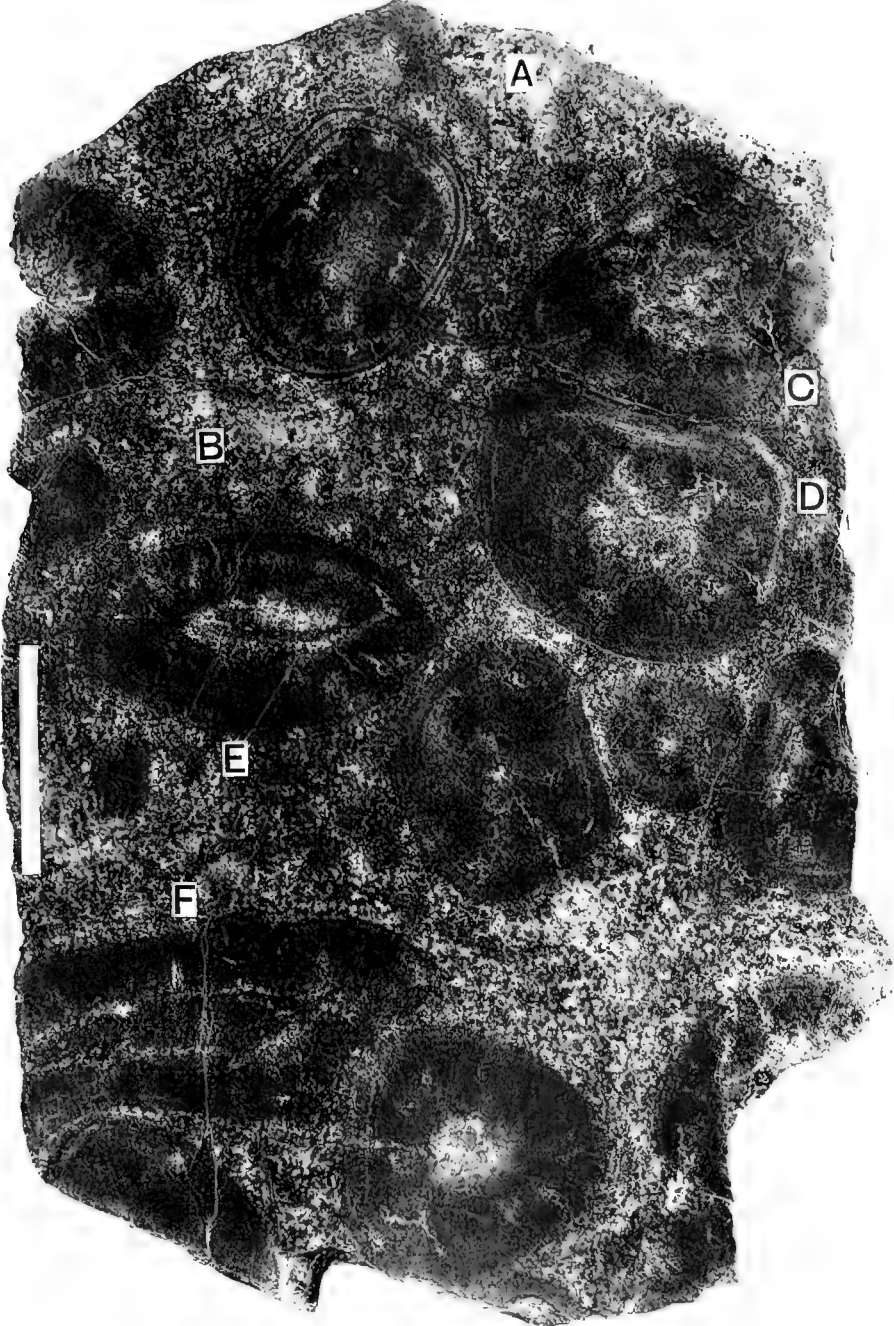
Polished surface of orbicular granite of Mullaghderg. The white band on the slab represents one decimetre.

A, B, fairly normal biotite-granite of the cauldron. C, D, spherulites with granite cores, which have reacted on the inner surfaces of the radial zone (the scale of the photograph does not allow all the details of "stopping" in this zone to be seen). The form of C has influenced its neighbour D. E, elongated spherulite, with a flake of biotite-schist as a nucleus, surrounded by a zone of granite, outside of which the radial zone occurs. F, elongated spherulite, with schistose core, into which red porphyritic feldspars pass from a thin surrounding zone of granite. The form has been influenced by a neighbour on the right.

## PLATE V.

Polished surface of the back of the slab shown in Plate IV, the interval between the two surfaces being 5 cm. The white band represents one decimetre.

G, the normal biotite-granite, with darkening by partially assimilated material in streaks and patches. H, vein of later granite of aplitic type, cutting the spherulite I and the main granite. I, the same spherulite as that shown at D in Plate IV, with resorption and foundering on the inner side of the radial zone. K, spherulite destroyed on one side by melting. L, the same spherulite as F in Plate IV.











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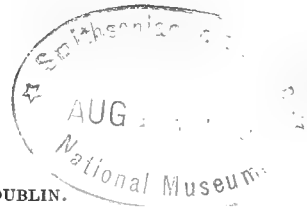
AN ABNORMALITY IN THE ARTERIAL SYSTEM  
OF THE RABBIT.

BY

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[COMMUNICATED BY PROFESSOR G. H. CARPENTER, M.Sc.]



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## EVENING SCIENTIFIC MEETINGS.

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XVI.

AN ABNORMALITY IN THE ARTERIAL SYSTEM OF THE RABBIT.

By EDMOND J. SHEEHY, A.R.C.Sc.I.,

Demonstrator in Zoology in the Royal College of Science, Dublin.

(COMMUNICATED BY PROFESSOR G. H. CARPENTER, M.Sc.)

[Read NOVEMBER 28. Published DECEMBER 19, 1916.]

WHILST working recently in the biological laboratory of University College, Galway, my attention was drawn by Professor Mangan to an irregular arrangement of the aortic branches in the blood system of a rabbit. I am much indebted to him for having afforded me an opportunity of examining this abnormality, and of giving an account of it. My thanks are also due to Professor Carpenter for some valuable suggestions.

The well-known normal arrangement of the rabbit's great arteries is shown in figure 1. In the specimen now described the innominate artery

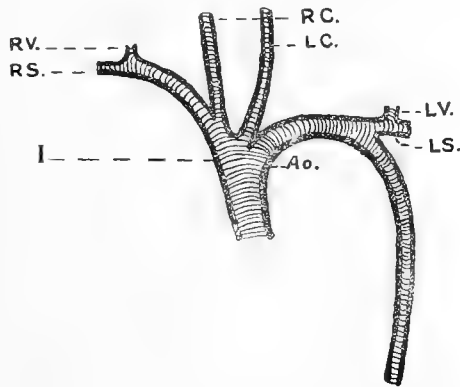


FIG. 1. —NORMAL ARRANGEMENT OF BLOOD-VESSELS IN RABBIT.

|                       |                    |                |
|-----------------------|--------------------|----------------|
| R.V. Right vertebral. | L.C. Left carotid. | I. Innominate. |
| R.S. „ subclavian.    | L.V. „ vertebral.  | Ao. Aorta.     |
| R.C. „ carotid.       | L.S. „ subclavian. |                |

gives off the two carotid trunks, but does not give rise to the right subclavian. A blood-vessel, serving as a right subclavian, that is, supplying the



right vertebral and the arteries of the right arm, arises from the descending aorta dorsally and slightly caudal to the left subclavian: it passes dorsal to the heart and oesophagus, and appears on the right side in its proper position in the vicinity of the first rib (figure 2). The arrangement of the nerves is

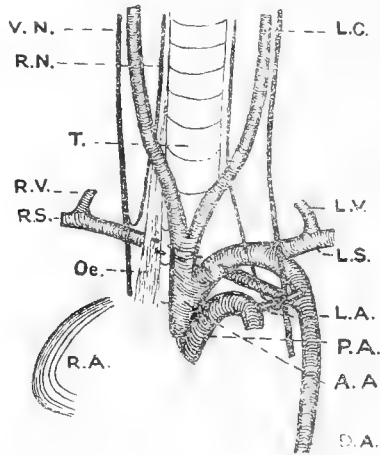


FIG. 2.—ABNORMAL RIGHT SUBCLAVIAN.

|                                 |                             |                             |
|---------------------------------|-----------------------------|-----------------------------|
| V.N. Vagus nerve.               | R.S. Right subclavian.      | L.S. Left subclavian.       |
| R.N. Recurrent laryngeal nerve. | Oe. Oesophagus.             | L.A. Ligamentum arteriosum. |
| T. Trachea.                     | R.A. Right auricle of heart | P.A. Pulmonary artery.      |
| R.V. Right vertebral.           | L.C. Left carotid.          | A.A. Ascending aorta.       |
|                                 | L.V. „ vertebral.           | D.A. Descending aorta.      |

normal; the recurrent branch of the vagus returns round the ligamentum arteriosum (the solidified ductus arteriosus) on the left, and on the right takes its usual course round the position of the subclavian branch of the innominate, even though the vessel which it would embrace normally is absent.

Abnormalities of a similar nature in the human subject have been reported, and the phenomenon has been attributed to the persistence of embryological conditions.<sup>1</sup> Mr. Ramsey Smith records the occurrence of a similar abnormal right subclavian in a rabbit,<sup>2</sup> but he does not mention the arrangement of the nerves associated with it.

The origin of the aortic arches in the mammalian blood system is

<sup>1</sup> Quain's "Anatomy," 9th edition, vol. i. Macalister's "Human Anatomy," 1889, pp. 555, 556.

<sup>2</sup> "Journal of Anatomy and Physiology," April, 1891.

illustrated in outline in figure 3. The aortic bulb, or anterior portion of the ventricular part of the developing heart, divides symmetrically, giving off branches to the visceral arches of the embryo on each side. Changes are effected in this system by the backward movement of the heart, from its

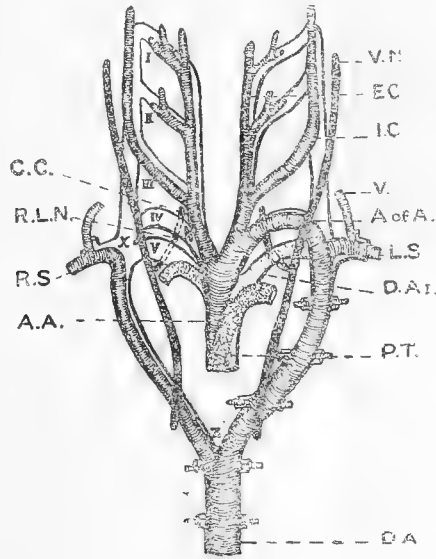


FIG. 3.—DEVELOPMENT OF ABNORMAL CONDITION.

|                                   |                         |                                       |
|-----------------------------------|-------------------------|---------------------------------------|
| C.C. Common carotid.              | V.N. Vagus nerve.       | L.S. Left subclavian.                 |
| R.L.N. Recurrent laryngeal nerve. | E.C. External carotid.  | D.A <sub>1</sub> . Ductus arteriosus. |
| R.S. Right subclavian.            | I.C. Internal carotid.  | P.T. Pulmonary trunk.                 |
| A.A. Ascending aorta.             | V. Vertebral.           | D.A. Descending aorta.                |
|                                   | A. of A. Arch of aorta. |                                       |

original position beneath the head, into the thorax, by the severance of the continuation of arches I, II, and III, and by the junction of the lateral descending portions of the primitive aortae dorsally into a single median tube—the descending aorta. Taking the abnormality in the rabbit in question to be due to the persistence of an unusual portion of the embryological visceral blood system, the darkened portions in figure 3 represent those parts of the system which continued in the abnormal adult after the outline of the embryological arrangement had been lost. Usually arch IV continues on the right side as the subclavian; its continuation, forming the right descending aorta (figure 3, x to z), disappears, and in the adult the persisting proximal part (N to x) appears as a branch from the innominate. In this case the proximal portion must have disappeared, and the right descending aorta must have persisted. Disproportionate development soon caused the vessels to lose their symmetry, and the right

descending aorta—the abnormal subclavian—came to look like a small branch from the left descending aorta. In the normal human subject the remains of the right descending aorta exist as the arteria aberrans.<sup>1</sup>

Invariably the recurrent branch of the vagus nerve supplying the larynx is entrapped in the arms of the arches because these pass dorsalwards from a ventral position, and the nerves are pulled back in loop fashion by them. On the left the nerve evidently loops round arch v, because it there persists round the ductus arteriosus, which is the persistent fifth left arch. On the right it presumably loops round the fifth also, but that vessel afterwards disappears. If from the right side all the arches were to disappear and the recurrent still assumed the same position, the fact would suggest that the nervous system was well developed previous to the disappearance of the arches. It is evident that all the five arches were severed on the right side of this particular rabbit in such a way that the recurrent, if it had not continued to grow in length as in a normal specimen, might have receded to its original direct position. It lies, however, in the normal situation, and its position there proves that at one time this recurrent nerve must have embraced a blood-vessel which branched from the aortic bulb through one of the visceral arches, probably the fifth, but at least as far back as the fourth. Then as the aortic bulb with the heart moved caudalwards the recurrent was brought to its present position, where it remained after the vessel which distorted its course had been absorbed. Correlated with a similar abnormal development of the right subclavian in man there is generally a direct, not recurrent, course of the right inferior laryngeal nerve.<sup>2</sup>

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<sup>1</sup> Macalister's "Human Anatomy," 1889, p. 555.

<sup>2</sup> *Ibid.*, p. 556.

## SCIENTIFIC PROCEEDINGS.

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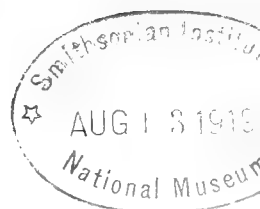
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THE FATIGUE OF NICKEL AND IRON WIRES  
WHEN SUBJECTED TO THE INFLUENCE  
OF TRANSVERSE ALTERNATING MAGNETIC  
FIELDS.

BY

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[*Authors alone are responsible for all opinions expressed in their Communications.*]

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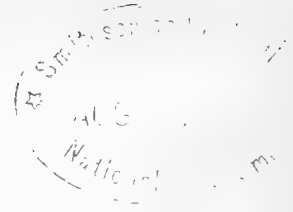
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## XVII.

THE FATIGUE OF NICKEL AND IRON WIRES WHEN SUBJECTED  
TO THE INFLUENCE OF TRANSVERSE ALTERNATING  
MAGNETIC FIELDS.

By WILLIAM BROWN, B.Sc.,

Professor of Applied Physics, Royal College of Science for Ireland, Dublin.

Read NOVEMBER 28, 1916. Published JANUARY 3, 1917.

DURING the year November, 1914, to November, 1915, I brought before this Society the results of some experiments on the fatigue of nickel and iron wires when they were subjected to the influence of *longitudinal* alternating magnetic fields of frequencies 50 to 250 cycles per second.<sup>1</sup>

The present communication gives the results of experiments on the fatigue of nickel and iron wires when subjected to the influence of *transverse* alternating magnetic fields of frequency 50 per second.

The transverse magnetic fields for these experiments were obtained as follows, referring to Fig. 1:—

*I* is an iron tube, with a slot 3·5 cms. wide cut down its whole length, the tube being 226 cms. long, 6·1 cms. external diameter, and 5·1 cms. internal diameter. The five copper wires *C* down the middle of the tube were each 0·4 cms. in diameter, and were well insulated from each other, as well as from the wooden support *W*, the circuit being so arranged that the current went through the five wires in the *same direction*, and produced a transverse alternating magnetic field across the gap of the iron tube.

The relation between the current in the copper wires *C* and the magnetic field in the gap of the iron tube was found in the usual way by means of an exploring coil, earth inductor, and ballistic galvanometer. On plotting the

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<sup>1</sup> Scient. Proc. Roy. Dubl. Soc. (1915), vol. xiv, No. 26, p. 336, No. 39, p. 521, and vol. xv (1916), No. 1, p. 1.



total current through the wires as abscissae and the corresponding values of the magnetic field as ordinates, the points were found to lie on a straight line passing through the origin; thus, if a straight line be drawn from the origin to the point corresponding to current = 200 amperes (40 amperes in each wire) and magnetic field = 90 c.g.s. units, all the intermediate points will lie on that line.

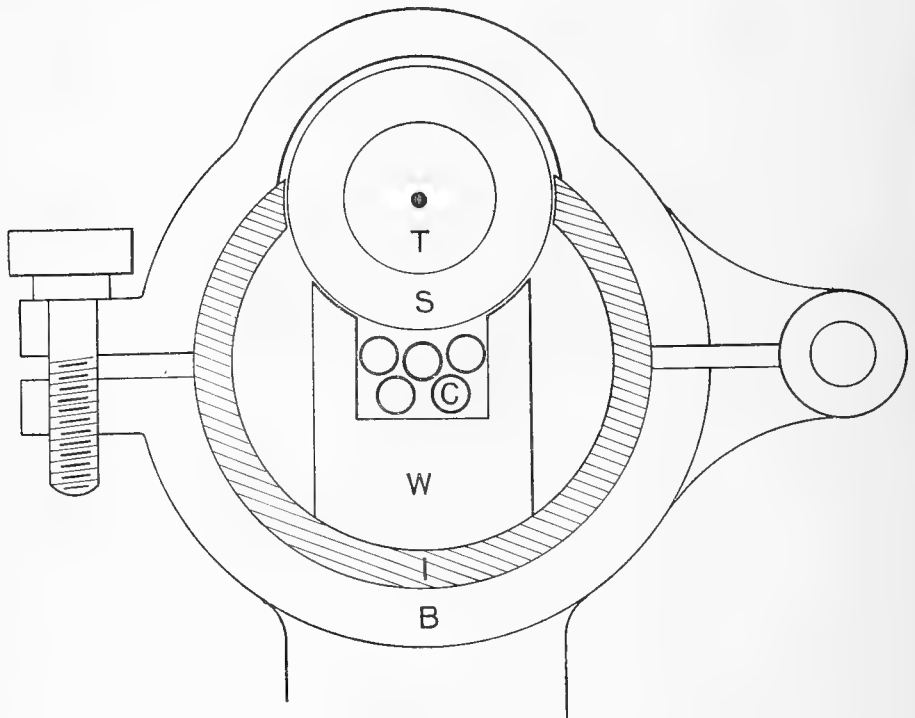


FIG. 1.

*S* is a solenoid 236 cms. long, consisting of 7707 turns in four layers, and giving a longitudinal magnetic field of 41 c.g.s. units per ampere, this field being uniform throughout the length of the coil to within 5 cms. of each end. *T* is the wire under test, and *B* is one of the two hinged brass clamps which support the apparatus on a strong vertical piece of hard wood, that can be adjusted in two directions by means of suitable screws. The wire *T* is suspended from an independent support, and hangs vertically in the middle of the solenoid *S*.

To the lower end of the wire is fixed a non-magnetic load, and from a plane mirror attached to this end, a beam of light is thrown on to a millimetre scale placed at a distance of 167 cms. and by this means the twist of the lower end of the wire may be read to within 0.2 mm. on the scale. On

the lower side of this non-magnetic load is fixed a vertical steel pin, which dips into a basin of mercury, thus enabling a current to be sent through the wire *T*.

There are three independent electric circuits to be dealt with in the experiment, viz. (1) an alternating current circuit through the wires *C*; (2) a direct current circuit through the solenoid *S*; (3) a direct current circuit through the wire *T*.

The method of operation in the experiment is as follows:—a certain steady direct current is sent through the solenoid *S*, which gives a longitudinal magnetic field round the wire *T*; another steady direct current is sent through the wire *T*, which gives a circular magnetic field, and the combination of these two fields causes the lower end of the wire *T* to twist. This initial twist is measured by the movement of the light spot on the scale, and will be referred to as *D*.

The circuits through *S* and *T* are then *opened*, and the circuit through *C* *closed* for say *one minute*, i.e. the wire *T* has been subjected to the influence of a transverse alternating magnetic field for one minute. The circuit through *C* is then *opened*, and the circuits through *S* and *T* *closed*, with exactly the same values of the currents through them as before; the twist produced now, as measured on the scale, will be found to be less than its initial value *D*, and will be referred to as *d*.

The closing and opening of the several circuits, and thereby the putting *on* and *off* of the separate currents, is continued until the deflection of the light spot on the scale is no longer diminished.

Now if *F* = the fatigue of the wire,

*D* = the unfatigued steady deflection or twist,

*d* = the fatigued steady deflection or twist,

$$F = \frac{D - d}{D}.$$

The former papers referred to above show that a good deal of work has been done on the fatigue of nickel and iron wires due to *longitudinal* magnetic fields, when in different states of rigidity, as well as when under different longitudinal loads. In the present case, therefore, it was thought to be sufficient to test only one nickel and one iron wire for fatigue due to *transverse* magnetic fields. For the sake of comparison the identical wires that were tested with longitudinal fields were tested under exactly the same conditions with transverse fields.

## SECTION I.

*Nickel wire.*

The wire was a No. 16 s.w.g. of simple rigidity  $790 \times 10^6$  grammes per sq. cm., the load on the lower end being  $1.5 \times 10^5$  grammes per sq. cm. The magnetic field in the solenoid *S* corresponding to this load, that is, to give the largest "Wiedemann effect,"<sup>1</sup> was 20 c.g.s. units, and the current through the wire *T* was *one* ampere. The experiments were performed as explained above, and the results are shown in Table I, where are also given for comparison the results previously found for the "same wire with longitudinal alternating magnetic fields of the same intensity as the transverse alternating magnetic fields now employed."<sup>2</sup> The letters *d* and *F* in the tables represent the deflection or twist and the fatigue respectively.

TABLE I.

| Time.<br>Minutes. | ALTERNATING MAGNETIC FIELDS. |          |               |          |
|-------------------|------------------------------|----------|---------------|----------|
|                   | Transverse.                  |          | Longitudinal. |          |
|                   | <i>d</i>                     | <i>F</i> | <i>d</i>      | <i>F</i> |
| 0                 | 11.5                         | 0        | 11.0          | 0        |
| 1                 | 11.0                         | 0.050    | 9.5           | 0.136    |
| 2                 | 10.5                         | 0.085    | 8.9           | 0.191    |
| 4                 | 9.9                          | 0.140    | 8.2           | 0.252    |
| 6                 | 9.4                          | 0.180    | 8.0           | 0.273    |
| 8                 | 9.0                          | 0.220    | 8.0           | 0.273    |
| 10                | 8.7                          | 0.240    |               |          |
| 12                | 8.6                          | 0.250    |               |          |
| 14                | 8.6                          | 0.250    |               |          |

From the values in Table I it will be seen that the maximum fatigue due to a transverse alternating magnetic field is about 8.5 per cent. less than that due to a longitudinal alternating magnetic field, and that it takes about

<sup>1</sup> Scient. Proc. Roy. Dubl. Soc., vol. xiii (1911), No. 3, p. 31.

<sup>2</sup> *Ibid.*, vol. xiv (1915), No. 26, p. 338.

double the time to attain that maximum. The results are better seen in Fig. 2 in the form of curves, where *L* and *T* indicate the curve showing the effect of the longitudinal and transverse alternating magnetic fields respectively.

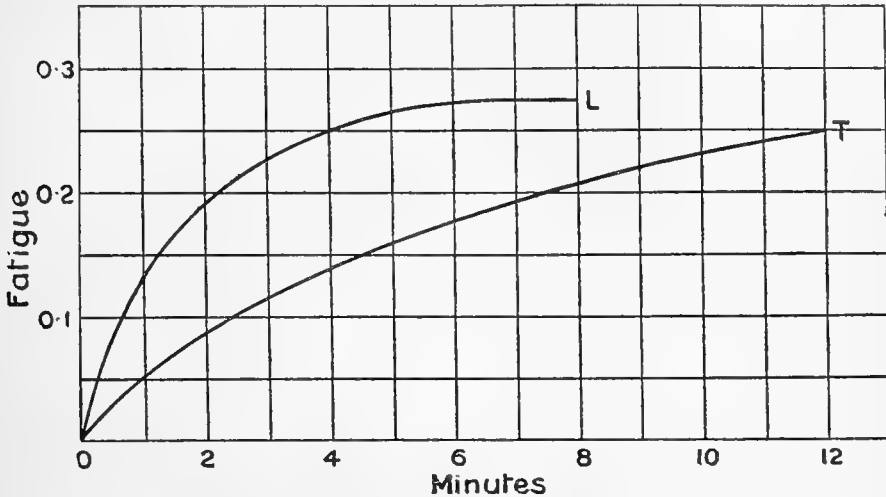


FIG. 2.

## SECTION 2.

*Iron Wire.*

The wire tested was a No. 16 s.w.g. of simple rigidity  $810 \times 10^6$  grammes per sq. cm., the longitudinal load on the lower end being  $10^5$  grammes per sq. cm. The magnetic field in the solenoid S corresponding to this load, that is, to give the largest "Wiedemann effect," was 2.5 c.g.s. units,<sup>1</sup> and the current through the wire under test *one* ampere.

The experiment was the same as that performed on the nickel wire, and the results obtained are given in Table II, where for comparison are also given the results formerly obtained for the same wire with longitudinal alternating magnetic fields of the same intensity as the transverse alternating magnetic fields now used.<sup>2</sup>

<sup>1</sup> *Scient. Proc. Roy. Dubl. Soc.*, vol. xii (1910), No. 36, p. 484.

<sup>2</sup> *Ibid.*, vol. xiv (1915), No. 26, p. 342.

TABLE II.

| Time.<br>Minutes. | ALTERNATING MAGNETIC FIELDS. |       |               |       |
|-------------------|------------------------------|-------|---------------|-------|
|                   | Transverse.                  |       | Longitudinal. |       |
|                   | $d$                          | $F$   | $d$           | $F$   |
| 0                 | 8                            | 0     | 7             | 0     |
| 5                 |                              |       | 6.5           | 0.080 |
| 10                | 7.4                          | 0.080 | 5.9           | 0.155 |
| 15                |                              |       | 5.5           | 0.215 |
| 20                | 6.9                          | 0.135 | 5.1 +         | 0.265 |
| 25                |                              |       | 4.9 +         | 0.290 |
| 30                | 6.8                          | 0.175 | 4.9           | 0.300 |
| 35                |                              |       | 4.9           | 0.300 |
| 40                | 6.4                          | 0.200 |               |       |
| 50                | 6.3                          | 0.215 |               |       |
| 60                | 6.2                          | 0.225 |               |       |
| 80                | 6.2                          | 0.225 |               |       |

From the values in Table II it will be seen that, in the case of iron wire, the maximum fatigue due to transverse alternating magnetic fields is about

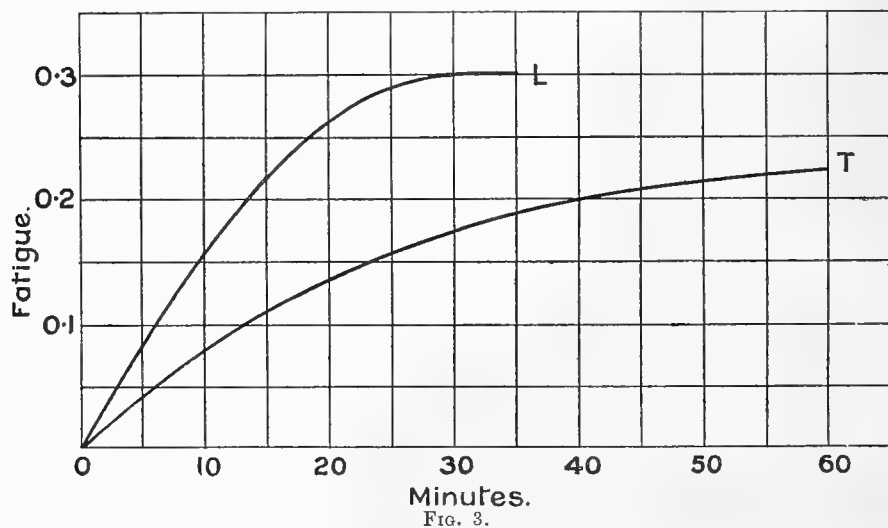


FIG. 3.

25 per cent. less than the maximum obtained with longitudinal alternating magnetic fields of the same strength, and that it takes about twice as long to attain the maximum.

The results are better seen in fig. 3 in the form of curves, where, as before  $L$  and  $T$  indicate the curve showing the effect of the longitudinal and the transverse fields respectively.

The results given in the present paper complete the work (as far as the torsional oscillations and fatigue of nickel and iron wire are concerned) which the author set himself to do a few years ago. There are one or two things arising out of the work that are not important enough to form the subject of a separate paper, but which for the sake of future workers should perhaps be put on record; I have, therefore, attached them here as appendices.

#### APPENDIX I.

Subsidence of torsional oscillations in a wire when carrying an electric current.

i. *Nickel Wire.*—A No. 16 s.w.g. nickel wire of rigidity about  $715 \times 10^6$  grammes per sq. cm. with a longitudinal load on the lower end of  $10^5$  grammes per sq. cm. was tested for damping or subsidence of torsional oscillations in direct and alternating magnetic fields both longitudinal and transverse, of value 17 units, the alternating fields having a frequency of 50 per second. The increased or decreased values of damping mentioned below for both nickel and iron are arrived at by comparing the amplitude of the 70th oscillation in each set of observations.

The following series of experiments were made:—

- A. When the wire was under the influence of the vertical component of the earth's magnetic force only.
- B. When the wire was in a direct longitudinal field.
- C. When the wire was in an alternating longitudinal field.
- D. When one ampere (direct) was through the wire and a direct longitudinal field round it.
- E. When one ampere (direct) was through the wire and an alternating longitudinal field round it.
- F. When one ampere (alternating) was through the wire and an alternating longitudinal field round it.
- G. The same as in (F) with a transverse alternating field superposed.

Comparing results obtained under conditions:—

- A and B, in B the damping is *increased* 44 per cent.
- B and D, in D the damping is *decreased* 12 per cent.
- C and E, in E the damping is *increased* 3 per cent.
- F and G, in G the damping is *decreased* 4 per cent.
- C and F there is no change.

ii. *Iron Wire.*—A No. 16 s.w.g. iron wire of rigidity about  $810 \times 10^6$  grammes per sq. cm. with a load of  $10^5$  grammes per sq. cm. was put through

a series of observations somewhat the same as was the nickel wire, but in magnetic fields of 2·5 units. The following sets of experiments were taken :—

- A. When the wire was in a direct longitudinal field.
- B. When the wire was in an alternating longitudinal field.
- C. When one ampere (direct) was through the wire and a direct longitudinal field round it.
- D. When one ampere (direct) was through the wire and an alternating longitudinal field round it.
- E. When one ampere (alternating) was through the wire and an alternating longitudinal field round it.

Comparing results obtained under conditions :—

- A and C, in C the damping is *increased* 2·5 per cent.
- B and E, in E the damping is *decreased* 2·2 per cent.
- B and D, there is no change.

#### APPENDIX II.

In this and previous papers on the fatigue of nickel and iron wires due to the application of alternating magnetic fields longitudinal and transverse, the fatigue has been defined and measured by reference to the "Wiedemann twist." It occurred to the present writer to try if any change in the resistance of nickel wire could be observed when the wire was fatigued. A No. 20 s.w.g. nickel wire, 226 cms. long and of rigidity about  $790 \times 10^6$  grammes per sq. cm. was wound longitudinally on a slotted wooden shuttle, 15 cms. long and 1·3 cms. diameter, and placed in a solenoid 30 cms. long, which afforded the means of applying a longitudinal alternating magnetic field to the wire. The wire thus wound was made one of the arms of a wheatstone bridge arrangement which was capable of measuring a change in the resistance of approximately 1 in 5,000, and of detecting a change of approximately 1 in 10,000.

The nickel wire (while in position in the bridge) was subjected for *three hours* to the influence of a longitudinal alternating magnetic field of strength 30 units and frequency 50 per second. The resistance was noticed after an interval of an hour to allow the temperature to come to its original value, and no change could be observed within the above limits. Previous work has shown that the nickel wire did not recover from fatigue within such a small interval as an hour, and it may be stated that the wire which was under slight tension on the wooden shuttle was not disturbed during the above tests.

It would seem, therefore, that what we call the fatigue and which can be measured by the magnetic twisting of the wire is not accompanied by any effect on the resistance, at least within the limits mentioned above.

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THE  
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JANUARY, 1917.

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THE CHEMISTRY OF FOUL MUD DEPOSITS.

BY

E. A. LETTS, D.Sc., &c.,

AND

FLORENCE W. REA, B.Sc.



[COMMUNICATED BY DR. W. E. ADENEY.]

*[Authors alone are responsible for all opinions expressed in their Communications.]*

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1917.

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*Price Sixpence.*

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## XVIII.

## THE CHEMISTRY OF FOUL MUD DEPOSITS.

By E. A. LETTS, D.Sc., &c., AND FLORENCE W. REA, B.Sc.

[COMMUNICATED BY DR. W. E. ADENEY.]

[Read NOVEMBER 28, 1916. Published JANUARY 4, 1917.]

THIS question does not appear to have received the attention which in view of its importance it would seem to deserve.

It divides itself naturally into two parts, viz.:—

1. More or less theoretical, as to the mechanism of the reactions leading to the evolution of sulphuretted hydrogen, and
2. The actual chemical changes occurring in foul mud deposits.

As regards the first of these two questions it is known that the evolution of the gas may be due to one or other of two causes, viz., first, the decomposition of albumenoid bodies, and the second, the decomposition of sulphides by acids, the sulphides being probably formed by the reduction of sulphates originally present; the acids being formed in all probability as products of the decomposition of the organic matter originally present.

Dittmar, in the "Challenger Reports,"<sup>1</sup> states that the sulphates present in sea-water are those of potassium, magnesium, and calcium.

Now, the question arises, which of the two above-named causes is usually active in the evolution of the gas, and, if both, what is the extent of each?

One of the authors of this paper, some years ago, suggested to Mr. J. L. M'Kee, B.A. (at that time one of his pupils in the Queen's University of Belfast), that he should submit this matter to an experimental investigation, and the results of his experiments will be found in Appendix VI to the seventh report of the Royal Commission on Sewage Disposal.<sup>2</sup>

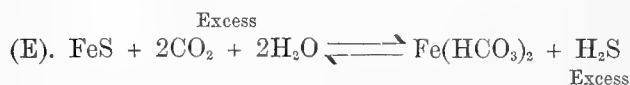
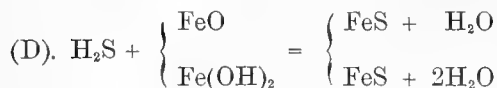
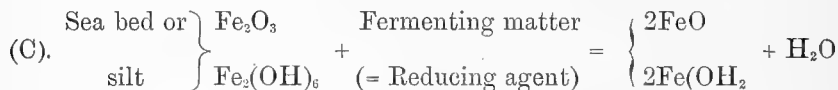
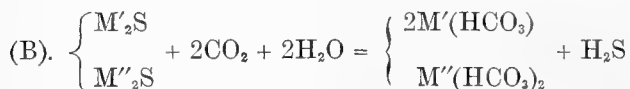
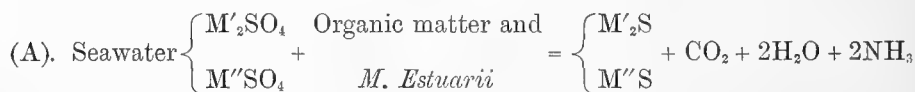
<sup>1</sup> Challenger Report, in which Dittmar gives the amounts of the sulphates present in sea-water as being approximately 100 per parts of the dried solids: potassium sulphate, 2.465; magnesium sulphate, 4.323; and calcium ditto, 4.070.

<sup>2</sup> "The Pollution of Estuaries and Tidal Waters," by Professor Letts and Dr. W. E. Adeney.

Mr. McKee's work is divided into four sections, as follow :—

1. Repetition of Beyerink and Van Delden's work on the reduction of sulphates by two distinct species of micro-organisms present in fresh and salt water respectively, namely, *Microspira desulphuricans* and *M. estuarii*.
2. The action of carbon dioxide on ferrous sulphide suspended in water.
3. Evolution of hydrogen sulphide from foul mud kept in contact with a saturated solution of carbon dioxide, and
4. Sulphuretted hydrogen production from putrefying green sea-weeds.

At the end of the paper, the mechanism of the reactions is discussed whereby the sulphates originally present in sea-water give rise to ferrous sulphide and eventually to hydrogen sulphide and ferrous carbonate, by the action of carbon dioxide on ferrous sulphide, thus :—



Where  $M'$  is a metal of the alkalis, *e.g.* sodium, and  $M''$  an alkaline earth metal, *e.g.* calcium.

The question next arose, how will carbon dioxide act on certain sulphides, namely, the four mentioned above (*i.e.* those of iron, calcium, magnesium, and sodium), and, conversely, how will hydrogen sulphide act on the carbonates of the same metals ?

#### *Action of Carbon Dioxide on Sodium Sulphide.*

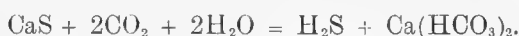
The first experiments were tried with sodium sulphide. A current of carbon dioxide being passed into a solution of that salt, when abundance of

hydrogen sulphide was evolved and eventually it was found that the reaction was quantitative, namely:—



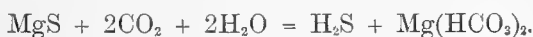
*Action of Carbon Dioxide on Calcium Sulphide.*

The next experiments were performed with calcium sulphide. When some of this was placed in water and a stream of carbon dioxide passed through the mixture, it was found that about 4·3 per cent. was decomposed in the sense of the reaction:—



*Action of Carbon Dioxide on Magnesium Sulphide.*

At first this was obtained from Kahlbaum, but later it was prepared by heating magnesium metal in a stream of hydrogen sulphide. This magnesium sulphide was then placed in water and a stream of carbon dioxide passed through, and the liberated hydrogen sulphide collected in a standard solution of arsenic chloride, when it was found that all the magnesium sulphide was decomposed, probably thus:—



*Action of Carbon Dioxide on Ferrous Sulphide.*

Mr. McKee proceeded as follows<sup>1</sup>:—

“A preliminary experiment showed that when carbon dioxide was passed through recently precipitated ferrous sulphide suspended in water, the escaping gas blackened lead paper.

“An experiment was next made to ascertain the amount of sulphuretted hydrogen which might be formed.

“For this purpose an apparatus was constructed, consisting of a carbonic anhydride generator (Kipp) connected with a wash-bottle containing water, and a second one containing a mixture of sodium carbonate and ferrous sulphate (solution, to remove oxygen, or traces of it); and finally the carbon dioxide passed into a flask provided with a cork and two tubes which contained water and ferrous sulphide. The purified carbon dioxide was led into this flask through a tube passing nearly to its bottom, and could either be allowed to escape through a shorter tube in the cork, or could be plugged with a clip.

“The method employed was as follows:—

“All the various parts of the apparatus were first filled with carbon dioxide.

<sup>1</sup> *Loc. cit.*, p. 124.

The ferrous sulphide was then prepared and transferred to the flask, made ready for it by means of a litre of air-free water which had been saturated with carbon dioxide. A rapid current of that gas was then passed through the contents of the flask for about ten minutes, and finally the shorter tube was plugged on account of the rapidity with which ferrous sulphide is oxidised by contact with the air; no attempt was made to weigh it, but the quantity precipitated from excess of ferrous sulphate solution by 10 c.c. of a particular solution of ammonium sulphide (freshly prepared) was rapidly washed and transferred to the flask with as little loss as possible, the amount transferred being determined afterwards (see below).

“The flask had a capacity of about  $1\frac{1}{2}$  litres, so that there was about  $\frac{1}{2}$  litre of carbon dioxide above the liquid. As the carbon dioxide was absorbed, the pressure above the liquid decreased, and more gas bubbled in, keeping the solution saturated.

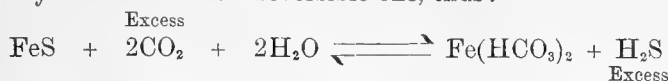
“The sulphide flasks were kept in an incubator at  $35^{\circ}$  C., the rubber tube connecting them passing through a small hole in the top. The apparatus was left undisturbed until all absorption of the carbon dioxide had ceased, which took about eight days. The sulphide flasks were then disconnected and the free hydrogen sulphide and undecomposed ferrous sulphide determined in the following manner:—

“10 c.c. of the clear supernatant liquid were run into excess of standard iodine solution (1 c.c. = 0.2 mgm. hydrogen sulphide) and titrated back again with sodium thiosulphate of corresponding strength. Next the flask was well shaken in order to distribute the ferrous sulphide evenly throughout the liquid, and, still shaking, 10 c.c. were withdrawn and run into excess of iodine solution strongly acidified with hydrochloric acid, and the excess of iodine determined as before. The first determination gave the amount of hydrogen sulphide set free, the second, the hydrogen sulphide equivalent of the ferrous sulphide, originally present, thus:—

|  |     |     |            |
|--|-----|-----|------------|
| (1). FeS + Distilled Water.                  |     |     |            |
| H <sub>2</sub> S originally present (as FeS) | ... | ... | 175 mgs.   |
| „ evolved (free)                             | ... | ... | 16 „       |
| (2). FeS + Sea Water.                        |     |     |            |
| H <sub>2</sub> S originally present (as FeS) | ... | ... | 178.5 mgs. |
| „ evolved (free)                             | ... | ... | 11.5 „     |

“The above figures show that quite enough hydrogen sulphide can be obtained to cause a serious nuisance, from the action of carbon dioxide on ferrous sulphide.

“Probably the reaction is a reversible one, thus:—



“The ferrous sulphide used was liable to contain traces of its oxidation products, but that would only reduce the amount of hydrogen sulphide evolved.

“The decomposition of ferrous sulphide in oceanic deposits has been frequently denied; but in the light of the experiments described above, there cannot be any doubt that this reaction does take place, though probably much less readily than the decomposition of the sulphides of the alkaline and alkaline earth metals by carbon dioxide.”

*Repetition of Mr. McKee's Experiments.*

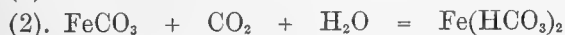
Rather more than one half gram of ferrous sulphide (·526 gm.) was prepared by the action of (colourless) ammonium sulphide on a weighed quantity of ferrous sulphate, and was placed in a flask containing one litre of distilled water (previously boiled to get rid of air and then saturated with carbon dioxide). This flask was connected with a Kipp's apparatus for generating carbon dioxide, and bulbs through which the latter passed, one containing ferrous carbonate (or rather mixed solutions of ferrous sulphate and sodium carbonate) to absorb traces of oxygen.

The flask containing the water and ferrous carbonate was closed with an india-rubber cork, through which three holes passed and glass tubes inserted one leading to the bottom of the flask, and two shorter ones; one of these latter being attached to a stopper, consisting of a short length of india-rubber tube and a piece of glass rod, while the other was attached to a Geissler bulb containing an acid solution of arsenious chloride.

From time to time the plug of the bulb containing the arsenious chloride was removed so that a stream of carbon dioxide passed through the flask and its contents.

The flask containing the ferrous sulphide was placed in an incubator, where it remained for about nine weeks, when all the ferrous sulphide had disappeared and a colourless solution of ferrous bicarbonate remained.

It is quite evident, therefore, that when ferrous sulphide is treated with carbon dioxide (and water), the two following reactions eventually occur:—



*Action of Hydrogen Sulphide on Metallic Carbonates or Bicarbonates.*

The action was investigated in the case of the bicarbonates of the same metals as those employed in the examination of the action of carbon dioxide



on sulphides, viz. :—those of sodium, magnesium, calcium, and iron, but in the case of the last of these, the bicarbonate was also investigated, as it is soluble in water, whereas the carbonate is insoluble.

*Action of Hydrogen Sulphide on Sodium Carbonate.*

An N/10 solution of sodium carbonate was employed. 50 c.c. of a solution of this were saturated with hydrogen sulphide for 24 hours, with occasional shaking, and the sulphur was then determined in the solution by means of a standard solution of sodium arsenite, when it was found that, after allowing for the dissolved hydrogen sulphide, 28 per cent. of the sodium carbonate had been converted into sulphide, according to the equation :—



*Action of Hydrogen Sulphide on Magnesium Carbonate.*

A stream of hydrogen sulphide, after having been washed by passing it through water, was bubbled through a flask containing powdered magnesium carbonate.

When all the air had been driven out of the apparatus, it was corked and left for 24 hours with occasional shaking.

10 c.c. of the solution were then removed and evaporated to dryness with sulphuric acid, the remaining magnesium sulphate weighed, when it was found to correspond with 0.0919 grm.  $\text{MgCO}_3$ . The following reaction had, therefore, occurred :—



*Action of Hydrogen Sulphide on Calcium Carbonate.*

Two experiments were made under somewhat different conditions, namely :—

- (1). So that carbon dioxide escaped.
- (2). „ „ „ „ did not escape.

(1). Hydrogen sulphide was passed through water in which 0.259 grm. calcium carbonate was suspended in 5 c.c. water for about 15 hours, when a yellow solution resulted.

This was filtered for the undissolved portion, and the filter and precipitate burned, when 0.1135 grm. calcium oxide was obtained, corresponding with 0.048 grm. calcium carbonate, and leaving 0.048 grm. calcium oxide acted upon, or about 19 per cent.

(1A). The experiment was repeated, only as the calcium carbonate was dissolved, more was added.

Eventually it was found that 50 c.c. of the solution contained a quantity of calcium corresponding with 0.109 grm. of the carbonate.

(2). An apparatus was constructed so that hydrogen sulphide could be passed into a vessel containing calcium carbonate and water, and when all the air had been displaced, the vessel could be corked, the hydrogen sulphide still continuing to enter the apparatus. After the experiment had continued for some 24 hours, 10 c.c. of the solution were removed and the calcium determined, when it was found that this contained calcium corresponding with 0.0109 gm. of the carbonate or 50 c.c. with 0.109 gm. of that compound. Therefore the action of hydrogen sulphide on the carbonate is slightly less when the carbon dioxide does not escape, as might be expected.

*Action of Hydrogen Sulphide on Ferrous Bicarbonate.*

0.6676 gm. of crystallized ferrous sulphate was dissolved in 100 c.c. of distilled water, and to this was added an equivalent amount (0.5087 gm.) of crystallized sodium carbonate.

Carbon dioxide was then passed through the mixture until the precipitated ferrous carbonate had dissolved with formation of the bicarbonate (a slight brownish precipitate was, however, left, probably ferric hydrate).

A stream of hydrogen sulphide was then passed through the solution for 20 minutes, a black precipitate forming immediately of ferrous sulphide.

The current of hydrogen sulphide was stopped, the solution boiled, and a stream of hydrogen passed through the mixture.

The boiling was continued for five hours, but even then some hydrogen sulphide continued to escape.

The current of hydrogen was then interrupted, some hydrochloric acid slowly added to the contents of the flask, the current of hydrogen again started, and the escaping gases passed into standard arsenious anhydride solution. The latter was then filtered from the precipitated arsenic sulphide, excess of sodium bicarbonate added, the solution filtered and titrated with N/10 iodine solution, when the following result was obtained:—

|                                      |        |           |
|--------------------------------------|--------|-----------|
| Hydrogen sulphide actually produced, | ...    | 0.016 gm. |
| "    "    calculated,                | ... .. | 0.014 "   |

The reaction proceeds quantitatively then, in the sense of the equation:—



EXAMINATION OF FOUL SEWAGE DEPOSITS.

(1). *Marine Mud.*

The first sample to be examined was obtained from Belfast Lough and had probably been formed from rotting *Ulva*.

A quantity was inserted into a flask, and the latter placed in an incubator heated to 90° F. (32° C.). The flask was connected with Liebig's bulbs containing arsenic chloride (to absorb hydrogen sulphide), and finally with a soda lime tube (to absorb carbon dioxide).

The experiment extended over three months, and the following results were obtained :—

|                               |        | Before<br>incubation.    |     | After<br>incubation.     |
|-------------------------------|--------|--------------------------|-----|--------------------------|
| S as soluble sulphate,        | ...    | 0·016                    | ... | 0·042                    |
| „ insoluble proteid,          | ...    | 0·383                    | ... | 0·522                    |
| „ soluble proteid,            | ...    | 0·475 <sup>1</sup>       | ... | 0·295 <sup>1</sup>       |
| „ sulphide,                   | ... .. | 0·205                    | ... | 0·185                    |
| „ evolved (H <sub>2</sub> S), | ...    | —                        | ... | 0·019                    |
| Total,                        | ... .. | <u>1·079<sup>2</sup></u> |     | <u>1·063<sup>3</sup></u> |

The *total* sulphur was determined by treating the sludge with fuming nitric acid, evaporating to dryness, and fusing the residue with sodium carbonate, evaporating to dryness with excess of nitric acid, dissolving the residue in water, and precipitating with barium chloride.

The sulphur as *soluble* proteid was determined by treating the sludge with dilute hydrochloric acid, filtering and precipitating the solution with barium nitrate.

The residue from this operation was dried, treated with fuming nitric acid, the solution evaporated to dryness on a water bath, and the sulphur precipitated in the solution with barium chloride, the precipitate collected, washed, dried, and weighed. This gave the sulphur as *insoluble* proteid.

Several other determinations of sulphur in its different forms in foul sludges were made, but, owing to the small quantity of sulphur present in them and the presence of large quantities of mineral matters, the determinations were not satisfactory.

It will be sufficient to enumerate the different varieties of sludge examined. They were :—

- (2). A second sample of the marine mud.
- (3). Two samples of sludge from the Belfast Pumping Station.
- (4). A sample of (probably) domestic sewage.
- (5). A sample of cesspool sludge.

<sup>1</sup> By subtraction : Thus total sulphur *minus* soluble *plus* insoluble equals soluble proteid.

<sup>2</sup> 0·874 by direct determination. }  
<sup>3</sup> 0·860 „ „ } These figures are probably too small.

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Vol. XV. (N.S.), No. 19.

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AWARD OF THE BOYLE MEDAL

TO

PROFESSOR HENRY HORATIO DIXON, Sc.D., F.R.S.,

1916.

DUBLIN:

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## XIX.

## AWARD OF THE BOYLE MEDAL

TO PROFESSOR HENRY HORATIO DIXON, Sc.D., F.R.S.,  
1916.<sup>1</sup>

## REPORT OF THE SCIENCE COMMITTEE.

PROFESSOR HENRY H. DIXON'S earliest paper is a communication to the Royal Dublin Society in 1892 on the "Walking of Arthropods," wherein he investigates the manner in which various insects, spiders, &c., walk. The paper displays ingenuity and resource in a remarkable degree. Having been appointed to the post of Assistant to the Chair of Botany in the University of Dublin in 1894, he definitely devoted himself to Botanical research; at first chiefly to plant anatomy and cytology. He published work on the anatomy of orchids, describing the structure of a previously unknown type of leaf, which shed light on the origin and development of cylindrical leaves in that group. In cytology he worked out the fertilization of *Pinus sylvestris*, and contributed some of the earliest observations on the reducing division in plants; he first described the strepsinema stage in this mitosis, and gave an account of its origin. Subsequent work on genetics has brought out the importance of the recognition of this stage in theories of heredity. In this connexion may be mentioned his observations on the nucleolus of cells, and his theory as to its function; and also the work done in elucidation of the structure of coccoliths and coccospheres and of their origin.

In 1893, in collaboration with Dr. J. Joly, he published the Tension Theory of the Ascent of Sap in Trees. In this work a problem of long standing was attacked, and a rational explanation found as to how the sap is raised in high trees. This theory, which has now been generally accepted, led to a great deal of physiological and physical experiment of a high order, carried out with a view to testing the applicability of the theory and its ability to explain the phenomena of the rise of water in trees. Among the researches carried out by Dixon in this connexion were investigations on

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<sup>1</sup> The presentation was made at the Scientific Meeting of the Royal Dublin Society, held on the 23rd January, 1917, when the Medal was handed to Professor Dixon by the President, The Right Hon. Lord Rathdonnell, H.M.L.



Transpiration into a Water-saturated Atmosphere; on Transpiration into various vapours and gases; on Transpiration in Dead Branches; on the Tensile Strength of Water; on the Tensile Strength of Sap, and on the Strength of Cell Walls; also on the resistance experienced by the transpiration stream. In these researches he further established the Tension Theory, and replied to criticisms on it; and he showed that the cells of the leaf have often an active part in applying the tension to the sap, and that the tension is transmitted downwards through the tree, and raises the sap in the stem without the intervention of forces exerted by the living cells of the stem.

A careful and laborious research on the temperature of the underground organs of plants carried out by means of thermocouples, in 1902, showed that such organs possess no detectable proper heat. A similar method of research was subsequently applied by Dixon to the determination of the freezing point of the sap of leaf-cells. He was thus enabled to determine with ease the osmotic pressure of these cells in many plants, and so to define their function in the raising of the sap. He had previously partly solved this problem by a direct method which had to be abandoned on account of the personal risk attending its use.

The thermo-electric method of cryoscopy thus devised has been extensively used by Dixon, in collaboration with Dr. W. R. G. Atkins, in the investigation, not only of the sap of leaf-cells, but of that of other organs, and much information as to the concentration of the sap in stem, root, and leaves has been obtained. The method has also afforded valuable information in their hands as to the constitution of the sap of the Transpiration Stream and respecting the obscure subject of root-pressure. They have shown that the Transpiration Stream has functions to perform in the distribution of carbohydrates as important as those in connexion with the transport of water and of mineral solutions in plants. The thermo-electric method has also proved efficient in studying the metabolism of the yeast cell and the changes brought about by it in wort.

In these researches it was found that the usual methods of extracting cell-sap did not yield an average sample of the tissues treated, and so a serious error in the cryoscopic investigations of previous workers was detected. At the same time it was shown that this error might be avoided by exposing the tissue under experiment to intense cold and so rendering the protoplasm permeable. This has proved a most useful observation, and has furnished a ready method for extracting enzymes from cells: often a problem of great difficulty. For example, an active preparation of zymase may be obtained by this method in a few minutes.

Recently Dixon, in collaboration with Lieut. T. G. Mason and Lieut. W. R. G. Atkins, has been making investigations on photosynthesis, and has succeeded in explaining the observation that a rise in sucrose and not in hexoses is observed in green cells immediately after illumination, when theory would demand that the formation of hexose should be preliminary to the production of sucrose. The explanation, which is founded on the localization of chemical reactions in special organs of the cell, has been rendered very probable by preliminary experiments.

In 1909 Dixon was invited to contribute to the international journal, "*Progressus Rei Botannicae*," an account of his theory of the Ascent of Sap. The resulting communication affords a standard account of the theory and of the experimental evidence which has accumulated around it. This is, however, surpassed in completeness by his recent volume appearing as one of Messrs. Macmillan's Science Monographs, entitled "*Transpiration and the Ascent of Sap in Plants*." This work is a model of exact scientific method applied to the complex conditions prevailing in the plant. And when it is remembered that the greater part of the book is a record of methods devised by the author himself and, although in some places carried out in collaboration with his pupils, yet always guided by his own scientific insight and learning, it does not seem too much to hope that it will remain an enduring monument of the author's principal work for Botanical Science.

In accordance with precedent we may be permitted to add a word as to that part of Dixon's work for Science which does not find record in his publications. A pupil of the late Professor Edw. Percival Wright, and, in a certain degree, also of the late Professor Strasburger of Bonn, Dixon has in his management of the Botanic Gardens and of the Herbarium of the University of Dublin worthily perpetuated the traditions of the Chair to which he succeeded in 1904 upon the retirement of Dr. Wright. At the same time it may be said that he first has introduced the experimental method of teaching Botanical Science into the University of Dublin. Working with diligence at every branch of his subject he has taught Botany as a fundamental branch of Biology, and one which requires of the student who would master the subject a training in the still more fundamental sciences which deal with the inorganic. In Botanical Science the medical student finds the best introduction not only to Biology, but to the technique of the Microscope. This Dixon has also recognized, and this has rendered his teaching of large classes of such students educational in the highest degree. The many brilliant young men who have gathered around him, and have worked with him, are a sufficient testimony to the stimulating nature of his teaching.

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The foregoing Report, and the Recommendation of the Committee of Science and its Industrial Applications, were adopted by the Council on the 14th December, 1916.

# SCIENTIFIC PROCEEDINGS.

## VOLUME XV.

1. The Subsidence of Torsional Oscillations and the Fatigue of Iron Wires when subjected to the Influence of Alternating Magnetic Fields of Frequencies up to 250 per second. By WILLIAM BROWN, B.SC. (January, 1916.) 6*d*.
2. Preliminary Notes on the Carbohydrates of the Musci. By THOMAS G. MASON, B.A., DIPLOM. AGRIC. (February, 1916.) 6*d*.
3. A New Form of very High Resistance for use with Electrometers. By JOHN J. DOWLING, M.A., M.R.I.A. (February, 1916.) 6*d*.
4. On the Path of a small Permeable Body moving with Negligible Acceleration in a Bipolar Field. By PHILIP E. BELAS, B.A., A.R.C.SC.I., and MARCUS HARTOG, M.A., D.SC. (N.U.I.). (Plate I.) (February, 1916.) 6*d*.
5. The Change of Length in Nickel Wires of Different Rigidities, due to Alternating Magnetic Fields of Frequencies up to 150 per second. By WILLIAM BROWN, B.SC. (February, 1916.) 6*d*.
6. Osmotic Pressures in Plants. VI—On the Composition of the Sap in the Conducting Tracts of Trees at Different Levels and at Different Seasons of the Year. By HENRY H. DIXON, SC.D. (DUBL.), F.R.S.; and W. R. G. ATKINS, SC.D. (DUBL.), F.I.C. (March, 1916.) 6*d*.
7. The Verticillium Disease of the Potato. By GEORGE H. PETHYBRIDGE, PH.D., B.SC. (Plates II–III.) (March, 1916.) 1*s*. 6*d*.
8. On the Boiling-points and Critical Temperatures of Homologous Compounds. By SYDNEY YOUNG, D.SC., F.R.S. (April, 1916.) 6*d*.
9. The Subsidence of Torsional Oscillations of Nickel Wires when subjected to the influence of Transverse Magnetic Fields up to 200 C.G.S. Units. By WILLIAM BROWN, B.SC. (April, 1916.) 6*d*.
10. On the Hydrocarbons of Beeswax. By HUGH RYAN, D.SC., and THOMAS DILLON, D.SC. (May, 1916.) 6*d*.
11. On Desoxy-Hydrocatechin-Tetramethyl-Ether. By HUGH RYAN, D.SC., and MICHAEL J. WALSH, M.SC. (May, 1916.) 6*d*.
12. The Change of Length in Nickel Wires due to Transverse Magnetic Fields Direct and Alternating. By WILLIAM BROWN, B.SC. (May, 1916.) 6*d*.
13. The Subsidence of Torsional Oscillations of Nickel and Iron Wires when subjected to the Influence of Transverse Magnetic Fields up to 800 C.G.S. Units. By WILLIAM BROWN, B.SC. (May, 1916.) 6*d*.
14. Note on Laminated Magnets. By WILLIAM BROWN, B.SC. (June, 1916.) 6*d*.
15. On the Mode of Occurrence and Origin of the Orbicular Granite of Mullaghderg, Co. Donegal. By GRENVILLE A. J. COLE, M.R.I.A., F.G.S. (Plates IV–V.) (October, 1916.) 1*s*.
16. An Abnormality in the Arterial System of the Rabbit. By EDMOND J. SHEEHY, A.R.C.SC.I. (December, 1916.) 6*d*.
17. The Fatigue of Nickel and Iron Wires when subjected to the Influence of Transverse Alternating Magnetic Fields. By WILLIAM BROWN, B.SC. (January, 1917.) 6*d*.
18. The Chemistry of Foul Mud Deposits. By E. A. LETTS, D.SC., &c., and FLORENCE W. REA, B.SC. (January, 1917.) 6*d*.
19. Award of the Boyle Medal to PROFESSOR HENRY HORATIO DIXON, SC.D., F.R.S., 1916. (January, 1917.) 6*d*.



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THE CHANGE IN YOUNG'S MODULUS OF NICKEL  
WITH MAGNETIC FIELDS.

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[*Authors alone are responsible for all opinions expressed in their Communications.*]

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# Royal Dublin Society.

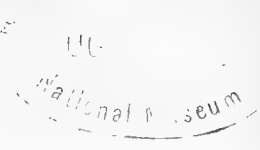
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## EVENING SCIENTIFIC MEETINGS.

THE Scientific Meetings of the Society are usually held at 4.15 p.m. on the third Tuesday of every month of the Session (November to June).

Authors desiring to read Papers before the Society are requested to forward their Communications to the Registrar of the Royal Dublin Society *at least* ten days prior to each Meeting, as no Paper can be set down for reading until examined and approved by the Science Committee.

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## XX.

THE CHANGE IN YOUNG'S MODULUS OF NICKEL WITH  
MAGNETIC FIELDS.

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[Read MARCH 27. Published APRIL 4, 1917.]

## INTRODUCTION.

IN a very interesting paper by Honda and Terada<sup>1</sup> on "The Change of Elastic Constants of Ferromagnetic Substances by Magnetisation," there are given, along with other data, the results of experiments on the change of Young's Modulus of elasticity in the case of nickel wires when under tensions varying from  $1.54 \times 10^5$  to  $4.5 \times 10^5$  grammes per sq. cm., and when subjected to the influence of direct longitudinal magnetic fields up to a maximum value of 400 c.g.s. units.

As far as the present writer knows, no observations or measurements have been made on the change of Young's Modulus in nickel wires when they were subjected to the influence of alternating longitudinal magnetic fields, or to direct and alternating transverse magnetic fields.

The present paper, therefore, gives results obtained with longitudinal alternating fields and with transverse fields direct and alternating, as well as for longitudinal direct fields, for the sake of comparison of their effects on the same wire.

The constant longitudinal loads employed in the experiments were  $10^5$  and  $2 \times 10^5$  grammes per sq. cm., which are smaller than the loads used by previous experimenters; and the working load, or the load which was put on and off in determining Young's Modulus, was 2 kilos. or about  $0.45 \times 10^5$  grammes per sq. centimetre.

The maximum magnetic field employed was 80 c.g.s. units, which was the highest that could be safely applied without special cooling arrangements.

On account of the great length of wire (226 cms.) used in the experiments, a direct method of observation was employed, the measurements being made by means of a microscope with a movable fine hair in the eye-piece.

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<sup>1</sup> Phil. Mag., Jan., 1907, p. 36.

The movement of the hair was made by means of a micrometer screw with graduated head or disc, the circumference of the disc being divided into 300 divisions; one whole turn of the micrometer screw gave a motion to the hair of  $6 \times 10^{-3}$  cms., and therefore one division on the disc corresponded to a motion of  $2 \times 10^{-5}$  cms. By turning the micrometer screw always in the one direction during the measurements—so as to avoid any back-lash on the thread—it was found that the same readings for a given magnetic field could be obtained, and each value of the reading taken is the mean of five distinct and separate measurements.

In order to get a definite and clearly defined mark for reading the elongation of the wire with the microscope, a light brass frame was fixed on the brass cylinder at the lower end of the wire; in this frame there were fixed two very fine crossed spider lines, and when these lines were illuminated by the light from a 50 c. p. electric glow lamp the point of crossing of the spider lines was sharply defined.

## SECTION I.

### *Longitudinal Magnetic Fields.*

The solenoid used in this part of the work was 236 cms. long and 2 cms. internal diameter, and consisted of 7707 turns of wire in four layers, giving an internal magnetic field of 41 c.g.s. units per ampere, the field being uniform throughout the length of the coil to within 5 cms. of each end. The wire under test was hung vertically in the middle of the solenoid, and its free length (226 cms.) was in a uniform magnetic field throughout. The upper attachment was made by means of a small three-jaw clutch which gripped the wire 5 cms. inside the solenoid, and was firmly fixed to a bracket, the bracket itself having been previously tested for rigidity. At the lower end of the wire there was a brass cylinder about 12 cms. long and one centimetre in diameter, having a three-jaw clutch at each end; one clutch gripped the lower end of the wire 5 cms. inside the solenoid, and in the other was fixed a parallel round steel rod. About half way down this steel rod or wire, there was soldered a piece of brass of square cross-section four centimetres long and 0.5 cm. on the side. This square brass piece worked smoothly in a square hole cut in a thick brass plate fixed on a slate slab, and when well lubricated with vaseline the friction was found to be negligible. To the lower end of the steel rod—which went through a hole in the slate slab—underneath the slab there was fixed a scale-pan for carrying the load on the wire under test.

The temperature of the room during the experiments was kept as uniform as possible at about  $17^{\circ}\text{C}$ ., and did not vary more than  $0.3^{\circ}\text{C}$ . on either side. According to Walker<sup>1</sup> the change in the Young's Modulus per  $1^{\circ}\text{C}$ . between  $16^{\circ}\text{C}$ . and  $20^{\circ}\text{C}$ . is for nickel about 0.21 of one per cent.; but the accuracy of the results recorded may be taken to lie between these limits. Previous to each set of observations for any given applied direct longitudinal magnetic field, the wire was demagnetised by applying a gradually decreasing alternating current round the solenoid, the alternating current having an initial maximum value equal to approximately that of the direct current about to be applied.

There was no perceptible heating of the wire when a direct longitudinal field was round it, but there was slight heating when alternating fields were used, and to overcome this, the following method of observation was adopted:—With the constant load on the wire, and a given alternating magnetic field round it, the hair in the microscope was set on the zero mark, that is, the point of crossing of the spider lines; the current was then put off and the reading on the disc of the micrometer taken, the working load of 2 kilos. was put on the scale-pan, the field put on, and the microscope again set to the mark; the field and the working load were then taken off and the zero again tested with the field on. From these readings, repeated five times for each separate magnetic field applied, the mean was taken as the correct reading. The largest current used round the solenoid was about 2 amperes, and a tap-key was employed in the circuit, so that, in every case the alternating current was on not more than five seconds each time, an interval of from 3 to 5 minutes being allowed between each reading in the set of five. An interval of about 10 minutes was allowed to elapse between the application of each value of magnetic field. It may be assumed, therefore, that any error due to the heating of the wire by the alternating field was very small and did not affect the results within the working limits of the investigation.

The nickel wire employed in the experiment, as stated above, was 226 cms. long and 0.1685 cm. in diameter, of simple rigidity, about  $715 \times 10^6$  grammes per sq. centimetre. The constant load on the wire was  $10^5$  grammes per sq. cm., and the working load 2 kilos. The wire was put through three sets of experiments, namely, when it was under the influence of direct longitudinal magnetic fields, and when under the influence of alternating longitudinal magnetic fields of frequencies 25 and 50 per second respectively.

The results are given in Table I, and shown in the form of curves in

<sup>1</sup> Proc. Roy. Soc. Edin., vol. xxxi.

fig. 1. In the table the column marked D.C. contains the results obtained with direct magnetic fields, and the columns marked A.C. the results for alternating fields of frequencies 25 and 50 cycles per second. In fig. 1 the two curves refer to the D.C. results, and the A.C. for a frequency of 50 per second. In all cases the Young's Modulus is expressed in dynes per sq. centimetre.

TABLE I.

Load =  $10^8$  grammes per sq. cm.

| Magnetic<br>Field<br>H | YOUNG'S MODULUS.       |                        |                        |
|------------------------|------------------------|------------------------|------------------------|
|                        | D. C.                  | A. C.                  |                        |
|                        |                        | n = 25                 | n = 50                 |
| 0                      | $13.11 \times 10^{11}$ | $13.11 \times 10^{11}$ | $13.11 \times 10^{11}$ |
| 5                      | 13.00 ,,               | 13.00 ,,               | 13.02 ,,               |
| 10                     | 12.86 ,,               | 12.89 ,,               | 12.91 ,,               |
| 15                     | 12.70 ,,               | 12.76 ,,               | 12.78 ,,               |
| 20                     | 12.60 ,,               | 12.67 ,,               | 12.70 ,,               |
| 30                     | 12.66 ,,               | 12.72 ,,               | 12.76 ,,               |
| 40                     | 12.74 ,,               | 12.81 ,,               | 12.87 ,,               |
| 50                     | 12.82 ,,               | 12.89 ,,               | 12.96 ,,               |
| 60                     | 12.90 ,,               | 12.98 ,,               | 13.03 ,,               |
| 80                     | 13.05 ,,               | 13.10 ,,               | 13.15 ,,               |

From the values in column 2 of Table I, and the curve marked D.C. in fig. 1, it will be seen that the modulus attains its minimum value in a magnetic field of about 23 c.g.s. units. This, in a way, is confirmed by the results obtained by Honda and Terada, because, if the constant loads on the wire be plotted as abscissæ, and as ordinates, the corresponding magnetic field in which the minimum modulus occurs, it will be found that the three points obtained by these experimenters and the one point obtained by the present writer all lie very approximately on a straight line.

The change in the Young's modulus is small for both direct and alternating fields, being for direct fields *decreased* a little under 4 per cent. between no field and a field of 23 units where the minimum occurs; it then *increases* a little under  $3\frac{1}{2}$  per cent. between the fields of 23 and 80 units.

The changes are smaller, or about 3 per cent., for the alternating fields of frequencies 25 and 50 per second.

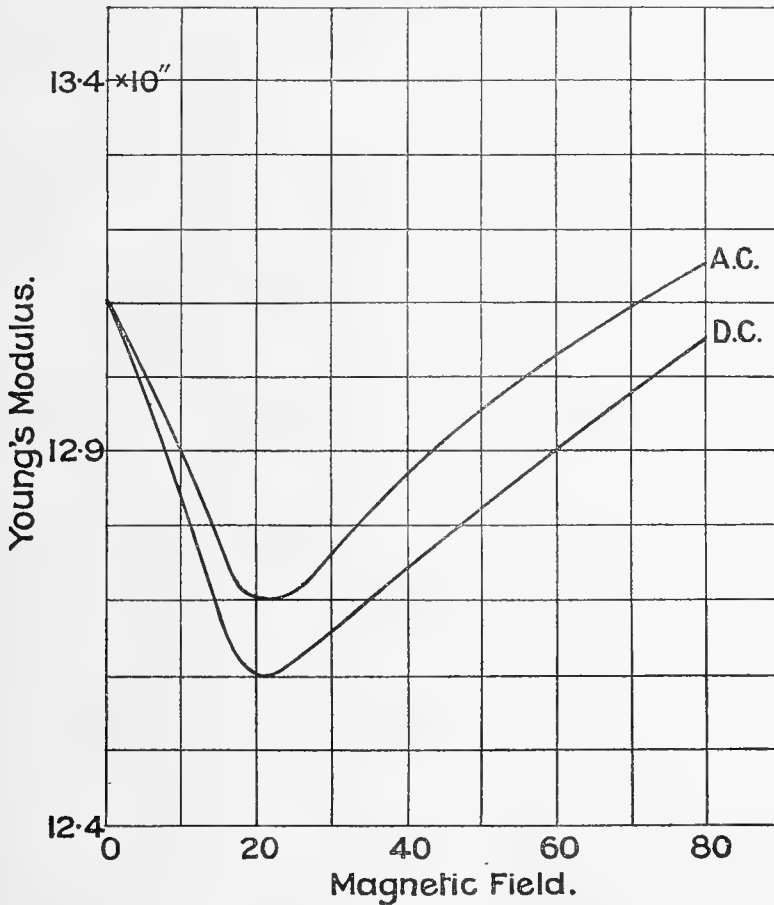


FIG. 1.

SECTION II.

*Transverse Magnetic Fields.*

In this part of the investigation the arrangement of the apparatus was the same as in the previous part, with the exception that the solenoid was replaced by a slotted iron tube. The transverse magnetic fields were produced in the gap of a soft iron tube by means of five insulated copper wires running down inside the tube. The iron tube had a slot cut through the wall along its whole length of 215 cms., the tube being 2.54 cms. external diameter, 1.6 cm. internal diameter, breadth of face of slot 0.47 cm., and width of slot 0.8 cm. The copper wires were well insulated from each other and from the iron tube, and were placed so that four wires were grouped

round one in the centre, the circuit being so arranged that the electric current passed through the five wires in the same direction, that is, the wires were in series, and the return circuit was at a distance of 2 metres.

The strength of the transverse magnetic field in the gaps was proportional to the total current through the wires. By plotting the values of the current as abscissæ, and the corresponding values of the field as ordinates, and if a straight line be drawn from the origin to the point corresponding to current = 50 amps. (10 amperes in each wire) and magnetic field = 139 units, then all the intermediate points will lie on that line.

The same nickel wire was used for the transverse fields as for the longitudinal fields, and in order to keep the wire in the middle of the slot in the iron tube, and to prevent its moving towards the face of the slot when a magnetic field was applied, there were smooth strips of wood—well lubricated on the inner faces touching the wire—fixed at both sides of the wire along its whole length. This prevented any lateral motion of the wire and at the same time did not interfere with the slight longitudinal motion produced during the experiment. With transverse fields the wire was tested when under two constant loads of  $10^5$  and  $2 \times 10^5$  grammes per sq. cm.; the same working load of 2 kilos. was also employed. The results for the smaller load are given in Table II and are shown as curves in Fig. 2.

TABLE II.

Load =  $10^5$  grammes per sq. cm.

| Magnetic<br>Field<br>H | YOUNG'S MODULUS.       |                        |
|------------------------|------------------------|------------------------|
|                        | D. C.                  | A. C. ( $n = 50$ )     |
| 0                      | $13.11 \times 10^{11}$ | $13.11 \times 10^{11}$ |
| 5                      | 13.20 ,,               | 13.18 ,,               |
| 10                     | 13.32 ,,               | 13.25 ,,               |
| 15                     | 13.45 ,,               | 13.31 ,,               |
| 20                     | 13.57 ,,               | 13.37 ,,               |
| 25                     | 13.68 ,,               | 13.42 ,,               |
| 30                     | 13.74 ,,               | 13.47 ,,               |
| 35                     | 13.78 ,,               | 13.51 ,,               |
| 40                     | 13.80 ,,               | 13.52 ,,               |
| 50                     | 13.72 ,,               | 13.43 ,,               |
| 60                     | 13.59 ,,               | 13.33 ,,               |
| 80                     | 13.39 ,,               | 13.17 ,,               |

From the values in Table II, or from the curves in Fig. 2, it will be seen that the behaviour of nickel in transverse fields is the reverse of that in longitudinal fields, that is, Young's Modulus at first increases and then decreases, the maximum (for this constant load) being attained in a field of about 40 units for both the D. C. and the A. C. fields.

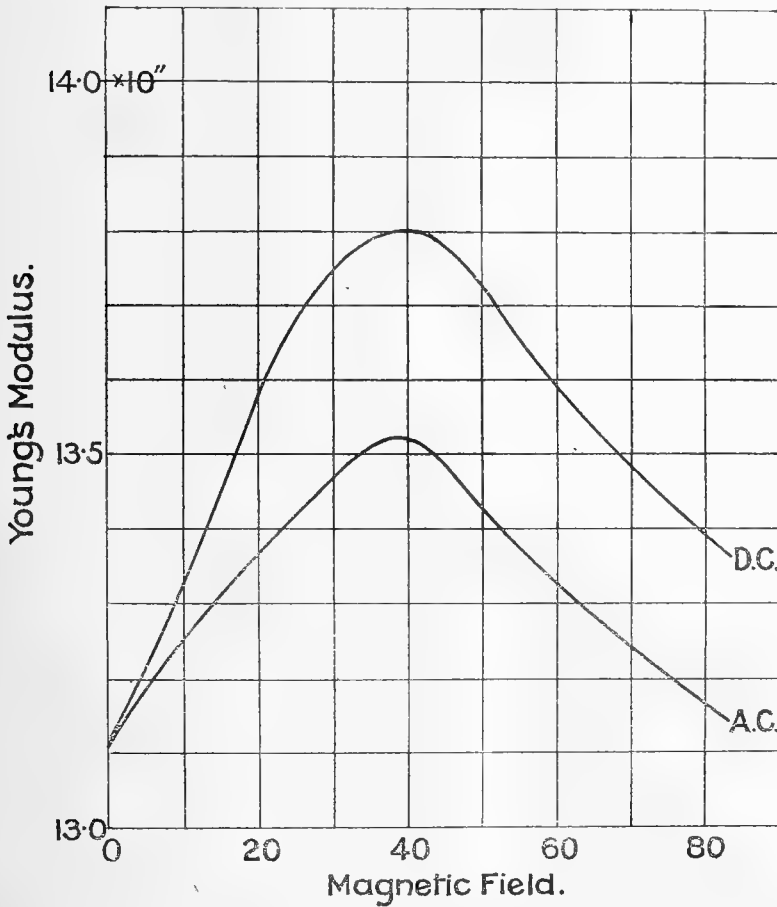


FIG. 2.

For the D.C. fields the increase is a little over 5 per cent. between no field and 40 units, and then a decrease of about 3 per cent. between the fields 40 and 80 units; and for the A.C. fields the increase is about 3 per cent., and the decrease about 2.5 per cent. between the same limits of field.

In Table III are given the results *with* the higher load for direct fields and alternating fields at three different frequencies.



TABLE III.

Load =  $2 \times 10^5$  grammes per sq. cm.

| Magnetic<br>Field<br>H | YOUNG'S MODULUS.       |                        |                        |                        |
|------------------------|------------------------|------------------------|------------------------|------------------------|
|                        | D. C.                  | A. C.                  |                        |                        |
|                        |                        | $n = 25$               | $n = 50$               | $n = 150$              |
| 0                      | $13.11 \times 10^{11}$ | $13.11 \times 10^{11}$ | $13.11 \times 10^{11}$ | $13.11 \times 10^{11}$ |
| 5                      | 13.24 „                | 13.21 „                | 13.20 „                | 13.16 „                |
| 10                     | 13.37 „                | 13.32 „                | 13.29 „                | 13.21 „                |
| 15                     | 13.51 „                | 13.44 „                | 13.39 „                | 13.27 „                |
| 20                     | 13.68 „                | 13.56 „                | 13.50 „                | 13.33 „                |
| 25                     | 13.81 „                | 13.70 „                | 13.60 „                | 13.39 „                |
| 30                     | 13.85 „                | 13.73 „                | 13.63 „                | 13.41 „                |
| 35                     | 13.80 „                | 13.51 „                | 13.51 „                | 13.35 „                |
| 40                     | 13.68 „                | 13.55 „                | 13.40 „                | 13.26 „                |
| 50                     | 13.53 „                | 13.38 „                | 13.26 „                | 13.12 „                |
| 60                     | 13.41 „                | 13.26 „                | 13.15 „                | 15.01 „                |
| 80                     | 13.23 „                | 13.09 „                | 12.98 „                | 12.81 „                |

With direct longitudinal magnetic fields Honda and Terada<sup>1</sup> showed that when the constant load on the nickel wire was *increased* the field in which the *minimum* value of the modulus occurred was *increased*, but that the actual value of the modulus was *diminished*.

From the second columns in Tables II and III, it will be seen that the reverse takes place with transverse magnetic fields, that is, when the constant load on the nickel wire is *increased* the field in which the *maximum* value of the modulus occurs is *decreased* and the actual value of the modulus in that field is *increased*.

From the values in Table III it will be seen that the maximum value of the modulus for D.C. and A.C. fields at the different frequencies takes place in the same field of about 28 units.

Comparing the maximum values in columns 3 and 5 of Table III, it will be found that when the frequency of the alternating field is *increased* 6 times the modulus is *decreased* about 2.5 per cent.

For assistance in this work I am indebted to Mr. R. Macaulay, the College Electrician.

<sup>1</sup> Phil. Mag., Jan., 1907, p. 36.

# SCIENTIFIC PROCEEDINGS.

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FURTHER OBSERVATIONS ON THE CAUSE OF  
THE COMMON DRY-ROT OF THE POTATO  
TUBER IN THE BRITISH ISLES.

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(PLATES VI-VII.)

[*Authors alone are responsible for all opinions expressed in their Communications.*]

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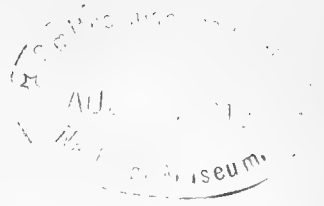
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XXI.

FURTHER OBSERVATIONS ON THE CAUSE OF THE COMMON  
DRY-ROT OF THE POTATO TUBER IN THE BRITISH ISLES.

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(PLATES VI.-VII.)

[Read FEBRUARY 27. Published JUNE 12, 1917.]

I.—INTRODUCTORY.

In a previous paper communicated to this Society and published nearly nine years ago<sup>1</sup> it was shown that the dry-rot of the potato tuber was due to a parasitic species of *Fusarium* which was then regarded as being *F. Solani* Sacc.

The object of that paper was to record evidence to show that this form of rot was in reality due to the *Fusarium* fungus, and to it alone, without the co-operation or intervention of bacteria or of other micro-organisms, which some previous authors held to be necessary to establish the rot. Since that time there has been no more controversy on this point.

It was assumed by the authors of that paper (as also by several previous authors, including Pizzigoni and Wehmer) that *Fusarium Solani* Sacc. was the correct name of the fungus which caused the rot. But beyond obtaining pure cultures of the fungus for the purpose of inoculation, no cultural or morphological studies of it were undertaken at that time, and no critical attention was paid to the actual identity or nomenclature of the fungus.

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<sup>1</sup> Pethybridge, G. H., and E. H. Bowers. Dry-rot of the Potato Tuber. Econ. Proc. Roy. Dublin Soc., vol. i. Part 14, August 1908, p. 547.

Recent investigations of the genus *Fusarium*, particularly those of Appel and Wollenweber,<sup>1</sup> have, however, shown that very great confusion prevails in the earlier literature as to what fungus is really and correctly represented by the name *Fusarium* (*Fusisporium*) *Solani*. It appears that the specific name *Solani* has been applied at one time or another to no less than nine distinct species of this genus; and even the original *Fusisporium Solani* of Martius proves to be a name which includes two distinct species, and these Appel and Wollenweber name *Fusarium Solani* (Martius pro parte) and *Fusarium Martii* (n. sp.).

This being so, it seemed eminently desirable to make a renewed study of the fungus causing the dry-rot of the potato in this country, with a view to ascertaining its exact identity, and whether only one species commonly causes the rot. This was all the more necessary in view of the fact that this disease of the potato has received an increasing amount of attention on the part of phytopathologists in recent years, notably in the United States of America; and it was important to know whether the prevalent dry-rot-producing organisms were identical on the two continents.

Before dealing with the further investigations which we have made concerning the disease, it is necessary to give a review of the literature on the subject which has been published since the appearance of the previous paper in 1908.

## II.—PREVIOUS LITERATURE.

In 1909 Miss Longman<sup>2</sup> published a description of the disease as it occurs in the south of England. Two types of fungus pustules are described as occurring on naturally affected tubers, viz. :—(1) those consisting of small tufts of hyphae bearing typical *Fusarium* conidia, usually white or buff-coloured, but sometimes pink; and (2) those in which the conidia are at first enclosed in a structure having a thin wall made up of closely interwoven hyphae, this wall being sometimes buff-coloured, but more often pink. Some of these structures possess no openings, but others have an apical pore, and are regarded by Miss Longman as being pycnidia. Owing to the production of these structures, the authoress proposed to remove the fungus from the genus *Fusarium* and place it in that of *Aschersonia* Mont.

Miss Longman states that if potatoes affected with dry-rot are not wholly

<sup>1</sup> Appel, O., and H. W. Wollenweber. *Grundlagen einer Monographie der Gattung Fusarium* (Link). Arb. Kais. Biol. Anstalt, Bd. viii. Heft 1, 1910.

<sup>2</sup> Longman, S. The Dry-rot of Potatoes. *Journ. Linn. Soc.*, vol. xxxix. Bot. ix. 270 1909, p. 120.

killed before the spring, the eyes on the sound parts of the tubers may sprout in a normal way; but as soon as the disease reaches the shoots, the latter shrink at their bases, their leaves blacken and they die. Nothing definite can be gleaned from Miss Longman's field infection experiments, since the plants in the uninoculated and control plots showed as much disease as those in the inoculated plots.

From the description and rather poor figures of the fungus given by Miss Longman, and referred to as *F. Solani*, it is difficult to decide with certainty which species was being dealt with. On the whole, it seems not improbable that the fungus was *F. caeruleum*. In our work with this species, however, we have failed to observe the "pycnidia" described by Miss Longman.

In England the dry-rot of the potato (or "Winter-Rot," as it has also been called there) was stated in 1904 by Masee<sup>1</sup> to be caused by *Nectria Solani* Pers., a name unfortunately adopted subsequently in official publications in that country. This name, however, is not traceable to Persoon, but to Reinke and Berthold,<sup>2</sup> and when this was realized the revised name *Nectria Solani* Reinke and Berthold was substituted in these publications. It is certain, however, that the fungus causing the dry-rot of the potato has nothing whatever to do with *Nectria Solani* Reinke and Berthold, an organism which these authors themselves showed to be a mere saprophyte, and to have a conidial form resembling not a *Fusarium* but a *Spicaria*.

Probably led astray by these official but erroneous publications, Eriksson<sup>3</sup> also wrongly ascribed the dry-rot of the potato to *Nectria Solani* Reinke and Berthold, while Evans,<sup>4</sup> probably similarly misled, ascribed it to *N. Solani* Pers. The same source doubtless accounts for the similar error made by Lounsbury.<sup>5</sup> The kind of evidence presented at a later date by Masee,<sup>6</sup> purporting to establish a connexion between *Nectria Solani* R. and B., *Fusarium* and various other fungi is quite inadequate to do so, or to show that any of them cause dry-rot.

<sup>1</sup> Masee, G. Some Diseases of the Potato. *Gardeners' Chronicle* April 24th 1904, p. 257.

<sup>2</sup> Reinke, J., and G. Berthold. *Die Zersetzung der Kartoffel durch Pilze*. Berlin, 1879, p. 39.

<sup>3</sup> Eriksson, J. *Hvitrota och Kräfta* ° potatis. *Centralanstalten för Jordbruksförsök*, Flygblad 8, Feb. 1909.

<sup>4</sup> Evans, I. B. P. Potato Rot (*Nectria Solani* Pers.). *Transvaal Agric. Journ.*, vii, 25, 1908, p. 64.

<sup>5</sup> Lounsbury, C. P. Dry-rot of the Potato. *Agric. Journ. Cape of Good Hope*, xxxv, 1909, p. 42.

<sup>6</sup> Masee, G. *Diseases of Cultivated Plants and Trees*. London, 1910, p. 182.



Turning now to the work of American investigators, it is necessary first to recall that of Smith and Swingle<sup>1</sup> published in 1904.

These authors regarded the rot of the tuber as being caused by *Fusarium oxysporum* Schlecht, this name being taken to be a synonym of *F. Solani* Sacc. A perusal of their account of the disease shows at once, however, that their form of rot differs in several essential points from the common dry-rot of the tuber, as we know it here; and they were apparently in error in supposing that the type of dry-rot described by European authors was identical with that studied by them. In Smith and Swingle's form of dry-rot the infection of the tuber is stated to occur normally at its heel end, through the diseased rhizome; and the subsequent decay of the tuber is stated to proceed from the region of the ring of darkened vascular tissue.

Further, Smith and Swingle's disease does not consist merely of a dry-rot of the tuber, but is one in which all of the underground parts of the plants may be attacked and killed, with the result that the overground portions also succumb, although the mycelium of the fungus does not penetrate upwards into the aerial stems. It is rather a disease of the potato plant as a whole, than merely a dry-rot of the tubers.

Some years later Manns<sup>2</sup> published an account of a similar disease, in which the plant becomes infected at its roots, and the tubers through their rhizomes. This author proved to his own satisfaction, by means of cultures, that the fungus which produced the wilt of the plant was identical with that which caused the subsequent rotting of the tubers during storage. He used for it the name *Fusarium oxysporum* Schlecht, but stated at the same time that he was quite aware that the name *Fusarium solani* was commonly used for it.

It is quite clear that Smith and Swingle, as well as Manns, concluded that the storage-rot of the tubers was caused by the same fungus as that which also produced the "wilt" disease of the growing plant (*Fusarium oxysporum* Schlecht). It seems, however, that they may have been mistaken in this matter. According to Wollenweber<sup>3</sup> the American *Fusarium oxysporum* Schlecht causes the wilt of growing potato plants, but only uses the xylem of the stem-end of the tubers for over-wintering, without producing a rot of the parenchyma. Further, after giving a morphological diagnosis of this species, this author states that it is a "vascular parasite, cause of wilt

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<sup>1</sup> Smith, E. F. and D. B. Swingle. The Dry-rot of Potatoes due to *Fusarium oxysporum*. Bull. 55. Bureau of Plant Industry. U.S.A. Dept. of Agric., 1904.

<sup>2</sup> Manns, T. F. The Fusarium Blight (Wilt) and Dry-Rot of the Potato. Bull. 229. Ohio Agric. Exp. Station. Wooster, 1911, p. 299.

<sup>3</sup> Wollenweber, H. W. Studies on the Fusarium problem. Phytopathology. vol. iii. No. 1. Feb. 1913, p. 24.

disease, but not tuber-rot, of *Solanum tuberosum* in the United States of America, possibly also in Southern Europe, and the potato districts of South Africa, Australia, &c.”

Quite a different type of dry-rot was described by Jamieson and Wollenweber in America<sup>1</sup> about four years ago, which, in its general aspects, much more closely resembles the common dry-rot of potato tubers in our own country, although it differs from the latter in some respects, as will be shown later (see p. 218). These authors state that this new form of dry-rot is clearly to be distinguished from the wilt and dry-rot ascribed by Smith and Swingle to *F. oxysporum*; and, presumably to emphasize this distinction, they refer to the new form as an *external* dry-rot. The cause of it was determined to be a new species of *Fusarium* to which the name *F. trichothecioides* was given. It is stated that tubers could be infected with the disease by merely rubbing their surfaces with a platinum loop bearing the fungus, although more certain results were obtained when the inoculation was made through an actual wound.

It is important to know whether this species not only rots tubers, but also causes a wilt of the plant, as *F. oxysporum* does. Apparently Jamieson and Wollenweber believe that it does cause a wilt, although they do not seem to be absolutely confident in the results of their experiments, for they do not include this important point in the summary which they give of their work.

What at first sight, at any rate, would appear to be yet another American type of dry-rot of the potato tuber was described in 1913 by Wilcox, Link, and Pool.<sup>2</sup>

Although in a general way this rot appears to be similar to the external dry-rot described by Jamieson and Wollenweber, yet the organism causing it was considered by the three authors to be a new one, and they named it *Fusarium tuberivorum*. They distinctly state that the fungus is incapable of infecting any part of the potato plant other than the tuber, hence it is not a wilt-producing parasite, and in this respect, therefore, it must be regarded as clearly differing from *F. trichothecioides*, if Jamieson and Wollenweber's views on this matter are correct.

Soon after the publication of Wilcox, Link, and Poole's description of *F. tuberivorum*, Wollenweber<sup>3</sup> stated that he, in common with Orton and

<sup>1</sup> Jamieson, C. O., and H. W. Wollenweber. An external Dry-Rot of Potato Tubers caused by *Fusarium trichothecioides* Woll. Washington, Academy of Science ii. No. 6, 1912, p. 146.

<sup>2</sup> Wilcox, E. M., Link, G. K. K., and V. W. Pool. A Dry-Rot of the Irish Potato Tuber. Research Bull. No. 1. Nebraska Agric. Expt. Station, 1913.

<sup>3</sup> Wollenweber, H. W. *Ramularia*, *Mycosphaerella*, *Nectria*, *Calonectria*, usw. *Phytopathology*. vol. iii. No. 4. 1913, p. 206.

Jamieson, regarded this species as being identical with the subnormal stage of *F. trichothecioides*. But if these two species be identical, it is difficult to see why one of them (*F. trichothecioides*) should cause a wilt of the potato plant and the other one (*F. tuberivorum*) should not do so.

To some extent this discrepancy may, perhaps, be regarded as explained by results obtained by Link,<sup>1</sup> and published in a paper which reached us whilst the present paper was in preparation for press. Link states that he agrees that *F. tuberivorum* Wilcox and Link is the same species as *F. trichothecioides* Woll. Contrary to what was stated in his previous paper, he now states that this species is capable of producing a wilt of the potato plant as well as a rot of the tuber, and further he shows that, contrary to Wollenweber's opinion, *F. oxysporum* is not only a wilt-producing organism, but does also cause a rot in tubers. In other words, both *F. oxysporum* and *F. trichothecioides* can produce both tuber-rot and wilt of the potato plant; but, according to Link, under field and storage conditions respectively, the former is more probably responsible for wilt, and the latter for tuber-rotting.

Pratt<sup>2</sup> describes the rot due to *F. trichothecioides* as a "powdery dry-rot," and states that it is apparently restricted to the arid and semi-arid sections of the western part of the United States. He agrees that *F. tuberivorum* is identical with *F. trichothecioides*, but, working with this fungus under western field and laboratory conditions, he states that he failed to produce an infection in any part of a growing potato plant. His results, therefore, are contrary to those of Jamieson and Wollenweber, agree with those of Wilcox, Link, and Pool, but differ from those of Link subsequently published.

Two further types of dry-rot have been described in America by Carpenter.<sup>3</sup> One, called a "stem-end and wound-invading dry-rot," was found to be caused by a new species of *Fusarium* for which the name *F. eumartii* was proposed. The second, similar in type to the first, is caused by *F. radiculicola* Wollenw. This author refers to the so-called "jelly-end" rot, which, he says, is a serious trouble in California, and he finds *F. radiculicola* and *F. oxysporum* associated with it. Carpenter agrees with Smith and Swingle (and with Link), but differs from Wollenweber in ascribing to *F. oxysporum* the power of causing tuber-rot. *F. hyperoxysporum* Wollenw. was also proved to be capable of producing a tuber-rot.

<sup>1</sup> Link, G. K. K. A physiological study of two strains of *Fusarium* in their causal relation to tuber-rot and wilt of potato. Bot. Gaz. lxii. No. 3. 1916, p. 169.

<sup>2</sup> Pratt, O. A. Control of the Powdery Dry-Rot of Potatoes caused by *Fusarium trichothecioides*. Jour. Agric. Research. vol. vi. No. 21. 1916, p. 817.

<sup>3</sup> Carpenter, C. W. Some potato tuber-rots caused by species of *Fusarium*. Journ. Agric. Research. v. No. 5. 1915, p. 183.

Pratt<sup>1</sup> calls the rot due to *F. radicum* "a field black-rot," and states that this fungus is capable of causing a jelly-end rot, but that under field conditions other factors are in part responsible. Both black-rot and jelly-end rot appear to be field rather than storage rots.

Haskell<sup>2</sup> isolated *F. eumartii* from tubers affected with a heel-end form of dry-rot in New York, and he proved as the result of pure culture inoculations that this species was capable of producing not only a wilt of the plant but also a rot of the tuber.

It will be clear from what has been said that considerable attention has been devoted during recent years in the United States of America to the various types of potato tuber dry-rot found there, but further critical study is necessary to clear up the important discrepancies which at present appear to exist between the results obtained by the various authors.

Before concluding this survey it is necessary to refer briefly to certain recent publications which deal with the question of the pathogenicity of some of the better known species of *Fusarium* towards the potato.

Wollenweber & Schlumberger<sup>3</sup> maintained in 1911 that, of the five species—*F. Solani* (Mart.) A. & W., *F. caeruleum* (Lib.) Sacc., *F. orthoceras* A. & W., *F. subulatum* A. & W., and *F. discolor* A. & W., all were incapable of causing a rot in tubers. In the case of the first two species, however, the conidia used for inoculation did germinate within the tubers and caused some local decay which did not spread, and in no case led to the rot of the whole tuber.

In a later report<sup>4</sup> from the same institution it is stated that preliminary infection experiments with species of *Fusarium* had shown that *F. discolor* var. *sulphureum* (Schlecht) and *F. caeruleum* (Lib.) were the species which most energetically attacked the tuber. *F. subulatum* App. & Wr. and *F. rubiginosum* App. & Wr. did so to a less degree, while *F. Solani* (Mart.) App. & Wr., *F. Martii* App. & Wr., and other species, gave negative results. Further trials showed that *F. discolor* var. *sulphureum* was distinctly the most active parasite, followed by *F. subulatum*, *F. metachroum* and *F. caeruleum*. Nine other species are mentioned which caused some damage to inoculated

<sup>1</sup> Pratt, O. A. A western field-rot of the Irish potato tuber caused by *Fusarium radicum*. Journ. Agric. Research. vi. No. 9. 1916, p. 297.

<sup>2</sup> Haskell, R. J. Potato wilt and tuber-rot caused by *Fusarium eumartii*. Phytopathology. vi. No. 4. 1916, p. 321.

<sup>3</sup> Wollenweber u. Schlumberger. Infektionsversuche mit kartoffelbewohnenden Pilze. Mitt. K. Biol. Anstalt f. Land u. Forstwirtschaft. Heft. 11. 1911, p. 15.

<sup>4</sup> Appel u. Fuchs. Zur Kenntniss der *Fusarium*fäule der Kartoffeln. Mitt. K. Biol. Anstalt, Heft 14. 1913, p. 16.

tubers when the latter were kept at rather high temperatures, viz. from 27°C. to 33°C.

In his most recent paper<sup>1</sup> Wollenweber mentions eight species of *Fusarium* as being capable of rotting potato tubers. The four most important species in this respect are stated to be:—

- (1). *F. cæruleum* (Lib.),
- (2). *F. discolor* var. *sulphureum* (Schlect.),
- (3). *F. trichothecioides* Wr.,
- (4). *F. ventricosum* App. & Wr.,

for all of them are capable of producing total destruction of tubers when inoculated through artificial wounds.

Of the other four *F. orthoceras* App. & Wr. is said to be the probable cause of the jelly-end rot of the potato tuber; *F. rubiginosum* is a wound parasite on cereals, and is also found on potato tubers, where it is less active than the first three species mentioned above. *F. gibbosum* is said to be a probable cause of potato tuber-rot, but the results of infection experiments were not so uniformly positive as in other species. *F. subulatum* is parasitic only under conditions of high humidity and restricted air supply, and is less active than *F. cæruleum* and others.

It will be observed that unanimity between the various authors does not always prevail. Our experience leads us to believe that, in studying the pathogenicity of the various species of *Fusaria* towards the potato tuber, there are certain factors which have a very considerable influence on the results which may follow inoculation. These are—(1) the variety of the tuber; (2) its condition of maturity; (3) the length of time that the fungus used for inoculation has been in purely saprophytic culture, and (4) the prevailing temperature and moisture conditions. In comparative tests of pathogenicity these factors should as far as possible be identical.

Finally, reference must be made to the most recent study of the various species of *Fusarium* associated with decaying potato tubers, namely, that of Sherbakoff,<sup>2</sup> who describes no less than sixty-one species and varieties, including all those already mentioned in the present paper. This author's work consists, in the main, of a description of the various species and varieties of *Fusarium*, according to their morphological and cultural characters; but

<sup>1</sup> Wollenweber, H. W. Studies on the *Fusarium* problem. *Phytopathology*. vol. iii. No. 1. Feb. 1913, p. 24.

<sup>2</sup> Sherbakoff, C. D. *Fusaria* of Potatoes. Cornell. Univ. Agric. Expt. Station. Memoir No. 6. 1915.

a certain amount of attention is also devoted to the question of the pathogenicity of the different species towards the potato. Inoculations of potato plants with all of the species described gave negative results as far as wilt production was concerned, but the author does not conclude that all of these species are incapable of producing wilt, given the proper conditions. Inoculations of tubers showed that a considerable number of the species caused more or less rapid decay, and that most of them only readily caused rotting after the tubers had begun to sprout. The commonest rot-producing organism, at least in the eastern United States, is said to be *F. caeruleum* (Lib.) Sacc.

It is stated<sup>1</sup> that this organism was isolated repeatedly from diseased tubers, and every strain isolated proved capable of producing more or less dark-coloured dry-rot in tubers. Further, Sherbakoff states that a white-rot of tubers is produced by *F. lutulatum* and some of its allies, a distinctly striate rot by *F. striatum*, a brownish rot by *F. trichothecioides*, and a more or less pinkish rot with large cavities by *F. subulatum* and its variety *brevius*. Of all these *F. caeruleum* is stated to be the commonest and most vigorous wound parasite of potato tubers, the next perhaps being *F. subulatum*, and its variety *brevius*.

It is apparent from a review of the literature that the potato tuber is capable of being destroyed by several totally distinct species of *Fusarium*, and that in most cases the decay is of the nature of a dry-rot. It is also clear that some of these species may produce a "wilt" of the potato plant. Our object was therefore to find out whether one or more of these species, and if so which of them, was responsible for our common dry-rot, and to ascertain whether the species concerned also caused a wilt-disease of the plant.

### III.—INVESTIGATION WORK.

The investigations dealt with in the present paper have been in progress, concurrently with studies of other potato diseases, during the past three or four years.

Naturally, much of the diseased material examined has been of Irish origin, but we have also been fortunate in securing for detailed investigation a number of characteristic specimens of the disease from England and Scotland<sup>2</sup> sufficient to lead us to believe that there is but one commonly occurring form of dry-rot affecting potato tubers in the British Isles.

<sup>1</sup> loc. cit. p. 261.

<sup>2</sup> We desire to express our thanks to Mr. A. D. Cotton, of Kew; to Mr. E. S. Salmon, of Wye; and to Dr. W. G. Smith, of Edinburgh, for their kindness in providing us from time to time with supplies of typically diseased material from England and Scotland.

*Cause of the Rot.*—We may at once anticipate the general conclusion at which we have arrived as a result of our studies by stating here that the fungus which we have found to be the cause of our common dry-rot is *Fusarium cæruleum* (Lib.) Sacc., and that although it does directly cause the decay of potato tubers, it does not produce hadromycosis (wilt) of the plant, such as is produced by *Verticillium albo-atrum*,<sup>1</sup> and, according to some authors, by certain species of *Fusarium*. Nor do we believe that it causes a disease of the potato plant by attacking the roots.

This species has been recognized on the Continent of Europe since the beginning of the nineteenth century, but has not usually been regarded as a definite parasite. Saccardo<sup>2</sup> records it as occurring in putrid tubers, and Rabenhorst<sup>3</sup> on rotting potatoes. More recently Appel and Wollenweber<sup>4</sup> in Germany state that it is a comparatively rare species on potato tubers; and these authors suggest that this may perhaps be accounted for by its slow growth when compared with other species such as *F. solani*. This does not necessarily conflict with our view that *F. cæruleum* is the species commonly causing dry-rot, for the tubers examined by these authors were evidently not merely those which had been destroyed by dry-rot, but must also have included many killed by *Phytophthora infestans*, parasitic bacteria, &c., on which various saprophytic species of *Fusarium* subsequently flourish.

Not nearly so much attention has been paid in America to this species as to *F. oxysporum*, *F. trichothecioides*, and others, although (as previously mentioned), according to Sherbakoff, *F. cæruleum* is the commonest rot-producing *Fusarium* in the United States, at any rate so far as the eastern States are concerned.

As a British fungus the species is recorded by Masee,<sup>5</sup> who gives an extremely brief description of it, and states that it occurs "on rotten tubers of potato," thus suggesting rather a saprophytic than a parasitic habit. In British phytopathological literature the species is conspicuous by its absence from mention. We cannot now be certain on the point, but a re-examination of the fungus present on affected tubers, preserved both dry and in spirit from the time of our 1908 paper, leads us to suspect strongly that what we then called *F. solani* was in reality *F. cæruleum*.

Eleven distinct cases of the disease have carefully been studied by us.

<sup>1</sup> Pethybridge, G. H. The *Verticillium* Disease of the Potato. *Sci. Proc. Roy. Dublin Soc.* xv. (N.S.) No. 7. p. 63. March 1916.

<sup>2</sup> Saccardo. *Syll. Fung.* iv. 1886, p. 705.

<sup>3</sup> Rabenhorst. *Kryptog. Flora*, I. 9, p. 574.

<sup>4</sup> *Loc. cit.* p. 84.

<sup>5</sup> Masee, G. *British Fungus Flora*. vol. iii. 1893, p. 481.

In each of them *F. caeruleum* was proved to be the cause of the rot, and eleven strains of the fungus have been isolated, and studied in very considerable detail. Except for slight variations in their relative degrees of pathogenicity, these strains have proved to be identical with each other, and also with a strain of *F. caeruleum* procured from the Central Bureau of the International Association of Botanists in Amsterdam.

Two further cases of the rot were met with when our cultural work was nearly completed; and in these cases also it was proved that the fungus responsible for the decay was *F. caeruleum*.

*Occurrence of the Disease.*—The most serious cases of the disease have usually been met with in seed tubers of early varieties such as May Queen and Ninety-fold, but it is by no means confined to such varieties. Complaints regarding it are more commonly made in the early months of the year than in the autumn, and this is probably correlated with the fact (to be discussed later) that the maturity of the tuber has a good deal to do with the incidence of the disease. We have never observed a case of the disease on tubers still attached (as they are in summer and early autumn) to the parent plants, nor have we seen it at the time of digging. The rot is essentially a storage one, the visible effects of which are seen during the winter, and particularly in the early spring.

*Description of the Rot.*—The rot may begin in any external region of the tuber, and is not associated with the heel or stem-end more than with any other part. It very frequently originates at obvious wounds or lesions of the skin, but often such injuries are not apparent where infection has occurred, and, as will be shown later (see p. 213), infection can occur in the absence of damage of this kind. A single tuber may be affected in several distinct regions at one and the same time, but as time progresses the decayed regions approach one another, and ultimately coalesce.

In the earliest visible stages of attack the skin becomes somewhat darker in colour than usual, and is slightly sunken. As time goes on the diseased area spreads, the sunken dark skin becomes folded or ridged into more or less parallel or concentric wrinkles, while fungus pustules break out through it. During this time the rot also penetrates more deeply into the inner tissues of the tuber. (See fig. 1, Plate VI.)

The rot as a rule proceeds until the tuber is entirely destroyed. During its progress much water is lost, the tuber shrinks, and finally becomes light in weight, dry, and quite hard. In this condition it is quite difficult to cut it with a knife. (See fig. 2, Plate VI.)

If a partially rotted tuber be cut open, it will be observed that the older decayed tissues are rather dry and brown in colour, but the browning has



no special association with the "vascular ring." Affected tubers often show a few cavities more or less completely filled with mycelium, which, however, as a rule, does not in these circumstances bear many conidia or chlamydo-spores. The newly killed tissues are still moist, more or less yellowish in colour, and of a granular consistency. The line of demarcation between the diseased and healthy tissues is not always strongly marked when an affected tuber is first cut open, but on standing exposed to the air the diseased portion gradually becomes distinctly browned.

In the interior of a completely rotted tuber, cavities containing a luxuriant growth of mycelium are also present. The mycelium lining the walls of these cavities is frequently distinctly blue; and very often this colour also pervades the dead tissues for some little depth around the cavities. The intervening portions of the dead tissues are, at this stage, of a dirty white colour, and are more or less easily reduced to powder on being rubbed between the fingers.

Microscopical examination of sections made at the junction of the diseased and healthy tissues reveals the presence of branched, septate mycelium between the cells of the diseased tissues. In the completely browned and nearly dry, dead tissues, however, the mycelium is found to be both intra- as well as intercellular. The starch grains remain unattacked.

The fungus pustules present on the wrinkled skin are not arranged in any definite order or system, nor are they all absolutely alike, either as regards shape and size or colour. They are, as a rule, white on their surfaces; but if the outer layers be rubbed or scraped away, or if the pustules be sectioned, their bases are seen to be deep blue in colour. Occasionally the pustules are superficially blue, while they may also be distinctly pink, especially if the rotting tubers have been exposed to a good light.

The base of each pustule is made up of a compacted mass of hyphae running more or less at right angles to the surface of the tuber, and blue in colour. From this base a very large number of branched *conidiophores* bearing septate, fusiform conidia arise. The conidiophores are illustrated in fig. 1, Plate VII. The ultimate branches of the conidiophores (*sterigmata*) are somewhat swollen, more or less fusiform cells. At the apex of each sterigma, after the first and each subsequent conidium has been formed, there remains a not-easily-discerned, slightly funnel-shaped, projecting, empty sheath or collar, formed from the cell-wall at the point where the first conidium and the sterigma part company.

The base of each succeeding conidium remains for a longer or shorter period within this sheath, and, doubtless, it is this fact (as we found Appel

and Wollenweber had already suggested) which gives rise to the foot-like shape sometimes exhibited by the basal-cells of the conidia.<sup>1</sup>

The conidia produced on the pustules are slightly sickle-shaped and rather bluntly pointed at both ends. In general shape they somewhat resemble that of a pea-pod; and, just as the latter is enclosed at its base by the persistent calyx of the flower, so the base of the conidium rests within the sheath, as described above.

Typical conidia are shown in fig. 2, Plate VII. When produced in great quantities, under moist conditions, the conidia form rather slimy masses on the surfaces of the pustules. The conidia on the pustules are usually from 0- to 3-septate; i.e. from 1- to 4-celled; but the 3-septate forms always predominate. (In cultures 5- and 6-celled conidia are also produced.) In size they vary considerably, according to the conditions of moisture under which the tuber is decaying. The averages (in microns) for the various forms are as follows:—

|            |            |            |            |
|------------|------------|------------|------------|
| 0-septate. | 1-septate. | 2-septate. | 3-septate. |
| 14 × 3·7.  | 19 × 4·1.  | 21 × 4·3.  | 27 × 4·8.  |

In healthy artificial cultures the conidia produced are generally somewhat larger than those found on the pustules.

The *chlamydospores*, which occasionally occur on the pustules, are more or less spherical, possess somewhat thick, smooth walls, and are blue in colour. They are produced singly, in pairs, in chains, or in irregular groups. Their average diameter is 8 to 9  $\mu$ . Chlamydospores are shown in figs. 4 and 5, Plate VII.

<sup>1</sup> It may, perhaps, be pointed out that the explanation of the origin of this "foot" structure of the basal cell of the conidium given by Wilcox, Link and Pool (*loc. cit.* p. 23) does not appear to be correct. The figures on which the explanation given by these authors is based are of hyphae, and not of conidia. If their explanation is correct, both the apical and the basal cells of a conidium should show the "foot"; but we have not found this to be the case.

The sterigma-sheath is clearly illustrated by Sherbakoff (*loc. cit.* p. 129, fig. J) for *F. cuneiforme*, but its significance is not alluded to. We have found that the foot-like appearance of the basal cell is most strongly developed in old and nearly-exhausted cultures, in which conidia are produced only slowly. In such cases the extremity of the basal cell must remain confined within this sheath for a considerable time, while the part immediately beyond it is free to expand. Since the conidium seldom sits symmetrically in this sheath, the small heel-like swelling usually occurs only on one side, and thus gives the foot-like appearance to the basal cell.

Seeing that the shape of this basal cell is, therefore, dependent on conditions of growth or culture, too much stress must not be laid on it as a morphological character for any particular species. In *F. caeruleum* it is not usually a very marked character, and frequently it is entirely absent.

*Germination of the Conidia.*—In hanging drops of rain-water ripe conidia germinate within a few hours. The individual cells of the conidium first become swollen, and it thus becomes somewhat constricted in the regions of the septa. Germ tubes may arise from any or all of the cells of a conidium. No fragmentation of the conidia into their constituent cells with a subsequent rounding off, previous to germination, as described by Smith<sup>1</sup> for *Fusisporum Solani* Mart., has been observed by us in *F. caeruleum*. Germinating conidia are shown in fig. 3. Plate VII.

*Isolating the Fungus.*—In no group of fungi is it more essential than in the genus *Fusarium* that the starting-point of a pure culture should be a single conidium, and we used this method. There is no particular difficulty in the matter in this case, seeing that the spores are large; and isolated individuals can, with comparative ease, be found and kept under observation under the microscope, on poured plates of suitably diluted conidia-suspensions. Thence transference singly to media in tubes is not a matter of real difficulty to a skilled worker. Appel and Wollenweber found the isolation of this species difficult, but that is probably because the material from which they started was a more or less heterogeneous mixture of the various kinds of organisms found associated together on rotten potatoes, and was not, as in our case, a pustule produced on the surface of a tuber in the comparatively early stages of a definite dry-rot.

If diseased material in not too advanced a stage of decay is available, it is also a comparatively easy matter to obtain cultures by removing, under aseptic conditions, small portions of tissue from the junction between the still healthy and the diseased portions of the tuber, and placing them on suitable nutrient media. Many of such cultures, if prepared with skill, will be found to be pure; others will become contaminated with stray germs during preparation. Failing diseased material in just the right condition it can be prepared by first inoculating a previously externally-disinfected, healthy tuber from a conidial pustule, and, when the rot has proceeded sufficiently far, by removing small portions of tissue, as described, to suitable media. For critical work, of course, this method is not admissible. Nevertheless, we have found that in the case of *F. caeruleum*, at any rate, a considerable proportion of the cultures thus obtained are pure.

*Growth in Pure Cultures.*—The fungus has been cultivated on more than a dozen different media, but they have not all proved equally suitable.<sup>2</sup> The

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<sup>1</sup> Smith, Worthington G. *Diseases of Farm and Garden Crops*. London. 1884. p. 31.

<sup>2</sup> It should be stated that in none of our cultures have any forms of fructification other than conidia or chlamydo-spores been developed, although we have been successful in obtaining the development of perithecia *in vitro* with pure cultures of *Hypomyces Solani*, *Nectria Rubi*, and with one or two other fungi.

best of those used were Quaker Oat agar, oat extract agar,<sup>1</sup> slices of cooked potato tuber, and cooked potato stalks. In all cases where gelatine media were used, the fungus caused liquefaction of the gelatine. On the four media mentioned the fungus grew well, developed both conidia and chlamydo-spores, and exhibited the characteristic blue coloration which its specific name implies. When grown on ordinary beef-extract agar or gelatine, or on potato-juice gelatine, the colour was not produced, and chlamydo-spores were absent. The colour was, however, produced in cultures on beer-wort gelatine, but here, again, no chlamydo-spores were developed.

On Quaker Oat agar the growth is at first white. Later on the medium which the mycelium permeates becomes claret-coloured, while the aerial mycelium shows all stages of colour, from white to claret and blue. The conidia are borne in more or less slimy or viscous masses on the surface of the medium, and these masses vary in colour, from dirty white, through cream, to light green and light blue. On this medium isolated, hard masses of compacted, blue mycelium, of a sclerotial nature, are produced in considerable numbers. On oat extract agar growth is similar, but rather less luxuriant.

On slices of cooked potato tuber the mycelium produces a distinct blue colour in the medium, while the moist masses of the conidia on the surface are coloured distinctly light green. Chlamydo-spores are produced abundantly, and so are the blue sclerotium-like bodies already alluded to.

On cooked potato-stalks the growth is very similar. Chlamydo-spores are present, but the blue sclerotium-like bodies are not developed.

*Influence of Light.*—Our cultures were carried out in test tubes 15 cm. long, which for convenience sake were grouped in tens, and were placed in round tins about 8 cm. high. Even when standing in the laboratory the amount of light which could reach the culture was therefore but small; and when, as was often the case, they were kept in a dark cupboard, light was, of course, totally excluded. Under these circumstances, the substratum and mycelium were as a general rule of a more or less indigo blue colour, while the superficial moist conidial masses were coloured light green.

Parallel cultures were carried out in light and in darkness to ascertain what influence (if any) light had on the coloration produced. The cultures were kept in a window facing north, so that they were not exposed to direct sunlight. One half of them were fully exposed and the other half were carefully covered with thick black paper in such a way as to exclude all

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<sup>1</sup> For the method of preparing these media see *Sci. Proc. Roy. Dublin Society*, xiii, (N.S.). No. 36. March 1913, p. 578 and p. 580.

light. The inoculum used in each case consisted of a portion of a green, moist mass of conidia, together with a small amount of adhering mycelium.

The experiment lasted forty days. In the dark the conidial masses were, as a rule, of the greenish blue colour already familiar to us, with occasionally some which were white or dirty white in colour. In the light, however, the conidial masses were of a "bitter-sweet pink" (Ridgeway) colour.

*Influence of Moisture.*—This experiment was repeated in a slightly modified form. Not only were the cultures divided between light and darkness, but the effect of an abundant and of a restricted amount of moisture was studied at the same time. With regard to the latter, no effect was observable as far as development of colour was concerned, but the extra moisture merely led to a more luxuriant growth of the culture. As in the previous experiment, however, it was found that the presence of light caused the development of the bitter-sweet pink colour in the masses of conidia, while in the absence of it they were light green. It has already been pointed out that the fungus pustules present on rotting tubers become pink in colour when exposed to a good light.

Appel and Wollenweber describe the pure colour of the conidia of *F. ceruleum* as being reddish-ochre when grown in bright daylight, but brownish white with a minimum of light. The verdigris-green colour often observed in the conidial masses is regarded by these authors as being a mixture of the brownish-white of the conidia with the indigo blue of the substratum. We, however, were not able to confirm this.

*Nature of the Colouring Matter.*—If a portion of a culture in which the blue colour is well developed (as, for instance, one on cooked potato) be boiled in water, no extraction takes place. The colour, however, is extracted by dilute hydrochloric acid in the cold, and it at once changes to pink. The addition of an alkali to the pink solution causes it to become blue.

*Influence of Acid or Alkaline Reaction of Media.*—Cultures were carried out on media, made both distinctly alkaline and distinctly acid, and in the former case the colour developed was deep blue. In the acid medium the fungus grew satisfactorily, but the colour first produced was of a wine-red tint. Subsequently, when the acidity of the medium had become neutralized by the alkalinity, developed as the result of the growth of the fungus, the colour changed to blue. It may be remarked here that the juice expressed from the diseased portion of an affected tuber gives an alkaline reaction to litmus, while the normal juice of a healthy tuber is, of course, slightly acid.

*Proofs of Pathogenicity.*—A large number of experiments involving the inoculation of healthy potato tubers with the various strains of the fungus

were made. Into the exact details of all of these space does not permit us to enter, and a general account of them must suffice.

In every infection experiment undertaken controls were used, consisting of tubers similar to those used for inoculation, and treated similarly to the latter, except that no actual inoculation of them was made. In every case these control tubers remained sound and free from rot.

The general method adopted for practically all of the inoculation experiments consisted, first, in carefully selecting healthy tubers with undamaged skins. These were then well washed in water, and next steeped for a short time in a weak solution of formaldehyde. Finally, they were washed in sterile water and then allowed to dry. The inoculating material was introduced through wounds specially made with a sterile scalpel. A more or less tetrahedral or conical cut was made into the tuber, and the cone of tissue, still attached by a small portion of skin at its base, was everted. The inoculum was placed in the bottom of the cavity thus produced; the apex of the cone cut off and its base closed down on the inoculum. By this means a gaping wound was avoided, and the chance of contamination from stray spores minimized.

A positive result was only regarded as having been obtained when the rot produced was extensive and progressive. In such cases the whole tuber ultimately became rotten, if kept long enough. Cases where a certain amount of rot at first proceeded from the inoculation wound, but did not progress further owing to the formation of a layer of cork cutting off the infected area, were regarded as negative.

The inoculated tubers were kept in covered glass dishes, at least for a short period after the inoculation had been made, at laboratory temperatures. Later on the lids were sometimes removed, and, when once the rot had definitely started, its rate of progress did not appear to be affected in any very marked degree by varying conditions of dryness or moisture.

Out of a total of 848 inoculated tubers there resulted in 577 cases (i.e. sixty-eight per cent. of them) complete rotting of the tubers. The failure to cause rot was sometimes due to non-maturity of the tubers used, or to the variety used being more or less resistant. In the total mentioned we have included all the trials made, and these factors are of considerable importance in deciding whether infection will occur or not. One hundred and eighty-two tubers were inoculated at various times with the strain of *F. caeruleum* obtained from Amsterdam, and in eighty-four of them (i.e. forty-six per cent.) the typical rot was produced.

It was not considered necessary in more than a few cases to complete the detailed proof that the fungus used for inoculation purposes was in reality the

cause of the rot by isolating it again from the decaying tubers. This was, however, done in six cases, and the fungus obtained in pure culture in each case.

*Pathogenicity towards Plants other than the Potato.*—Attempts were made to infect onions, mangels, carrots, parsnips, and apples with pure cultures of *F. caeruleum*; but the fungus proved itself to be non-pathogenic in these cases, at least under the conditions of the experiments, which were similar to those under which positive results were obtained with potato tubers.

Similar trials were made with tomato fruits, the fungus being inoculated through wounds made for the purpose. In both of two sets of experiments positive results were obtained. The decay produced in the fruit is not particularly rapid, only about one quarter of the inoculated fruit becoming involved during the course of a fortnight.

The surface of the decayed area becomes somewhat sunken and covered with a layer of conidiophores bearing conidia which, in the mass, are of a pinkish-cream colour. Cavities occur in the decayed tissue of the fruit, which are more or less completely filled with white mycelium. The decayed tissue is of a spongy consistency, and is thoroughly permeated with mycelium.

From small portions of such diseased tissue, removed under aseptic conditions and placed upon suitable media, the fungus was re-isolated in pure culture, thus completing the proof that it was the cause of the decay. Control fruits treated similarly to the inoculated ones, but not inoculated, remained perfectly healthy.

It is clear, therefore, that this fungus is pathogenic to the fruits of the tomato provided wounds are present. Whether it can attack the uninjured fruit or not we are not in a position to say.

*Influence of Maturity of the Tuber on the Susceptibility to Infection.*—Some of our infection experiments were made in the summer and early autumn, and the results were more or less negative. Further trials soon aroused the suspicion that the age or maturity of the tubers had a considerable influence on the susceptibility to infection, and specific experiments were, therefore carried out to ascertain whether the suspicion was well-founded or not.

For this purpose tubers of the varieties "May Queen" and "Ninety-fold," known to be susceptible, were used. It was found that one of the strains of *F. caeruleum* when inoculated in the early summer into May Queen tubers of the previous season produced dry-rot with ease and certainty; but that when the same strain was used to inoculate tubers of the same variety newly dug in July, the results were almost entirely negative. Hence a series of periodic inoculations was carried out, the details and results of which are summarized in the following table. The tubers used were specially grown

for the purpose and the same stock used throughout the trials. In addition to one of our own strains of *F. caeruleum* we also used the one obtained from Amsterdam for inoculating purposes, this being done through wounds as already described for other such experiments. Controls were of course used in all cases, and in every instance they remained sound.

| Inoculated with   |                        | <i>F. caeruleum</i><br>(own strain). |              | <i>F. caeruleum</i><br>(Amsterdam strain). |              |
|-------------------|------------------------|--------------------------------------|--------------|--|--------------|
| Variety of Tuber. | Dates of Inoculations. | No. of Inoculations.                 | No. of Rots. | No. of Inoculations.                       | No. of Rots. |
| May Queen         | July 31, 1915          | 20                                   | 1            | 20   | 1            |
|                   | Oct. 22, ,,            | 10                                   | 2            | 10   | 1            |
|                   | Nov. 22, ,,            | 20                                   | 7            | 20   | 9            |
|                   | Dec. 22, ,,            | 20                                   | 15           | 20   | 13           |
|                   | Jan. 22, 1916          | 20                                   | 16           | 20   | 17           |
|                   | Feb. 22, ,,            | 20                                   | 20           | 20   | 20           |
| Ninety-fold       | Sept. 8, 1915          | 20                                   | 0            | 20   | 0            |
|                   | Oct. 22, ,,            | 10                                   | 7            | 10   | 0            |
|                   | Nov. 22, ,,            | 20                                   | 17           | 20   | 9            |
|                   | Dec. 22, ,,            | 20                                   | 16           | 20   | 12           |
|                   | Jan. 22, 1916          | 20                                   | 20           | 20   | 15           |

The table clearly shows that there is a progressive susceptibility to rot, the maximum being reached early in the new year. This fact probably explains why it is that complaints of serious losses due to dry-rot are not made as a rule until some months after storage has begun.

The cause of the increased susceptibility is perhaps to be looked for in some change in the chemical composition of the contents of cells of the tuber, and with this in view, an attempt was made to increase the susceptibility to decay in autumn by keeping the tubers for some twenty hours or so in a vessel surrounded with a mixture of ice and salt before inoculation. This treatment was so arranged as not to be severe enough to kill the tubers by freezing, and they sprouted quite normally subsequently. It was found, however, that the tubers were not thus rendered more susceptible to infection. Two experiments of this kind were carried out, and when the



second gave negative results like the first the matter was not pursued further. It was thought that possibly the development of sugar was the factor which influenced infection, but the matter does not appear to admit of so simple an explanation.

*Varieties naturally resistant to Infection.*—Seeing that dry-rot is more frequently met with in some varieties than in others, it is natural to suppose that certain of them are more resistant than others, and that some may even be quite immune.

Two series of infection tests were carried out with nine varieties of early potatoes raised for the purpose at the temporary phytopathological station at Clifden, Co. Galway.

The inoculations were made as previously described, and the culture used was one which produced one hundred per cent. of rots in inoculations of tubers of "May Queen" just previous to the experiment. Ten inoculations were made in each case, and the results are summarized in the following table—

| Variety of Tuber.       | No. of cases of Rot in |            |
|-------------------------|------------------------|------------|
|                         | Series I.              | Series II. |
| Ninety-fold, . . .      | 10                     | 10         |
| Early Puritan, . . .    | 10                     | 10         |
| Sharpe's Express, . . . | 8                      | 10         |
| May Queen, . . .        | 8                      | 10         |
| Duke of York, . . .     | 6                      | 10         |
| Midlothian Early, . . . | 4                      | 10         |
| Eclipse, . . .          | 6                      | 7          |
| Windsor Castle, . . .   | 3                      | 4          |
| Epicure, . . .          | 0                      | 2          |

The results point to the conclusion that at least the varieties Eclipse, Windsor Castle, and Epicure, are less susceptible to attack than the other varieties; and they suggest that a systematic trial of the pathogenicity of the fungus towards an extended list of varieties might yield important economic results.

Since liability to infection is influenced both by the variety of the tubers used and by their degree of maturity, it follows that in any studies as to the

pathogenicity of members of the genus *Fusarium* towards the potato cognisance must, as has already been explained, be taken of these factors. Possibly some of the conflicting results obtained by earlier workers may be accounted for by failure to appreciate the significance of these factors, although perhaps it is just as likely that in some cases the species under investigation by the different authors were not really identical.

*How Tubers become Infected.*—Attention has already been called to the fact that naturally infected tubers frequently exhibit wounds from which, it is fairly clear, infection started. Seed potatoes are frequently transported in sacks and, under the conditions of transit, the tubers are exposed to a good deal of bruising. Such bruising frequently results in small cracks being produced in the skin. It was proved by experiments with three varieties of potato that the fungus could infect the tubers through wounds deliberately produced by bruising and thus cause the rot; and it is believed that bruising in transit may well be an important factor leading to infection.

It was also proved that the wounds resulting from the breaking off of the young shoots from sprouted tubers formed very favourable points of entrance for the fungus. The careless handling and planting of sprouted tubers often results in some of the sprouts being broken off. Some of the cases in which presumably healthy seed-tubers have been observed to decay from dry-rot in the ground after planting may probably be explained by the entry of the fungus through wounds of this kind.

Infection experiments were also carried out with tubers which, so far as careful examination with a good lens could disclose, had perfectly intact skins. In one case infection occurred at an eye, and in several cases at lenticels. Since these results were somewhat unexpected, the experiments were extended. Nine specially selected tubers of the Variety Early Puritan, which, except for a few small scab spots, had perfectly intact skins, were carefully washed in sterile water and allowed to dry. Some of them were unspouted and some had sprouts about 5mm. long. They were not treated with any disinfectant, for fear of causing any damage to the eyes or the sprouts. Five of these tubers were then steeped for a few seconds in a suspension of the spores of *F. caeruleum* in sterile water, while the remaining four were steeped for the same length of time in sterile water alone.

Both lots were then kept in a moist atmosphere in covered glass dishes at laboratory temperature. The four tubers which were steeped in sterile water remained absolutely free from any kind of rot. Dry-rot was set up, however, in a short time at many points in the five tubers steeped in the spore suspension. Ten cases of infection through scab spots and lenticels were noticed, while infection occurred also in six cases through unspouted

and uninjured eyes. In one case a sprout of about 1 cm. long became infected at its uninjured tip, and the fungus passed back through this sprout, killing it, and eventually reaching the tissue of the tuber. In five other cases sprouts became similarly infected, but at the conclusion of the experiment the decay had not extended from them to the tuber.

It is, therefore, clear that although this fungus is, perhaps, most frequently a wound-parasite, yet, under favourable conditions, it can attack uninjured tubers through lenticels, eyes, or young sprouts.

*Results of Planting Infected Tubers.*—Nearly every season we have brought to our notice one or more cases where early potatoes have failed to make a stand, or have made only a very bad one. Almost invariably these have been cases in which cut sets were planted, which were found when dug up to be seriously decayed with dry-rot. In such cases of course it is impossible to say after the event whether the seed tubers used were at fault, or whether the sets became infected from the soil, subsequent to planting.

In order to ascertain what happens when naturally infected whole tubers are planted, nine such tubers, ascertained to be infected with *F. caeruleum*, were planted in pots of soil in an unheated greenhouse. Healthy tubers were planted in pots of similar soil for purposes of comparison. Three of the infected tubers rotted completely in the soil and gave rise to no plants. The other six produced small plants, which remained perfectly healthy, died off eventually in a natural way, and in *post-mortem* examination showed no evidence of attack by *F. caeruleum*, or other organism.

Four tubers artificially inoculated with the fungus were also planted after the rot had become well established. All four produced small, healthy plants, which died off naturally, and no traces of the fungus could be found in them on subsequent microscopical examination.

It is our experience that if, when planted, a tuber is already seriously decayed with dry-rot, and particularly if the decay is in close proximity to the eyes or sprouts, the probability is that no plant will be produced. If, however, when the tuber is planted the amount of decay is slight, or is not in the immediate neighbourhood of the eyes or sprouts, the latter have time to grow and produce overground shoots having their own roots; and these shoots do not subsequently become invaded by the fungus.

*Does F. caeruleum cause a Disease of the Potato Plant as a whole, or only a Rot of the Tuber?*—If this fungus were capable of attacking the whole roots of the potato plant, and of thus killing it, we should have expected this to happen when either naturally or artificially infected tubers were planted. It would seem almost certain that under such conditions the roots on the underground portions of the stalks would be exposed to infection by contact with the

decaying tubers themselves. Since, however, as described above, the plants produced from diseased tubers remained healthy, we conclude that the fungus is not capable of attacking the roots.

Experiments were made to ascertain whether *F. caeruleum* is capable (like *Verticillium albo-atrum*) of producing hadromycosis, that is, of growing in and choking up the wood vessels, and thus causing a type of "wilt" disease.

As a result of several preliminary trials it was found that this fungus refused to grow on freshly cut, living portions of potato stalks, whether inoculated on the freshly-cut surfaces, on the uninjured surface, or even into freshly-made wounds in such stalks. These trials were made with portions of stalks a few centimetres long, from which the leaves were removed, and which were kept moist in test tubes provided with cotton-wool plugs.

Further trials were next made by inoculating the fungus into rather deep wounds, traversing all the tissues, made in various regions of the stems of leafy stalks cut from the parent plant, and kept with their cut ends in water. By occasionally changing the water and renewing the cut surface at the base of the stalk such leafy shoots, if kept in a good light, will remain in good condition, and continue to grow for some weeks. Uninoculated cut shoots were, of course, also kept under similar conditions for purposes of comparison and control.

The results of these trials were entirely negative. After four weeks the inoculated stalks showed no signs of wilting, and microscopical examination of the tissues showed that there had been no extension of the fungus from the inoculation wound either in the cavities of the wood-vessels or elsewhere.

The inoculation of plants growing in pots was then proceeded with, three series of experiments being made. In the first series the stalks, when about twenty centimetres high, were inoculated (under as aseptic conditions as possible) just below soil level, the wound being made at a node. After inoculation the wounds were bound up with tinfoil, and the disturbed soil replaced. Inoculation with *Verticillium albo-atrum* in this manner invariably results in causing a wilt disease of the plant, but in no case did this happen with *F. caeruleum*.

One of the six inoculated plants did, it is true, die prematurely, but this, it is believed, was due to the effects of a somewhat drastic fumigation rendered necessary by an attack of aphides from which both the inoculated and control plants temporarily suffered. The dead plant was thoroughly examined microscopically, but no mycelium was found in the stem except at the inoculation wound from which no spread had occurred. The same was

found to be the case with the other inoculated plants which remained healthy, and were microscopically examined three months after the inoculations were made. The controls behaved in a similar manner.

The second series of inoculations was a repetition of the first. Eight healthy plants were inoculated as in the previous series. They remained healthy, except in one case, and after a period of two months they were subjected to microscopical examination. The seven plants showed no traces of the fungus in them, except immediately at the inoculation wound, from which it had not spread. The eighth plant died after the expiration of one month. Mycelium was found in its vessels, but this, as the result of cultural trial, was found to be *Verticillium albo-atrum*. Examination of the undecayed parent tuber showed that this fungus was also present in it; and there can be little doubt but that this tuber was infected with *Verticillium* before it was planted.

In the third series the tubers selected for use were first carefully tested to make sure *Verticillium* was not present in them. The *Verticillium*-free tubers were then allowed to sprout, and when the sprouts were from two to three centimetres long, one main sprout on each was inoculated with *F. cæruleum*, through a wound made for the purpose. The other sprouts and eyes were removed. The tubers were planted, and all six of them produced perfectly healthy plants, as also did four tubers (not inoculated in the sprouts) used as controls. The stalks were subjected to microscopical examination, but no mycelium was found in their wood vessels. The newly-produced tubers were also examined, and found not to be invaded at their heel-ends by any fungus.

As a result of these experiments we conclude that *F. cæruleum* does not cause a wilt disease of the plant, and in this respect it appears to differ from *F. oxysporum* and *F. trichothecioides*.

*Control of Dry Rot.*—Our experience with this disease is that when once a tuber begins to rot it is practically impossible to effect a cure. From twenty naturally affected tubers the diseased portions (which were then comparatively small) were very carefully cut out on December 19th, 1913. Flowers of sulphur was then thoroughly rubbed into the wounds. After two months, however, nineteen of these tubers had completely rotted. Either the whole of the diseased tissue had not been cut out originally, in spite of the care exercised, or re-infection from spores had then or subsequently occurred, and this in spite of the presence of sulphur.

Ten healthy tubers (variety Windsor Castle) were washed and dried. Five were then inoculated with *F. cæruleum* through wounds as previously described. Just before the other five were quite dry they were rolled in

flowers of sulphur. They were then wounded, and into the wounds flowers of sulphur was thoroughly rubbed. Finally, *F. caeruleum* was inoculated into the sulphured wounds.

Both lots of tubers were kept under the same conditions at laboratory temperature, and were examined at the end of a month. It was then found that the rot had become thoroughly established in all ten tubers, and that the presence of the sulphur had exercised no influence either in preventing infection or in retarding decay. Hence the use of sulphur for the control of this rot as suggested by Masseur<sup>1</sup> cannot be recommended. A similar experiment was carried out using slaked lime in the place of sulphur, and the result was identical.

It might be expected that at low temperatures the rot would be inhibited. Yet it must not be forgotten that it proceeds in potato pits and stores during the winter months when the temperatures in them certainly cannot be high. It was found that tubers artificially inoculated with the fungus and kept in an unheated greenhouse, where the temperature varied from 0°C. to 6°C. during the nights, and on some occasions rose to a maximum of 25°C. during a portion of the day, became infected quite as easily and rotted quite as rapidly as others inoculated at the same time and kept in an incubator at a constant temperature of 20°C., while a similar lot inoculated and kept at 30°C. remained quite free from infection. It is doubtful, therefore, whether keeping tubers at an unusually low temperature, even if this could be managed in practice, would be a successful method of control, and it is by no means certain that such treatment would be good for the tubers themselves.

Affected tubers should certainly not be used for seed, for they give either no produce or only a poor "stand." Cutting sets from affected seed tubers and planting them is likely to lead to disastrous results, and this should be avoided.

In the raising and subsequent handling of potatoes care should be taken not to bruise or wound them, particularly if they are intended for seed purposes. This applies with special force to some of the early varieties, which have comparatively thin skins, and are often raised before they are thoroughly ripe, when the skins are peculiarly liable to abrasion and other injury. Care should also be taken when planting sprouted potatoes to avoid breaking off the sprouts. The practice of deliberately breaking off the sprouts to induce the growth of a further set is one which is to be condemned from all points of view.

"Prevention is better than cure," but seeing that we do not yet really

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<sup>1</sup>Diseases of Cultivated Plants and Trees, p. 183.

know for certain the source from which the infection primarily comes, it is not easy to suggest preventive measures. Presumably the fungus is a normal inhabitant of the soil, but research on this point is much needed.

*Other Species of Fusarium.* *F. arthrosporioides*, &c.—In addition to isolating and cultivating the various strains of *F. caeruleum* as described above, a very considerable amount of time has also been devoted to the study of other species of Fusarium, principally *F. Solani* (Mart. pro parte) A. & W., *F. Martii* A. & W., *F. discolor* A. & W. var. *sulphureum* (Schlecht.) A. & W., and *F. trichothecioides* A. & W. Strains of the first three species were obtained from the Central Bureau in Amsterdam, while the fourth was kindly supplied by the U.S.A. Bureau of Plant Industry.

In some respects *F. Solani* and *F. Martii* resemble *F. caeruleum*, but they both differ from the latter in the essential point that they are non-pathogenic to the potato tuber. We were unable in spite of repeated trials to produce a rot in tubers by inoculating with *F. discolor* var. *sulphureum*—a species which other authors have found to be pathogenic to potatoes. Possibly the strain used had lost its pathogenic character, owing to prolonged saprophytic culture.

With *F. trichothecioides*, however, a dry-rot of potato tubers was readily produced. The form of rot caused by this fungus is somewhat different from that caused by *F. caeruleum*. Characteristic of the *caeruleum*-rot is the presence of comparatively few internal cavities which contain mycelium often of a blue colour and relatively few conidia. The pustules which break through the skin are compact and firm, and are blue at their bases. There is a faint but pleasantly aromatic odour in the decaying tubers. In the case of *trichothecioides*-rot the attacked tissues are at first more spongy, owing to the considerable development of cavities. The mycelium in these cavities is never blue, and it bears an abundance of conidia. The external pustules are more loose in texture, and there is no aromatic odour. These differences, however, with the exception perhaps of the presence or absence of the blue colouring matter, are scarcely well marked enough to make a differentiation between the two kinds of rot an easy matter without having resort to cultures.

During the past three or four years in which our attention has been specially directed to the matter we have never seen a case of natural dry-rot in the potato tuber produced by any species of Fusarium other than *F. caeruleum*, but further study and experience may possibly bring such to light. We have, however, found at least one other species in this country which has proved, on trial, to be pathogenic to potato tubers. A tuber of an

early variety partially affected with "blight" (*Phytophthora infestans*) was lying, still attached to the parent plant, with part of its surface exposed. On this surface were two pinkish pustules made up largely of *Fusarium* conidia. These conidia were mainly 5-septate and measured on the average  $40\mu \times 4\mu$ . From a conidium a pure culture of the fungus was obtained.

Inoculations into healthy tubers with this pure culture caused dry-rot to occur in them, rather less readily in the month of November than in February, when the rot occurred in all the cases tried (twenty-nine altogether). That the fungus inoculated into the tubers was responsible for the rot was proved by re-isolating it in pure culture from one of the rotted tubers. The halves of a tuber inoculated at each end with this species, and cut longitudinally after the rot had become established, are shown in fig. 5, Plate VI.

An extended series of cultures was made of this species on various media, but it is not proposed to go into details concerning them here. It may be stated, however, that the colour of the conidial masses produced on sterilized potato stems varied from buff-pink<sup>1</sup> to pinkish cinnamon. On some media, such as Quaker Oat agar and oat extract agar, it was noted that the production of masses of conidia (pseudo-pionnotes) was accelerated by pushing aside the aerial mycelium and thus exposing the surface of the medium. No chlamydospores were observed in cultures on any of the media used.

Characteristic of the fungus when growing on several media was the production of a surface layer of a colour varying from "spinel-red" to "pansy-purple." When the medium was made acid this colour became yellow, like honey, but when made alkaline it turned reddish-purple.

A culture on cooked potato was boiled with dilute caustic potash solution and filtered, when a claret-coloured filtrate was obtained. On acidifying and again filtering, a honey-yellow filtrate was obtained. This filtrate made alkaline again returned to the original claret-colour. These colour-changes are therefore quite different from those described in the case of *F. caeruleum*.

From a study of its morphological and cultural characters we believe that this fungus is identical with *Fusarium arthrosporioides* Sherb., so that this species must now be regarded as pathogenic to the potato tuber. It is interesting to note that Sherbakoff gives as the habitat of this species "In discoloured tissues of tuber of *Solanum tuberosum*, Ireland." We have only met with this species once, and only on a single tuber, and it was not clear

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<sup>1</sup> The colours mentioned here are named according to Ridgeway's "Color Standards and Color Nomenclature." 1912.



whether it or *Phytophthora infestans* was the more responsible for the decay of the tuber on which it was found. It certainly is not the cause of our common dry-rot, but the possibility that it may occasionally be a cause of dry-rot must not be overlooked.

#### IV.—CONCLUSION.

The dry-rot of the potato tuber which commonly occurs in the British Isles is due to the attacks of *Fusarium caeruleum* (Lib.) Sacc. The two species, *F. oxysporum* Schlecht. and *F. trichothecioides* Woll., which are largely responsible for a somewhat similar type of rot in certain parts of the United States of America, have not been met with in this connexion up to the present in the British Isles.

On a single occasion *F. arthrosporioides* Sherb. was met with and was proved to be capable of causing a dry-rot of the potato tuber. Further research may perhaps show that this and possibly some other species of *Fusarium* are occasionally responsible for the production of dry-rot here.

*F. caeruleum* does not produce hadromycosis of the potato plant, nor does it kill the plant by attacking the roots. It can destroy tomato fruits, but does not attack onions, mangels, carrots, parsnips, or apples.

Infection frequently occurs through mechanical wounds such as those caused by implements, by bruising, and by breaking off the sprouts. It may also occur through scab spots. Wounds, however, are not essential, for infection can take place through the lenticels, eyes, or young sprouts of uninjured tubers.

Potatoes become more susceptible to infection as they become more mature, hence the rot is more prevalent during the later than during the earlier period of storage. Some varieties of potatoes are more resistant to infection than others.

Affected tubers cannot be cured, and the application of sulphur or lime for preventing infection or retarding the rot is of no practical value.

V.—EXPLANATION OF PLATES.

PLATE VI.

Fig.

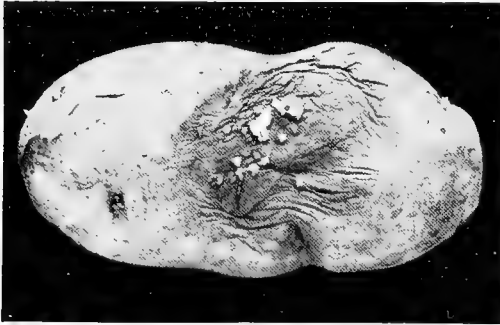
1. A tuber naturally infected with *Fusarium caeruleum* at a comparatively early stage of dry-rot, showing the characteristic shrinking and wrinkling of the skin over the affected portion, and the white conidia-bearing pustules of the fungus breaking through. (December, 1916.)
2. A naturally infected tuber in the last stages of dry-rot. Having been exposed in a window to a good light, the numerous fungus pustules were pinkish in colour. The tuber was much shrunken, dry, light in weight, and very hard. Infection, in all probability, occurred at the wound visible in the centre. (April, 1916.)
3. Four tubers artificially inoculated through wounds with a pure culture of *F. caeruleum*. In the case of the two upper tubers the rot had been in progress for nine, and in the lower two for four and a half, weeks at the time when the photograph was taken. (November, 1914.)
4. Four tubers ten weeks after being inoculated with a pure culture of *F. caeruleum* by applying it to the skins after scratching them. (January, 1915.)
5. The two halves of a tuber five weeks after having been inoculated with *F. arthrosporiooides* through two wounds on the upper surface, one near each end. (March, 1916.)

PLATE VII.

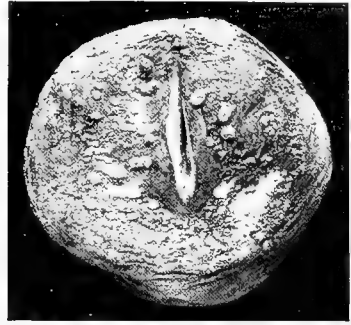
1. A branched conidiophore of *F. caeruleum*, from a 26-days old culture on Quaker Oat agar, showing the "collar" at the extremity of each sterigma except the one on the left to which a young conidium is attached. ( $\times 500$ .)

Fig.

2. Typical conidia of *F. caeruleum* from a culture on oat-extract agar.  
(× 840.)
3. Conidium from a 21-days old culture of *F. caeruleum* on oat-extract agar, germinating after five hours in a hanging drop of water at laboratory temperature.
4. Chlamydo spores of *F. caeruleum* from a culture on oat-extract agar.  
(× 840.)
5. Chlamydo spores of *F. caeruleum* germinating. (× 840.)



1



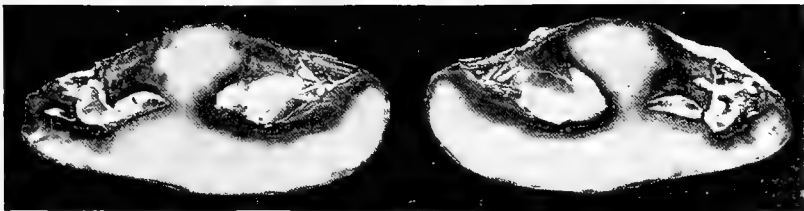
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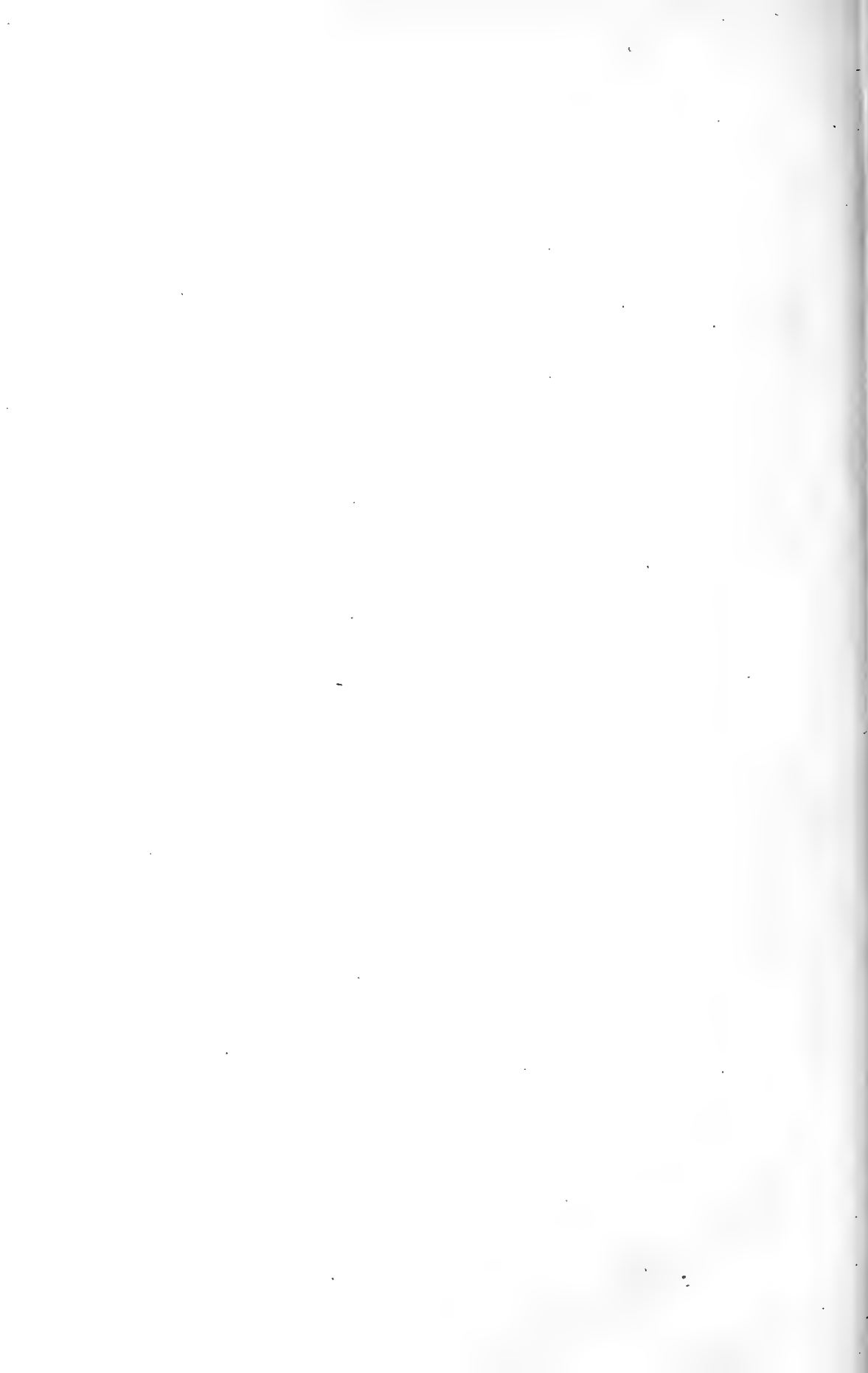
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## SCIENTIFIC PROCEEDINGS.

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1. The Subsidence of Torsional Oscillations and the Fatigue of Iron Wires when subjected to the Influence of Alternating Magnetic Fields of Frequencies up to 250 per second. By WILLIAM BROWN, B.SC. (January, 1916.) 6*d*.
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SCIENTIFIC PROCEEDINGS

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THE GYMNOSOMATOUS PTEROPODA OF THE  
COASTS OF IRELAND.

BY

ANNE L. MASSY.

[COMMUNICATED BY ERNEST W. L. HOLT.]



(PLATE VIII.)

*[Authors alone are responsible for all opinions expressed in their Communications.]*

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## XXII.

THE GYMNOSOMATOUS PTEROPODA OF THE COASTS OF  
IRELAND:

BY ANNE L. MASSY.

[COMMUNICATED BY ERNEST W. L. HOLT.]

(PLATE VIII.)

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THE species listed here were taken during the course of investigations carried out on board the Department's fishery cruiser "Helga." The area explored included the waters off the west, south, and east coasts, from the latitude of Aran Island, Co. Donegal, to that of Cahore Point, Co. Wexford. The hauls were made at all seasons of the year, from August, 1901, to May, 1914.

The minute size and extraordinary powers of contraction possessed by these little animals render it impossible in some instances to distinguish nearly allied species without following Bonnevie's plan (1913, p. 59), of dissecting out the buccal parts and boiling the radula and hook-sacs in caustic potash, even if the species seems to be represented by only a single specimen. Over 120 of the specimens recorded here have been thus investigated. Of the 12 species, 6 appear to be new to science, and 4 have not previously been recorded from the British and Irish area. 11 species occurred over soundings of deep water, chiefly between latitudes 50° and 52° N., and between longitudes 11° and 13° W. One of these, however, *Pneumodermopsis paucidens* (Boas), appears to resort chiefly to shallow water, occurring more or less inshore at all seasons from Inishbofin, Co. Galway, to St. George's Channel. This would appear to be the only species in the present list occurring in sufficient numbers to be of value as a fish food. The records show that it was very numerous, larval specimens predominating, off the Fastnet, in autumn, 1903, 1908, and 1911, and larvae were abundant in autumn, 1905 and 1912, off the Blaskets, Co. Kerry. It should, however, be remarked that two-thirds of the hauls in which this species occurred were made in autumn. The only specimen of *Cephalobrachia Bonneviei*, sp. n., occurred off the Blaskets. *Pneumodermopsis oligocotylya*, sp. n., and *Thliptodon atlanticus*, sp. n., were found furthest north, occurring close together at about



100 miles west of Co. Donegal. *Pneumodermopsis Michaelsarsi*, Bonnevie, occurred further west, being met with off the Porcupine Bank, about 200 miles west of Co. Galway, over soundings of 860 fathoms. All the species enumerated by Bonnevie among the Gymnosomata, taken by the "Michael Sars" North Atlantic Deep Sea Expedition of 1910, are represented here except *Pneumoderma atlantica*, Bonnevie; *Fowlerina Hjortii*, Bonnevie; *Microdonta longicollis*, Bonnevie; and *Clione limacina*, Phipps. The last-named has been purposely omitted, having previously (Massy, 1909) been shown to be very abundant in the area. The fact that Bonnevie got no specimens of *Pneumodermopsis paucidens* seems to suggest that, although originally described from a specimen taken on a voyage from Brazil, this species may have its headquarters in the Atlantic off the south-west coast of Ireland.

All the specimens were examined and measured after preservation in 5 per cent. formalin. In the records which follow, the localities are indicated by station numbers, of which particulars are given at pp. 241, 242.

*List of Gymnosomatous Pteropods taken in British and Irish Waters.*

- Pneumodermopsis ciliata* (Ggbr.).  
 „ *paucidens* (Boas).  
 „ *Michaelsarsi*, Bonn.  
 „ *macrochira*, Meis.  
 „ *oligocotyla*, sp. n.  
*Spongebranchaea polycotyla*, sp. n.  
*Clionopsis longicirrata*, sp. n.  
*Clione limacina*, Phipps.  
 „ *gracilis*, Massy.  
*Cephalobranchia macrochacta*, Bonn.  
 „ *Bonnevii*, sp. n.  
*Notobranchaea tetrabranchiata*, Bonn.  
*Thliptodon atlanticus*, sp. n.  
 „ *rotundatus*, sp. n.

Pelseneer (1887, p. 10) drew up a key of the seven genera of Gymnosomatous Pteropods known in his day, basing his system on the gills. Bonnevie (1913, p. 62) has shown what inconsistent organs these are; and in his table (*loc. cit.*, pp. 60-61) the median tooth of the radula is regarded as the most important character. Partly owing to the incomplete condition of some of the new species here described, which necessitated a somewhat provisional classification, and also on account of the paucity of our knowledge of this

group, the key given below is not based on any particular system, but is merely intended as a means by which the species mentioned can be readily separated from one another. All the genera yet known are enumerated. The sizes given do not define the known limit of growth, but indicate that the characters noted in the key have been observed in specimens of that age.

The following genera and species included in the key have not been recorded from British and Irish waters, but it seems probable that some of them may yet be found:—

- Pneumoderma.*
- Schizobrachium.*
- Paraclione.*
- Thalassopterus zancleus*, Kwiet.
- Halopsyche.*
- Fowlerina Hjortii*, Bonn.
- Microdonta longicollis* (Bonn).

*Key for the Identification of British and Irish Gymnosomatous Pteropods.*

Suckers present (1).

Suckers absent (2).

(1) Median sucker group present (3).

Median sucker group absent (4).

(3) Median group with 4 lateral and 1 terminal suckers on an appendage (5).

Median group with 2 suckers not on an appendage (6).

Median group with 5 small suckers on long stalks not on an appendage = *Pneumodermopsis macrochira*, Meis., 6–8 mm.

(5) Distal paired suckers of median arm greatly enlarged, and each armed with a spine = *Pneumodermopsis ciliata* (Ggbr.), 2.50–15 mm.

Distal paired suckers of median arm not enlarged and without spines = *Pneumodermopsis paucidens* (Boas), 2–4.50 mm.

(6) Lateral sucker-bearing arms present. Lateral teeth of radula relatively short = *Pneumodermopsis Michaelsarsi*, Bonn., 3–7 mm.

Lateral sucker-bearing arms absent. Lateral teeth of radula relatively long = *Pneumodermopsis oligocotylo*, sp. n., 4–5 mm.

(4) Median tooth of radula absent in adult = *Pneumoderma*.

Median tooth of radula present in adult with 3 denticles (7).

Median tooth of radula present in adult with 2 denticles = *Schizobrachium*.

- (7) Few suckers (16-20) present = *Spongeobranchaea australis*, d'Orb., 8-22 mm.  
 Numerous suckers (ca. 280) present = *Spongeobranchaea polycotylo*,<sup>1</sup> sp. n., 13 mm.
- (2) Buccal cones present (8).  
 Buccal cones absent (9).
- (8) Radular formula : 6 to 14-1-6 to 14 (10).  
 Radular formula : 3-1-3 = *Paraclione*.  
 Radular formula : 3-1-1-1-3 = *Thalassopterus zancleus*, Kwiet., larvae 1-2 mm.
- (10) Body broad in centre, more or less pigmented, head small = *Clione limacina*, Phipps, 10 mm.  
 Body slender, unpigmented, head large = *Clione gracilis*,<sup>2</sup> Massy, 10 mm.
- (9) Jaw a single row of small spines (11).  
 Jaw a double or triple row of small spines ; anterior tentacles long and forked = *Halopsyche*.  
 Jaw (?) a group of small spines ; two unbranched nuchal tentacles exceeding the body in length = *Clionopsis longicirrata*, sp. n., 3 mm.  
 Jaw (and gills) absent. Hook-sacs very large (12).
- (11) Radula having median tooth sickle-shaped with denticles ; a tetra-radiate posterior gill = *Notobranchaea tetrabranchiata*, Bonn., 4-16 mm.  
 Radula having median tooth resembling that of *Notobranchaea* ; posterior gill a membranous ring = *Fowlerina Hjortii*, Bonn., 5-9 mm.  
 Radula having median tooth sickle-shaped without denticles ; a tetra-radiate posterior gill = *Microdonta longicollis*, Bonn., 7 mm.
- (12) Radula having median tooth triangular with many denticles = *Cephalobranchia macrochaeta*, Bonn., 5-10 mm.  
 Radula having median tooth with straight margin and few denticles = *Cephalobranchia Bonnevi*, sp. n., 2-50 mm.  
 Radula having median tooth with a median projection, no denticles and up-turned shovel-like ends = *Thliptodon atlanticus*, sp. n., 3-7 mm.  
 Radula having median tooth crescentic, relatively large and with many denticles = *Thliptodon rotundatus*, sp. n., 3-4 mm.

<sup>1</sup> The number of sucker-bearing appendages was not ascertained. *S. australis*, the only other species of the genus yet known, has two lateral arms.

<sup>2</sup> Perhaps only a variety of *C. limacina*.

Family PNEUMODERMATIDAE.

*Pneumodermopsis ciliata* (Gegenbaur).

*Dexiobranchaea ciliata*, Boas.

- S.R. 443—Midwater otter trawl at 550 fathoms. Two.  
 S.R. 449—Midwater otter trawl at *ca.* 700 fathoms. Fourteen.  
 S.R. 751—Tow-net at 50 fathoms. Three.  
 S.R. 752—Midwater otter trawl at surface. Three. Tow-net at surface.  
 One.  
 S.R. 1385—Tow-net at 50 fathoms. Two.  
 S.R. 1386—Tow-net at 50 fathoms. Three.  
 S.R. 1387—Tow-net at 50 fathoms. Two.

The thirty specimens recorded above measure 1.50–15 mm. in length. The examples from station S.R. 751, measuring 1.50–2 mm. in total length, have an unpigmented body with ciliated rings, a long posterior lobe to foot, and the commencement of a lateral gill; about eighteen rows compose the radula of 5–1–5 or 6–1–6; the median tooth is without a central denticle, and its base is not so prolonged as in Boas' figure (1886, tab. 8, fig. 116). The specimens can be readily distinguished from similar-sized larvae of *P. paucidens* (Boas), as each hook-sac displays about thirty hooks instead of six, and also by the presence of the two very large suckers with a spine. The sucker on the summit of the median arm is developed, and there are six or seven suckers on each of the lateral arms. These specimens show a great advance in development when compared with a larva of *P. ciliata* of 1 mm. in length, described by Kwietniewski (1902, p. 11), in which the gill was still absent, the radula only 3–1–3, and but five or six spines were present in the hook-sacs; the acetabuliferous appendages in this larva were still rudimentary, each lateral arm possessing only two suckers, while the median arm only showed the large left sucker, and a prominence where the large right one would develop later, and there was no trace of a median sucker or of the lower lateral pair. Schiemenz (1906, p. 25, tab. 1, fig. 10) was unable to discover these latter suckers. In specimens in our hauls the lower pair of suckers is certainly developed on the median arm, but they are so much smaller than the suckers of the lateral arms, and on such delicate stalks of very variable length, that they are by no means easy to see. The unpaired sucker of the median arm is sometimes about twice the size of the suckers of the lateral arms, and at other times it is equal in diameter to four lateral arm suckers. The latter are usually equal in size, but in some specimens the proximal suckers are the smallest, and they increase in size distally. Nine were

present on each arm in the largest specimen of 15 mm. in length. The maximum length of this species is given by Meisenheimer (1905 a, p. 427) as 11–12 mm.; therefore our specimens of 14–15 mm. appear to be the largest yet met with. The central denticle in the median tooth does not seem to appear until the specimen has reached a certain length: thus it was absent in five specimens measuring from 1.50–10 mm., and present in three examples of 11–15 mm. In a specimen of 12 mm., in which the central denticle was occasionally distinct, and at other times absent, the left denticle of this tooth was usually missing. The base, even in these large specimens, is not so deep or so well-defined as in Boas' figure (*op. cit.*, fig. 116). The hooks are very variable in length, and in large specimens usually number about forty. Chromatophores were only observed in the largest example, and were restricted to the back of the neck. Schiemenz (*op. cit.*, p. 29) has remarked on the avidity with which the Gymnosomata feed on their relatives the Thecosomata. In the largest of the present specimens the gullet was observed to be of a lovely pink colour. On being opened this was found to be due to the presence of four oblong pink stomach-plates, and a square iridescent one, belonging to some species of the Thecosomata. Two Cladocerans were also present. The fact that these crystalline plates were in the gullet, instead of in the stomach, seems to suggest that such morsels may be too tough for digestion, the adult Gymnosomata having no trace of a masticatory stomach, and that the plates are rejected by the mouth after the animal which owned them has been absorbed, their large size and many angles preventing their passage through the narrow anal tube. Schiemenz (*op. cit.*, p. 30) found Pteropods breeding throughout the winter at Naples, but observed that reproduction occurred chiefly in the spring. He alluded also to the extraordinary forms which these animals sometimes exhibit. In some of the specimens from station S.R. 449 (a May haul), the reproductive organs seem to be so active that in order to make room for the sexual products the proboscis is evaginated to the utmost, and the radula, salivary glands, oesophagus (packed with food), and the liver-stomach can be observed through the transparent wall, all elevated above the anterior tentacles, and bent over the back, the acetabuliferous appendages being necessarily fully expanded. The penis is evaginated behind the right fin, and the rest of the body presents a normally plump appearance, although, naturally, the diaphragm separating the cephalic and visceral portions, which can usually be clearly seen through the outer integument, is absent. In three other specimens of this haul the digestive organs occupy their usual position, but a portion of the genitalia is placed externally on the right side below the fin.<sup>1</sup>

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<sup>1</sup> This abnormality is more fully noted under *P. paucidens*, p. 229.

In a specimen from station S.R. 1387, measuring 3 mm. in length, the genital gland is placed externally on the right side at the lowest ciliated band, and closely connected with the body. Just above, a mass composed of many white segments, apparently the accessory glands, joins the body below the lateral gill by a long thread-like attachment.

*Distribution.* — Atlantic, between 7° N. lat., and 61° N. lat., and Mediterranean.

**Pneumodermopsis paucidens (Boas).**

- L. 161 a—Tow-net at surface. Four.  
 CXVII d—Tow-net at surface. Two.  
 S.R. 24—Tow-net at surface. Seventeen.  
 S.R. 25—Tow-net at 35 fathoms. Twenty-nine.  
 S.R. 60—Tow-net at 35 fathoms. One hundred and thirty-eight.  
     Same station and net at 58 fathoms. *Ca.* two hundred and sixty.  
 S.R. 61—Tow-net at 36 fathoms. Forty-seven.  
 S.R. 66—Tow-net at 100 fathoms. One.  
 S.R. 76—Tow-net at 30 fathoms. Three; tow-net at 60 fathoms. Seven.  
 S.R. 249—Tow-net at 20 fathoms. Twelve.  
 S.R. 273—Midwater otter trawl at 30 fathoms. Twenty-nine.  
 S.R. 290—Tow-net at surface. Eleven.  
 S.R. 348—Tow-net at surface. Four.  
 S.R. 408—Tow-net at 36 fathoms. One.  
 S.R. 521—Tow-net at 19 fathoms. Three.  
 S.R. 595—Tow-net at 35 fathoms. One.  
 S.R. 636—Tow-net at 30 fathoms. Forty-three.  
 S.R. 639—Tow-net at 29 fathoms. Two.  
 S.R. 796—Tow-net at 25 fathoms. Four.  
 S.R. 798—Tow-net at 70 fathoms. Seven.  
 S.R. 848—Tow-net at surface. One.  
 S.R. 1049—Tow-net at 25 fathoms. Three.  
 S.R. 1050—Tow-net at 60 fathoms. Five.  
 S.R. 1096—Tow-net at 79 fathoms. One.  
 S.R. 1226—Tow-net at 49 fathoms. Sixty-nine.  
 S.R. 1232—Tow-net at surface. One.  
 S.R. 1387—Tow-net at 50 fathoms. One.  
 S.R. 1499—Tow-net at 70 fathoms. Forty-three.  
 S.R. 1537—Tow-net at 30 fathoms. One.  
 W. 265—Tow-net on dredge at 23 fathoms. One.



These twenty-nine records comprise over seven hundred specimens measuring .40-4.50 mm. in length; about half of them average 1 mm. in length, and only a very small number measure more than 2 mm. Professor D'Arcy Thompson took a small specimen (not preserved) outside Roundstone Bay, Connemara, which he referred (Nichols, 1900, under *Dexiobranchaea paucidens*, Boas) to this species. In a previous paper (1909, p. 41) I suggested that this record probably referred to *P. ciliata* (Ggbr.), of which species we had met with a number of examples. At that time the larvae recorded above had not been captured in some instances, and in others their small size caused them to be put aside until a sufficient number had accumulated for investigation. Our present records appear to show that *P. paucidens* is by far the most abundant of the two species off the coast of Ireland. Most of the hauls were made off the west coast, from Cleggan Head, Co. Galway, to the Fastnet Light, Co. Cork, over soundings of 23-470 fathoms. It occurred also in five hauls in St. George's Channel off the coasts of counties Waterford and Wexford, over soundings of 37-61 fathoms. Kwietniewski (1902, pp. 12-13) found this species to be much more numerous in the Mediterranean than *P. ciliata*. His largest specimen from amongst about thirty measured 4 mm. in length, and the largest described by Boas measured 5 mm. He observes that the larvae of the two species are difficult to distinguish exteriorly, but that *P. paucidens* is a little more pigmented. About one-sixth of the present specimens, measuring .50-3.50 mm., are devoid of pigment; the remaining examples, measuring from .40-4.50 mm., are usually thickly spotted with small dark chromatophores all over the body except the fins. The pigment, in some cases, is dispersed in clouds of pale purple-grey instead of spots. Whether coloured or unpigmented, the radula, jaw, and hooks proved to be identical in both these forms. In about sixty examples, including individuals from all the hauls, the radula has been examined. In the case of many others the suckers happened to be evaginated, so that no uncertainty could be felt as to their identification. As described by Boas, a large median sucker, with a smaller one on either side, followed by a lower pair, all attached by long stalks to the median stem, are always present; about ten or twelve much smaller suckers on short stalks are placed on a transparent membrane partially surrounding the median arm. The four lateral stalked suckers are larger in proportion to the median one than in Boas' illustration (1886, fig. 3, p. 158). The radula in the specimens examined was always 2-1-2, and the median tooth was without a central denticle; the inner laterals had square, and the outer narrow, bases. A specimen of .50 mm. has twelve rows, and one of 4.50 mm. has twenty-two rows in the radula; a specimen of .75 mm. has eighteen rows, and another of this length, and also

specimens of 1–2 mm. show only sixteen rows. The jaw spines are usually arranged like a miniature arbour such as that illustrated by Pouchet (1870, p. 278) for the construction of the Spotted Bower-Bird, *Chlamydera maculata*, Gould. An outer palisade is sometimes present at either side of the arch. The hooks always six in number, almost alike in size; their breadth at base nearly equal to their length. Specimens of 2 mm. in length usually show the lateral gill, and occasionally it is just evident at a still earlier age. In some specimens of 2–4.50 mm. the ciliated bands are absent, each being replaced by a row of raised white spots; these, when examined with a high power, seem to be bladder-like, yellow, various-sized cells, with at least one aperture. The smallest specimen without ciliated bands measures only 1.75 mm., and, in addition to the above-mentioned rows of spots, shows a cluster of them where the lateral gill would eventually appear. Some specimens of 3 mm. still possess ciliated bands. In very young examples the three lobes of the foot are all equal in size; the posterior lobe rapidly lengthens with age. Tesch (1904, p. 73), and recently Bonnevie (1913, pp. 67, 68), have described species of *Clionopsis* and *Pneumoderma* with external genital organs. Meisenheimer (1905, p. 282), with regard to Tesch's species, considers this to be due to some abnormal condition. Among the present records (twelve hauls of which were made in the month of November, nine in August, five in February, one in May, and one in September) there are five November and four August hauls, in three of which 4 per cent., in three others 25 per cent., in two 15 per cent., and in one 60 per cent. of the specimens (measuring 1–2.50 mm.) exhibit external accessory glands on the ventral surface of the body below the right fin, and the genital duct can be seen connecting them with the internally placed gonad at end of body; the penis is evaginated above the right fin, and has no outer connection with the accessory glands; in such specimens the distortion causes the head and foot to be much bent backwards. In one haul nearly all the specimens showed only the right fin; another specimen, in addition to having outer accessory glands, had a second pair of fins, and a second foot placed at posterior end of body on ventral surface; there was no second head, and the space below the extra foot was filled by the gonad. In some examples the gonad also is external, being connected with the body by a wide band which rapidly narrows, and joins the ventral surface at the right side, the posterior cavity in body which usually contains the gonad being found to be empty. The thin, brownish-yellow genital duct is also necessarily external, and after proceeding from the pale-yellow gonad, and rapidly expanding, and sometimes undulating, it narrows again before joining the white muciparous and albumen glands situated ventrally; the passage leading from accessory glands to penis is not visible externally, and seems to divide

into two narrow channels running side by side before entering the penis, which has a large pouch. The sexual precocity of the Gymnosomata is well known: thus, Pelseneer (1887, p. 49) alludes to *Clione flavescens* (Ggbr.) of hardly 2 mm. in length, and still possessing ciliated rings, as being able to lay eggs; and Kwietniewski (1902, p. 17) states that the sexual elements are known to develop with much precocity in other Pteropods besides the above species. Among the present specimens the smallest example with penis evaginated measures .75 mm. in length. A number of small specimens with no outer genitalia, but taken in hauls with those exhibiting them, have either the accessory glands or gonad so swollen below the ventral surface, towards the right side, that it seems inevitable that a rupture of the skin must occur, as the sexual elements seem to be developing at a much greater speed than the rest of the little animal.

*Distribution.*—Atlantic, on a voyage from Brazil (type); Mediterranean (Kwietniewski); off Brazil, one specimen (Schiemenz).

**Pneumodermopsis Michaelsarsi, Bonnevie.**

- S.R. 224—Midwater otter trawl at 700 fathoms. Two.  
 S.R. 438—Tow-net at 100 fathoms. One.  
 S.R. 803—Tow-net at 50 fathoms. One.  
 S.R. 943—Tow-net at surface. One.  
 S.R. 1845—Midwater otter trawl at 0-4 fathoms. One.  
 "Thor" 6. VI. '06. 48° 43' N., 15° 17' W., 300 m.w. One.<sup>1</sup>

All the above, measuring 1.30-11 mm. in total length have had the radula investigated. The median tooth is without a central denticle. The lateral teeth diminish in length outwardly, the smallest being usually about two-thirds of the length of the innermost tooth. The hook-sacs contain about thirty to fifty hooks, of very unequal size. The youngest specimen, of 1.30 mm. in length, has only about twenty hooks in each sac, and but fourteen rows of teeth in the radula, instead of twenty or twenty-two rows, as in larger specimens.

The jaw, in the present examples, is more like Boas's illustration (1886, tab. 8, fig. 119) of the same in *P. ciliata* (Ggbr.) than Bonnevie's drawing (1913, pl. vi, fig. 47). It equals the radula in width, and is about one-quarter of its length. Bonnevie (*op. cit.*, p. 66) was unable to loosen the acetabuliferous appendages of the type in toto, and, therefore, could not describe them further than by giving an illustration (*op. cit.*, fig. 48) of four suckers on

<sup>1</sup> This specimen was collected by the staff of the "Thor" somewhat south of our area, but is included here because of its interest.

short thick stalks. The specimens from stations S.R. 224 and S.R. 438 agree in having two lateral arms, like those of *P. ciliata*, each with eight suckers on short, thick stalks. The median arm appears to be represented by two suckers, placed side by side. These have a plain ring, without any spine, and are but little larger than the largest suckers of the lateral arms, and, like them, are supported by short thick stalks. It is quite possible that future research may show that this description of the median arm is incomplete, as the suckers are very easily detached, and their minute size renders it difficult to discern them, the enterprise being further complicated by anxiety not to injure the radula and hook-sacs. In the case of the specimens from the other stations, all that could be noted with certainty was that sixteen or eighteen suckers, very similar in size, and on short, thick stalks, were present. The posterior gill seems to have distinct lateral keels. Dorsal and ventral keels, if present, are very obscure. The youngest specimen is quite colourless, but a few chromatophores are present on the back of the head in most of the larger examples.

*Distribution.*—Near Canary Islands, 28° 2' N., 14° 17' W., a single specimen (Bonnie, 1913).

***Pneumodermopsis macrochira*, Meisenheimer.**

S.R. 470—Midwater otter trawl at 400–500 fathoms. One.

S.R. 503—Tow-net at 70–80 fathoms. One.

S.R. 1692—Midwater otter trawl at 350–0 fathoms. One.

The specimens measure 6–8 mm. in length, and possess about thirty-five small suckers, on short thick stalks, and one very large one on each of the two lateral acetabuliferous appendages. The radula is composed of about sixteen rows of about 6–1–6, and sixteen to twenty hooks are present in each sac. The jaw resembles that of *P. paucidens*, Boas. The specimens are almost colourless, but purple-grey chromatophores occur on the head and foot, and exhibit, when examined with a high power, the same bizarre forms figured by Tesch (1904, pl. vi, fig. 143) of the chromatophores in his *Clione punctata*. Bonnie (1913, p. 66, figs. 35, 36) describes a specimen with “a series of globe-like protuberances scattered round the base of the wings and feet.” He adds:—“Having seen this in only one individual, I cannot tell whether it should be considered a normal phenomenon.” The largest of the above specimens (station S.R. 1692) exhibits similar protuberances situated ventrally about half-way between fins and end of body. On opening the skin the swelling was found to be caused by the accessory glands of the reproductive organs. The gonad at posterior end of the body is spherical in shape in this specimen, and smaller than the accessory glands.

*Distribution*.—Southern part of Atlantic and Indian Oceans (Meisenheimer, 1905). Ten stations in the North Atlantic, extending from the latitude between Bermuda and the west coast of Morocco to 48° 29' N., 13° 25' W. (Bonnievie, 1913).

***Pneumodermopsis oligocotyla*, sp. n.**

(PLATE VIII, fig. 1.)

S.R. 197—Tow-net at *ca.* 300 fathoms. One.

S.R. 302—Midwater otter trawl at 300–350 fathoms. One.

Body narrow (fig. 1A), with two ciliated bands; foot with moderately long posterior lobe, without a tubercle. Neither lateral nor posterior gill discernible; but both specimens are much contracted. Length, 4–5 mm. Two very large suckers, with circular aperture, and on short, thick stalks, are placed directly on the ventral wall of the buccal cavity. Radula, 6–1–6 (fig. 1B); median tooth, with three denticles, the central being the smallest. Lateral teeth very long, with broad bases. Jaw of the type figured by Meisenheimer (1905, pl. xxvii, fig. 13) for his *Schizobranchium polycotylum*; the separate spines resemble minute claws (fig. 1C). Hooks (fig. 1D) short and hollow, measuring one-third to one-quarter the length of the lateral teeth; about forty in each sac. Skin unpigmented. Proboscis very transparent, with dermal glands forming raised white spots.

***Spongebranchaea polycotyla*, sp. n.**

(PLATE VIII, fig. 2.)

S.R. 654—Midwater otter trawl at 450–500 fathoms. One.

Body somewhat rounded (Pl. viii, fig. 2A); fins wide at base, not much expanded, rounded distally; foot with a very long posterior lobe. Shape and number of sucker-bearing appendages unknown. About 30 moderately large suckers, on long, narrow stalks, and at least 250 much smaller, also with long, narrow stalks, are present, the larger suckers being about six times the size of the smaller (fig. 2D). From the position which the large suckers have taken on the slide on which they are mounted, it seems probable that they occupied the distal end of the appendages. Fine longitudinal striae, which are probably muscle fibres, are present on all. Radula, 5–1–5 or 6–1–6 (fig. 2B). Median tooth broad, with three equal-sized denticles, and closely resembling Boas's figure (1886, pl. viii, fig. 120) of the median tooth in *Spongebranchaea australis*, d'Orb. Lateral teeth much like those figured by Boas (*op. cit.*, fig. 116) for those of *Pneumodermopsis ciliata* (Ggbr.), except that the outermost is smaller in proportion to the rest of the present species. Hooks (fig. 2E) varying in length, the longest

being more than twice the length of the largest lateral teeth. At least fourteen were counted, and they were probably more numerous, but they have escaped from their sacs, and are scattered amongst the teeth and suckers. Jaw spines (fig. 2c) very variable in size and shape. Posterior gill present, but too lacerated for description. The viscera have almost entirely disappeared through a large rent in the right side, and in consequence of this injury it is impossible to say if a lateral gill was present. Length, 13 mm.; breadth, 6 mm. Colour, bluish-white. It is very regrettable that this specimen is in such bad condition; and, unfortunately, the radula, on being boiled in caustic potash, came asunder; and the number of lateral teeth is based on assumption from their size. In many ways this specimen resembles *Schizobrachium polycotylum*, Meisenheimer; but that species has only two denticles in the median tooth, which is also much smaller in proportion to the lateral teeth than in the present species, at least six median teeth of which are in a good position for observation, and all show the wide shape, and three similar-sized denticles of *Spongeobranchaea*. Histologically the integument displays large round cells, with an opening in the centre, and a great number of oval, dermal glands, of much smaller size than the cells.

Family CLIONOPSIDAE.

*Clionopsis longecirrata*, sp. n.

(PLATE VIII, fig. 3.)

S.R. 481—Midwater otter trawl, at 600-900 fathoms. Two.

These specimens measure 3 mm. in length, and have a round, smooth, unpigmented body without ciliated bands (Pl. viii, fig. 3A). The only buccal appendages visible are two narrow nuchal tentacles exceeding the body in length; originating from a collar-like ridge at the back of the neck, they are widest at base, unbranched, and taper distally to fine points. Fins very broad and rounded distally, the left being the smallest in each specimen; at the posterior margin of the base of the fins a small projection is apparent, and would seem to be a posterior lobe to the foot, as a sort of muscular track can be traced from it across the relatively vast expanse of fins to the minute anterior lobes of the foot situated at the anterior fin-margin. No lateral gill; a posterior gill is present. Whether it is quadrangular cannot be ascertained, but lateral keels are certainly present in both specimens, and there seems to be a circular ring also. Radula; 3-1-3, relatively enormous; median tooth (fig. 3c) slightly curved and with edge serrated almost throughout its length with forty to fifty short denticles of varying size, the extreme ends alone being smooth; lateral teeth (fig. 3b) long with broad

bases, the outermost of each row being the smallest. Twelve to sixteen rows of median teeth and eight or nine rows of lateral teeth compose a radula: the front median teeth are more than twice the size of those placed furthest back, but the lateral teeth exhibit little diminution posteriorly. Hook-sacs very small in proportion to size of teeth and placed at a great distance from radula: sixteen to twenty short, equal-sized hooks of the *Pneumodermopsis* type are present in each sac. Between the hook-sacs, and much involved in the strong ring-musculature of the gullet, is a row of what appear to be small spines, which from their position would seem to be the jaw. The median tooth of this species is so aberrant in its almost bar-like straightness, and the large number of its denticles, that future research may prove it to be a member of a new family. It is provisionally placed with the Clionopsidae, as the median tooth seems to be nearer that of *Clionopsis microcephalus*, Tesch, than that of any other species of the Gymnosomata hitherto described. In Tesch's species this tooth is more semi-lunar in shape, and has but five denticles; the median notch or projection characterizing the median tooth in most of the Clionidae, and Notobranchaeidae, is, however, as in the present species, entirely absent. The median tooth of *Thliptodon rotundatus* described here (p. 239) is perhaps more like that of the present species, but the form of the lateral teeth and hook-sacs in the family Thliptodontidae is very different. It is interesting, nevertheless, to remember that *Thliptodon diaphannus*, Meisenheimer, shows the same wide separation between the anterior and posterior lobes of the foot. A posterior lobe to the foot has not hitherto been observed in the Clionopsidae, but Bonnevie (1913, p. 63) attributes only a specific value to the modifications of the foot. Another character favouring the admission of this species to the Clionopsidae lies in the fact that *Clionopsis Krohni*, Troschel, has the most developed tentacles of any Gymnosomatous Pteropod (Pelseneer, 1887, p. 34).

#### Family CLIONIDAE.

##### *Cephalobrachia macrochaeta*, Bonnevie.

S.R. 481—Midwater otter trawl at ca. 600–900 fathoms. One, 8 mm.

The enormous hook-sacs and radula are so well evaginated in this specimen that they can be seen clearly without dissection. Radula: 3–1–3, agreeing with type in shape, and composed of about ten rows. The curious glandular lip glitters as if powdered with gold dust. The foot and fins are deeply sunk in a skin pocket recalling that of the genus *Thliptodon*. The viscera completely fill the body.

*Distribution*.—48° 24' N., 36° 53' W., 500 metres; 45° 26' N., 25° 45' W., 750 metres; 48° 29' N., 13° 55' W., 750 metres (Bonnevie, 1913).

**Cephalobrachia Bonneviei, sp. n.**

(PLATE VIII, fig. 4.)

S.R. 529—Tow-net at 40 fathoms. One.

Body shaped like *Clione* (Pl. viii, fig. 4A), posterior end very narrow; total length 2.50 mm. Reproductive organs much expanded beneath the skin at the right side. Fins very narrow at base, broadening rapidly. Posterior lobe to foot small and pointed, and without a tubercle. No lateral gill or ciliated bands. Skin unpigmented. No buccal cones or acetaliferous appendages. Radula: 5-1-5 (fig. 4B), median tooth sickle-shaped with at least three denticles on a straight margin. Lateral teeth moderately long with square bases. The radula contained at least twenty rows of teeth. Unfortunately, owing to its minute size, I failed to find it after boiling it in caustic potash, so that the foregoing description, and the figure, are based only on sketches and notes made on seeing it dimly through the tissues after dissection. It was large in comparison to the size of the animal. Subsequently, I found that in the case of a very minute buccal mass a sufficiently good preparation could be made by placing it in a single drop of caustic potash on a slide, and holding it thus situated over a flame instead of putting it in a test tube. About sixteen very long hooks (fig. 4C), curved at the ends, were present in each sac, and closely resembled those of *Cephalobrachia macrochaeta*, Bonnevie, so that, in spite of the differences presented by the radula, it seems better to place the species provisionally in that genus.

Family NOTOBRANCHAEIDAE.

**Notobranchaea tetrabranchiata, Bonnevie.**

S.R. 270—Midwater otter trawl at 350 fathoms. Two.

S.R. 302—Midwater otter trawl at 300-350 fathoms. Three.

S.R. 476—Midwater otter trawl at 300 fathoms. One.

S.R. 1237—Midwater otter trawl at 450 fathoms. Five.

S.R. 1243—Tow-net on trawl, 670-692 fathoms. Two.

S.R. 1451—Midwater otter trawl at 400 fathoms. One.

These fourteen specimens measure 4-16 mm. in length. Some are long and narrow, others are short and broad, the extreme of the latter form being reached by the specimen from station S.R. 475, which measures 6 mm. in length by 9 mm. in breadth. All the specimens have had the buccal mass examined, and the radula was found to be in close agreement with the figures given by Bonnevie (1913, p. 75B) for the type. The outer lateral teeth, not shown



clearly in Bonnevie's fig. 53 (*op. cit.*, p. 76), are of the type seen in his fig. c (p. 75) for his *Microdonta longicollis*. In the largest specimen the radula is composed of thirty rows of 6-1-6; the hooks in each sac number fourteen, and the same number of spines appears in the jaw. A specimen 4 mm. in length has twenty-one rows of 5-1-5 in the radula, fourteen hooks in each sac, and twelve spines in the jaw. In addition to the clear cells behind each hook-sac observed by Bonnevie, some of the present specimens exhibit a few tear-shaped cells with a dark core extending in a single line on either side of the jaw to the hook-sacs, each cell being about half the size of one of the spines of the jaw.

*Distribution*.—45° 26' N., 9° 20' W., surface; 48° 29' N., 13° 55' W., 150 metres (Bonnevie, 1913).

#### Family THLIPTODONTIDAE.

##### *Thliptodon atlanticus*, sp. n.

(PLATE VIII, fig. 5.)

S.R. 270—Midwater otter-trawl, at *ca.* 350 fathoms. Nine.

S.R. 282—Tow-net at 750 fathoms, over soundings of 1000 fathoms. One.

S.R. 337—Midwater otter-trawl, at 400-450 fathoms. One.

S.R. 401—Tow-net on trawl, 600 fathoms. One.

S.R. 481—Midwater otter-trawl, fishing at *ca.* 600-900 fathoms. Two.

S.R. 590—Midwater otter-trawl, at 480 fathoms. Three.

The specimens, measuring 3-7 mm. in length, resemble the form of *T. diaphanus*, Meisenheimer (1905, pl. xvi, fig. 10), except that the portion of body above fins, containing the enormous hook-sacs, radula, and gullet-bladders, occupies about twice the bulk of the pointed posterior portion (Pl. viii, fig. 5A). Viscera not extending to end of body, which, in the best-preserved specimens, shows a ciliated ring. Foot: a small three-lobed plate, placed half-way between fins and top of head. Fins narrow at base, widening considerably distally. Sucking-disk present at centre of fins. Radula: 3-1-1-1-3. Lateral teeth (fig. 5C) of the type figured by Boas (1886, pl. viii, fig. 122) for his *Thliptodon Gegenbauri*. In the present species, the spur near the free end of the inner lateral tooth is placed towards the centre of the distal margin, instead of at the outer end. The median tooth (fig. 5B) consists of a thickened undulating ridge, somewhat variable in form, but always with a median projection and oblong, shovel-like ends, directed outwards instead of inwards, as in Meisenheimer's (1905, pl. xxvii, fig. 3 *m.z.*) figure of *T. diaphanus*. There are also anterior and posterior lines, but these are so delicate that it is

not easy to discern them. About twelve rows are usually present in a radula. The number of hooks (fig. 5D) projecting from the mouth of a sac varies from thirty to fifty. In large specimens, the penis is evaginated behind the right fin; in small examples, it is visible beneath the visceral envelope above and behind anus, the latter being placed on the right ventral side below the fin. A long projection is present at either side of anal aperture. Dr. Meisenheimer of Marburg, having made a superficial examination of some specimens previously recorded (Massy, 1909, pp. 49–50), thought that the example recorded above from station S.R. 401 was *T. Gegenbauri*, Boas. The other examples recorded at the same time are no longer available for examination, but the example from station S.R. 282, previously (*op. cit.*, p. 50) identified by Dr. Meisenheimer as *T. diaphanus*, must have been so named by him as a slip for *T. Gegenbauri*, as the lobes of the foot are placed close together, instead of being widely separated, as in *T. diaphanus*. An examination of the radula proves it to be *T. atlanticus*. The young example from station S.R. 337, and one of the specimens from station S.R. 270, have been previously recorded (*op. cit.*, p. 50) as *Thliptodon* sp. In the present list of seventeen specimens all have had the radula examined, with the exception of four examples (three from station S.R. 270, and one from station S.R. 590), in which it is missing from mutilation; but in all other respects these specimens agree with their companions from these hauls.

***Thliptodon rotundatus*, sp. n.**

(PLATE VIII, fig. 6.)

S.R. 443—Midwater otter-trawl, at 550 fathoms. Three.

S.R. 449—Midwater otter-trawl, at 700 fathoms. One.

S.R. 481—Midwater otter-trawl, fishing at *ca.* 600–900 fathoms. One.

These have a round body, the posterior portion below the fins being nearly equal in bulk to the anterior region (Pl. viii, fig. 6A). Length, 3–4 mm. by 2·50–3 mm. in breadth. A ciliated band is present posteriorly. Viscera extending nearly to end of body. Foot: three lobes (the posterior short and pointed), placed close together just above fins. The latter are not so narrow at base, or so wide distally, as in the last-named species. Sucking-disk present. The skin pockets, containing the foot and fins, seem to be deeper than in *T. atlanticus*, and the skin is much wrinkled elsewhere. Radula: 3–1–1–1–3. Lateral teeth (fig. 6c) of the type peculiar to the family. Inner lateral tooth with a rounded prominence towards the centre of outer edge and no spur at the free end. Median tooth (fig. 6B) crescent-shaped and

serrated along the median three-fifths of edge with minute denticles, and with the smooth portion somewhat expanded at each end. Nine to thirteen rows of teeth, diminishing considerably in size, are present in a radula; the median tooth would appear to be very flexible, an end being sometimes curved up completely and entangled among the lateral teeth, which latter are frequently broken. In size the median tooth far exceeds that of any other known member of the family, which as yet seems to be limited to the species of Boas and Meisenheimer, mentioned in the present paper, and *Thalassopterus zancleus*, Kwietniewski (1910, p. 271). The hook-sacs of the specimen, measuring 3 mm. in total length, measure 1.50 mm. in length by 1 mm. in breadth; each contains about fifty gold-glittering hooks, all reaching to the mouth of the sac; their roots form an oblong honeycomb pattern along inner side; the hooks nearest the mouth of sac are about one-third the length of those at the furthest extremity; all are widest at base and taper to curved points. The genital duct shows the bladder-like widening, as in *T. diaphanus*. The shape of penis with its pouch also agrees in general detail with that species.

PARTICULARS OF STATIONS.

| Station No. | Date.        | Position.                              | Depth in fathoms. |
|-------------|--------------|--|-------------------|
| CXVII d     | 23 viii '01  | 30 miles W.N.W. of Cleggan Hd.         | 74½               |
| L. 161 a    | 6 x '02      | ¾ mile W. by N. of High Island.        | 30                |
| S.R. 24     | 11 v '03     | 16 miles S.W. of Fastnet Lt., Co. Cork | 60                |
| S.R. 25     | 4 viii '03   | 70 miles S.W. of Fastnet Lt.           | 80                |
| S.R. 60     | 8 xi '03     | 51° 17' N., 9° 45' W.                  | 58                |
| S.R. 61     | 9 xi '03     | 51° 29' 30" N., 9° 57' 30" W.          | 37½               |
| S.R. 66     | 10 xi '03    | 52° 4' N., 11° 30' W.                  | 104               |
| S.R. 76     | 1 ii '04     | 51° 6' N., 9° 50' W.                   | 67                |
| S.R. 197    | 11 ii '05    | 54° 57' N., 10° 51' W.                 | 1,000             |
| S.R. 224    | 12 v '05     | 53° 7' N., 15° 6' W.                   | 860               |
| S.R. 249    | 25 viii '05  | 51° 14' N., 9° 43' W.                  | 61½               |
| S.R. 270    | 3 xi '05     | 50° 20' N., 11° 15' W.                 | 470               |
| S.R. 273    | 6/7 xi '05   | 52° 2' 30" N., 10° 55' W.              | 78                |
| S.R. 282    | 18 xi '05    | 54° 59' N., 10° 53' W.                 | 1,000             |
| S.R. 290    | 1 ii '06     | 52° 26' 20" N., 5° 51' W.              | 43                |
| S.R. 302    | 5/6 ii '06   | 51° 54' N., 11° 54' W.                 | 460               |
| S.R. 337    | 12/13 v '06  | 51° 21' 30" N., 12° 9' W.              | 768               |
| S.R. 348    | 4/5 viii '06 | 51° 14' N., 9° 43' W.                  | 58                |
| S.R. 401    | 5 ii '07     | 51° 14' N., 11° 51' W.                 | 606-660           |
| S.R. 408    | 11 ii '07    | 51° 55' N., 6° 46' 30" W.              | 37                |
| S.R. 438    | 15 v '07     | 51° 49' N., 12° 22' W.                 | 584               |
| S.R. 443    | 16/17 v '07  | 51° 28' N., 12° 5' W.                  | 683               |
| S.R. 449    | 19 v '07     | 50° 28' 30" N., 11° 39' W.             | 950               |
| S.R. 470    | 24 viii '07  | 50° 16' N., 11° 27' W.                 | 770               |
| S.R. 476    | 26 viii '07  | 51° 42' N., 12° 20' W.                 | 640               |
| S.R. 481    | 29 viii '07  | 50° 59' N., 11° 52' W.                 | 920-1,064         |
| S.R. 503    | 12 ix '07    | 50° 42' N., 11° 26' W.                 | 990               |
| S.R. 521    | 6 xi '07     | 51° 45' N., 6° 49' W.,                 | 39½               |
| S.R. 529    | 8 xi '07     | 52° 2' 30" N., 10° 56' W.              | 80½               |
| S.R. 590    | 3 viii '08   | 51° 51' 30" N., 12° 8' W.              | 480               |
| S.R. 595    | 7 viii '08   | 50° 55' 30" N., 9° 56' W.              | 72½               |
| S.R. 636    | 7 xi '08     | 51° 55' N., 6° 49' W.                  | 37                |

PARTICULARS OF STATIONS—*continued.*

| Station No. | Date.          | Position.                           | Depth in fathoms. |
|-------------|----------------|-------------------------------------|-------------------|
| S.R. 639    | 12 xi '08      | 51° 14' N., 9° 42' 30" W. . . .     | 59                |
| S.R. 654    | 8 ii '09       | 51° 52' N., 12° 11' 30" W. . . .    | 567               |
| S.R. 751    | 16 v '09       | 51° 54' N., 11° 58' W. . . .        | 386               |
| S.R. 752    | 16/17 v '09    | 51° 48' N., 12° 11' 30" W. . . .    | 523-595           |
| S.R. 796    | 12 viii '09    | 51° 14' N., 9° 43' W. . . .         | 58                |
| S.R. 798    | 12 viii '09    | 50° 19' N., 10° 21' W. . . .        | 78                |
| S.R. 803    | 14 viii '09    | 51° 56' N., 11° 43' W. . . .        | 215               |
| S.R. 848    | 8 xi '09       | 51° 14' N., 9° 43' W. . . .         | 57                |
| S.R. 943    | 16 v '10       | 51° 49' N., 12° 23' W. . . .        | 606               |
| S.R. 1049   | 9 xi '10       | 51° 14' N., 9° 43' 30" W. . . .     | 58                |
| S.R. 1050   | 9 xi '10       | 50° 56' N., 9° 56' W. . . .         | 72                |
| S.R. 1096   | 11 ii '11      | 50° 19' N., 10° 22' W. . . .        | 79                |
| S.R. 1226   | 10 viii '11    | 50° 19' N., 10° 22' W. . . .        | 79                |
| S.R. 1232   | 12 viii '11    | 52° 3' N., 10° 59' W. . . .         | 82                |
| S.R. 1237   | 12 viii '11    | 51° 54' N., 12° 29' W. . . .        | 569               |
| S.R. 1243   | 14/15 viii '11 | 51° 37' N., 12° 1' W. . . .         | 670-692           |
| S.R. 1385   | 13 v '12       | 51° 59' N., 11° 28' 30" W. . . .    | 134               |
| S.R. 1386   | 13 v '12       | 51° 57' N., 11° 44' W., . . .       | 214               |
| S.R. 1387   | 13 v '12       | 51° 55' N., 12° 0' W. . . .         | 406               |
| S.R. 1451   | 21 viii '12    | 51° 22' N., 11° 49' W. . . .        | 625               |
| S.R. 1499   | 16 xi '12      | 52° 2' N., 10° 56' W., . . .        | 75                |
| W. 265      | 18 xi '12      | 4½ miles S.S.W. of Dingle Lt. . . . | 23                |
| S.R. 1537   | 15 ii '13      | 51° 16' N., 6° 32' W. . . .         | 61                |
| S.R. 1692   | 19/20 viii '13 | 51° 32' N., 11° 56' W. . . .        | 524-756           |
| S.R. 1845   | 21/22 v '14    | 50° 57' N., 11° 38' W. . . .        | 625-804           |

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## EXPLANATION OF PLATE.

Fig.

1.—*Pneumodermopsis oligocotyla*, sp. n.1 A.—The entire animal, ventral view.  $\times 12$ .  $s$  = suckers:1 B.—Radula.  $\times 230$ .1 C.—Spines from jaw.  $\times 230$ .1 D.—Spines of hook-sac.  $\times 230$ .2.—*Spongeobranchaea polycotyla*, sp. n.2 A.—The entire animal, ventral view (restored).  $\times 4$ .  $n$  = nuchal tentacle ;  
 $p$  = posterior gill.

2 B.—Isolated teeth from radula, greatly enlarged.

2 C.—Types of jaw spines, greatly enlarged.

2 D.—Group of suckers (the largest not drawn), greatly enlarged.

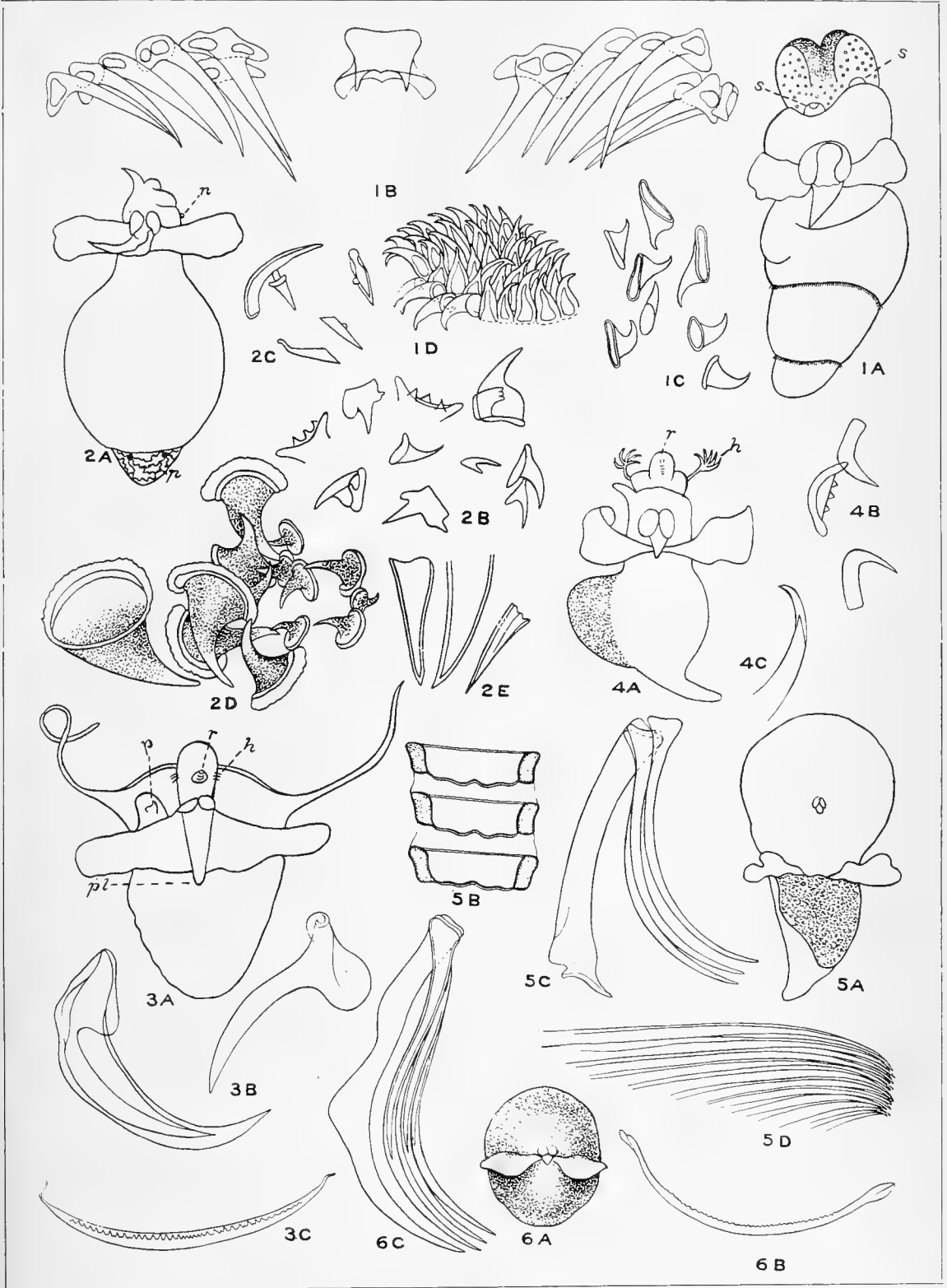
2 E.—Separate spines from the hook-sac, greatly enlarged.

3.—*Clionopsis longecirrata*, sp. n.3 A.—The entire animal, ventral view.  $\times 14$ .  $r$  = radula ;  $h$  = hooks ;  
 $p$  = penis ;  $p.l.$  = posterior lobe to foot.3 B.—Types of lateral teeth of radula.  $\times 230$ .3 C.—Median tooth of radula.  $\times 150$ .4.—*Cephalobranchia Bonnevi*, sp. n.4 A.—The entire animal, ventral view.  $\times 14$ .  $r$  = radula ;  $h$  = hooks ;  
 $g$  = gonad.

4 B.—A median and two lateral teeth from radula, greatly enlarged.

4 C.—A spine from hook-sac, greatly enlarged.

5.—*Thliptodon atlanticus*, sp. n.5 A.—The entire animal, ventral view.  $\times 6$ .5 B.—Median tooth of radula.  $\times 90$ .5 C.—Lateral tooth of radula.  $\times 40$ .5 D.—Spines of hook-sac.  $\times 26$ .6.—*Thliptodon rotundatus*, sp. n.6 A.—The entire animal, ventral view.  $\times 6$ .6 B.—Median tooth of radula.  $\times 230$ .6 C.—Lateral teeth of radula.  $\times 150$ .







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*SPERMOLITHUS DEVONICUS*, GEN. ET SP. NOV.,  
AND OTHER PTERIDOSPERMS FROM THE  
UPPER DEVONIAN BEDS AT KILTORCAN,  
CO. KILKENNY.

BY

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(PLATES IX–XIV.)

[*Authors alone are responsible for all opinions expressed in their Communications.*]

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## XXIII.

*SPERMOLITHUS DEVONICUS*, GEN. ET SP. NOV., AND OTHER  
PTERIDOSPERMS FROM THE UPPER DEVONIAN BEDS  
AT KILTORCAN, CO. KILKENNY.

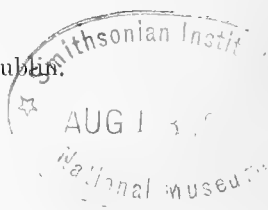
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Professor of Botany in the Royal College of Science for Ireland, Dublin.

(PLATES IX-XIV.)

Read JUNE 26. Published AUGUST 20, 1917.

THE realization of the existence of the Pre-Tertiary group of *Cycadofilices*, and the discovery of several genera of the group with attached seeds leading to the segregation of such, as the *Pteridosperms* (1), added considerable interest to the re-examination of the material collected from the Upper Devonian (Yellow Sandstone) beds of Kiltorcan, Co. Kilkenny. Beautiful large stipulate fronds of *Archaeopteris hibernica* Forbes sp., both sterile and fertile, have been known since 1846 (2). In 1911 the presence in the Kiltorcan deposits of *Archaeopteris Tschermaki* Stur., previously known only from the Culm of the Continent, was noted (4). The Irish specimen shows signs of the bifurcation of the frond seen in *Sphenopteridium* Schimper, to which *A. Tschermaki* has been transferred. Gothan (5), writing in 1913, considers this genus, partly on account of the appearance of transverse striae or sclerotic bands in its rachis, to be a *Pteridosperm*, allied to *Heterangium*. The specimen of *S. (A.) Tschermaki* found at Kiltorcan was in a fertile state, showing a sporophyllule, indistinguishable as an impression from that of typical *Archaeopteris hibernica*. This latter species was for a long time after its discovery naturally regarded as a fern, and the small stalked spindle-shaped bodies of the fertile fronds as its sporangia (3). For six or seven years past I have examined a great deal of material (quarried for road-repairing at Kiltorcan!) (4) in the hopes of finding something more than the isolated fronds known up to the present. I had hopes, too, that seeds might be unearthed,



particularly as Dr. D. H. Scott had expressed the opinion to me verbally that *Archaeopteris* would turn out to be a *Pteridosperm* and not a Fern. The quarry has yielded many examples (Pl. IX, fig. 1) of the stipulate leaf-bases first described by Kidston (6). The base of attachment is broad, grooved (Pl. IX, fig. 2), and makes a constant characteristic angle (Pl. IX, fig. 3) with the rachis proper, which is swollen on its adaxial side proximally (Pl. IX, fig. 4, and fig. 2, Pl. XIV). Comparison may be made with the swollen base of the petiole of the *Pteridosperm*—*Rhetinangium Arberi*—which Gordon (7) shows is due to excessive development of cortical parenchyma, and forms a weak tearing region. Several slabs show short thick stumpy stems bearing spirally arranged stipulate leaf-bases like those of *Archaeopteris*. The figure (5), Pl. IX, shows at A such a stem, and lying on the slab another slab which at B shows a known leaf-base of *Archaeopteris* which is externally suggestive in its basal part of that of *Angiopteris* or other modern *Marattiaceous* plant. It does not appear, however, to have ended apically in a rosette of fronds. Figure 1, Pl. X, which represents a stem, apparently belonging to the same fossil as *Archaeopteris*, suggests that the *Archaeopteris* stem was elongated apically and bore distant fronds—that possibly it was of a straggling if not climbing habit. This Kiltorecan stem of *Archaeopteris* reminds one very forcibly of the illustration Dawson (8) gives of his tree-fern *Caulopteris Lockwoodi* from the Upper Devonian beds of Gilboa, New York. It is not improbable that this *Caulopteris* is the stem of *Archaeopteris*, the foliage of which is recorded from the same deposits.

True *Archaeopteris* had, so far as we know, an unforked stipulate tripinnate frond with sessile pinnules borne directly on its rachis. The veins are dichotomous and numerous. There is no midrib in the pinnule as in *Sphenopteris* usually; two or three bundles enter the rachidule from each pinnule, as is also the case for each pinna at its point of insertion on the rachis. Apparently four, five, or more bundles enter the stem from the rachis, whether separately or, as in *Rhetinangium*, as one continuous band I cannot say.

On the distal side of the leaf-base cushion on the adaxial surface there is to be seen in some of the impressions a forked appendage represented in fig. 1, Pl. X. This appendage may be connected with reproduction. It suggests comparison with the abaxial fertile appendages discovered by Nathorst (9) in *Cephalotheca* and with the basal appendage in *Heterangium hibernicum* (10). Its occurrence made me hesitate to refer such specimens to *Archaeopteris*, where forking is a rarity as compared with *Sphenopteris Hookeri*.

Though the sterile pinnules are not lobed, the fertile ones are sometimes markedly so to such an extent as to deserve the term "digitiform." This occurrence of segmentation in the fertile pinnule ought not to be overlooked

in considering the affinities of *A. hibernica*. It reaches its extreme development in the sterile pinnules of *A. fimbriata* Nathorst, of the Devonian of Bear Island. *S. (A.) Tschermaki* has a bifurcate pinnate frond. The pinnae are more or less oblong and lobed, but are not divided into pinnules. The basal pinnae may be basally pinnatisect. W. Gothan does not appear to attach due importance to this degree of segmentation, since in his valuable work on the coal plants of Upper Silesia he speaks of *Sphenopteridium Dawsoni* Stur sp. as standing nearest to, *if not identical with, S. Tschermaki* (which is itself allied to *Heterangium*), yet *S. Dawsoni* has a typical bifurcate bipinnate frond with distinct obovate lobed pinnules. If these marked differences in the degree of segmentation of a frond are to be regarded as of no systematic value, many names of fossil species must fall. Even in *Archaeopteris* proper the species are ill-defined and insufficiently illustrated. It is, in consequence, difficult to contrast satisfactorily *A. hibernica* with Dawson's many American species. It would be a distinct advantage to have a revised photographic untouched-illustrated account of these species for comparison with those of Bear Island, Kiltorcan, and the continent of Europe.

The search at Kiltorcan has brought to light many specimens of fertile fronds of *Archaeopteris hibernica* showing the general characters, now well known. The fertile pinnule represented in fig. 1, Pl. XI, is new and of considerable interest. Several such were found, but always in a detached state, until that shown in fig. 2, Pl. XI, was observed, enabling me to refer the structure to *Archaeopteris hibernica*.

The stalked palmatisect wedge-shaped pinnule is seen divided into two segments, each of which is again divided. The four lobes carry on their edges normal stalked sporangia. The cauloid position of the fan-shaped pinnule (fig. 2, Pl. XI) is interesting, though not surprising, as the simple pinnules inserted on the rachis between the pinnae are a generic character of *Archaeopteris*. So far I have failed to find anything indicative, as I hoped, of the conversion of a stalked sporangium into a seed. Examination of the contents of the sporangia has not as yet shown any signs of a differentiating heterospory tending towards a distinction into seeds and microspores. Up to the present the only kind of spore found is that shown in fig. 3a, Pl. XI, in surface view, and in *b* in optical section. The spore is spherical, 50  $\mu$  in diameter, and shows a pitted wall, suggestive of numerous possible pores of dehiscence. I have, however, found many slabs covered in patches or streaks with minute black bodies. These are generally isolated, but are sometimes stalked. Sometimes the stalk is forked, and occasionally curved or spirally coiled. The dark bodies occur singly, now and then apparently paired. They



suggested comparison with the sporangia of *Dimeripteris gracilis* described by Schmalhausen (11), from the Devonian beds of Donetz, where shells of *Productus* and of other Molluscs scarcely distinguishable, it is stated, from those of the Upper Devonian beds of America, had already been found. These Donetz beds also revealed several species of *Archacopteris fissilis*, *A. archetypus*, *A. cf. obtusa*. Schmalhausen himself compares his *Dimeripteris* (*D. fasciculata* and *D. gracilis*) with—(1) *Sphenopteris Hitchcockiana* Dawson, which is clearly, judging from the figure, a fertile frond of *Archacopteris*, and, as Dawson himself suggests, probably of *A. (Cyclopteris) Jacksoni*; (2) *Sphenopteris Condrusorum* Gilkinet, of the Upper Devonian of Belgium (12).

I do not myself agree with Schmalhausen in his comparisons, based, I think, largely on the rough figure of *S. Hitchcockiana*. There is nothing in *Archacopteris* like the repeated forking of the slender sporangial stalks seen in figures 23–25 (*op. cit.* pl. 11) of his *Dimeripteris*. In the Kiltorecan material stalks are scarce. When present they agree in general with those figured of *Dimeripteris*. When the dark bodies already mentioned were removed from the slab and suitably treated, they proved to be sporangia containing spores, one of which is shown in fig. 5, Pl. XI. The appearance of pairing of the sporangia may be due to their valvular apical dehiscence (fig. 6, Pl. XI). I had begun to despair of finding anything definitely suggestive of seeds when the impression represented in fig. 1, Pl. XII, was noticed. In this slab one may see, in addition to the dot-like micro-sporangia, barrel-shaped bodies,  $5 \times 2.5$  mm. in size, in some cases faintly longitudinally ridged, and occasionally stalked. Sometimes one finds a fairly thick, radially striate, ovate envelope enclosing the softer carbonaceous matter of the central part of the body. The rounded area represented in fig. 1, Pl. XII, is also usually observable. There can be little doubt that these oval bodies are true seeds, and that the black speck-like ones are male sporangia. They cannot, however, be referred to *Archacopteris*. Scraps of foliage of *Sphenopteris Hookeri* frequently occur mixed with them on the slabs. The frequency suggests affinity, but it is not conclusive.

When one of these oval bodies is enlarged eight times, the general likeness to the seed of *Lagenostoma* or *Sphaerostoma* is strikingly brought out (fig. 2, Pl. XII). This untouched photograph shows the scooped-out base (*b*) where the stalk was inserted, while the apical papilla is suggestive of the region of the pollen chamber of *Lagenostoma*. Can the central ring represent the limits of the embryo sac? There is nothing suggestive of a cupule or an involucre—the detached seed was apparently “naked,” and of the radiospermic type. It is to be regretted that Kiltorecan gives impressions only, no

petrifications. The impressions indicate that we have here the seed and micro-sporangia of a Devonian plant, and that heterospory was already well pronounced at this epoch. I collected the first samples of this material in 1912, and reserved them for description in the unfulfilled hope that specimens showing the parentage of the seed would turn up. The few seeds found generally occur quite detached, and hollowed out basally. They are rarely even stalked. This scrappy character of the seed material adds naturally to the difficulty of ascertaining its affinities. So much is this the case that it seems better to give the seeds and associated micro-sporangia a name apart, and to call them *Spermolithus devonicus*.

In 1914 an account of the foliage of the Kiltorcan Ginkgophyte *Ginkgophyllum Kiltorkense* was given (13). Since that date a fair number of samples of *Ginkgophyllum* have turned up, and I am now able to add considerably to its story. A surprising feature is the character of its foliage. The leaf is a composite heteromorphic one, consisting of the lobed fan-shaped lamina already described and united with it, a forked ribbon-like portion. The leaf is a combination of that of a *Baiera* with that of a *Dicranophyllum* or *Trichopitys*. In the first description of *G. Kiltorkense* I mentioned the possibility that the forked filaments figured (*op. cit.*, Pl. X, fig. 2) might belong to *Trichopitys*. The more complete material now available leaves no doubt (fig. 3, Pl. XII, and fig. 3, Pl. XIV) of the organic continuity of the two as parts of the same leaf. It looks as if in the course of time this Devonian Ginkgophyte has given rise to one branch of the order with lobed fan-shaped leaves seen in the Mesozoic *Baiera*, and ending in the bilobed cuneate leaf of extant *Ginkgo* itself, and to another branch of the order with forked filamentous leaves seen in *Trichopitys* or *Dicranophyllum*, which died out in the Mesozoic. The considerable amount of stem material which was gradually accumulating from Kiltorcan seemed at one time destined to be placed in the collective form genus *Caulopteris*. The difficulty of generic identification is increased by the frequency with which specimens occur showing a rootstock carrying naked leaf-stalks or rachids with no trace of a lamina, tempting one to follow Matthew, and to refer such specimens to his genus *Himantophyton* (14).

The discovery of the composite nature of the *Ginkgophyllum* leaf and its ribbon-like stalk led ultimately to the recognition amongst these stems of that of *Ginkgophyllum*. It is not unlike a short, stumpy Cycad stem, with an apical tuft of leaves, and capable apparently of branching (figs. 4 and 5, Pl. XII, 1 and 2, Pl. XIII). The leaf-base is slightly expanded, not decurrent, as in the type *Ginkgophyllum* (15). It is difficult to decide whether the expansions deserve to be called stipules or not. In view of the differences

from *Ginkgophyllum* now revealed it might be better to call the Kiltorcan plant *Kiltorkensia devonica*. The illustrations show the rootstock as seen from various aspects. Some of the leaves seen in fig. 4, Pl. XII, are reduced, and almost scale-like. The specimen (Pl. XIII, fig. 1) was found of a revealing nature. There is a well-pronounced stem, from which arises an apical tuft of spirally arranged leaves. Here and there may be seen a lobed, wedge-shaped leaflet. The rachis, to which a leaflet is seen attached, shows several vascular bundles traversing it, reduced to a leaf-trace or two (?), at the point



BOTRYCHIUM SIMPLEX (restored).

of insertion. Such a specimen suggests comparison with several groups of plants, and even with the leafy spur of *Ginkgo* itself. Just as in ontogeny, the many buds are a repetition and multiplication of the plumule of the seedling, so phylogenetically the apex of the *Ginkgophyllum* rootstock might find itself multiplied in the shoots of the arboreal *Ginkgo*. Accepting the view that the leaf is differentiated into two dissimilar portions—one laminated and lobed (*Ginkgo-like*), the other ribbon-like and forked (*Trichopitys* or *Dicranophyllum-like*)—an interesting question arises. Are both portions

purely vegetative in character? In several cases the branching filaments carry towards their tips small oval bodies which are clearly sporangia (figs. 3 and 4, Pl. XIII), arranged not unlike, strange to say, the sporangia of *Botrychium*.

It would be rash to say that the filamentous character of one portion of the leaf is a reduction of the lamina caused in all cases by the presence of the reproductive bodies. Still the similarity of differentiation of function in the same leaf observable here and in the *Ophioglossaceae* is worthy of note. The restored herbarium specimen of *Botrychium simplex* (p. 250) shows the frond with its twofold function and the marked dichotomy of the venation. It would be a defensible position to assert, so far as impressions only are considered, that *Ginkgophyllum* is a Devonian member of the *Ophioglossaceae*. While the oval bodies mentioned are clearly organically traceable in their continuity with *Ginkgophyllum*, I have found nothing suggestive of a seed so connected. Several seed-like bodies borne on veined stalks (e.g. fig. 5, Pl. XIII) which are not unlike the veined leaf filaments of *Ginkgophyllum* have been found. Further evidence is needed to enable one to arrive at a definite decision as to the exact nature and affinity of these bodies. So far the material collected shows that *Ginkgophyllum Kiltorkense* possessed a rootstock bearing an apical tuft of compound leaves with a non-decurrent sheathing, if not stipulate, base of attachment, a well-marked rachis, carrying *Baiera*-like leaflets and also *Trichopitys*-like leaflets, which latter, in some cases at any rate, bore groups of oval sporangia at their tips. Dichotomy is as pronounced a feature in the leaf and veins as in *Botrychium*. The fertile bodies are either sporangia comparable to those of *Botrychium*, or are the microsporangia of a heterosporous plant. The evidence suggestive of the possession of seeds by *Ginkgophyllum* is at present slight. It is, I think, clear that the possibilities of additions to our knowledge of the Devonian flora from the deposits at Kiltorcan are not yet exhausted.

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EXPLANATION OF PLATES.

(The illustrations are from photographs taken by H. Patterson.)

PLATE IX.

Fig.

1. Leaf-base of *Archæopteris hibernica*, showing vascular stipules and pinnules.
2. Another leaf-base of *A. hibernica*, showing grooves on detached surface.
3. Side view of leaf-base of *A. hibernica*.
4. Stem of *A. hibernica*, showing dilatation of base of leaf-stalks.
5. Stem of *A. hibernica* (A) with attached leaves. B, slab showing a detached leaf-base of *A. hibernica*, placed in position for comparison with A.

PLATE X.

1. Stem of *A. hibernica*, showing the forking leaf appendages, &c.
2. Stem of *A. hibernica*, showing the more distant, slenderer leaf-bases in the upper part.
3. Adventitious roots arising from the stem of *A. hibernica*.
4. Stem of *A. hibernica*, showing the pendulous collapsing and delaminated leaf-stalks.
5. A portion of a leaf of *A. hibernica*, showing dilations and curvature of base of rachis of pinnæ.

PLATE XI.

1. Fertile palmatisect pinnule of *A. hibernica*, detached.
2. A similar pinnule attached to *Archæopteris* stem (upper left-hand).
- 3 *a, b*. Two views of isolated spore of *A. hibernica* ( $50\mu$  in diameter).
4. Slab showing the speck-like microsporangia of *Spermolithus devonicus*.
5. An isolated microspore of *S. devonicus*.
6. A dehiscing microsporangium of *S. devonicus*, slightly enlarged.

## PLATE XII.

Fig.

1. Slab showing several seed impressions and numerous microsporangia of *S. devonicus*.
2. A single such seed impression.  $\frac{8}{1}$ .
3. Heteromorphic foliage of *Kiltorkensia devonica* (*Ginkgophyllum Kiltorkense*).
- 4 and 5. Rootstock of *Kiltorkensia devonica*, from two different aspects.

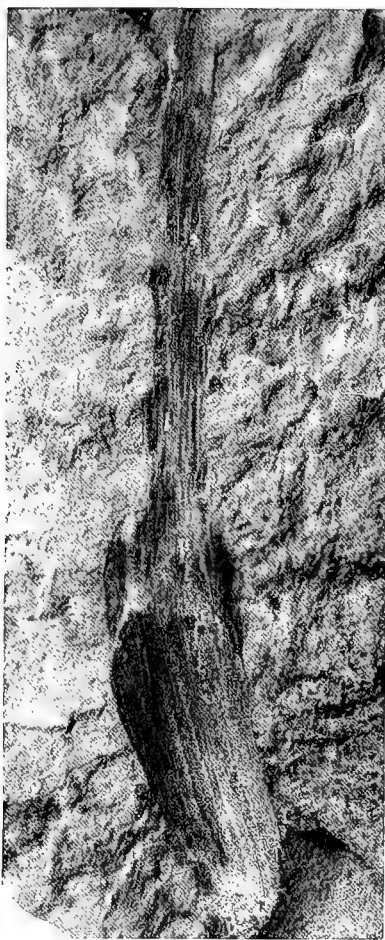
## PLATE XIII.

- 1 and 2. Rootstock of *Kiltorkensia* with Ginkgo-like pinnules, more obvious in fig. 1.
- 3 and 4. Botrychium-like branching sporangiferous pinnules assigned to *Kiltorkensia*. (Similar bodies are to be seen in Plate X, fig. 2, of my paper on *Ginkgophyllum*. (Sci. Proc. Roy. Dublin Soc., 1914, vol. xiv, No. ix, p. 169.) Attention was not called to them at the time, as there was not enough evidence of affinity.)
5. Pendulous seed-like body of unknown affinities (*Kiltorkensia* ?)  $\frac{8}{1}$ .

## PLATE XIV.

1. Stem of *Archæopteris*, showing adaxial forked appendage.
2. Another stem of *Archæopteris*, showing leaf-bases.
3. *Kiltorkensia devonica* (*Ginkgophyllum kiltorkense*), composite foliage.

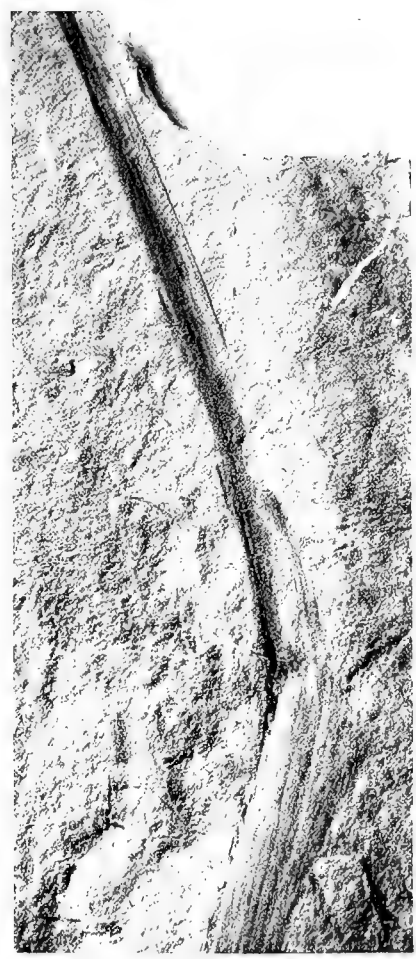
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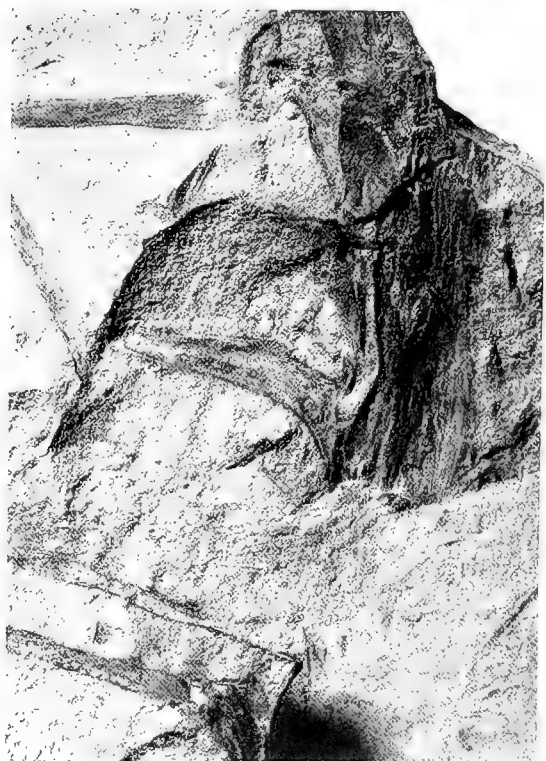
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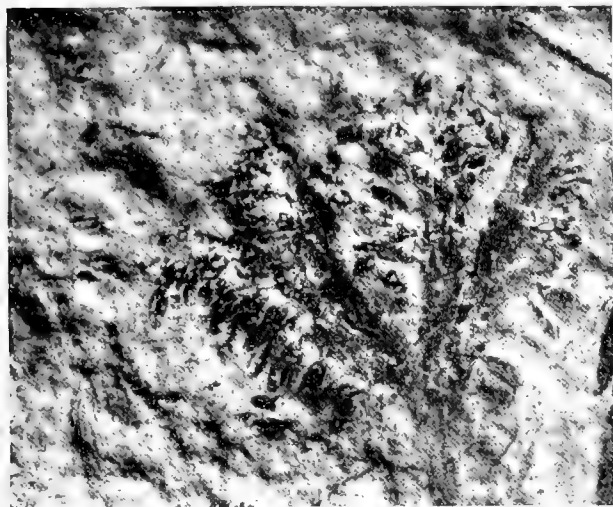


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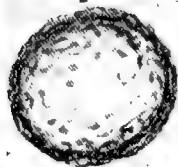




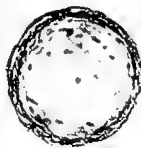
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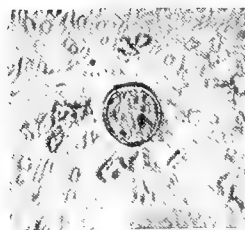
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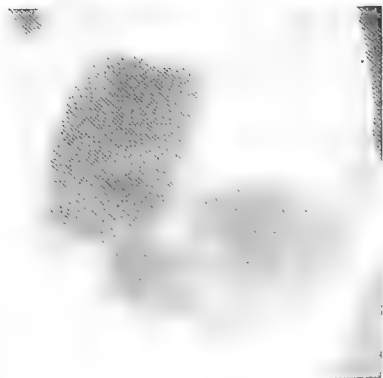
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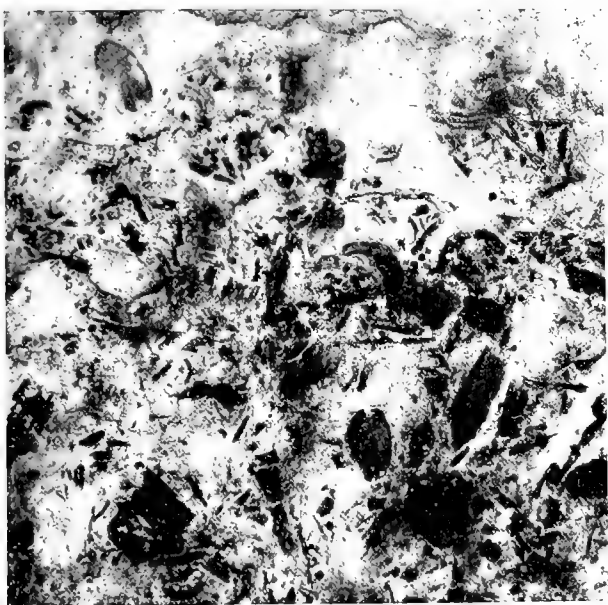


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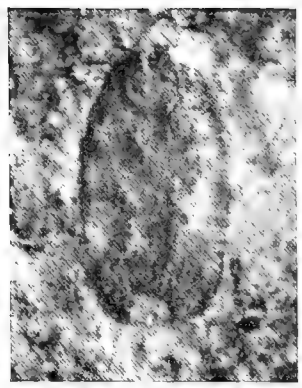


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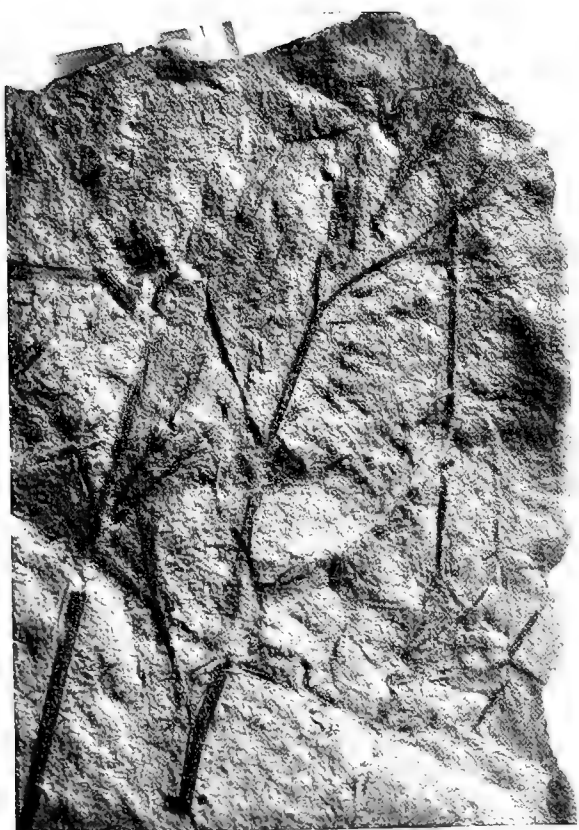




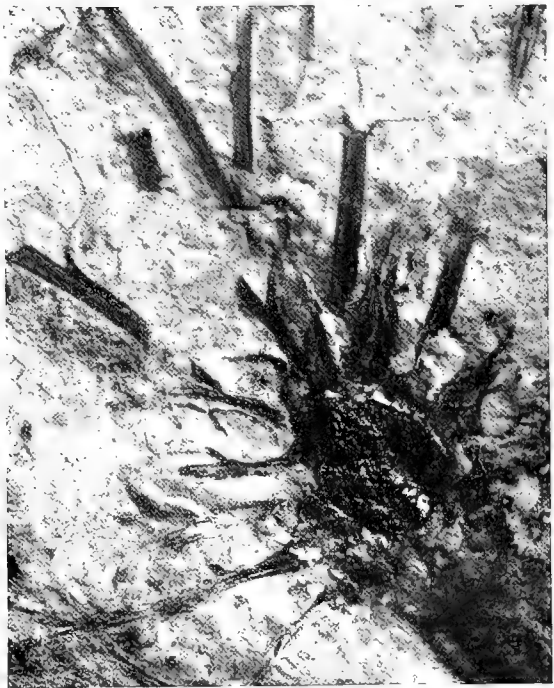
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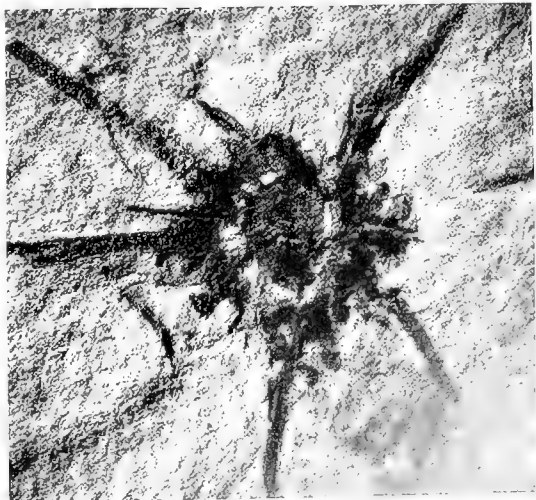
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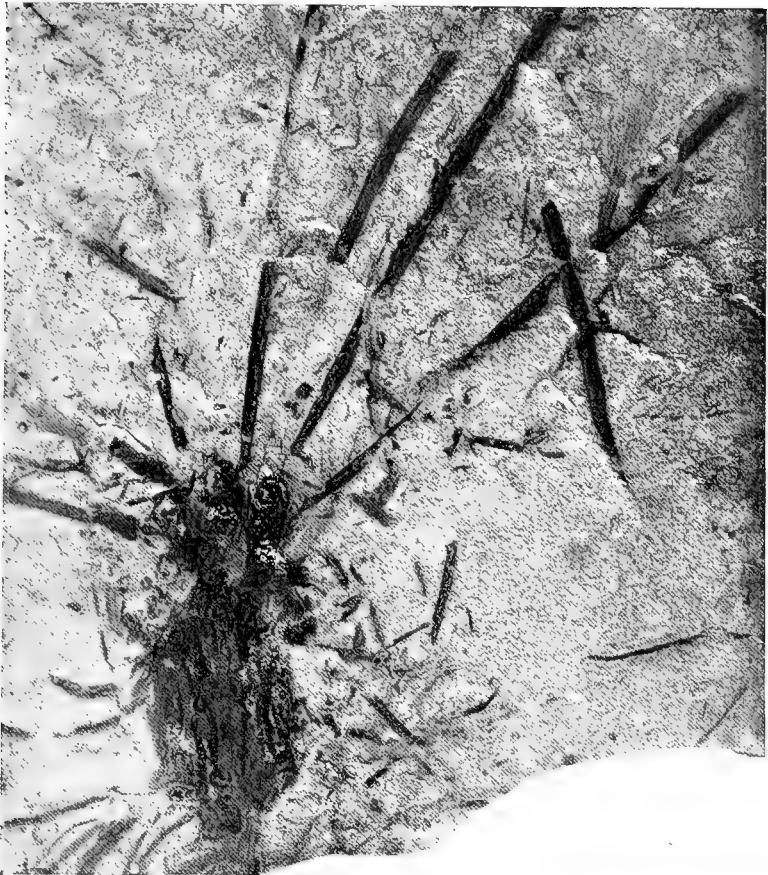
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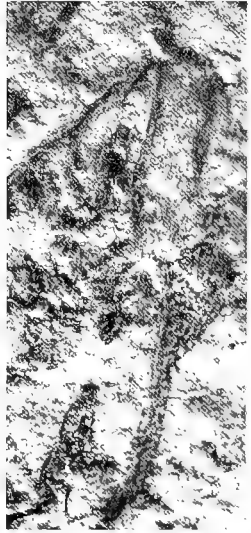




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THE GENUS *TAENITIS*, WITH SOME NOTES  
ON THE REMAINING *TAENITIDINAE*.

BY

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BOTANICAL DEPARTMENT, UNIVERSITY COLLEGE, DUBLIN.

[COMMUNICATED BY PROFESSOR H. H. DIXON, F.R.S.]



(PLATE XV.)

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## XXIV.

THE GENUS *TAENITIS*, WITH SOME NOTES ON THE  
REMAINING *TAENITIDINAE*.

By ELIZABETH J. LEONARD, M.Sc.,  
Botanical Department, University College, Dublin.

(COMMUNICATED BY PROFESSOR H. H. DIXON, F.R.S.)

(PLATE XV:)

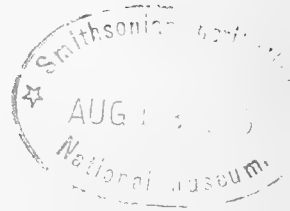
[Read NOVEMBER 27, 1917. Published FEBRUARY 13, 1918.]

THE genus *Taenitis* Willd. was founded in 1804. In 1809 Schkuhr described and figured the only species then known, namely, *Taenitis pteroides*, now designated *Taenitis blechnoides*. This is a form with pinnate leaves; but later on the genus was extended to include species in which the leaves were simple. In 1836 Presl (10) confined the genus to *T. blechnoides* and *T. interrupta*, both with pinnate leaves. The latter is now regarded as a variety of *T. blechnoides*. So far, therefore, the only species with definite claims to being called *Taenitis* is *T. blechnoides*, the pinnate form. Presl, however, mentions seven other species once known as *Taenitis*, and all with simple leaves. These he places under various other headings, reserving *Taenitis* for the forms with compound leaves.

Hooker and Baker (7) again, included forms with simple leaves, as does Jenman (8), the three forms he mentions for Jamaica all being simple—*T. angustifolia*, *T. lanceolata*, and *T. swartzii*.

Diels (5) only mentions *T. blechnoides* without definitely stating the number of species. Christensen (4) gives two species, *T. blechnoides* Willd. and *T. stenophylla* Christ, both being forms with pinnate leaves. Christensen also mentions thirty-five other different forms which were once known as *Taenitis*. Of these four are now regarded as varieties of *T. blechnoides*, eleven are regarded as *Vittarieae*, sixteen other *Taenitidinae* (Diels' classification), two *Polypodium*, one *Blechnum*, and one *Cyclophorus*.

One of the two species that Christensen mentions—*T. stenophylla* Christ—has merely been recorded as a new species (3). The grounds for





separating it from *T. blechnoides* are slight; and until we get more positive information regarding it, it may be neglected.

For all working purposes, therefore, *Taenitis* is a genus of only one species—*T. blechnoides* Willd.

The position given to this small genus by various systematists is interesting. Presl (1836) (10) places it under *Grammitideae* between *Pteropsis* (a genus which no longer exists, but is now merged in the *Vittarieae* and *Taenitidinae*) and *Drymoglossum*. In the *Synopsis Filicum* (1874) it is placed under *Grammitideae* between *Vittaria* and *Drymoglossum*. Prantl (1892) (9) placed it under *Polypodiaceae*, sub-group *Taenitidinae*, along with such forms as *Cheiropleuria* and *Platytaenia*. Christ (1897) (2) places it under the *Polypodiaceae* between *Paltonium* and *Drymoglossum*. Diels (1902) (5) places it in the *Taenitidinae* (*Polypodiaceae*) along with *Drymoglossum*, *Hymenolepis*, *Paltonium*, *Platytaenia*; but widely apart from the *Asplenieae-Blechnae* (2, p. 245), which includes *Blechnum* itself. In Engler's syllabus (1912) (6) it is again placed under the *Taenitidinae* along with *Drymoglossum*, and ranked under the *Polypodiaceae*; while *Blechnum*, with which it has often been related, lies apart from it in the *Asplenieae*.

The following will be an attempt to study, as far as possible, the structure of *Taenitis* with a view to placing it in its true phyletic position.

#### *External Morphology.*

The rhizome of *Taenitis blechnoides* may be variously inclined to the vertical. Leaves arise on all sides at a distance of about half an inch apart and roots may occur at any point on the surface. The leaves are erect, of about a foot to a foot and a half in length, and they are simply pinnate. There is no dimorphism of the leaves, sterile and fertile ones being identical in size. The sorus forms a continuous line midway between the margin and the mid-rib; but towards the distal end of the pinna it usually becomes broken into short portions, and finally disappears. Similar interruptions may also occur occasionally lower down on the leaf blades. There is no indusium visible in the mature state.

On the base of the petiole is frequently found a bud situated marginally on the stalk. Both the stem and the base of the petioles are covered with hairs and very simple scales.

#### *Dermal Appendages.*

The hairs (Plate XV, B, 1) consist of a single row of cells, the terminal one being glandular as in *Blechnum*. The cells at the base are larger than

those towards the distal end, and they are crowded together in such a way as to suggest intercalary growth. On the older part of the stem are found simple scales. The distal portion of these is similar to that of the hairs, and, like them, it terminates in a glandular cell. The basal portion consists of a number of cells adjoining one another to form a simple plate (Plate XV, B, 2 & 3). Intermediate forms between the hair and the scale are also found; some in which there is a doubling of the basal cell and others in which there may be three or more cells at the base (Plate XV, B, 4 & 5). It is thus necessary to correct previous statements on this point, such as those of Christ ((2), p. 130), and of Diels ((5), p. 304), both of whom describe the rhizome as bearing hairs only.

#### *Anatomy.*

*The Stem.*—In young stems a solenostele is found (Fig 1, 1, & Plate XV, Fig A). The ground tissue, both of the cortex and within the vascular ring, is sclerotic, with the exception of two or three rows of cells adjoining the endodermis. These are thin-walled rounded cells with numerous intercellular spaces. These cells become more numerous at the point of formation of a leaf-trace, and adjoining the gap where the leaf-trace has departed.

The first appearance of the leaf-trace is made apparent by the thinning down of the ring on one side of the solenostele (Fig 1, 2). This thin portion breaks away, first on one side and then on the other, to form an individual horse-shoe-shaped leaf-trace (Fig. 1, 4). The further behaviour of the leaf-trace will be considered later.

In the specimen investigated, which was of fairly advanced age, the gap left by the formation of the lowest leaf is considerably longer than any of the succeeding ones. It gradually closes down (Fig. 1, 6), and at the same time a second leaf-trace is forming on the opposite side of the stele. The second leaf-gap is formed just as the first closes, thus giving rise to a very simple dictyosteles lightly removed from the solenostelic state. After the formation of the third leaf-trace the gaps were found to overlap considerably (Fig. 1, 11), and so dictyostely is well established. Sometimes in the mature stem, however, there may be reversion to the solenostelic state.

We see, therefore, that while the stele of the adult *Taenitis* is a radial dictyostele, it is a very simple one, not far removed from solenostely, to which it has been seen occasionally to revert. The position of the protoxylem elements is not recognizable in the mature stem.

*The Root.*—The structure of the root is that of a typical Fern. It is diarch, and has a very definite pericycle and endodermis. The cells of the cortex are brown-walled, but are hardly, if at all, sclerosed.

*The Petiole.*—It has been seen already that the leaf-trace is formed by the separation of a sector of the stele. Very early a perforation appears at

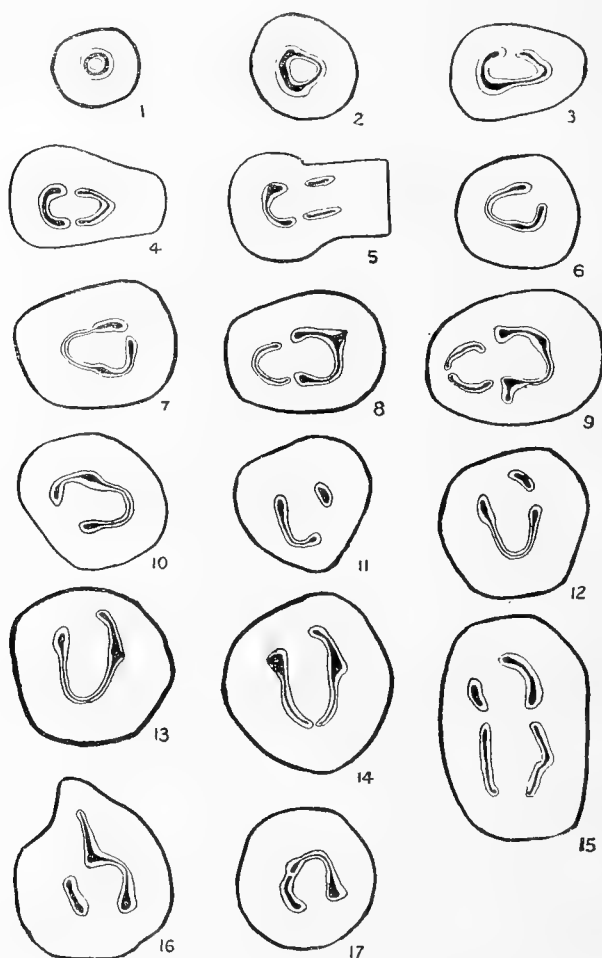


FIG. 1.—Diagrammatic drawings showing structure of stele of *Taenitis blechnoides*.

the middle of the leaf-trace, thus dividing it into separate straps. In some cases this perforation may be formed before the leaf-trace is separated from the stele (fig. 1, 14). There is no definite rule, and we may regard the latter case as merely being a form in which the perforation is continued downwards a little farther than in the former. The perforation continues

upwards for a long distance into the petiole, but disappears before the first pinnae are formed, the two straps fusing into a single meristele (Fig. 2, 5).

When a bud is present on the side of the petiole, the vascular supply to it is taken from the adaxial end of the adjacent strap (Fig. 2, 2 and 3). There is nothing remarkable about the position of the protoxylem groups. There are four groups altogether, two in each strap. When the perforation disappears and the leaf-trace becomes horse-shoe shaped, the four protoxylem

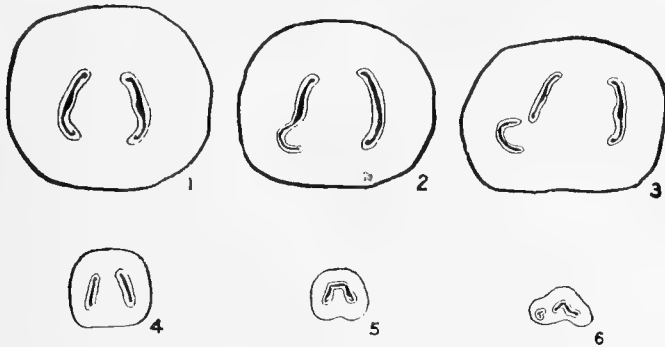


FIG. 2.—Diagrammatic drawings of leaf-trace of *T. blechnoides*.

groups still persist; but when the pinna-traces are formed, the upper two groups are replaced by a single median one.

The pinna-traces arise from the margin of the leaf-trace (Fig. 2, 6).

### *The Leaf.*

The leaf is about twelve to eighteen inches, and the pinnae about six inches in length. In one of Lobb's specimens from Singapore in the Herbarium at Glasgow University two of the lower pinnae are forked about one inch from their insertion on the rachis.

*Venation.*—The venation of the leaf is reticulate (Fig. 3*a* and *b*); see also Presl (10). These reticulations are found about equally numerous on the area between the midrib and the fusion-sorus, and on that between the latter and the margin. But underlying the reticulation is a general course of the veins towards the margin comparable with that seen in *Blechnum braziliense*. Beneath the sorus is a continuous vascular supply or commissure like the commissure found in *Blechnum* (Fig. 3*b*). In cases where the sorus is not continuous, the commissure disappears also. Thus it is seen that the venation of *Taenitis* corresponds essentially with that of *Blechnum*, but with the addition of reticulations, which are a sign of advance.

*Fusion Sorus.*—Both the sorus and the commissure are situated midway between the margin and the midrib. It is a mixed sorus, and in the mature condition, at any rate, is devoid of an indusium. It becomes a question of

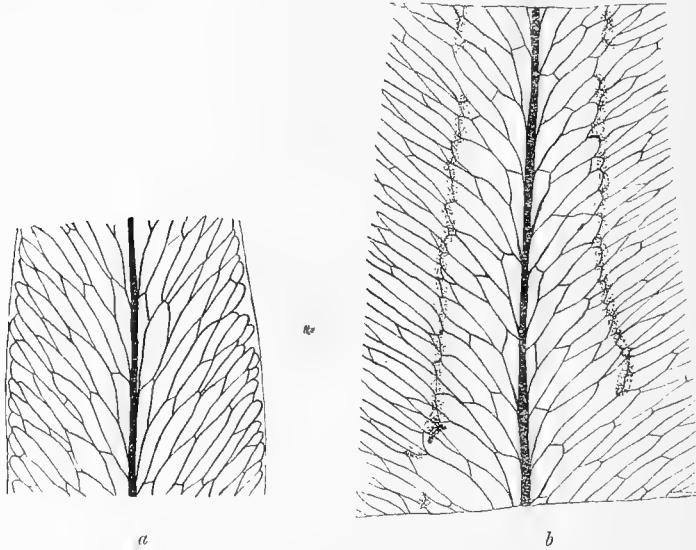


FIG. 3.—*T. blechnoides*.

(a) Venation of sterile leaf. (b) Venation of fertile leaf, showing commissural vein.

interest whether or not an indusium is present in earlier stages of development. The youngest material available is that figured in Fig. 4, from which it is seen that the indusium at that stage is absent. From this

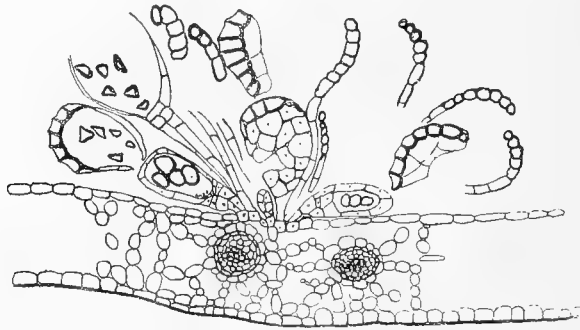


FIG. 4.—*T. blechnoides*. Transverse section through sorus.

drawing may also be seen the mixed character of the sorus; some of the sporangia being mature and their spores shed, while others are in the initial stages of development. A vein, which is the commissural vein, directly underlies the sorus. This commissure and its relation to the sorus is seen

better in the longitudinal section shown in Fig. 5; (a) is a vein cut transversely in its course out towards the margin, and (b) is the commissure cut longitudinally. It is seen how the sporangia are formed along its whole length and are developed irregularly.

Young material for developmental purposes was obtained from Singapore, but it was too young to show the first origin of the sorus. There can be no doubt, however, that they are of superficial origin, since in some cases an expanse of leaf of over half an inch in width extends beyond the sorus, with a complicated network of veins.

*Sporangia.*—The mature sporangium does not differ markedly from the type seen in *Blechnum*. No obliquity has been seen in the annulus, and rupture takes place by means of a lateral slit. The annulus is composed of

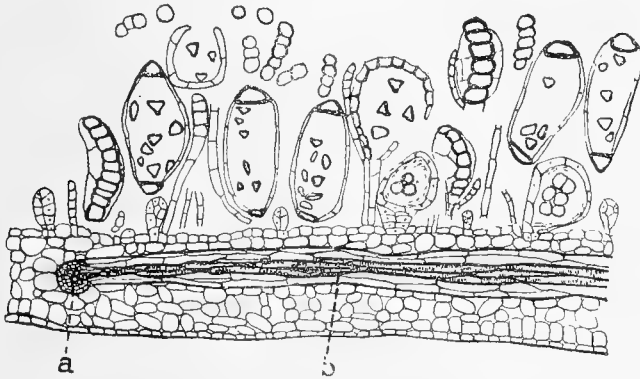


FIG. 5.—*T. blechnoides*. Longitudinal section through sorus.  
(a) Vein cut transversely. (b) Commissural vein cut longitudinally.

from sixteen to eighteen indurated cells—a smaller number than that of the typical *Blechnum*, and it is interrupted at the stalk. The stalk is three-celled, and of medium length. The spores are tetrahedral.

From the stalk of the sporangium there grows a hair. Being inserted on the stalk below the sporangial head, it is similar in position to the glandular hair of *Nephrodium*. It is probable that its function is a protective one, and that it takes the place of the absent indusium, since in some cases the hairs were seen to arch over the sporangia and cover them.

## THE REMAINING GENERA COMMONLY KNOWN AS *TAENITIDINAE.*

### ESCHATOGRAMME.

Of the remaining *Taenitidinae*, the genus which resembles *Taenitis* most closely is *Eschatogramme*. This Fern has been known under many names. Its present designation was introduced by Trevisan (1850). Diels ((5), p. 303)

calls it *Dicranoglossum* J. Sm. Amongst its other generic synonyms are *Pteropsis* J. Sm., *Cuspidaria* and *Taenitis*. This uncertainty of nomenclature would seem to show that systematists have been doubtful of its exact position. The only species is *Eschatogramme furcata* (L.) C. Chr.

The leaves are simpler than those of *Taenitis*, for though they may be deeply divided, the dichotomous character appears more obviously in their branching, so that they can scarcely be spoken of as pinnate leaves. They hold, in fact, an intermediate position between the pinnate leaf of *Blechnum* and of *Taenitis*, and the simple leaf as seen in some of the other *Taenitidinae* and the *Vittariaceae*.

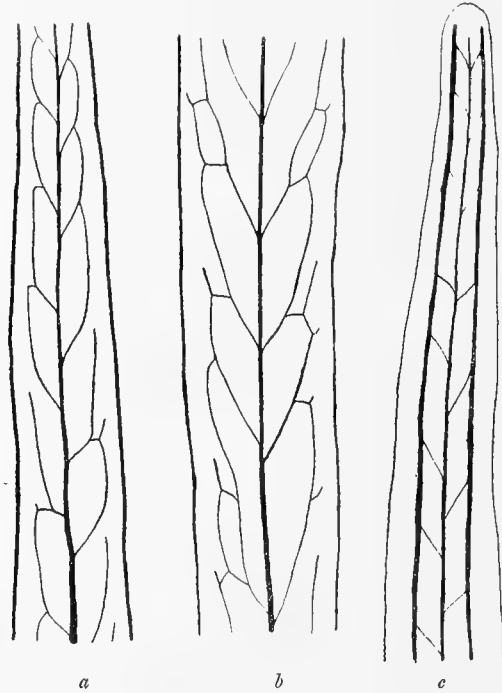


FIG. 6.—*Eschatogramme furcata*. (a) Venation of upper portion of sterile leaf. (b) Lower portion of same leaf. (c) Venation of fertile leaf.

No mention is made in Synopsis Filicum or Engler and Prantl of an indusium, and none was visible on the Herbarium specimens available for examination.

Diels ((5), p. 303) notes that in *Dicranoglossum furcatum* (Willd.) J. Sm. (= *Eschatogramme*) the leathery leaf bears small scales on its lower surface. This is remarkably well seen in herbarium specimens collected by Hooker in Trinidad, and by Pamplin in Caraccas. It has an added interest for comparison with *Blechnum*, since *Taenitis* is without them on the leaf surface, though, as has been seen, small scales are present on its rhizome. There is a linear sorus on either side of the midrib.

The venation of *Eschatogramme* is similar to that in *Taenitis*, and unlike the remaining form in the absence of intra-areolar vein-endings. The reticulation is rather meagre, consisting chiefly of a series of large areolae on either side of the midrib, while free vein-endings are directed outwards towards the margin. It might readily be held as reduced from the condition seen in *Taenitis* (Fig. 3, *a* and *b*).

Diels ((5), p. 303) says that the veins of the sterile leaves of *Dicranoglossum* (= *Eschatogramme*) are mostly free and seldom anastomose. It will be seen from the drawings of the sterile leaves (Fig. 6, *a* and *b*) that, on the other hand, the veins are mostly anastomosed, and seldom free. In the fertile leaves, there is a very definite commissure beneath the sorus (Fig. 6 *c*, and (5), p. 304). This is another point of resemblance to *Taenitis* and *Blechnum*.

The reticulation of the veins, and the presence of a soral commissure, are close links to *Taenitis*, and it seems probable therefore that there is a phyletic sequence from *Taenitis* to *Eschatogramme*, and on to forms in which the pinnation of the leaf has completely disappeared, the result being the simple leaf.

The sporangia are very similar to those of *Taenitis*. There is an interrupted annulus with a variable number of indurated cells—12 to 18. The stalk is a three-celled one, and the spores are thin-walled and two-sided.

#### DRYMOGLOSSUM.

*Drymoglossum* was first described by Presl in 1836. It has gone under various synonyms, amongst them being *Taenitis*, in which genus it was placed by Mettenius in 1856. Its habit is seen in (5), fig. 160. It has a slender elongated rhizome which is covered with scales. The leaves which are dimorphic arise some distance apart from each other. The fertile leaves are long and linear, while the sterile are small and ovate. The sorus is continuous and without a covering. There are nine species, of which *D. carnosum* and *D. heterophyllum* were available for examination.

#### *Dermal Appendages.*

The dermal appendages of *Drymoglossum* are scales only (Fig. 7, *a*). They are broad and well-developed, and are attached to the epidermis at approximately their centre (x). They form a striking contrast to the small hair-like scales of *Taenitis*, and this is probably in relation to its epiphytic habit.

#### *Anatomy of Stem and Leaf.*

The stelar anatomy of *Drymoglossum* shows an advanced dictyostelic condition. The number of meristemes present vary from four to seven, and there



are numerous perforations. This condition is a very much more advanced one than that found in *Taenitis*. The leaf-trace is formed by the passage outwards of two meristemes. These afterwards fuse to form a single bundle in the midrib before the venation of the leaf is begun.

#### The Sorus.

It has been already noted that the leaves of *Drymoglossum* are dimorphic, the sterile leaves being ovate while the fertile are linear, and approximately three times the length of the sterile.

The sori are also linear, and are somewhat sunken and parallel, one running on each side of the midrib about midway to the margin. Interruptions may occur in the sorus. There is no indusium, but the sporangia are

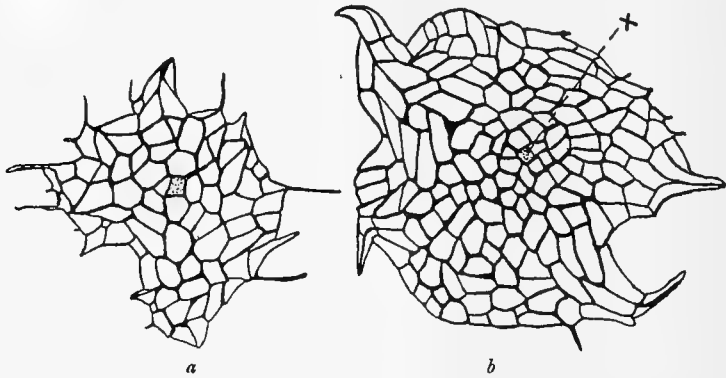


FIG. 7.—*Drymoglossum carnosum*.  
(a) Scale from sorus. (b) Scale from rhizome.

completely covered by a thick felting of scales. These scales are similar in form to those found on the stem, but they are smaller (Fig. 7, b).

The sporangia are smaller than those seen in *Taenitis*, there being only thirteen or fourteen indurated cells in the annulus. Sterile hairs are not present. The annulus is a vertical one, and there is a large, very prominent stonium of six cells. The stalk of the sporangium is three-celled. The spores are two-sided.

#### Venation.

It will be remembered that the venation in *Taenitis* showed a well-developed reticulum, with no blind endings. Fig. 8, a shows that in the sterile leaves of *Drymoglossum*, on the other hand, intra-areolar blind-endings are

very numerous. But there are none in the fertile leaf of *Drymoglossum* (Fig. 8, *b*), and a commissural vein is seen to run underneath the sorus, as in *Taenitis*. At points where interruptions of the sorus occur, the commissural vein is also missing, showing that it bears the same relation to the sorus as

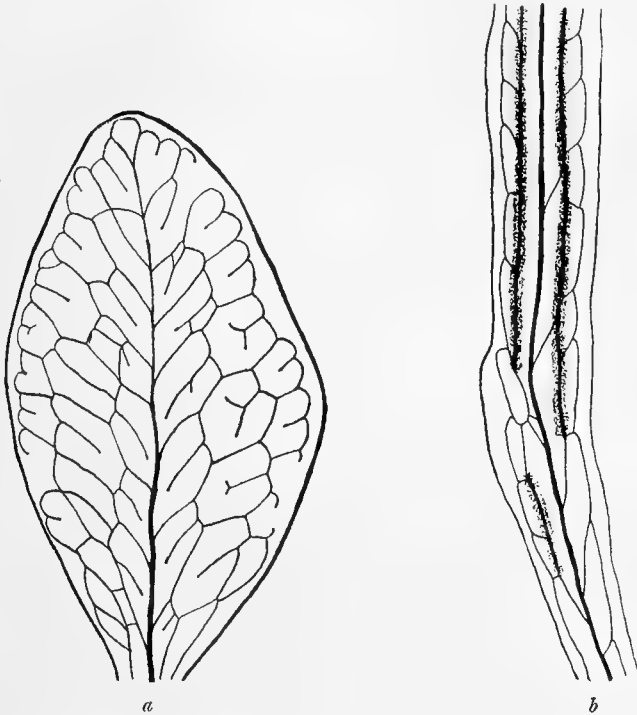


FIG. 8.—*Drymoglossum carnosum*.  
(*a*) Venation of sterile leaf. (*b*) Venation of fertile leaf.

does the similar vein in *Taenitis* and *Blechnum*. The natural conclusion is that the linear sorus of *Drymoglossum* is really a fusion-sorus of the same nature as that of *Taenitis*, or *Blechnum*.

#### PALTONIUM.

The genus *Paltonium* was first named by Presl in 1849. Diels gives it the title of *Heteropteris* after Fée, and it was also described as a species of *Taenitis*, as *T. lanceolata*, by R. Brown, in 1868. It is not unlike *Drymoglossum* in the slender straggling stem, but the leaves, which are linear, differ in the absence of dimorphism, and they are broader than the fertile leaves of *Drymoglossum*. There is a linear sorus over which the margin curls, forming a false indusium. There are only two species, of which *P. lanceolatum* was available for examination, from collections by Professor Bower, in Jamaica.

*Dermal Appendages.*

Like *Drymoglossum* the dermal appendage of *Paltonium* is a scale (Fig. 9, a) the cell-walls of which are very much thickened. It differs from that of *Drymoglossum* in its mode of attachment to the epidermis—being attached

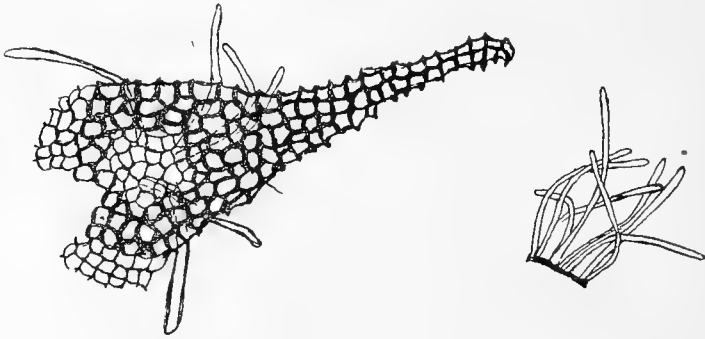


FIG. 9.—*Paltonium lanceolatum*. Scale and hairs from rhizome.

at the base, while that of *Drymoglossum* is peltate, being attached in the middle; and, secondly, in its bearing numerous unicellular hairs, which grow out from the thinner cells in the centre of the scale.

*Anatomy.*

The stem, which is about twice as thick as that of *Drymoglossum*, has an advanced dictyostele, with numerous perforations. The number of meristemes present vary from 9 to 11. Roots arise externally from the centre of the meristemes.

The leaf-trace consists of two bundles, which divide and fuse again, so as to form a series of perforations at the base of the petiole. Higher up the original two bundles are reverted to, and these finally fuse into one.

*Sorus.*

The sorus is linear, and lies close to the margin, which rolls over it, forming a false indusium. The sporangia (Fig. 10) are like those of *Drymoglossum* in their vertical annulus, with thirteen to fourteen indurated cells, and the three-celled stalk. It also resembles *Drymoglossum* in having two-sided spores.

*Venation.*

The venation of the fertile leaf of *Paltonium* is shown in Fig. 11. It will be seen that a commissure is present below the sorus; but it here appears

marginal, while between it and the midrib is a reticulum, in which intra-areolar blind-endings are found. In this respect it compares generally with the sterile leaf of *Drymoglossum*; but in this genus the commissure of the fertile leaf is not marginal. The question may then arise on this point, whether the relationship of *Paltonium* may not be with the Pterid series

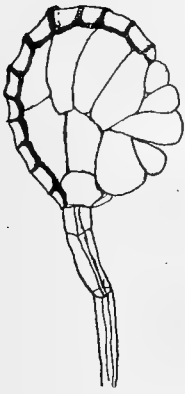


FIG. 10.—*Paltonium lanceolatum*.  
Sporangia.

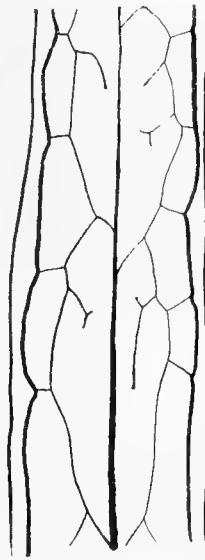


FIG. 11.—*Paltonium lanceolatum*,  
Venation of fertile leaf.

where the fusion sorus is actually marginal. Doubtless this may have been the reason for the name *Heteropteris* assigned to this fern by Fée.

This possible alternative must for the present be left open, till the structural details are available from more extensive material than that at present in hand.

#### HYMENOLEPIS.

*Hymenolepis* was first described by Kaulfuss in 1824. Like *Drymoglossum* and *Paltonium* it has also been included by some authors in *Taenitis*. It differs in habit from these in having a short, creeping rhizome, and in its leaves being more closely packed together ((5), fig. 161). The leaves are simple, broader than those of *Paltonium*, and are thick and fleshy in relation to its epiphytic habit. Dichotomy of the tip of the leaf was observed in one instance. The sorus is continuous, and is situated intra-marginally on the leaf, and is devoid of indusium. Material of the epiphytic species *H. spicata* was available for examination, collected from tree-tops in Queensland by Professor Osborn, of Adelaide, South Australia.

*Dermal Appendages.*

The dermal appendage, which is a scale, is shown in Fig. 12. It is a thin-walled scale, and the tip of it breaks up into a number of small hairs.

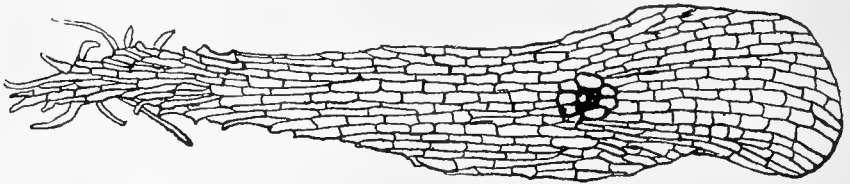


FIG. 12.—*Hymenolepis spicata*. Scale from rhizome.

It is attached to the epidermis at about one-third its length from the broader end.

*Anatomy.*

The stelar anatomy of *Hymenolepis* shows the same perforated dictyostelic structure as *Paltonium* and *Drymoglossum*, except that in *Hymenolepis* the leaf-traces come off closer together owing to the crowding

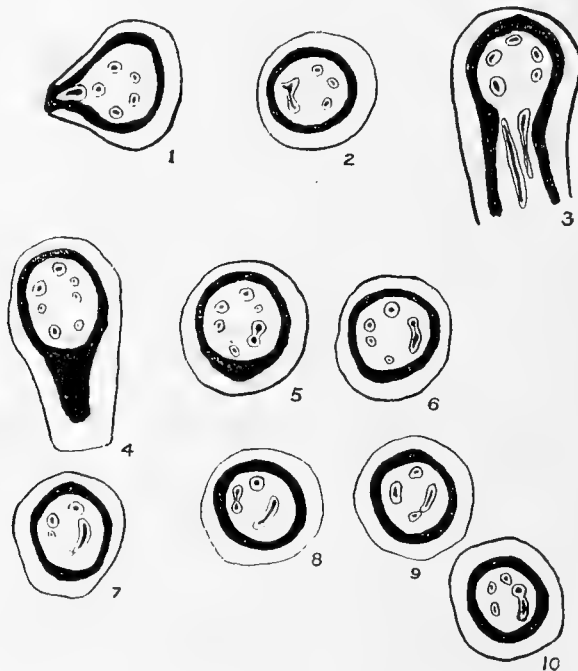


FIG. 13.—*Hymenolepis spicata*. Diagrammatic drawings of stele.

of the leaves. Fig. 13 illustrates the stele of *H. spicata*. There are normally five meristele (1), and the root-traces arise externally from the centre of

them. A perforation is seen closing in (2), but the meristeles have again separated in (3). The leaf-trace consists of two straps, which, taking a course for some distance along the stem after entry, appear to increase the number of meristeles present to seven (4); but later they fuse with the others, so that finally the original five meristeles are established once more.

The leaf-trace is of the same character as those of the last two genera, in consisting of two straps, which fuse into one in the course of the petiole.

#### *The Sorus.*

The leaf is linear and about an inch to an inch and a half at its widest point. The sorus is also linear and devoid of an indusium. It may extend down the whole length of the leaf, or it may be confined to the distal end. Sometimes at the tip of the leaf, in the mature state, the sorus may spread

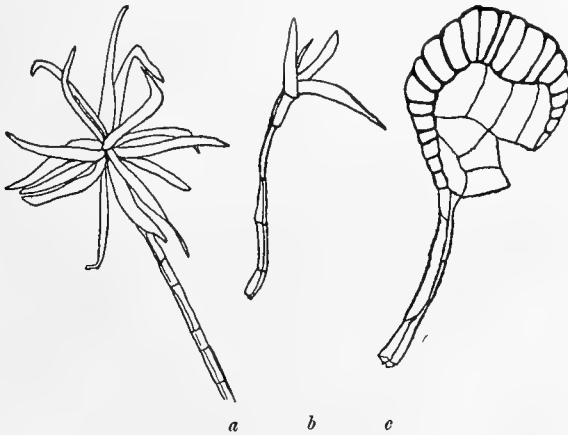


FIG. 14.—*Hymenolepis spicata.*

(a) and (b) Stellate hairs from sorus. (c) Sporangium.

inwards, and even give the appearance of meeting at the midrib, thus suggesting an acrostichoid state.

There are numerous paraphyses among the sporangia which consist of a stalk bearing from three to a large number of spreading hairs on its tip. (Fig. 14 a and b.)

The sporangia are large with eighteen indurated cells in the annulus. (Fig. 14 c.) The annulus is vertical, and there is a very long three-celled stalk. The spores are two-sided.

#### *Venation.*

It was difficult to demonstrate the venation of *H. spicata* owing to the fleshiness of its leaves. But in Engler and Prantl (fig. 161) the venation is

shown to be similar to that of *Drymoglossum* and *Paltonium* in the presence of numerous intra-areolar blind-endings. The figure does not show whether there is a commissural vein underlying the sorus, but, from the general course of the veins, it is possible that such a vein is present.

There was no material available for a developmental study of *Drymoglossum*, *Paltonium*, and *Hymenolepis*.

Sufficient of the soral and anatomical characters of the *Taenitidinae*—excluding *Platytaenia*—have now been described to justify an attempt to place them in their proper relationship to one another.

They fall naturally into two series, *Taenitis* and *Eschatogramme* on the one hand, and *Drymoglossum*, *Paltonium* and *Hymenolepis* on the other. The points of connexion between *Taenitis* and *Eschatogramme* are first, the similar venation, and secondly, the form of the leaf. There was no material of *Eschatogramme* available except herbarium material, so that its anatomy could not be fully worked out. Whether the resemblance to *Taenitis*, so marked in the venation, would be borne out in other points of its structure, cannot of course be stated.

The other three genera differ widely from *Taenitis*. The principal points of difference apart from their habit and leaf-form are (*a*) the presence of well-developed scales instead of the hairs and imperfectly formed scales of *Taenitis*; (*b*) the advanced structure of the stele and the leaf-trace; and (*c*) the venation with its profusion of blind-endings—a point sufficient in itself to divide these genera from *Taenitis*.

We may therefore separate *Taenitis* and probably also *Eschatogramme* from the remaining *Taenitidinae*. *Taenitis* and *Eschatogramme* are held to show a nearer character of their leaves, both in outline and in venation, to the genus *Blechnum*, with which genus they seem to be more nearly related than to any other series. The general appearance of these Ferns and the form of their leaf are distinctly blechnoid, and the resemblance extends to many other characters.

The dermal appendages of *Taenitis* are simpler than any recorded for *Blechnum*; but still they are of the nature of scales, though much reduced. In *Eschatogramme*, however, well-developed scales are present. The presence of a gland on the appendage of *Taenitis* is a point in common with the *Blechnum* scale.

The stele is a dictyostele, as is the stele of the *Blechnum*; but that of *Taenitis* is simpler than of any recorded *Blechnum*. This we may explain by comparing the habit of the typical *Blechnum* with its crowded leaves with that of *Taenitis*, where the leaves are relatively more remote. This accounts

for the crowding of the leaf-gaps in *Blechnum*, and the consequent complications of the dictyostele.

Hand in hand with the simple stele of *Taenitis* goes also the simple leaf-trace.

In the leaf, besides the general form, the great point of resemblance to *Blechnum* is the intra-marginal commissure. It is formed in exactly the same way as that of *Blechnum*, and, like it, breaks up with the dissolution of the sorus (1).

A commissure is also seen in the other three genera, but it is not always intra-marginal, an exception being seen in *Paltonium*. The presence of this commissure is a leading point of resemblance between them and *Taenitis*. Whether this is a sufficient ground for basing a relationship must not be granted offhand, since a commissure is also found in the Pterid series. It is a point which must be left over until further developmental work, especially on *Paltonium*, is available. On all other points of comparison the three genera, *Drymoglossum*, *Paltonium*, and *Hymenolepis*, are sufficiently different from *Taenitis* for us to keep them in a measure apart from it.

The absence of an indusium in *Taenitis* is a point of difference from the typical *Blechnum*; but in *Brainea*, which is a *Blechnum* derivative, the indusium is also absent. It seems probable that in both abortion of the indusium has occurred.

*Taenitis* may be regarded as an advanced type, though its scales are relatively narrow, and the stelar structure does not progress beyond a relatively juvenile stage. The well-formed reticulate venation is to be held as an advanced feature. As regards the sorus, it is possible that it has developed from indusiate forms such as *Blechnum*, but that the sorus protection has been lost in the course of evolution, as is seen to be the case in *Brainea*.

A suggestion has been made by Eva Schumann (11) that there is a possible relationship between *Taenitis* and *Pteris*. This seems highly improbable, for in *Pteris* the commissure is marginal, while in *Taenitis* the commissure is intra-distal with a well-developed venation between it and the margin of the leaf. The fact seems to be that in the Pterids and Blechnoids a similar lateral fusion of sori, into linear fusion-sori, has taken place. But the former are Ferns with their sori marginal; the latter have their sori superficial.

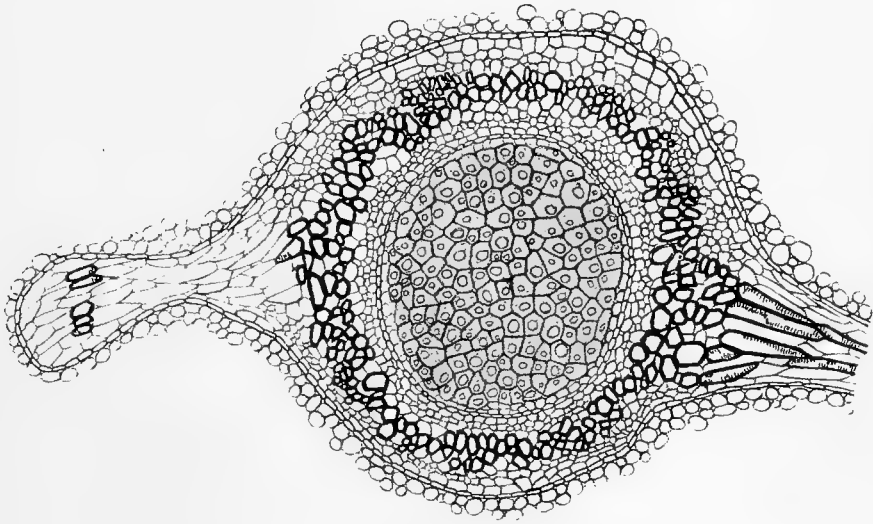
Frau Schumann also suggests that the structure of *Platytaenia* bears the same relation to that of *Taenitis* as does *Acrostichum aureum* to *Pteris*. *Platytaenia* is certainly a form with an acrostichoid sorus, and comparison indicates *Taenitis* as a probable point of origin. But it is to be borne in



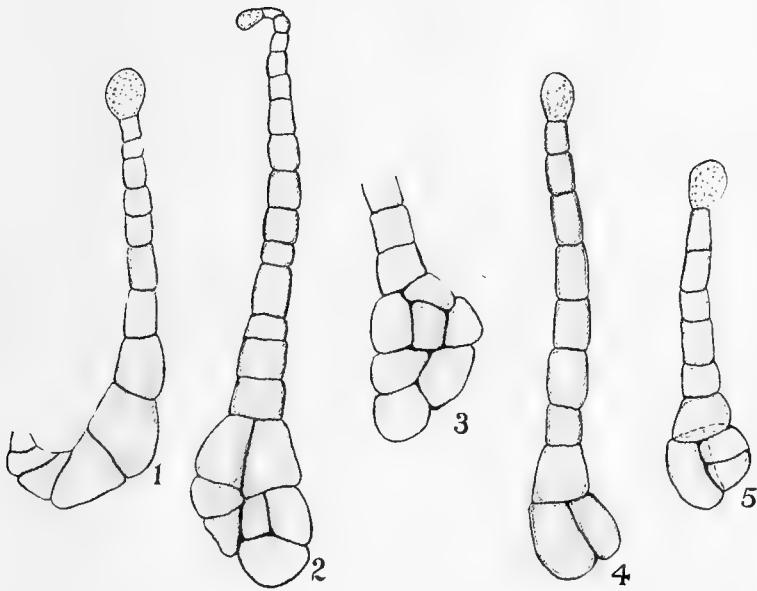
mind that the starting-point has been different here from that of a *Pteris*, to produce *Acrostichum aureum*. In the latter case the acrostichoid spread was from the margin inwards. But in the case of *Platytaenia*, if the start were from *Taenitis*, the spread would be not from a marginal fusion sorus, but from one definitely intra-marginal. The spread might then be either outwards to the margin, or inwards to the midrib, or both. We know that in *Brainea*, on the disappearance of the indusium, the sorus spreads outwards, which is exactly the opposite of the inward spread to produce *Acrostichum aureum*. It must remain for developmental examination to show what is actually the case in *Platytaenia*. But in any case, it is only an analogy which cannot be closely drawn in view of the essential difference of the Pterid from the Blechnoid type.

The above revision of characters of the genera examined leads to the probability that they are all Blechnoid derivatives with the possible reservation of *Paltonium*. The nearest genera to the true Blechnoids would be *Taenitis* and *Eschatogramme*. The rest have diverged more widely in relation to the epiphytic habit which they show, and consequently their relation to the Blechnoid stock is more or less obscured. There is, however, reason to believe that they are all properly to be regarded as offshoots of the Blechnoid series, characterized by the fusion-sorus of intra-marginal position.

The work for the above paper was done in Glasgow University during the tenure of a Travelling Studentship from the National University of Ireland. I wish to express my gratitude to Professor Bower of Glasgow University, not alone for having welcomed me to his department, and having given me every facility for the carrying out of the work, but also for his continued interest in its progress, and his kind assistance and direction throughout.



A.



B.



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THE QUANTITATIVE SPECTRA OF LITHIUM,  
RUBIDIUM, CAESIUM, AND GOLD.

BY

A. G. G. LEONARD, A.R.C.Sc.I., B.Sc., Ph.D.,

AND

P. WHELAN, A.R.C.Sc.I.

(PLATE XVI.)



[*Authors alone are responsible for all opinions expressed in their Communications.*]

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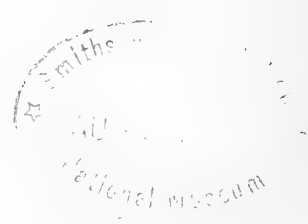
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EXPLANATION OF PLATE XV.

Fig.

- A. *Taenitis blechnoides*. Transverse section of young stem, showing solenostelic condition. Camera lucida drawing.
- B. *Taenitis blechnoides*. Dermal appendages. 1 shows the simple hair with the glandular tip. 2 to 5 show variations in the form of the scale. Camera lucida drawings.



## XXV.

THE QUANTITATIVE SPECTRA OF LITHIUM, RUBIDIUM,  
CAESIUM, AND GOLD.

BY A. G. G. LEONARD, A.R.C.Sc.I., B.Sc., PH.D.,

AND

P. WHELAN, A.R.C.Sc.I.

(PLATE XVI.)

[Read JANUARY 22; published FEBRUARY 15, 1918.]

THIS work is a continuation of that begun in 1907 by Pollok and Leonard<sup>1</sup> with a view to facilitating the use of the spectrograph in detecting the metallic elements when present in solution in small quantities.

It was then pointed out that a knowledge of the metallic lines, which appear in the spark spectra of dilute solutions, is of great importance from the analytical standpoint. The strongest lines of the metallic spectra are not necessarily those which have the greatest persistency as solution lines, and, consequently, the identification of the metals in a dilute solution by comparison of the few lines observed with a complete list of all the lines in the spectrum becomes laborious and, in many cases, uncertain.

Knowledge of the dilution spectra, on the other hand, renders identification rapid and certain.

The work was carried out with a one-prism quartz spectrograph recently purchased from Messrs. Hilger of London. The dark slide is so made as to take specially thin glass photographic plates in slightly curved form, by which means the whole spectrum from  $\lambda$  7000 to  $\lambda$  2000 is received on the plate in very good focus. This effects a considerable saving in time, as it obviates the

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<sup>1</sup> Proc. R. D. S., vol. xi, 1907, pp. 184, 217, 229.

necessity of making separate adjustments for portions of the spectrum of widely different refrangibility.

The spark was obtained from a Ruhmkorff's Induction Coil with a current of 5 ampères, a self-induction coil and condenser being placed in circuit.

Small conical glass tubes were previously used to keep the solution under examination up to the level of the top of the electrodes. By making the electrode of foil wrapped in the shape of a tube about 1 mm. bore, the glass tubes were dispensed with.

Wratten and Wainwright's panchromatic plates were used throughout, and it will be seen from the illustration how strongly the red hydrogen line at  $\lambda$  6563 develops on these plates. The plates were developed with pyro-soda in total darkness for three minutes.

The lines were measured on a micrometer reading to  $\frac{1}{10000}$  of an inch, and identified by reference to a carefully prepared curve.

Certain letters of the Greek alphabet have been used, as before, to denote the relative persistency of the lines.

Thus:—

$\tau$  = seen with the metal, not with strong solution.

$\sigma$  = seen with strong solution, not with 1% solution.

|            |   |       |   |   |       |   |       |
|------------|---|-------|---|---|-------|---|-------|
| $\phi$ =   | „ | 1%    | „ | „ | ·1%   | „ | ----- |
| $\chi$ =   | „ | ·1%   | „ | „ | ·01%  | „ |       |
| $\psi$ =   | „ | ·01%  | „ | „ | ·001% | „ |       |
| $\omega$ = | „ | ·001% | „ | „ |       |   |       |

Gold electrodes were used in the first instance, and when in certain cases solution lines were masked by coincidence with gold lines, the exposures were repeated, using copper electrodes. An attempt to use lead electrodes was unsuccessful, as the lead was rapidly attacked by the hydrochloric acid present, and gave a spectrum so dense as to render difficult the observation of the lines due to the solution under examination. In the examination of the lines given by gold solutions, platinum and silver electrodes were employed, the latter giving the more satisfactory results.

*Exposure*.—The exposures were one minute for the electrodes (long), and two minutes for the solutions (short).

*Metallic Spark Spectra*.—The spectra of lithium and rubidium were obtained by sparking the metals in an atmosphere of hydrogen in a glass

tube provided with a quartz window. By this means we were able to compare the solution and metallic spark spectra directly. We were not able to procure a specimen of metallic caesium for comparison with the spectrum of the chloride.

A line at  $\lambda$  2478 occurs in the spectra of metallic lithium and rubidium, but not in the spectra of the chlorides. We were not able to establish the identity of this line, and have marked it with a query.

### LITHIUM.

Solutions of lithium chloride were examined with gold electrodes, and the persistency of the lines recorded. The lithium line at  $\lambda$  4602.5 appeared; however, to be masked by coincidence with Au  $\lambda$  4601.6, and it was thought advisable to repeat the experiments with copper electrodes. Examined in this way the line was well shown, and was easily followed through the dilutions.

The most persistent lines are at  $\lambda\lambda$  6708.2 and 4602.5.

#### *Quantitative Spectrum of Lithium Chloride.*

| Scale Measurement. | Wave-length. | Intensity and Persistency. | Scale Measurement. | Wave-length. | Intensity and Persistency. |
|--------------------|--------------|----------------------------|--------------------|--------------|----------------------------|
| 125.1              | 6708.2       | 3 $\omega$                 | 250.6              | 4132.6       | 2 $\psi$                   |
| 142.5              | 6103.8       | 5 $\psi$                   | 348.5              | 3383.0       | Ag no. 15                  |
| 200.4              | 4792.8       | Au no. 9                   | 376.2              | 3232.8       | 2 $\phi$                   |
| 212.8              | 4602.5       | 3 $\omega$                 | 488.1              | 2799         | 1 $\psi$                   |
| 220.9              | 4488.4       | Au no. 10                  | 613.0              | 2478 (?)     | 2 $\tau$                   |
| 234.1              | 4315.4       | Au no. 11                  |                    |              |                            |

## RUBIDIUM.

Rubidium chloride solutions were examined with gold and copper electrodes. The lines did not exhibit any remarkable persistency, only one,  $\lambda$  4571.8, appearing with the 1% solution.

*Quantitative Spectrum of Rubidium Chloride.*

| Scale Measurement. | Wave-length. | Intensity and Persistency. | Scale Measurement. | Wave-length. | Intensity and Persistency. |
|--------------------|--------------|----------------------------|--------------------|--------------|----------------------------|
| 200.4              | 4792.8       | Au no. 9                   | 257.4              | 4065.2       | Au no. 12                  |
| 214.6              | 4571.8       | 1 $\chi$                   | 270.1              | 3940.6       | 2 $\sigma$                 |
| 234.4              | 4315.4       | Au no. 11                  | 275.1              | 3898.0       | Au no. 13                  |
| 236.0              | 4294.1       | 1 $\sigma$                 | 312.9              | 3601.4       | 2 $\sigma$                 |
| 237.9              | 4273.3       | 1 $\tau$                   | 315.1              | 3586.7       | Au no. 14                  |
| 240.4              | 4244.5       | 3 $\sigma$                 | 324.7              | 3522.2       | 1 $\sigma$                 |
| 242.9              | 4215.7       | 2 $\sigma$                 | 348.5              | 3383.0       | Ag no. 15                  |
| 244.1              | 4202.0       | 5 $\sigma$                 | 376.4              | 3230.8       | Au no. 16                  |
| 253.2              | 4104.5       | 1 $\sigma$                 | 612.9              | 2478 (?)     | 10 $\tau$                  |

## CAESIUM.

The solution of the chloride showed a fair number of lines. The most persistent were at  $\lambda\lambda$  4593.5, 4555.5, 4540.2, and 2525.8.

*Quantitative Spectrum of Caesium Chloride.*

| Scale Measurement. | Wave-length. | Intensity and Persistency. | Scale Measurement. | Wave-length. | Intensity and Persistency. |
|--------------------|--------------|----------------------------|--------------------|--------------|----------------------------|
| 200.4              | 4792.8       | Au no. 9                   | 467.8              | 2859.5       | 2 $\sigma$                 |
| 213.7              | 4593.5       | 6 $\omega$                 | 478.2              | 2825.6       | Au no. 20                  |
| 216.1              | 4555.5       | 5 $\omega$                 | 542.2              | 2641.6       | Au no. 23                  |
| 217.1              | 4539.5       | 5 $\omega$                 | 546.4              | 2630.7       | 3 $\chi$                   |
| 220.9              | 4488.4       | Au no. 10                  | 558.6              | 2600.5       | 1 $\sigma$                 |
| 257.4              | 4065.2       | Au no. 12                  | 559.9              | 2597.0       | 2 $\phi$                   |
| 267.4              | 3959.8       | 3 $\sigma$                 | 587.0              | 2535.5       | Ag no. 25                  |
| 271.2              | 3925.8       | 3 $\sigma$                 | 590.5              | 2525.8       | 1 $\omega$                 |
| 275.1              | 3898.0       | Au no. 13                  | 609.2              | 2485.6       | 1 $\phi$                   |
| 304.5              | 3661.5       | 2 $\sigma$                 | 623.8              | 2456.0       | 1 $\phi$                   |
| 348.5              | 3383.0       | Ag no. 15                  | 656.6              | 2393.0       | 1 $\phi$                   |
| 368.9              | 3268.5       | 2 $\phi$                   |                    |              |                            |

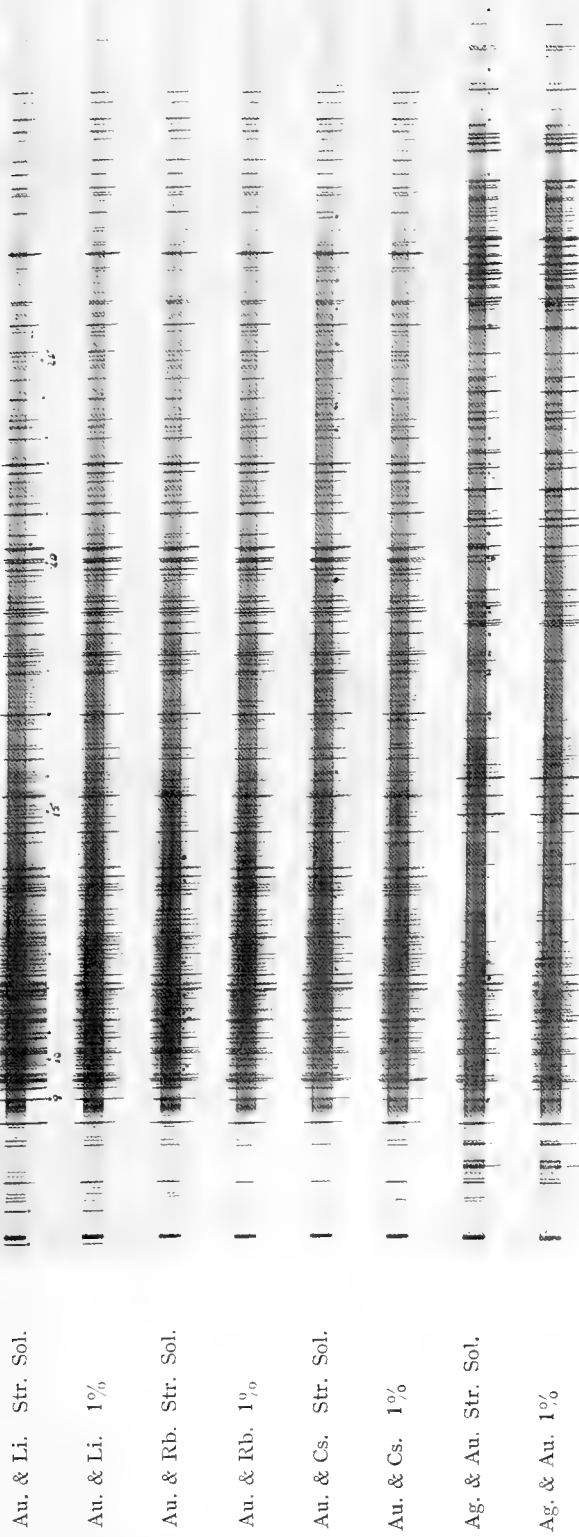
## GOLD.

Gold chloride examined with platinum electrodes shows a good number of lines, and with silver electrodes some lines coincident with platinum lines are revealed. The solution lines are not very persistent, no lines appearing with  $\cdot 01\%$  of metal in solution. The lines showing in a  $\cdot 1\%$  solution are  $\lambda\lambda$  4792.8, 4310.7, 3927.8, 3133.2, 3122.9, 2918.5, 2676.1, 2641.6, and 2201.4.

*Quantitative Spectrum of Gold Chloride.*

| Scale Measurement. | Wave-Length. | Intensity and Persistency. | Scale Measurement. | Wave-Length. | Intensity and Persistency. |
|--------------------|--------------|----------------------------|--------------------|--------------|----------------------------|
| 198.6              | 4822.0       | 2 $\phi$                   | 480.2              | 2820.1       | 2 $\sigma$                 |
| 200.4              | 4792.8       | 8 $\chi$ No. 9             | 484.7              | 2805.4       | 6 $\sigma$                 |
| 220.9              | 4488.4       | 1 $\sigma$ No. 10          | 485.7              | 2802.3       | 10 $\sigma$                |
| 234.7              | 4310.7       | 1 $\chi$                   | 491.9              | 2780.9       | 1 $\sigma$                 |
| 257.3              | 4065.2       | 1 $\sigma$ No. 12          | 503.0              | 2748.4       | 6 $\phi$                   |
| 262.0              | 4016.3       | 1 $\sigma$                 |                    | 2688.8       | 1 $\phi$                   |
| 270.7              | 3927.8       | 4 $\chi$                   | 524.1              | 2688.2       | 1 $\phi$                   |
| 314.7              | 3586.7       | 8 $\phi$ No. 14            |                    | 2687.7       | 1 $\phi$                   |
| 397.1              | 3133.2       | 5 $\chi$                   | 528.7              | 2676.1       | 7 $\chi$                   |
| 398.7              | 3122.9       | 10 $\chi$ No. 17           | 541.6              | 2641.6       | 7 $\chi$                   |
| 419.9              | 3038.3       | 1 $\sigma$                 | 600.3              | 2503.4       | 3 $\phi$                   |
| 420.9              | 3033.2       | 5 $\phi$                   | 678.4              | 2352.7       | 4 $\phi$                   |
| 429.5              | 2995.1       | 4 $\sigma$                 | 707.2              | 2304.9       | 1 $\phi$                   |
| 430.9              | 2990.4       | 4 $\sigma$                 | 720.7              | 2283.4       | 2 $\phi$                   |
| 440.2              | 2954.5       | 1 $\sigma$                 | 732.8              | 2263.8       | 1 $\sigma$                 |
| 451.3              | 2918.5       | 8 $\chi$                   | 763.5              | 2219.4       | 1 $\sigma$                 |
| 453.3              | 2913.6       | 1 $\sigma$                 | 767.7              | 2213.2       | 1 $\sigma$                 |
| 473.5              | 2838.1       | 1 $\phi$                   | 776.3              | 2201.4       | 1 $\chi$                   |
| 477.6              | 2825.6       | 3 $\sigma$                 |                    |              |                            |

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Au. & Li. Str. Sol.

Au. & Li. 1%

Au. & Rb. Str. Sol.

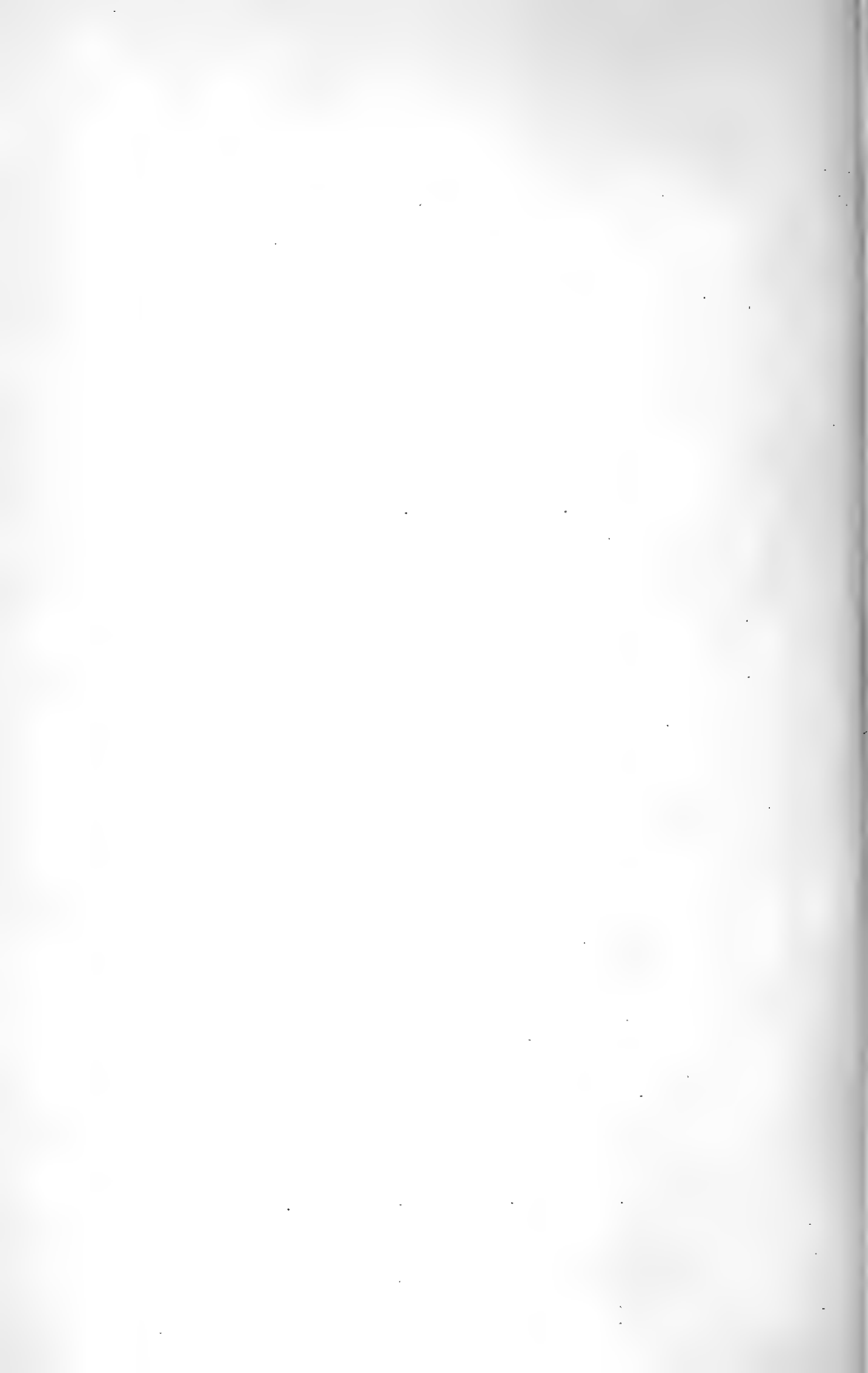
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THE POLARISATION OF A LECLANCHÉ CELL.

BY

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AND

R. J. FEELY, A.R.C.Sc.I.



[*Authors alone are responsible for all opinions expressed in their Communications.*]

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1918.

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## XXVI.

## THE POLARISATION OF A LECLANCHÉ CELL.

By FELIX E. HACKETT, Ph.D.,

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AND

R. J. FEELY, A.R.C.Sc.I.

[Read NOVEMBER 27, 1917; published MARCH 22, 1918.]

THIS investigation arose out of an examination of the conditions required for the accurate measurement of the internal resistance of a cell as an experiment in an elementary course in electricity. It is well known that the polarisation of a Leclanché cell makes it difficult to attain any precision in this measurement. By polarisation is understood, here, the temporary change in E.M.F. of a voltaic cell brought about by the passage of a current through it. During a preliminary examination of the manner in which the polarisation grows when the circuit is closed and decays on open circuit a theory was developed which led to a simple formula for the curve of recovery of the cell. This theory indicated that the decay of polarisation follows the law for the velocity of bi-molecular reactions obeyed by the ionisation of gases. It will be convenient to consider the results of the experimental work arranged to test it under the following heads:—

- (1) General characteristics of the polarisation.
- (2) The types of polarisation shown by the recovery curve.
- (3) Summary of observations on the Leclanché cell.
- (4) The polarisation of the Weston cadmium cell.

(1) *General Characteristics of the Polarisation.*

A Leclanché cell was arranged in circuit with a variable resistance adjusted by aid of a similar cell so that the initial current was 0.2 ampère.

The voltage between the cell terminals was measured by a Weston voltmeter.

This instrument is almost dead-beat and very suitable for measuring with fair accuracy a varying voltage. By estimation readings could be made to 0.01 volt.

The initial value of the voltage on open circuit was taken. The circuit was then closed, and the voltage on closed circuit was read at intervals for 10 minutes, during which the current was maintained at the constant value of 0.2 ampère. The circuit was then opened and the recovery of the cell from polarisation noted until it had almost recovered its initial value.

It is unnecessary to give the observations. A typical curve is given in Fig. 1. This series of observations was repeated several times, during which the initial value of the E.M.F. fell from 1.52 to 1.41 volts. In spite of this alteration in the cell, the recovery in each case was represented by the same curve, as was shown by the coincidence of the curves plotted on transparent paper. The cell was allowed to stand for three weeks, and the experiment repeated. Practically the same recovery curve was obtained. The same regularity was not shown in the growth of polarisation when the current was passing through the cell which was represented by slightly varying curves. The polarisation was therefore studied by the recovery curve in all the subsequent work.

(2) *The two Types of Polarisation shown by the Recovery Curve.*

The recovery curve may be described, in general terms, as rising very rapidly, and becoming almost parallel to the axis of time after about 10 minutes. In the set of observations represented in fig. 1, the voltage rose 0.63 volt during the first 10 minutes to 1.43 volts. In another 60 minutes the recovery was 0.04 volt. The initial value 1.50 volts was registered 30 hours afterwards. We are, therefore, led to divide the period of recovery into two sections: (1) the first part, characterized by a rapid rise, and practically completed within an hour, (2) the second, a slow creep going on for several hours, and perhaps not entirely completed for several days. On the ionic theory the polarisation occurs at the carbon-manganese-dioxide electrode due to the arrival of positive ions which are not discharged instantaneously. A surplus of positive ions thus accumulates at the electrode in the electrolyte, and a corresponding negative charge appears on the electrode. The process is analogous to the charging of a condenser which has a faulty insulation, and so discharges itself when the charging current is

withdrawn. In addition the electrolysis which accompanies the discharge of the ions involves changes in the electrolyte bathing the electrode. This, in itself, may involve an alteration in the potential difference between the electrode and the electrolyte. The difference of potential for a tenfold change in concentration is of the order of 0.05 volt, and therefore can only

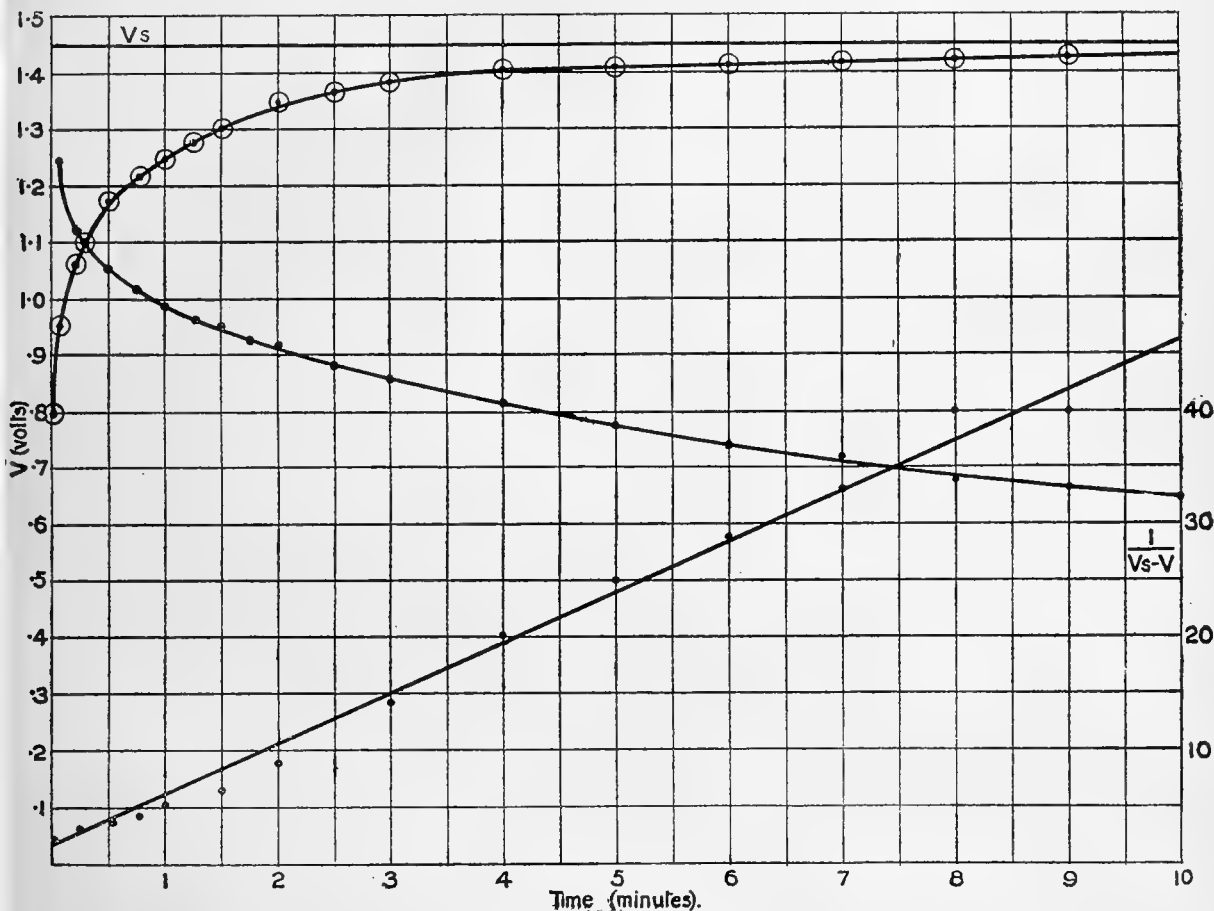


FIG. 1.

account for a small fraction of the polarisation. This is the order of that part of the polarisation which recovers slowly, suggesting some concentration effect such as could only disappear by equalisation of the concentration through diffusion, an essentially slow process. We shall, therefore, provisionally ascribe this part of the polarisation to changes in concentration, and term it the concentration-polarisation. We turn now to that part of the

polarisation which shows a rapid recovery, and which must be due to a surplus of ions over that required for equilibrium. The conditions existing resemble those in an ionised gas close to an electrode. The rate at which ionisation disappears in a gas is represented by

$$\frac{\partial n}{\partial t} = -an^2,$$

where  $n$  is the number of ions of one sign per unit volume. This suggested a similar relation for the ions in the polarisation layer, and an attempt was made to see if a relation such as

$$\frac{\partial P}{\partial t} = -aP^2 \quad (1)$$

held good for the disappearance of the polarisation of the cell. Here  $P$  must be taken as representing that part of the polarisation which is due to the excess of the ions, and is associated with the rapid recovery of the cell. For brevity we shall term this the ionic polarisation.

Owing to the presence of the slow recovery, it is difficult to assign a precise value to  $P$ . If there were no concentration polarisation, the voltage would quickly rise to a stationary value  $V_s$ , but, owing to its presence, this is only approximately true, as is shown by the recovery curve. The E.M.F. becomes almost steady after 10 or 15 minutes, but a slow creep persists for a long time afterwards. Writing

$V_0$  = initial E.M.F. at the instant of opening the circuit;

$V$  = E.M.F. of cell at any subsequent time;

$V_s$  = quasi-stationary value of E.M.F.;

$P = V_s - V$ ;

Equation (1) then gives

$$(V_s - V)^{-1} = at + (V_s - V_0)^{-1}. \quad (2)$$

The linear graph in fig. 1 shows that it is possible to select a value  $V_s$  which brings the observed values of  $(V_s - V)^{-1}$  to a close fit with a straight line over the period of rapid recovery. The most suitable value of  $V_s$  can be determined by trial within 0.01 volt.

This result gives strong support to the analysis of the decay of polarisation into two processes. The close agreement with the relation required by (2) shows that a simple process is at work during the rapid rise, and that the slow creep which persists for a long time afterwards has a very small effect on the initial observations.  $V_s$  should be the asymptote to the recovery curve. This is, however, only approximately so, but it is of assistance in

selecting a suitable value. As time goes on, the slow process of recovery becomes more important than the final stages of the first process, and the curve of recovery will gradually rise above  $V_s$  to the final steady value.

*Summary of Observations on Leclanché Cell.*

The analysis just described has been applied to some 30 sets of observations on Leclanché cells over a range of values for the polarising currents. In all cases, in order to fix the conditions of the experiment, the current through the cell was maintained constant until the conditions of the cell had

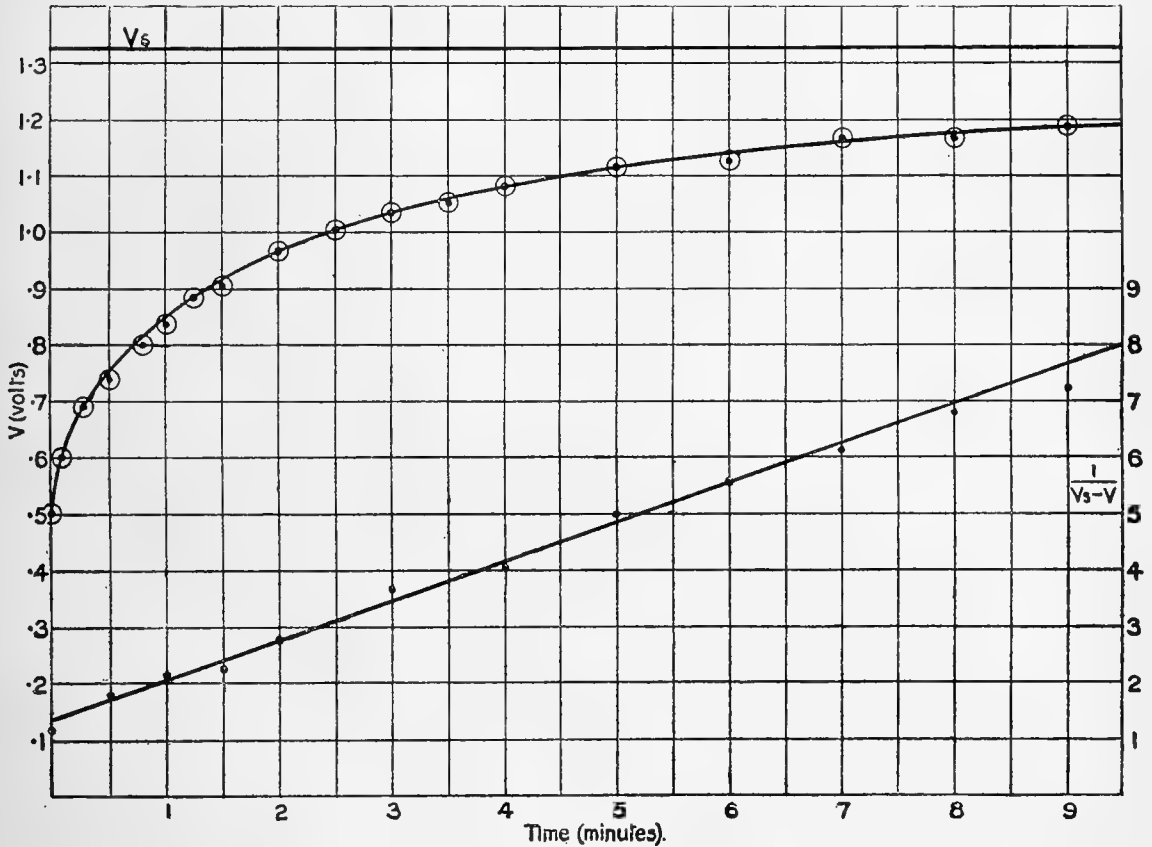


FIG. 2.

become nearly steady. Fig. 1 shows that this stage is reached in about 10 minutes. The voltage of the cell during its recovery was observed with a Weston voltmeter. Its use, however, is subject to some obvious criticisms. This instrument, though convenient, is not sufficiently accurate when the changes in voltage are very rapid or when they are small. In addition the



current through the voltmeter produces a small polarisation which has a slight disturbing effect, even if the voltmeter key is only depressed when taking observations. In spite of these defects, the results were sufficiently accurate, in all cases, to be cast into the form of equation (2). We shall merely reproduce here the observations for an exceptionally large polarisation obtained for a cell which had been in use for some time. The recovery curve was also very slow. In consequence it was easy to obtain accurate readings with the voltmeter. As will be seen by reference to fig. 2, the linear relation required by equation (2) is well satisfied. We find the linear graph gives

$$(1.32 - V)^{-1} = 0.694 t_{min} + 1.38.$$

The manner in which this equation represents the observations may be seen from Table I.

TABLE I.

*Recovery of a Leclanché Cell polarised by 0.32 amp. for 5 minutes.*

| <i>t</i> min.  | 0   | 0.25 | 1    | 3     | 6    | 9    | 11   | 13    | 17   |
|----------------|-----|------|------|-------|------|------|------|-------|------|
| <i>V</i> obs.  | .5  | .69  | .84  | 1.025 | 1.13 | 1.19 | 1.21 | 1.25  | 1.27 |
| <i>V</i> calc. | .59 | .68  | .836 | 1.03  | 1.14 | 1.18 | 1.21 | 1.224 | 1.24 |

The agreement is generally close, except at the beginning, where the reading of the voltmeter cannot record accurately the value of the E.M.F. on opening the circuit, and towards the end where the slower rise has begun to exert its influence.

Another example may be taken from observations for polarisation with small currents made by a modified potentiometer method. A potentiometer was arranged to measure the E.M.F. of the cell, using as a galvanometer a Paul unipivot which had a sensibility of one division per microampère. Small deviations from the null-point were measured by the deflection of the galvanometer, which was shunted off a rheostat so as to give readings over the full length of the scale. A Pohl commutator was arranged as a three-way key so that throwing it over opened the cell circuit and connected the cell to the potentiometer. The following device was used to set the potentiometer to the voltage of the cell immediately on opening the circuit. The cell circuit was closed until the polarisation had become nearly steady. The key was then rocked backwards and forwards so that the cell was alternately either on closed circuit or connected to the potentiometer. The null-point so obtained is the voltage of the cell immediately on opening the cell circuit, for the

rapid opening and closing of the cell circuit does not produce any appreciable effect on the polarisation when it has reached its approximate steady value.

After this adjustment had been made the cell circuit was opened; the deflections of the galvanometer measured the change in the E.M.F. of the cell from its initial value just after opening the circuit. This method eliminates any initial error, and the motion of the pointer recorded with sufficient

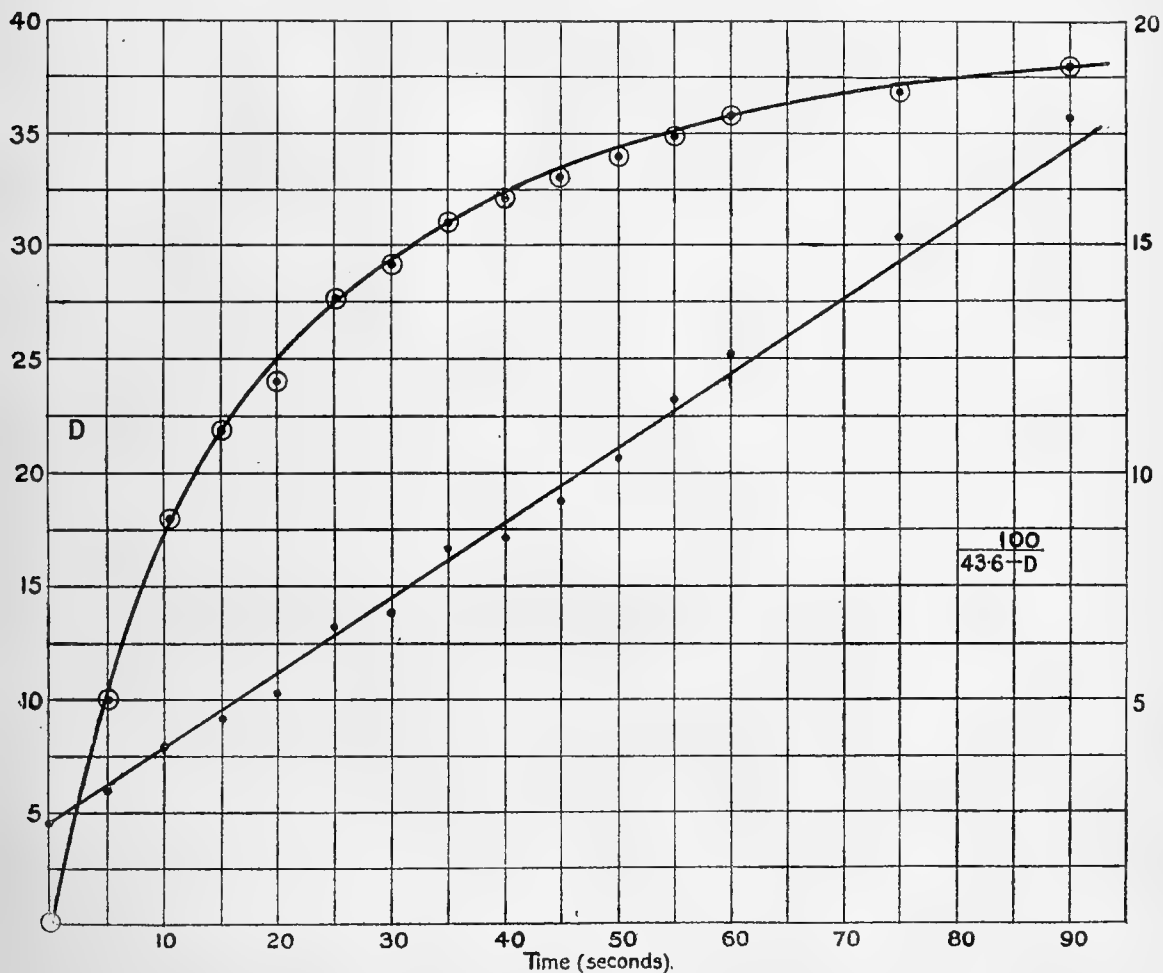


FIG. 3.

accuracy the changes in E.M.F. if they are not too rapid. A sensible error due to this cause can easily be recognized in the observations, but there was no positive evidence of it.

The observations taken in this way for the recovery of a Leclanché cell polarised by a current of 0.035 ampère are plotted in fig. 3,

Writing  $D$  for the deflection of the galvanometer (one division of which was equivalent to 0.0038 volt), the linear graph gives the relation:—

$$(43.6 - D)^{-1} = 0.0980t_{min} + 0.0236.$$

Table II shows the correspondence of the values calculated from this equation with the observations.

TABLE II.

*Recovery of a Leclanché Cell polarised by 0.035 amp. for 16 minutes.*

|           |      |      |      |      |      |      |      |      |      |      |      |      |      |
|-----------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| $t$ sec.  | 0    | 5    | 10   | 15   | 20   | 25   | 30   | 35   | 40   | 45   | 50   | 55   | 60   |
| $D$ obs.  | 0    | 10   | 18.0 | 22.0 | 24.0 | 27.8 | 29.2 | 31.0 | 32.0 | 33.0 | 34.0 | 35.0 | 35.7 |
| $D$ calc. | 1.3  | 12   | 18.5 | 22.8 | 25.8 | 28.1 | 29.8 | 31.2 | 32.3 | 33.3 | 34.1 | 34.8 | 35.4 |
| $t$ min.  | 1.25 | 1.50 | 1.75 | 2.0  | 3    | 4    | 5    | 6    | 7    | 8    | 9    | 10   | 14   |
| $D$ obs.  | 37.0 | 38.0 | 38.7 | 39.1 | 40.5 | 41.2 | 41.7 | 42.2 | 42.3 | 42.6 | 42.9 | 43.0 | 43.7 |
| $D$ calc. | 36.7 | 37.7 | 38.5 | 39.1 | 40.5 | 41.2 | 41.7 | 42.0 | 42.2 | 42.4 | 42.5 | 42.6 | 43.0 |

The agreement is on the whole satisfactory, especially where the deflection is varying rapidly. As in Table I the observed values towards the end of the period of observation rise above the calculated values due to the slow creep which becomes prominent at this stage. The deviations are such as may be expected in the observation of a moving pointer over a scale where tenths of a division have to be estimated instantaneously. Possibly some oscillations of the pointer due to the motion may be superimposed on the deflection due to the change in voltage. At any rate the results justify the expectation that more refined methods of observation would eliminate the irregularities due to the imperfections of the method used in the above experiment.

We may therefore conclude that the empirical equation put forward to represent the rate of recovery of a Leclanché cell, based as it is on imperfect theoretical considerations, is substantially verified, and that it has a physical significance, which remains to be explored. This conclusion is supported by its application to observations on the polarisation of the Weston cadmium cell, which we shall now consider.

#### *The Polarisation of the Cadmium Cell.*

The importance of the cadmium cell as an international standard has led to careful studies of its polarisation which have been placed on record by many observers.<sup>1</sup>

<sup>1</sup> Barnett, "Physical Review," vol. xviii, p. 104. 1904. Smith, "Phil. Trans. R. S. Lond.," series A, vol. ccvii, p. 393. Wold, "Physical Review," vol. xxviii, p. 132. 1909.

We shall consider here those by S. J. Barnett, who has given the polarisation as a percentage of the initial value of the E.M.F. of the cell. The E.M.F. was measured by a modification of the sum and difference method, using a second cadmium cell with a heavily damped galvanometer whose deflections became steady 6 seconds after closing the circuit. As will be seen in fig. 4, the inverse of the polarisation percentage bears a linear relation to the

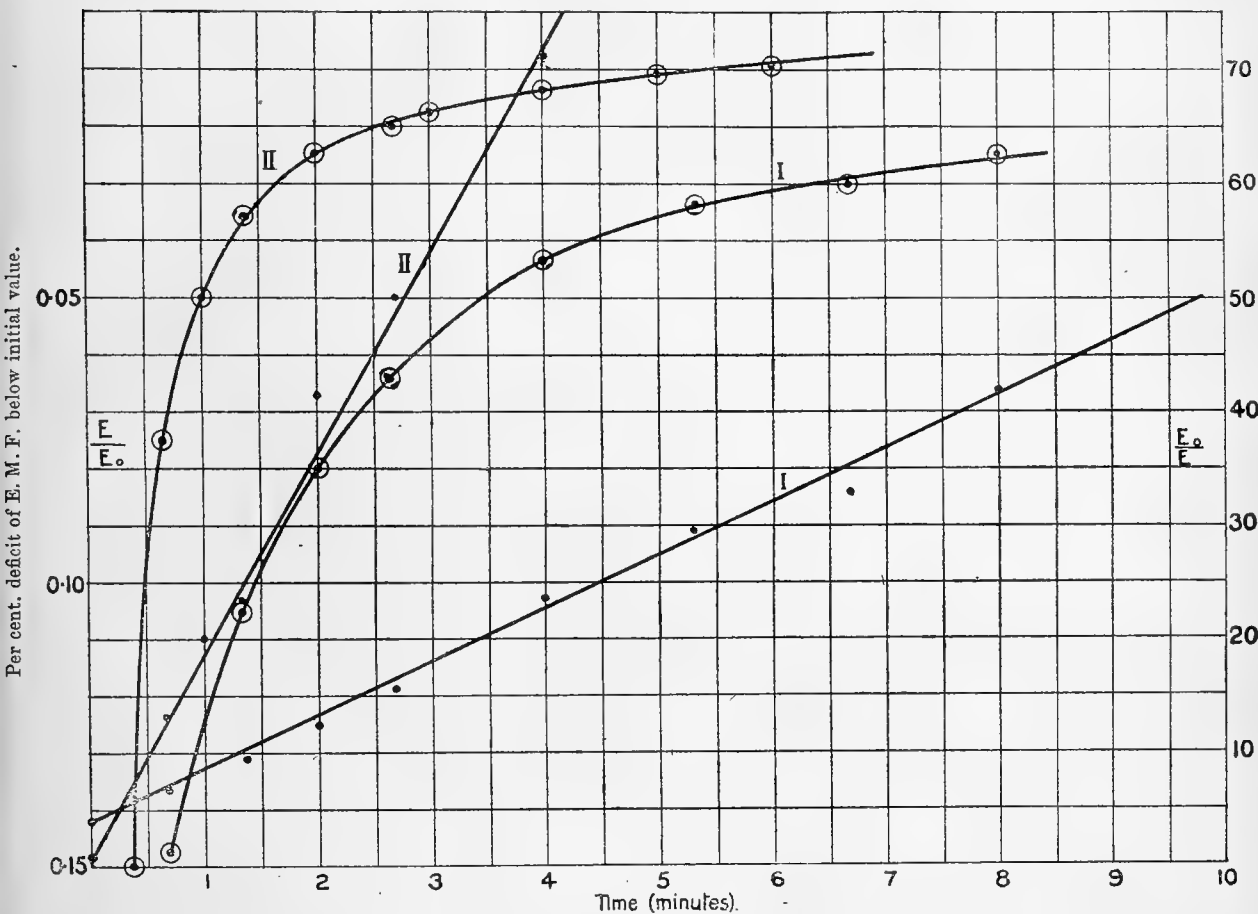


FIG. 4.

time. The graphs indicated by I refer to a cell not previously used, except for potentiometer measurements, which had a resistance of 351 ohms. The graph shows its recovery from a short circuit for 15 minutes. The graphs indicated by II refer to a cell which had a resistance of 401 ohms. This cell had already been used for polarisation experiments a month previously. It was on short circuit for 3 minutes. After allowing 23 minutes for recovery

the process was repeated, and 40 minutes were now allowed for recovery. The cell was again short circuited for 3 minutes, and the recovery observations taken.

When it is borne in mind that the sensibility of the method of observation was 0.001 per cent., the correspondence to the linear relation is remarkable. There does not seem to be any correction required for slow rise, as in the case of the Leclanché cell. A deduction of 0.0008 per cent. from the observations in set II before taking the reciprocal was found to be an improvement; but as this lies within the range of experimental error, no great reliance can be placed on it. A single process would thus seem to govern the recovery of the cadmium cell from polarisation. Its existence alone yields strong support to the physical reality of the analysis we have made of the recovery of the Leclanché cell.

#### CONCLUSION.

The study of the recovery of the Leclanché cell from polarisation has shown that it may be divided into two sections: an initial stage of rapid recovery in which almost 90 per cent. of the polarisation disappears in about 10 minutes; followed by a slow return, extending over several hours, to the initial value of the E.M.F.

The initial stage can be represented by an equation of the type,

$$(V_s - V)^{-1} = at + (V_s - V_0)^{-1},$$

where  $V$  represents the E.M.F. of the cell at any time  $t$ . This equation shows that the decay of polarisation is governed by the same law as the decay of ionisation in a gas. It may be put into the form expressing the velocity of a bimolecular reaction,

$$\frac{dV}{dt} = a(V_s - V)^2.$$

A similar relation has been shown to apply to the polarisation of the Weston cadmium cell, and seems to account for the whole process of the disappearance of the polarisation. This is independent justification of the physical significance of the analysis of the recovery of the Leclanché cell, and leads to the expectation that the law may apply generally to all types of depolarising electrodes.

The discussion of the theoretical interpretation of this result, and of its application to the phenomenon of over-voltage, and other associated questions, is reserved for a subsequent paper.

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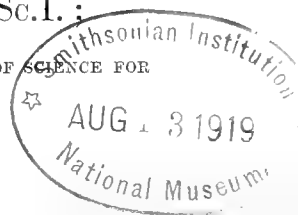
THE ELECTRICAL RESISTANCE OF PORCELAIN  
AT DIFFERENT TEMPERATURES.

BY

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[COMMUNICATED BY PROFESSOR WILLIAM BROWN.]



[*Authors alone are responsible for all opinions expressed in their Communications.*]

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XXVII.

THE ELECTRICAL RESISTANCE OF PORCELAIN AT  
DIFFERENT TEMPERATURES.

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(COMMUNICATED BY PROFESSOR WILLIAM BROWN.)

[Read MARCH 26; published JUNE 14, 1918.]

THE electrical resistance of porcelain, in common with other insulating materials, diminishes enormously with increase of temperature. This change has been quantitatively investigated by a number of workers.

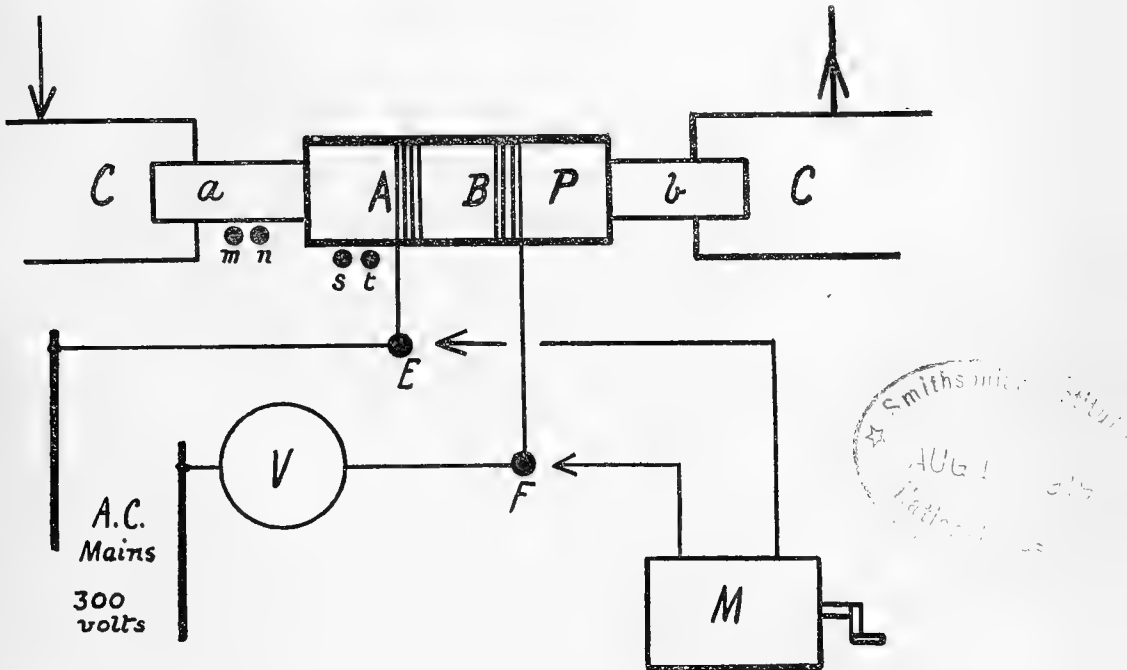


FIG. 1.—Arrangement for a simple test to show change of resistance of porcelain with temperature.

A simple experiment was made to show this change, by using the arrangement of fig. 1. *P* was a porcelain tube of inner diameter 0.8 cm.

and outer diameter 1.1 cms.; *ab* a carbon rod, on which *P* was threaded; *CC* larger carbon rods; *A* and *B* tightly wrapped bands of copper wire; *V* a hot-wire voltmeter used as a milliammeter; and *M* a megger.

*M* was first connected to *E* and *F*, with *A* and *B* about 3.5 cms. apart, and a current was passed through *ab*. The reading of *M* was infinity until *ab* became more heated; when dull-red the resistance was 20 megohms, and at incandescence 15,000 ohms. On switching off the current, the resistance gradually increased as cooling proceeded, reaching infinity again.

The distance between *A* and *B* was then reduced to about 1.5 millimetres, and *E* and *F* connected through *V* to alternating-current mains of voltage 300 and frequency 51.5.

When *ab* was incandescent, *V* indicated 80 milliamperes, so that the resistance of the porcelain between *A* and *B* was  $\frac{300}{0.08} = 4000$  ohms nearly. On switching off the heating current, the reading of *V* fell quickly to zero.

In order to test whether any effect was produced by gaseous or ionic conduction, *E* and *F* were connected to two points, *s* and *t*, one millimetre apart, near the surface of *P*, and afterwards to two similar points, *m* and *n*, close to the carbon when *ab* was incandescent, but in both cases *V* indicated zero.

The first important investigation of the resistance of porcelain and other substances was made by Fousserau in 1894. His sample was in the form of a small tube, closed at one end, and mercury was used for the inside and outside contact surfaces. The results<sup>1</sup> obtained by him for a sample of porcelain were given for a range of temperature from 50° C. to 210° C. At the former temperature the resistance of the sample was  $2150 \times 10^6$  megohms and 6510 megohms at the latter. That is, the resistance at 50° C. was 330,000 times the value of that at 210° C.

In 1909 Pirani and Siemens investigated the change of resistance of porcelain in the form of tubes for different temperatures ranging from 613° C. to 900° C. for one sample, and from 727° C. to 1292° C. for another. Among the values<sup>2</sup> given for the first sample were 1.098 megohms for 613° C., and 68,700 ohms for 900° C. For the second sample 100,000 ohms for 727° C., and 3,400 ohms for 1292° C. were given.

Dietrich, in 1910, made a similar investigation upon certain insulators, including porcelain, and obtained results<sup>3</sup> for a sample of the latter material at temperatures ranging from 20° C. to 189° C. At the former temperature

<sup>1</sup> *Ann. de Chim. et de Phys.*, 6<sup>m</sup>e Sér., vol. 5, 1885, p. 371, Table 29.

<sup>2</sup> *Zeitschr. Elektrochem.* 15. 1909. p. 969. Tables 5 and 6.

<sup>3</sup> *Phys. Zeit.*, 11 January, 1910, Table, p. 188.

the resistance was found to be  $129 \times 10^6$  megohms, and  $0.385 \times 10^6$  megohms at the latter temperature.

The present paper deals with the insulation resistance of samples of porcelain in various forms at different temperatures, ranging from about  $80^\circ \text{C}$ ., or lower in some cases, to about  $250^\circ \text{C}$ ., or sometimes  $300^\circ \text{C}$ .. A description of these samples is given in the following list.

## LIST OF SAMPLES TESTED.

| SAMPLE. | DESCRIPTION.   |
|---------|--|
| A       | A low tension porcelain insulator for transmission wires, obtained from the British Insulated and Helsby Cables Co., Ltd., and catalogued as K 49 large. |
| B       | An insulator similar to A, but of different size, obtained from the same Company and catalogued as K 43.   |
| C       | An old porcelain insulator of similar form to A and B marked:<br>Reg. No. Jan. 10. 1862.   |
| D       | An evaporating dish of German manufacture.   |
| E       | A long porcelain tube; inner diameter 0.8 cm. and outer 1.1 cms. Berlin mark.  |
| F       | A porcelain lid of a crucible. German manufacture.   |
| G       | A china bowl. Aynsley, Stoke-on-Trent. Portland china.   |
| H       | An evaporating dish. Royal Worcester mark.   |

The arrangement used for testing these samples is shown in fig. 2. *T* is the sample with mercury electrodes; *M* the megger; *C* a condenser with mica dielectric; *E. V.* an electrostatic voltmeter, Lord Kelvin's multicellular

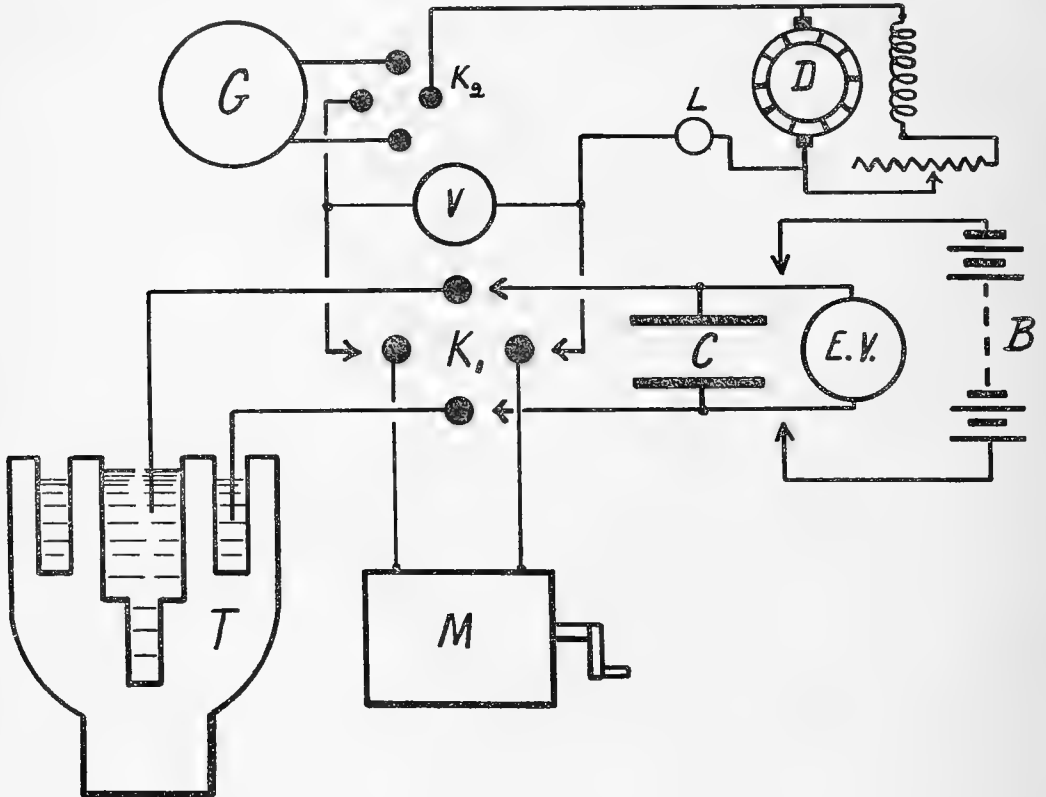


FIG. 2.—Diagram of the arrangement used for testing the samples.

type; *G* a galvanometer; *D* a shunt-wound dynamo, whose field rheostat was adjusted to give different voltages when required; *B* a battery of about 100 volts; *K*<sub>1</sub> and *K*<sub>2</sub> reversing keys. *K*<sub>1</sub> was made of four small cylinders of paraffin wax, well separated, and mounted on a base of vulcanite, which in turn was mounted on glass. Cavities at the top of the cylinders held mercury.

The three methods of testing were used for checking each other. This may be done in the case of the megger and galvanometer methods, as their ranges are more nearly alike; but the range of the leakage method is to a large extent outside that of the other two.

Most of the results of this investigation were obtained by using voltages of about 100 for the leakage method, and a capacity of 0.5 microfarad, or

0.005 microfarad for the lowest temperatures. A voltage of about 120, or lower, as required, was used for the galvanometer method, and the voltage of the megger at rated speed was 500.

The range of the megger was 10,000 ohms to 40 megohms, and could only be used for the higher temperatures.

In the case of the galvanometer it was found that 0.363 volt operating through a resistance of 10,000 ohms gave a deflection of 152 divisions. From this the formula

$$R = 4.19 \frac{E}{D} \text{ megohms}$$

was derived;  $E$  being the volts across the sample,  $D$  the deflection of the galvanometer, and  $R$  the resistance of the sample in megohms.

By using  $E$  as 100, and the lowest value of  $D$  as 4, a resistance as high as about 100 megohms could be determined by the galvanometer method.

The range of the leakage method depends upon the capacity and time of leakage. Assuming a capacity of 0.005 microfarad, an initial voltage of 102, and a voltage of 100 after 10 minutes' leakage, the corresponding resistance is given by

$$R = \frac{t}{2.3 C \log_{10} \frac{V_1}{V_2}} \text{ megohms} = \frac{600}{2.3 \times 0.005 \times \log 1.02}$$

which is roughly equal to about  $6.5 \times 10^6$  megohms.

The determination of a high *specific* insulation resistance will depend upon the effective area and thickness of the sample as well as upon the range of the method.

From the area and thickness of each sample the formula for determining  $\sigma$ , the value of the insulation resistance in megohms per cm. cube, in terms of  $R$ , was found to be as follows:—

| Sample. | Value of $\sigma$ . |
|---------|---------------------|
| A       | 51.7 R              |
| B       | 90 R                |
| C       | 32 R                |
| D       | 214 R               |
| E       | 1480 R              |
| F       | 86.5 R              |
| G       | 367 R               |
| H       | 336 R               |

$R$  being the resistance of the sample in megohms. In the case of sample  $E$  a mean value is given, the expansion of the long length, about 37 cms., of mercury being appreciable.

As the accuracy of the leakage method depends upon the insulation resistance of the test being independent of the voltage, it was necessary to investigate whether this was so or not.

A limited demonstration of this is the agreement of the galvanometer and megger methods, the former dealing with voltages below 120, while the latter subjects the test to 500 volts. Another indirect method is to show whether the leakage-curves are logarithmic or not.

The agreement between megger and galvanometer methods was generally fairly good, the closest agreement found being given in Table I for sample A.

TABLE 1.

For sample A.

| t° C. | Megger, $\sigma$ . | Galvanometer, $\sigma$ . |
|-------|--------------------|--------------------------|
| 174   | 1140               | 1140                     |
| 183   | 645                | 660                      |
| 194   | 372                | 372                      |
| 203   | 232                | 245                      |
| 213   | 134                | 150                      |
| 222   | 98                 | 103                      |
| 237   | 46.5               | 48.5                     |

A comparison of the three methods is given in Table 2 for sample D, and by graphing  $\sigma$  and temperature, the agreement will be found satisfactory.

TABLE 2.  
For sample D.

| $t^{\circ}\text{C.}$ | Megger, $\sigma.$ | Galvanometer, $\sigma.$ | Leakage, $\sigma.$ |
|----------------------|-------------------|-------------------------|--------------------|
| 149                  | —                 | —                       | 28,200             |
| 150                  | —                 | —                       | 22,000             |
| 152                  | —                 | 21,000                  | —                  |
| 153                  | —                 | —                       | 20,300             |
| 156                  | —                 | 18,000                  | 18,400             |
| 166                  | —                 | —                       | 9,800              |
| 168                  | 8,140             | —                       | —                  |
| 171                  | 6,400             | —                       | —                  |
| 176                  | 4,700             | —                       | —                  |
| 179                  | —                 | 4,300                   | —                  |
| 182                  | —                 | —                       | 3,350              |
| 183                  | 3,200             | —                       | —                  |
| 186                  | —                 | 2,800                   | —                  |
| 191                  | 2,140             | 2,140                   | —                  |

In Fig. 3 are shown some of the leakage curves obtained for sample B, and these are found to be approximately logarithmic.

. A direct voltage test was made on sample B, and the results obtained by the galvanometer method are given in Table 3.

TABLE 3.  
For sample B.

| Temp. 187° C. |      |               | Temp. 180° C. |     |               |
|---------------|------|---------------|---------------|-----|---------------|
| E             | D    | $\frac{E}{D}$ | E             | D   | $\frac{E}{D}$ |
| 40            | 27.5 | 1.45          | 138           | 54  | 2.55          |
| 96            | 61   | 1.57          | 158           | 62  | 2.55          |
| 120           | 75.5 | 1.60          | 236           | 91  | 2.60          |
| 131           | 83   | 1.62          | 242           | 92  | 2.63          |
| 149           | 94   | 1.58          | 416           | 164 | 2.55          |
| 161           | 103  | 1.57          | 432           | 166 | 2.60          |
| 170           | 110  | 1.55          | 770           | 308 | 2.50          |
| 188           | 125  | 1.50          | 780           | 312 | 2.50          |



E is the voltage applied to the sample, and D the galvanometer deflection. For the set of higher voltages the galvanometer was shunted with 196 ohms.

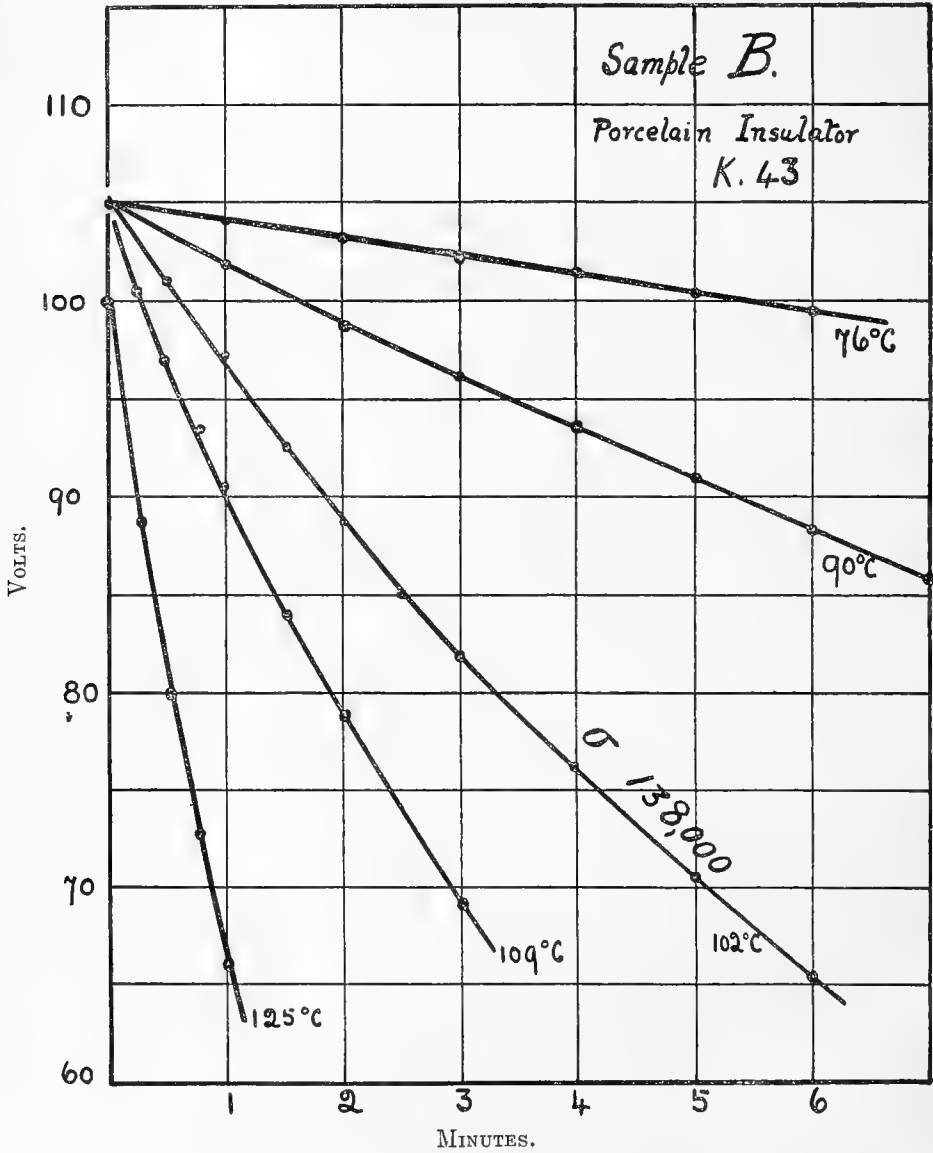


FIG. 3.—Leakage Curves for Sample B.

Thus, for a range of voltage from 40 to about 800 volts, the insulation resistance of the sample at the given temperatures is approximately independent of the voltage.

Sample D was also tested for voltages up to 230 at a temperature 213°C., and the results obtained were :—

|               |      |      |      |      |      |
|---------------|------|------|------|------|------|
| <i>E</i>      | 230  | 212  | 122  | 85.5 | 50.5 |
| <i>D</i>      | 364  | 336  | 179  | 120  | 70   |
| $\frac{E}{D}$ | 0.63 | 0.63 | 0.68 | 0.71 | 0.72 |

The investigations of Curtis and others show that the insulation resistance of some materials depends upon the applied voltage. His results are tabulated<sup>1</sup> for different substances for a range of 50 to 500 volts, and only one-third of the number given show variation of resistance with the applied voltage.

Another test was tried on sample B to determine whether, by using a given area of contact-surface in one case and then diminishing it to one-half, the resistance of the sample would be doubled. The results obtained were as follows; the resistance being in megohms :—

| Full Length. |        | Half-Length. |        |
|--------------|--------|--------------|--------|
| Temp.        | Resis. | Temp.        | Resis. |
| 156          | 35     | 158          | 65     |
| 170          | 16     | 171          | 30     |
| 178          | 11     | 179          | 22     |

The resistance is therefore practically doubled in the latter case, and this suggests an absence of creepage over the top of the walls of the sample.

The samples, excepting E, were heated by means of a sandbath, and those in the form of a dish were loaded with mercury to a suitable height, and floated on mercury contained in a larger vessel. Sample E was placed in another tube, which was immersed in oil heated electrically by a spiral of manganin wire wound round this tube. With care a steady temperature could be obtained during a set of observations.

It must be noted that, on account of dielectric absorption in some of the samples, the galvanometer sometimes took several minutes before indicating a steady value. This was accompanied by a directional effect; the resistance being greater in one direction through the walls of the sample than in the other.

<sup>1</sup> Bulletin of the Bureau of Standards, 1915, vol. ii, no. 3, p. 359. Table I.

The latter was much more pronounced at the higher temperatures used, and a further test on two samples at 350° C. showed a still higher increase in dielectric absorption.

While samples D, E, and F showed the latter to an appreciable extent, the others were practically free from it.

The directional effect for sample D is represented as follows, and is typical also of the cases of E and F.

| Method. | Temp. | R +    | R -    |
|---------|-------|--------|--------|
| Megger  | 236   | 1.25   | 1.15   |
|         | 217   | 2.85   | 2.75   |
|         | 178   | 20.50  | 19.5   |
| Leakage | 155   | 665    | 665    |
|         | 87    | 10,000 | 10,000 |

in which the (+) indicates that the megger and leakage currents flowed from the inside to the outside mercury, and (-) in the reverse direction. This effect is still under investigation.

The data for the leakage curves were often obtained several times for a given temperature and found to be practically the same both for (+) and (-) directions even in the case of the samples showing dielectric absorption at the higher temperatures.

As the results of the present work could only be regarded as approximately representative of the insulation resistance of porcelain at different temperatures, all the calculations were made with the slide-rule.

The method of entry of the results is that used by Rasch and Hinrichsen, who, in an important paper,<sup>1</sup> showed that the change of resistance with temperature of porcelain among other materials followed approximately a simple law.

Thus, if  $\sigma$  is the specific insulation resistance of the sample and  $T$  its absolute temperature,

$$\log \sigma = \frac{a}{T} + b,$$

in which  $a$  and  $b$  are constants for a given material.

<sup>1</sup> Zeit. Elektrochem. 14, 1908, p. 41, Table 3, fig. 19.

These workers in the case of porcelain used the results of Fousseureau, already referred to on p. 290, and showed that this formula applied to that material.

Pirani and Siemens, whose results are referred to on p. 290, demonstrated from them that this formula represented also the change of resistance of porcelain with higher temperatures ranging from 600° C. to 1300° C. An equivalent formula was also given by Dietrich in his paper referred to on p. 290.

The following Tables represent the results obtained for the eight samples of porcelain named on p. 291. The thickness of each sample is given at the top of each table. Specific insulation resistance in megohms per cm. cube is represented by  $\sigma$ ;  $t$  is the mean temperature of the mercury contact-surfaces reckoned from zero in degrees centigrade; and  $T$  is the absolute temperature, namely,  $t + 273$ . In each case the porcelain is of the glazed variety, excepting the inner surface of the E, which, though unglazed, was very smooth.

TABLE 4.

Sample A.

Thickness 0.7 cm.

| $t$ . | $T$ . | $\frac{1}{T}$ .       | $\sigma$ . | $\text{Log}_{10} \sigma$ . |
|-------|-------|-----------------------|------------|----------------------------|
| 76    | 349   | $28.6 \times 10^{-4}$ | 900,000    | 5.95                       |
| 81    | 354   | 28.2 „                | 565,000    | 5.75                       |
| 96    | 369   | 27.1 „                | 240,000    | 5.38                       |
| 122   | 395   | 25.3 „                | 28,300     | 4.50                       |
| 127   | 400   | 25.0 „                | 19,500     | 4.29                       |
| 144   | 417   | 24.0 „                | 6,250      | 3.80                       |
| 164   | 437   | 22.9 „                | 2,000      | 3.30                       |
| 168   | 441   | 22.6 „                | 1,550      | 3.19                       |
| 174   | 447   | 22.4 „                | 1,140      | 3.06                       |
| 183   | 456   | 21.9 „                | 650        | 2.81                       |
| 194   | 467   | 21.4 „                | 370        | 2.57                       |
| 213   | 486   | 20.6 „                | 140        | 2.15                       |
| 249   | 522   | 19.2 „                | 31         | 1.49                       |

This, in common with the other Tables, shows the enormous decrease of insulation resistance with increase of temperature.

TABLE 5.

Sample B.

Thickness, 0.65 cm.

| $t$ . | $T$ . | $\frac{1}{T}$ .       | $\sigma$ .  | $\text{Log}_{10} \sigma$ . |
|-------|-------|-----------------------|-------------|----------------------------|
| 25    | 298   | $33.5 \times 10^{-4}$ | 118,000,000 | 8.07                       |
| 43    | 316   | 31.6 ,,               | 27,000,000  | 7.43                       |
| 55    | 328   | 30.5 ,,               | 9,200,030   | 6.96                       |
| 76    | 349   | 28.6 ,,               | 1,170,000   | 6.07                       |
| 90    | 363   | 27.6 ,,               | 380,000     | 5.58                       |
| 102   | 375   | 26.6 ,,               | 138,000     | 5.14                       |
| 110   | 383   | 26.1 ,,               | 75,000      | 4.88                       |
| 125   | 398   | 25.1 ,,               | 26,500      | 4.42                       |
| 139   | 412   | 24.2 ,,               | 9,360       | 3.97                       |
| 150   | 423   | 23.6 ,,               | 4,770       | 3.68                       |
| 161   | 434   | 23.0 ,,               | 1,980       | 3.30                       |
| 174   | 447   | 22.4 ,,               | 1,150       | 3.06                       |
| 187   | 460   | 21.8 ,,               | 560         | 2.75                       |
| 210   | 483   | 20.7 ,,               | 175         | 2.24                       |

The results for samples A and B, the low tension porcelain insulators supplied by the same company, clearly show that the material is practically the same as far as insulation resistance is concerned.

In Fig. 6 the results for A and B fall upon the same straight line; B being represented by the full line and A by the small circles associated with it. The straight line relation of Rasch and Hinrichsen is thus practically true for these two samples.

Figs. 4 and 5 also show the nearness of the curves relating insulation resistance and temperature in the cases of A and B.

It may also be deduced from Fig. 6 that the value of  $\sigma$ , namely  $118 \times 10^6$  megohms per cm. cube for temp.  $25^\circ \text{C}$ ., is probably somewhat underestimated, as the point representing this value lies a little above the line drawn for B.

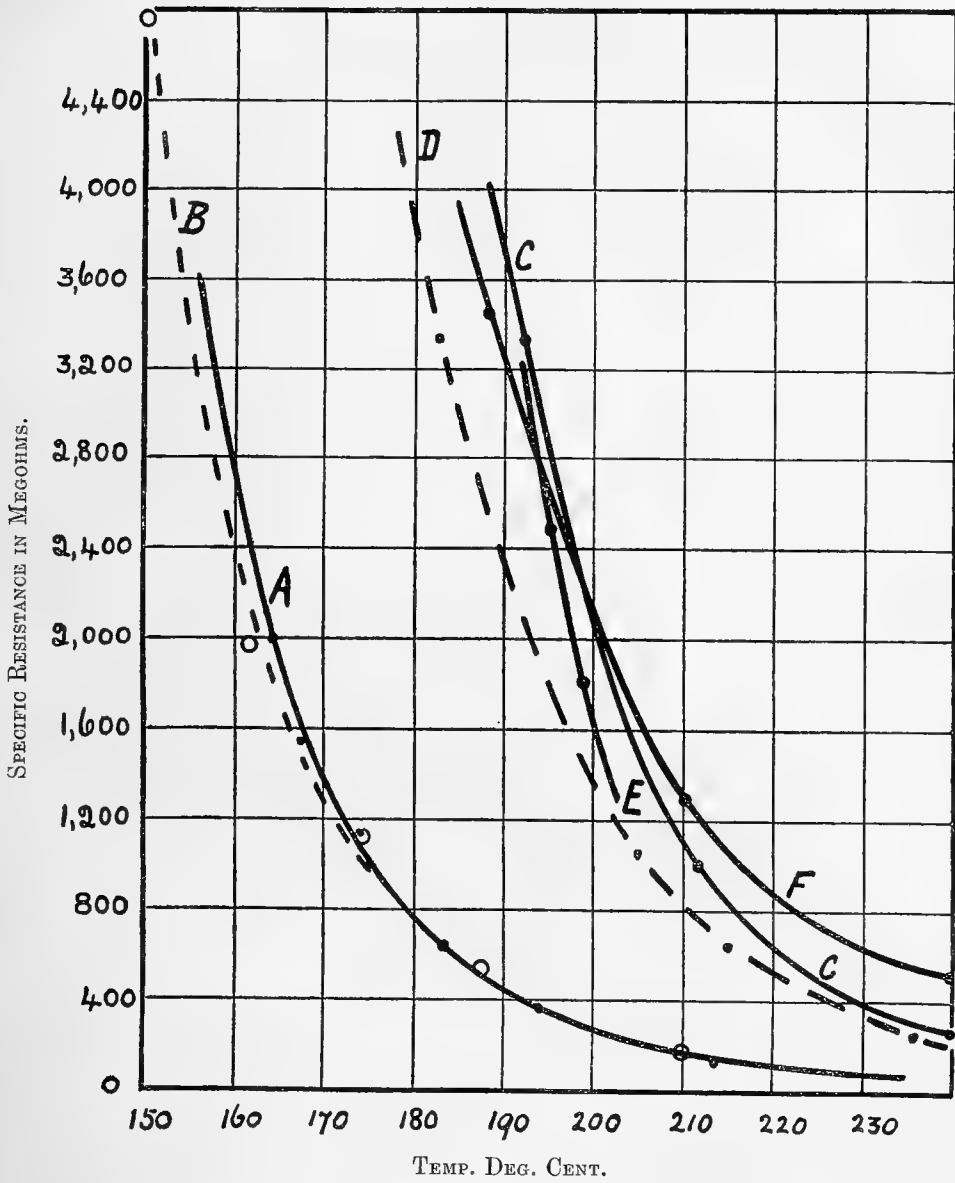


FIG. 4.—Resistance-Temperature Curves for samples A, B, C, D, E, and F.

TABLE 6.

Sample C.

Thickness 0.65 cms.

| $t.$ | $T.$ | $\frac{I}{T}$         | $\sigma.$ | $\log_{10} \sigma.$ |
|------|------|-----------------------|-----------|---------------------|
| 116  | 389  | $25.7 \times 10^{-4}$ | 470,000   | 5.67                |
| 130  | 403  | 24.8 ,,               | 160,000   | 5.20                |
| 160  | 433  | 23.1 ,,               | 22,000    | 4.34                |
| 192  | 465  | 21.5 ,,               | 3,350     | 3.53                |
| 211  | 484  | 20.7 ,,               | 990       | 3.00                |
| 240  | 513  | 19.5 ,,               | 250       | 2.40                |

From Figs. 4, 5, and 6 it is at once seen that this old type of insulator was made of different material from that of the recent low tension insulators A and B. Its material possessed a higher insulation resistance. The line or C is not drawn in Fig. 6, but it falls nearest to that drawn for F.

TABLE 7.

Sample D.

Thickness 0.22 cms.

| $t.$ | $T.$ | $\frac{I}{T}$         | $\sigma.$  | $\text{Log}_{10} \sigma.$ |
|------|------|-----------------------|------------|---------------------------|
| 56   | 329  | $30.4 \times 10^{-4}$ | 36,500,000 | 7.56                      |
| 77   | 350  | 28.5 ,,               | 6,600,000  | 6.82                      |
| 87   | 360  | 27.8 ,,               | 2,140,000  | 6.33                      |
| 95   | 368  | 27.2 ,,               | 1,340,000  | 6.13                      |
| 103  | 376  | 26.6 ,,               | 540,000    | 5.73                      |
| 114  | 387  | 25.8 ,,               | 286,000    | 5.46                      |
| 125  | 398  | 25.1 ,,               | 132,000    | 5.12                      |
| 132  | 405  | 24.7 ,,               | 85,500     | 4.93                      |
| 142  | 415  | 24.1 ,,               | 42,000     | 4.62                      |
| 149  | 422  | 23.7 ,,               | 28,000     | 4.45                      |
| 153  | 426  | 23.5 ,,               | 20,000     | 4.30                      |
| 166  | 439  | 22.8 ,,               | 9,800      | 3.99                      |
| 171  | 444  | 22.5 ,,               | 6,400      | 3.81                      |
| 182  | 455  | 22.0 ,,               | 3,350      | 3.53                      |
| 205  | 478  | 20.9 ,,               | 1,070      | 3.03                      |
| 215  | 488  | 20.5 ,,               | 640        | 2.81                      |
| 236  | 509  | 19.7 ,,               | 256        | 2.41                      |
| 254  | 527  | 19.0 ,,               | 110        | 2.04                      |

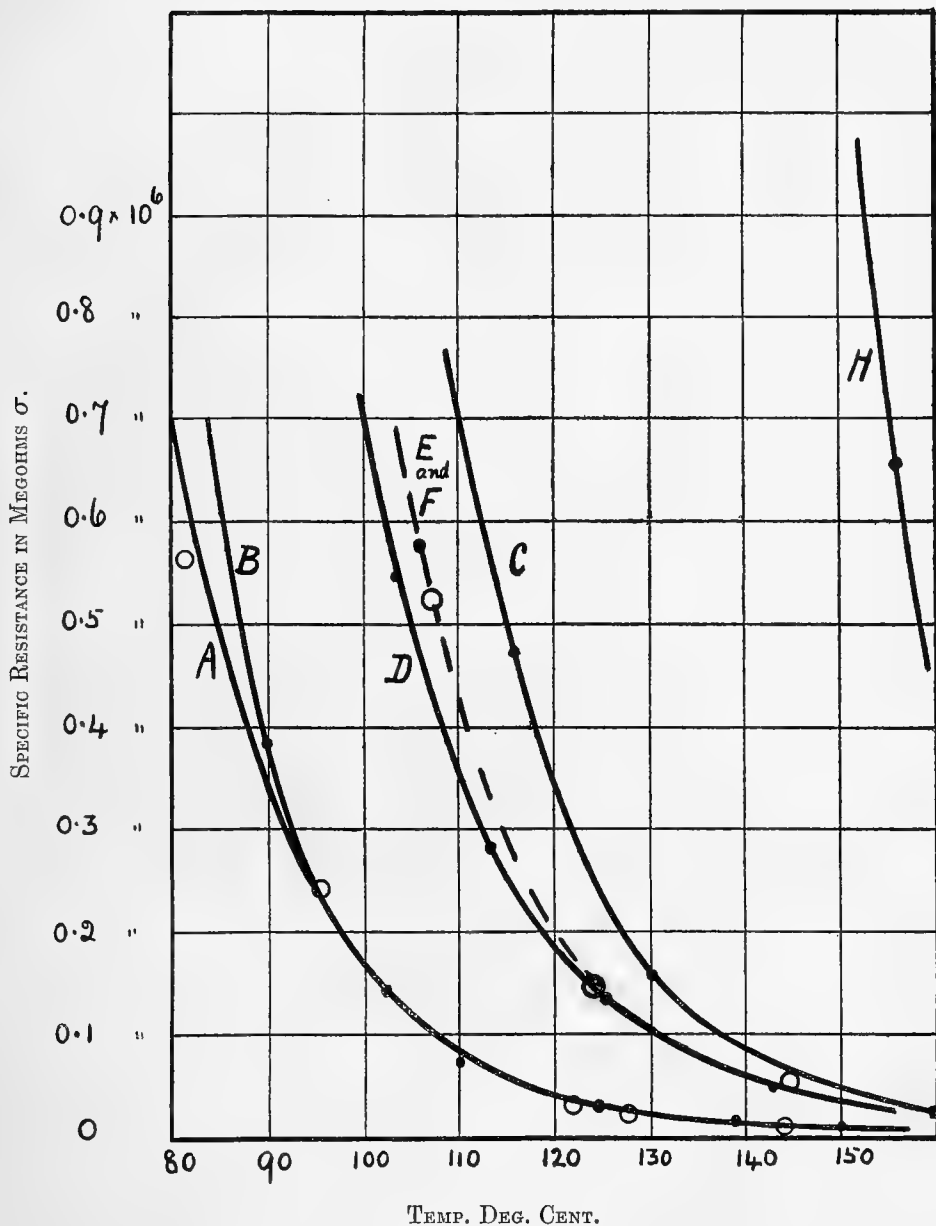


FIG. 5.—Resistance-Temperature Curves for samples A, B, C, D, E, F, and H.



The straight line law is again well illustrated by this sample D. This line runs nearly parallel to that of A and B, and shows that for the range of temperature used it is superior to them in insulation resistance.

TABLE 3.

Sample E.

Thickness 0·15 cm.

| $t$ . | $T$ . | $\frac{l}{T}$ .           | $\sigma$ .             | $\log_{10} \sigma$ . |
|-------|-------|---------------------------|------------------------|----------------------|
| 17    | 290   | $34\cdot5 \times 10^{-4}$ | $3,300 \times 10^6$    | 9·52                 |
| 29    | 302   | 33·1 ,,                   | $520 \times 10^6$      | 8·72                 |
| 42    | 315   | 31·7 ,,                   | $217 \times 10^6$      | 8·15                 |
| 53    | 326   | 30·7 ,,                   | $33 \times 10^6$       | 7·52                 |
| 69    | 342   | 29·2 ,,                   | $15\cdot6 \times 10^6$ | 7·19                 |
| 86    | 359   | 27·8 ,,                   | $4\cdot3 \times 10^6$  | 6·30                 |
| 107   | 380   | 26·3 ,,                   | 520,090                | 5·72                 |
| 123   | 396   | 25·2 ,,                   | 146,000                | 5·16                 |
| 145   | 418   | 24·5 ,,                   | 60,000                 | 4·78                 |
| 158   | 431   | 23·2 ,,                   | 22,400                 | 4·34                 |
| 166   | 439   | 22·8 ,,                   | 12,000                 | 4·08                 |
| 195   | 468   | 21·4 ,,                   | 2,500                  | 3·40                 |
| 199   | 472   | 21·2 ,,                   | 1,800                  | 3·26                 |

Fig. 6 shows that the straight line for sample E, which is of Berlin manufacture, is practically coincident with that for D, which is also of German make. The larger contact area of this sample made it possible to obtain a roughly representative value for such a low temperature as 17° C. The line for E is represented by the small circles associated with the line drawn for D.

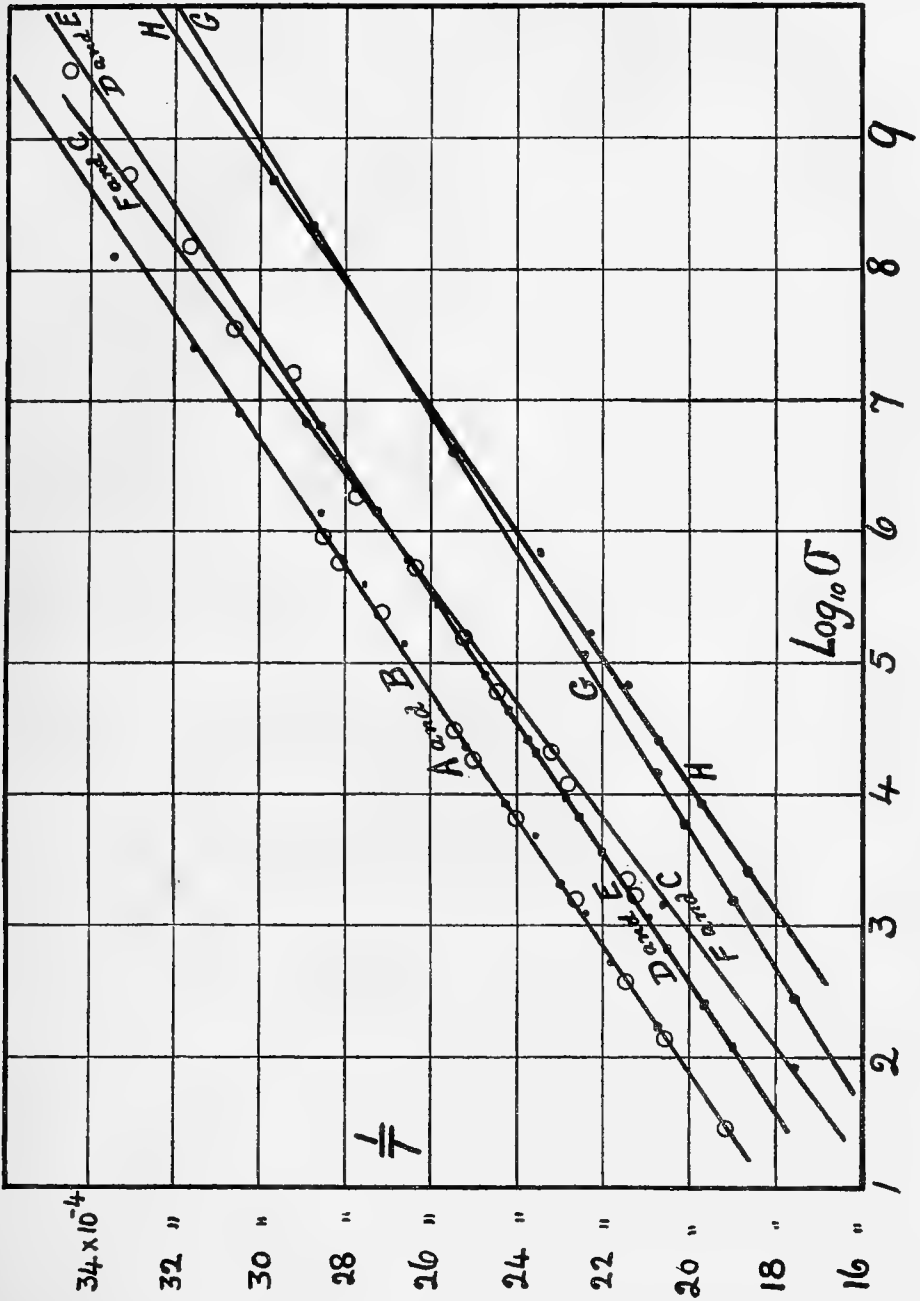


FIG. 6.—Relation of  $\text{Log } \sigma$  and  $\frac{1}{T}$ .

TABLE 9.

Sample F.

Thickness, 0.16 cm.

| $t.$ | $T.$ | $\frac{l}{T}$         | $\sigma$  | $\text{Log}_{10} \sigma.$ |
|------|------|-----------------------|-----------|---------------------------|
| 74   | 347  | $28.8 \times 10^{-4}$ | 7,800,000 | 6.89                      |
| 106  | 379  | 26.4 ,,               | 580,000   | 5.76                      |
| 128  | 401  | 24.9 ,,               | 118,000   | 5.07                      |
| 144  | 417  | 24.0 ,,               | 37,500    | 4.57                      |
| 160  | 433  | 23.1 ,,               | 24,700    | 4.39                      |
| 170  | 443  | 22.6 ,,               | 19,600    | 4.29                      |
| 181  | 454  | 22.0 ,,               | 9,500     | 3.98                      |
| 188  | 461  | 21.7 ,,               | 3,450     | 3.54                      |
| 210  | 483  | 20.7 ,,               | 1,300     | 3.11                      |
| 240  | 513  | 19.5 ,,               | 520       | 2.72                      |
| 257  | 530  | 18.9 ,,               | 216       | 2.33                      |
| 275  | 548  | 18.2 ,,               | 140       | 2.15                      |
| 295  | 568  | 17.6 ,,               | 87        | 1.94                      |

The straight line for sample F is drawn in Fig. 6; but, to avoid confusion, only three points upon it are indicated.

TABLE 10.

Sample G.

Thickness, 0.22 cm.

| $t.$ | $T.$ | $\frac{l}{T}$         | $\sigma.$   | $\text{log}_{10} \sigma.$ |
|------|------|-----------------------|-------------|---------------------------|
| 74   | 347  | $28.8 \times 10^{-4}$ | 194,000,000 | 8.29                      |
| 174  | 447  | 22.4 ,,               | 106,000     | 5.03                      |
| 211  | 484  | 20.7 ,,               | 14,700      | 4.17                      |
| 223  | 496  | 20.1 ,,               | 5,700       | 3.76                      |
| 253  | 526  | 19.0 ,,               | 1,470       | 3.17                      |
| 293  | 566  | 17.6 ,,               | 300         | 2.48                      |

TABLE 11.  
Sample G.  
Thickness, 0.22 cm.

| $t$ . | $T$ . | $\frac{1}{T}$ .       | $\sigma$ . | $\log_{10} \sigma$ . |
|-------|-------|-----------------------|------------|----------------------|
| 116   | 389   | $25.7 \times 10^{-4}$ | 9,600,000  | 6.98                 |
| 140   | 413   | 24.1 ,,               | 680,000    | 5.83                 |
| 171   | 444   | 22.5 ,,               | 119,500    | 5.08                 |
| 175   | 448   | 22.3 ,,               | 111,000    | 5.05                 |
| 182   | 455   | 22.0 ,,               | 49,000     | 4.69                 |
| 210   | 483   | 20.6 ,,               | 10,000     | 4.00                 |
| 228   | 501   | 19.9 ,,               | 3,000      | 3.48                 |

Table 10 gives the results obtained for sample G, using mercury for the contact surfaces, and Table 11 when using graphite in place of mercury. The operation is necessarily slower with the inferior conductor, and its liability to blow about and bridge the contact surfaces makes careful manipulation and precaution very essential. The results obtained in the two cases do not differ from each other to an exceptionally large extent.

Fig. 6 shows that sample G has a comparatively much higher insulation resistance than the preceding samples.

TABLE 12.  
Sample H.  
Thickness, 0.16 cm.

| $t$ . | $T$ . | $\frac{1}{T}$ .       | $\sigma$ .  | $\text{Log}_{10} \sigma$ . |
|-------|-------|-----------------------|-------------|----------------------------|
| 66    | 339   | $29.5 \times 10^{-4}$ | 487,000,000 | 8.69                       |
| 121   | 394   | 25.4 ,,               | 3,700,000   | 6.57                       |
| 156   | 429   | 23.3 ,,               | 660,000     | 5.82                       |
| 164   | 437   | 22.9 ,,               | 260,000     | 5.42                       |
| 177   | 450   | 22.2 ,,               | 185,000     | 5.27                       |
| 197.  | 470   | 21.3 ,,               | 64,500      | 4.81                       |
| 210   | 483   | 20.7 ,,               | 26,000      | 4.42                       |
| 234   | 507   | 19.7 ,,               | 8,400       | 3.93                       |
| 263   | 536   | 18.7 ,,               | 2,500       | 3.40                       |

Sample H in Fig. 6 shows a higher insulation resistance than sample G for temperatures above 100° C., and less for temperatures below this value.

The following table was derived from the curves of Fig. 6 for a few ordinary temperatures, and the results may be regarded as rough representations of the insulation resistance in megohms per cm. cube of the different samples of porcelain experimented with. For the lower temperatures the lines were continued onward a little farther than that given in the figure:—

TABLE 13.

| Sample.               | 10° C.                    | 20° C.                    | 30° C.                   | 40° C.                   |
|-----------------------|---------------------------|---------------------------|--------------------------|--------------------------|
| <i>G</i>              | 500,000 × 10 <sup>6</sup> | 126,000 × 10 <sup>6</sup> | 25,500 × 10 <sup>6</sup> | 10,000 × 10 <sup>6</sup> |
| <i>H</i>              | 200,000 ,,                | 71,000 ,,                 | 17,800 ,,                | 6,300 ,,                 |
| <i>D</i> and <i>E</i> | 11,200 ,,                 | 3,209 ,,                  | 850 ,,                   | 250 ,,                   |
| <i>F</i> and <i>C</i> | 3,980 ,,                  | 1,260 ,,                  | 397 ,,                   | 158 ,,                   |
| <i>A</i> and <i>B</i> | 1,590 ,,                  | 446 ,,                    | 129 ,,                   | 40 ,,                    |

Professor Miles Walker in a table<sup>1</sup> of insulating materials gave the specific insulating resistance of porcelain at 25° C. as ranging from 10<sup>6</sup> to 10<sup>9</sup> megohms per cm. cube for different samples. Excepting *G* and *H*, Table 13 shows that the values found are of the same order as those given by him, but the range for the samples used, including *G* and *H*, is not quite so extensive.

Curtis in his paper, referred to on page 297, gives 300 × 10<sup>6</sup> megohms per cm. cube for the value of unglazed porcelain at a temperature of 22° C., which corresponds to the value found for A and B.

By continuing the curves of Fig. 6 in the direction of higher temperatures the insulation resistance for temperatures beyond that experimented with may be roughly determined.

The results of the present investigation are:—

1. A further demonstration that, whatever the quality, thickness, or form of the porcelain as illustrated by the eight samples used, the relation of Rasch and Hinrichsen between insulation resistance and absolute temperature is approximately true.

An important use of this fact is that by finding the insulation resistance for two representative temperatures, the value for other temperatures may be approximately determined.

<sup>1</sup> Specification and Design of Dynamo-Electric Machinery.—Miles Walker, p. 176, Table 9, 1915 edition.

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OBSERVATIONS ON THE MORPHOLOGY OF  
*LARIX LEPTOLEPIS*.

BY

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(PLATES XVII and XVIII.)

[*Authors alone are responsible for all opinions expressed in their Communications.*]

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2. For temperatures below about 250° C. the insulation resistance of some samples of porcelain is practically independent of the voltage, and nearly so in the case of the others tested. Sample B was tested up to 800 volts at temp. 180° C., and its insulation resistance found to be approximately independent of the voltage. Others were tested up to 200 volts.

3. The enormous differences between the values of the insulation resistance for the different varieties of porcelain are shown by Table 13 and Fig. 6.

Thus Portland China and Royal Worcester porcelain as represented respectively by G and H have a very much higher insulation resistance than the other varieties of porcelain, especially that used for the low tension porcelain insulators A and B.

D, E, and F, representing some kinds of German porcelain, have their lines in Fig. 6 roughly grouped together, and these throughout the tests showed more dielectric absorption than the other samples.

In Fig. 6 the line of A and B is nearly parallel to that of H, so that the ratio of the insulation resistance of the latter to that of A or B is almost independent of the temperature for the range given, and the value of this ratio is about 140.

The insulation resistance of the 1862 porcelain insulator represented by line C is higher than that of either of the recent types, namely A and B.

Thus by means of a diagram such as Fig. 6 one may determine the probable identity of a sample of unknown porcelain by experimentally determining its insulation resistance at two suitable temperatures.



## XXVIII.

OBSERVATIONS ON THE MORPHOLOGY OF *LARIX*  
*LEPTOLEPIS*.

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Botanical Department, University College, Dublin.

(PLATES XVII and XVIII.)

Read MARCH 26. Published AUGUST 9, 1918.

THE discovery and demonstration of the Pteridosperms early in the first decade of our century gave an impetus to the study of the Gymnosperms as a whole. No little share of this work was devoted to the problem of the living Coniferales, their relations with each other, and their primitive ancestors. But even though one might say that every cell of most of them has by now been drawn or photographed, still the problem is sufficiently far from solution to justify further inquiry. An especially attractive study is afforded by the case of *Larix*, since its gametophyte history is markedly incomplete. To elucidate the matter is the purport of this work, which, however, as the sequel will show, is still in a somewhat incomplete condition. Certain points which have come to light in the course of the investigation, as well as some conclusions regarding them, seem, however, to be worth placing on record here.

The facts recorded, then, deal with the reproductive structures—the male strobilus and gametophyte, and the female strobilus and gametophyte. They can, therefore, be set down in succession under these headings.

## I.—THE MALE STROBILUS AND GAMETOPHYTE.

*The Male Strobilus.*

The male strobili are carried terminally on dwarf branches of the slightly older twigs. They are readily recognizable by their greater size at the end of October, by which time the buds are fairly mature. When the bud bursts the scale leaves in the spring, the base of the cone pedicel is encircled by small

foliage leaves; but a definite bare length of pedicel intervenes between these and the lowest microsporophylls. This characteristic is in marked contrast to the female strobilus. But, apart from this, two facts appear of interest.

A. *Cavities in the Sporophyll.*—In a longitudinal section of a microsporophyll the terminal lamina is quite large and distinct, and is occupied by a conspicuous cavity. Text fig. 1 shows an outline drawing of the arrangement. It is worthy of note that the cavity is limited to the lamina, and that in the bud stage this cavity is especially noticeable. Pl. XVII, fig. 1, shows a longitudinal section of a mature winter male bud, the cavity in this stage appearing very well in the lowest sporophyll.

Pl. XVII, fig. 2, is a transverse section of a similar bud from which we learn that the cavity is really a double cavity which may become, and during growth usually does become single as a result of fusion. The struc-

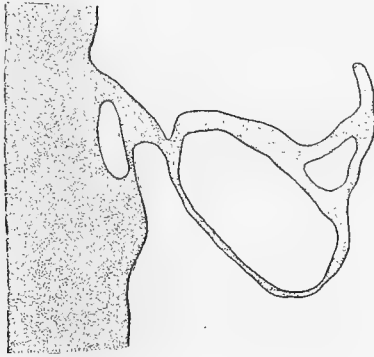


FIG. 1.—Longitudinal section of microsporophyll of *Larix leptolepis*, showing relatively large "knob" and marked cavity in it even at full maturity.  $\times 50$ .

tures marked A are the apical knobs of the next lowest sporophylls. Special attention is directed to those actually labelled A. Both figures make it evident that the cavities are not in communication with the cortical canals of the cone pedicel.

Now, Coulter and Land (4) have maintained for *Pinus laricio* that the two small cavities in the microsporophyll apex are possibly abortive sporangia, *Taxus*, *Torreya*, and *Pinus* thus representing a series in degeneration from a primitive peltate type. Miss Starr (23) makes a similar claim for *Ginkgo*. Although a primitive peltate stamen of a "sporangiphoric" type has much to recommend it in theory, we find certain points in the structure of *Larix* that certainly seem to oppose it in fact.

Thus, turning to Pl. XVII, fig. 3, we see a transverse section of a vegetative bud of *Larix leptolepis*, in which the two canals so common in the conifer leaf

are clearly seen.<sup>1</sup> If now we compare any one of these leaves with the structures marked A, in fig. 2 of this Plate, and consider that in both vegetative bud and male bud they are limited to the respective leaves and microsporophylls, one feels justified in considering the dorsal sacs of the microsporophyll of *Larix* and other Abietineae as really the paired canals of the vegetative leaf. If, as is commonly believed, the microsporophyll is a differentiated leaf carrying sporangia, it would, in any case, be the more natural interpretation. Further, while in *Larix* the cavities are confined to the apical knob, this is not so, for example, in *Cedrus atlantica*, as illustrated in text fig. 2 (A). Here the knob is thin and solid, but the canals of the pedicel turn out and

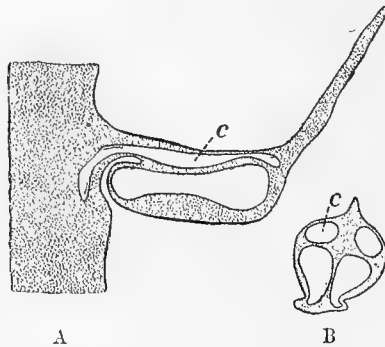


FIG. 2.—Canal arrangement in microsporophyll of *Cedrus atlantica*.  $\times 20$ .

A. Longitudinal section.

B. Transverse section.

The canals in both are marked C.

run dorsally, as shown, to the end of the sporangia. In fig. 2 (B) they are seen to be paired, and here the cavities are obviously the homologues of those in the leaf. Remembering that Miss Starr admits that the resin cavities of the leaf develop just like the alleged abortive sporogenous tissue in the sporophyll, it would appear that, so far as the evidence goes, we must regard the apical cavities, when present in the microsporophylls, at any rate of the Abietineae, as merely resin or mucilage cavities.

Before leaving the question of these cavities, it is worth noting that a comparison with other male buds shows that in the case of *Abies*, *Picea*, and *Pinus* there is no visible cavity, or only a very small one; in *Cedrus atlantica*, the condition already described prevails, while in *Pseudotsuga* alone of those

<sup>1</sup> The bud of *Larix*, it may be noted, is peculiar in this marked canal development in the bud. It is not shown in *Picea*, *Abies*, *Cedrus*, *Pinus*, or *Pseudotsuga*. In these, at most, sporogenous-like tissue appears in the site of the future canal. In *Pseudolarix* the canals are to be seen; but quite small when compared with *Larix*.

obtainable is the *Larix* condition approached. Text fig. 3 shows the situation clearly. This fact will be made use of later.

B. *The microsporangial wall.*—Pl. XVII, fig. 4, shows a portion of the pollen-sac wall of *Larix*. It is cut from a cone in which the lowest sacs have already opened, so that maximum degeneration of the non-thickened wall elements has taken place. We obviously have here an epidermal method of dehiscence—an annulus. The stomium is visible, and barred thickening appears, for instance, in cells at A. This condition in the wall of the microsporangium of *Larix* seems fundamental in the conifers, since *Larix* agrees in this respect with the Taxaceae and the Araucarians; nay, more, it seems fundamental in the sporangium itself, as *Larix* agrees in this with the Primofilices, the Cycadofilicales, the Cordaitales, and the main Lycopodiacean

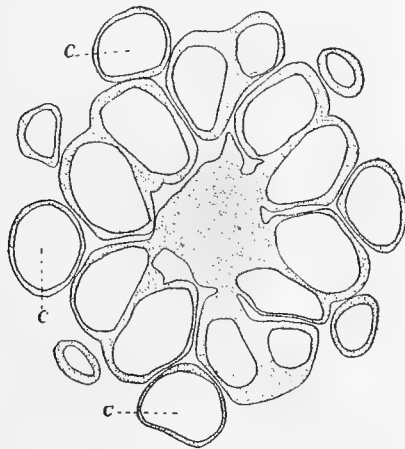


FIG. 3.—Transverse section of male cone bud of *Pseudotsuga*, to show marked cavities (C) in apical "knob" of microsporangia as in *Larix*.  $\times 40$ .

and Equisetian lines of the Palaeozoic epoch. (See, however, (13) for an opposite view.)

#### *Male Gametophyte.*

For reasons appearing later on, only the mature pollen grain of *Larix*, its variations and development, were followed.

In a general way the pollen-grain structure of the genus can be made out by piecing together brief accounts of earlier investigators. (Schacht (21), Strasburger (24, 25), Tschistiakoff (28).) No one account, however, is complete and accurate in itself.

1. *Mature Grain.*—Pl. XVII, fig. 5, shows the grain which at once seems peculiar. Rather circular, with a slight oral tendency; it has been just a

little distorted by plasmolysis. It is without wings—a well-known fact which merits repetition, as even in the revised edition of Coulter and Chamberlain's text-book (3), the impression is given that *Pseudotsuga* is remarkable as *the* wingless Abietinean. That it does share this characteristic with *Pseudotsuga* is of interest. Usually, though by no means always, it is shed with the stalk and body-cell already cut off, as in *Pseudolarix*, *Picea*, and *Abies*. The nuclei at this stage are always extremely compact and deeply staining. On the whole it is a large grain, and when its definite prothallial cells and variations are later on demonstrated, it should help finally to disprove the hypothesis that in the Cupressineae, Taxineae, and Taxodineae the lack of prothallial cells is to be regarded as an adaptive reduction of weight in the absence of any aids to flight (Robertson (20)).

The two prothallial cells are comparatively large, and are most clearly bound by regular cellulose walls. The wall of the second prothallial cell joins that of the first, and the wall of the latter is in a very definite continuity with that of the intine. But the unusual appearance is presented of two horn-like growths running out from the innermost wall and fading away in the cytoplasm. In some grains the appearance is so definite as to be remarkable. One such is Pl. XVII, fig. 6. Here the prothallial walls are massive, the second prothallial cell being so large that its nucleus has gone back to the typical resting stage before degenerating. The generative nucleus has not divided in this grain, and the horns give one the impression of a degenerated wall which normally should bound the generative cell. Pl. XVII, fig. 7, is a photomicrograph of the grain to show that the drawing is in no way exaggerated. Pl. XVII, fig. 8, also justifies this interpretation. In this grain, too, the generative nucleus has not divided, while only the cytoplasm of the tube-cell appears, although its nucleus was visible in the next section on the slide. Here, owing to plasmolysis, the continuation of the horns can be clearly seen swinging round the generative cell. Only one such cell was found, and unfortunately the encircling wall was not quite continuous on the left. On the right another thin membrane loses itself in the cytoplasm. Whether the surrounding wall was a cellulose wall or only a plasmic layer was not determined, as it was only found, of course, when the slide was fully stained and finished. Fortunately, owing to plasmolysis, it was free from the cytoplasm on both sides; and, though thin, it was quite distinct, and stained definitely blue with iron alum haemotoxylin, just as the normal intine, prothallial walls and horns always do.

It is worthy to note, in passing, that this grain may explain an earlier and peculiar account of the pollen grain of *Larix europea*. Tschistiakoff (28) describes its development in these words (p. 100):—"Drei aufeinander

folgende Scheidewände entstehen, . . . ; die Scheidewände welche die grössere Pollenkörnzelle von der anderen kleineren abgrenzt, ist immer mehr nach innen gewölbt als die anderen Scheidewände." No figures are given, so the reference is not clear. It may refer to a three-prothallial cell development, but such has not been observed by me in *Larix leptolepis*.

2. *Variations in the grain.*—Practically speaking, Pl. XVII, fig. 5, shows a typical mature grain—the prothallial cells a little variable, but always very distinct. The variations to be mentioned presently were found in only a small percentage of the total grains; but actually they should not be counted in the bulk, because they never appeared in the top sacs of a cone, only in the lower sacs, and mainly in the last two whorls. Some cones are singularly free from these variations, but in others they comprised at least 50 per cent. of the grains of a sporangium.

Some of these double-pollen grains are shown in Pl. XVII, figs. 9, 10, 11, 12, 13. Some are marked by much degeneration, but a perfect double grain appears in fig. 13.

Irregularities of this type have already been indicated in *Picea excelsa*, by Pollock (19); *Picea canadensis* and *Abies balsamea*, by Hutchinson (7, 8); and by Coker (2) in *Larix europea*. Only in *Picea canadensis* (7) have they been fully described. But even so, we find Coker's brief account of double-pollen development differs from Hutchinson's. With the latter the double grain arises as a result of the twisting through a right angle of the normal first division spindle, the resulting wall running straight across the cell. With Coker the pollen mother-cell divides occasionally into two only; and although here the wording is not quite clear, with the help of his figures we can gather that these do not separate, but that the wall between them remains as the median wall of the double grain. Hutchinson, not recognizing this, even says that his fig. 13 is the same as Coker's fig. 6. Really they are absolutely distinct. In Coker's fig. 6 the outline is the wall of the pollen mother-cell; the median line is really the adjacent and distinctly separate walls of the two grains within. Hutchinson's fig. 13 has one outer line—the intine, and one thin median wall continuous with it. In view of this, it was thought useful to follow fully the development of the grain of *Larix leptolepis*.

3. *Development of Male Gametophyte.*—The pollen passes the winter in the mother-cell stage. Its resting period is not long if the season is mild. Thus the first tetrad divisions were completely missed in January, 1916, even though the first collection was made in the middle of the month, every cone examined having passed the stage. The second week of February is the other limit. The development is rapid and, as usual, irregular. All stages can be found during the last week of February, while the tree has shed all the pollen



at the latest by March 20th. This early activity is in marked contrast in the Botanic Gardens to the other sluggish pines.

The tetrad formation in *Larix leptolepis* presents nothing new. The omission of the second division, as described by Coker, can be confirmed, but prolonged search failed to reveal the permanent adhesion of any such pair of grains. That Coker's interpretation of the origin of the double grains of *Larix* is, then, erroneous is verified by the appearance found in a later sac, and shown in Pl. XVII, fig. 14. One grain has divided most irregularly, almost as if it were a complete tetrad which has not separated; but its position and its shape relative to its fellows show that they are really three from a tetrad, one of which has prematurely divided.

The exact parallel with *Picea*, however, is quite clear. Rounding off rapidly, the large nucleus, Pl. XVII, fig. 15, remains for a little while in the resting condition. Nucleoli are very distinct and large, and may be in number up to three. Their function is, as usual, in doubt, because when the nucleus is preparing for division the spireme stage may be far advanced and the nucleoli unchanged, Pl. XVII, fig. 16. By the time the spireme becomes segmented into chromosomes they have disappeared. Evidence as to their extrusion into the cytoplasm was present, but the cytology was not followed. In the majority of grains the first division in the young grain was normal (Pl. XVII, fig. 17), cutting off a small prothallial cell in which the nucleus and cytoplasm rapidly degenerated in the typical way. The wall was distinctly connected to the intine (Pl. XVII, fig. 18). If, however, a little more cytoplasm than is usual is cut off, the prothallial nucleus may go to a large resting-stage before slowly degenerating. Such an occurrence is very common, and accounts for the markedly large prothallial cells with definite walls in so many mature grains (Pl. XVII, fig. 19).

Sometimes the division and the spindle were oblique (Pl. XVII, fig. 20), and the result was the cutting off of a cell about one-third of the whole grain (Pl. XVII, fig. 21). The spindle may be at right angles to its normal position (Pl. XVII, fig. 22), and the result is the division of the cell into equal or sub-equal cells (Pl. XVII, fig. 23, and compare figs. 9, 10, 12, 13, Pl. XVII). Finally, no wall at all may be formed, leaving two nuclei free in the cytoplasm (Pl. XVII, fig. 24). This is exactly the course of things in *Picea canadensis* (7). We may presume a similar course in *Abies* (8).

After division, the primary nucleus returns to the resting condition (Pl. XVII, fig. 18), and then resuming, almost invariably cuts off a cell which rapidly passes into a typical degenerated prothallial cell. Pl. XVIII, fig. 1, shows the normal condition. The second prothallial wall is always an out-growth, as it were, from the first and is equally distinct. If the first division

cut off approximately one-third of the whole, the second prothallial cell is still typical and normally placed (Pl. XVII, fig. 11, and Pl. XVIII, fig. 2.) The first large persistent "prothallial" cell can itself divide (Pl. XVII, fig. 11). If the first division results in two equal cells, the second prothallial cell is usually small, and may be normally placed relative to the long axis of the grain in both halves of the double grain, as in Pl. XVII, fig. 13, or normally placed in one against the middle membrane, as in Pl. XVIII, fig. 3, while the other is laterally placed. Compare also Pl. XVII, figs. 9 and 12. In fig. 9—a giant grain—there was even sign of rapid degeneration, the nuclei being most uncertain. In Pl. XVII, fig. 12, any structure in the left half comparable in succession to a second prothallial is large and massive, much more so even than in the laterally placed one in Pl. XVIII, fig. 3. The position in Pl. XVII, fig. 10, was only found once, while, owing to the loss of a few sections from the slide at this point, the actual nature of the lower cells was not made clear; presumably the empty space is a large prothallial cell in this portion. Lastly, no matter how perfect the double grain may be, never more than this single second prothallial cell is cut off. One can gather that the same is characteristic of *Picea canadensis*, though it is not explicitly stated. Pollock seems to describe the presence of two prothallial cells in one half of a double grain of *Picea excelsa*, but it is worthy of note that even he never found two prothallial cells in both halves; if there were two at one side of the middle wall, there was never found more than one at the other. Of such a case he figures one, and even without his own confession that the course of the central wall was not clear, it is just as easy to interpret his figure as having one prothallial only at each side as in our figure, the apparent extra prothallial really being a small "stalk" cell—and this while of course allowing the possibility of his interpretation being correct, since the prothallial number in *Picea excelsa* is variable. It would appear, then, that as far as *Larix leptolepis* is concerned, the number of divisions is normally definite. The primary nucleus divides twice before advancing to the formation of what we may term the "antheridial" cells. If the first division results in a very large cell, the fixed appearance of only one evanescent cell in each of the first two sister cells forces us to consider the large half cell as the homologue of the *typical* first and normally degenerating prothallial cell.

After returning again to the resting stage, the division into tube and generative cell follows. Pl. XVIII, fig. 4, shows the nearest approach to a resting stage following this division. As far as could be seen, the nuclear material became rapidly compact, even if no further division took place (Pl. XVII, fig. 6). Most often the generative cell again divided into the stalk cell and body cell, as before, with compact nuclei. In this stage the grain

is shed. This last division must follow the previous one with great rapidity, because, not even once in two years' gatherings was the division into stalk and body cell seen, or any stage of it. Only in typical grains did it occur. Even if the first division cut off one-third—as also in the cases of equal division—the final stage, unless degeneration, as was common, intervened, was the tube cell and generative cell condition. See especially Pl. XVII, figs. 10 and 13, and Pl. XVIII, fig. 3. *Picea excelsa* (19), however, goes on to the next division, while *Larix europæa* agrees with *Larix leptolepis*.

Again, a comparison between Pl. XVII, fig. 12, and Pl. XVIII, fig. 3, is of interest. The "horns" characteristic of the single grain are visible in Pl. XVIII, fig. 3. Pl. XVII, fig. 12, can be interpreted without strain as due to a complete formation of such a wall, the three cells on each side being tube, generative, and "second" prothallial.

Finally, a comparison between the grain of *Larix* and that of *Dacrydium* brings out an interesting point. On the authority of Miss Young's paper (31), it can be stated that in *Microcachrys* each of the two prothallial cells is bounded by a cellulose wall; in *Saxegotheca* only the first prothallial cell is so bounded, the second being marked off only by a distinct plasmatic membrane: while in *Dacrydium*, the first as well as the second prothallial cell is bounded by such a layer only. Do we strain a point in considering these plasmatic layers as reduced cellulose walls? Again, the generative cell in *Dacrydium* is marked off from the tube cell by just such a distinct plasmatic membrane. Can we not compare the ephemeral wall round the generative nucleus of *Larix*—for so we earlier interpreted it—with this distinct membrane in *Dacrydium*, both representing a primitive cellulose wall bounding the generative nucleus, with this difference, that it remains complete as a plasmatic membrane in *Dacrydium*; while in *Larix*, though fading and rudimentary, it has retained its cellulose-wall nature? If this be so, it seems that the claim put forward (12), that the grain type as seen in, say, *Pinus*, is ancestral for all conifers, means that *Larix* and *Dacrydium* must both have evolved anew a wall round the generative nucleus and lost it again.

## II.—THE FEMALE STROBILUS AND GAMETOPHYTE.

It is mainly on this side of the gametophyte history of *Larix* that the gaps already indicated exist, and for these reasons:—The work was begun in the spring of 1915, in which year, as little time was available, it was decided to make only collections sufficient to show the approximate periods of the year in which critical stages should be sought. This was, perhaps, necessary in any case, as the monthly stages of no species of *Larix* were known, and,

in view of comparatively early cone development, it did not seem advisable merely to follow the periods named for other forms. With the aid of the data so acquired it was hoped to make collections in 1916 that would yield an accurate and complete series of stages. But on the tree available there appeared in 1916 only about half-a-dozen cones. In the spring of 1917—the hard spring—the tree, on the advent of mild weather in mid-March, bore a profusion of young female cones, and prospects seemed rosy; but, on visiting the tree on the morning following two nights of sudden and severe frost, every cone was shrivelled and dead. It was decided then to commit to paper such facts as had appeared in the 1915 gatherings, and to relinquish the intention of completing the work.

A. *The Female Strobilus, and Pollination.*—When freed from the bud-scales the lower part of the cone-pedice! is clearly covered with small leaves, which gradually pass into the bracts subtending the still small axillary

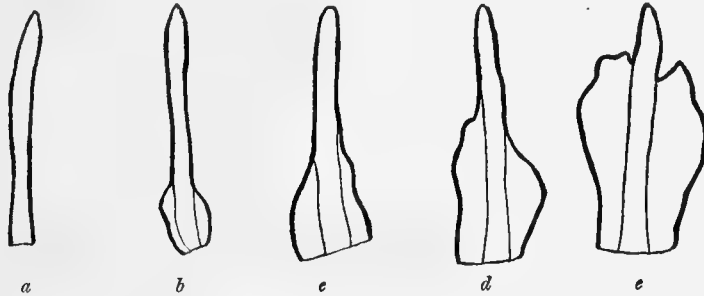


FIG. 4.—Outline drawings to show the gradual transition from small vegetative leaf at base of cone to typical cone bract of *Larix leptolepis*.  $\times 6$ .

ovuliferous scales—a passage which is gradual in every sense. Text-fig. 4 shows the change in the structures themselves, from the typical small needle-leaf on the left to the typical cone-bract of *Larix* on the right. The complete similarity between the lowest leaf-structures and ordinary vegetative leaves is evident from Pl. XVIII, fig. 5, a photograph of structure “a” in the text-fig. 4, in transverse section. The double canal still persists in the typical bract, well up in the cone (Pl. XVIII, fig. 6). The axillary structure also gradually changes. Appearing first in the axil of the bract at stage “c” it is only a bump of sterile tissue, while slightly higher up an ovule, which never matures, can be seen embedded in it. Then, at last, well into the cone, it shows the form of the typical young scale, with two good ovules. For the demonstration, if such were desired, of Professor Bower’s “Selago” condition in Gymnosperms, no better object could be found than the megasporangiate strobilus *Larix*. When the cone is about one inch long it is of interest that the ovuliferous scales are of little larger size than is

necessary for the attachment of the two ovules, whose volume is much greater than that of the scale.

The same gradual transition is characteristic of *Pseudotsuga*.

B. *The Ovule*.—Attention has already been directed (5) to the micropylar arrangement in *Larix*, an arrangement which it shares with the hitherto unique ovule of *Pseudotsuga*, as described by Lawson (15). So similar are the two ovules that the likeness can best be emphasized by quoting Lawson's account of the ovule of *Pseudotsuga Douglasii* with reference to Pl. XVIII, fig. 7, which represents a median section of the ovule of *Larix leptolepis*. Lawson says :—"The pollen-receiving device in *Pseudotsuga* is quite peculiar, and unlike anything yet described for Gymnosperms. For some little time after pollination the nucellus presents the form of a small protuberance, with a perfectly rounded apex. The integument extends for a considerable distance beyond the nucellus. At a point immediately above the apex of the nucellus the integument bends inward in such a fashion as to partly close or narrow the micropylar canal, and then sharply bends out again. This results in the formation of a distinct structure midway between the apex of the nucellus and the mouth of the micropyle. As a result of this peculiar curvature of the integument, the micropylar canal is not a straight passage of uniform width, but consists of two chambers, one immediately above the apex of the nucellus, and the other near the mouth of the micropyle. In addition to this narrowing in the middle region of the micropyle the integument is still further modified. The extremity of the integument, which forms the mouth of the micropyle, is folded inward. On the inner surface of this infolding extremity numerous fine hair-like processes are present. A close examination makes it clear that they were not cellular in structure, but were merely outgrowths from the external walls of the epidermal cells. They serve very effectively, however, as a stigmatic surface." The hairs in the *Larix* are firmer, and are large and small, the latter so compact as to give the impression of a basal cellulose plate (the dark, thickened mass in the figure). "The pollen grains were invariably in the upper chamber of the micropyle, and frequently entangled in the hair-like processes of the mouth."

So far the two genera are much alike, but there is one remarkable difference. The pollen-receiving device in *Larix* apparently always acts just as in *Pseudotsuga*, no grains ever having been seen on the nucellus at this stage. In passing, it should be stated that pollination is usually completed by mid-March, when the opening of the micropyle gradually closes over. To return to the difference between the genera, we recall the unique fact that in *Pseudotsuga* the grains are described by Lawson as germinating in

the tube, or from the stigmatic hairs. Now Strasburger (25) had earlier described the pollen grain of *Larix europea* as germinating, like the grains of other conifers, on the *nucellus*, so the following observations may be of interest:—It was found that all through late spring grains were to be seen in the upper micropylar chamber, but none were seen on the nucellus, not even in collections as late as June 9th, though grains were found frequently in the upper chamber. It is not, however, contended that there were absolutely no grains on any nucellus during this period. It is possible that if a larger number of ovules had been fixed and cut, a few examples of grains on the nucellus might have been found; but actually in those cut from the late spring collections none were found on the nucellus tip. Conditions were different, however, in the case of the collections of June 15th. In about one ovule in every five the nucellus was supplied with one single grain, with its pollen-tube mature, and fertilization already effected. In two ovules only were there two grains on the nucellus. So that Strasburger's observation for *Larix europea* is verified by this observation for *Larix leptolepis*.

We can therefore definitely state that *Larix* has a micropylar pollen-receiving device essentially similar to that of *Pseudotsuga*; but that, while the grains of the latter genus can germinate in the micropylar tube in mid-air, as it were, it appears that the pollen grains of *Larix* cannot so germinate, and only those grains which, by means at present not clear, are able to reach the nucellus can proceed to further growth. That there is some hindrance to their falling on the nucellus would appear from the paucity of grains found germinating, usually only one in any ovule.

Finally, it is tempting to look on this as a reduction from *Pseudotsuga*; nay, further, to assume with Burlingame (1) that perhaps the pollen-tube development and pollination of *Araucaria* are primitive in the conifer phylum, and so to present *Araucaria*, *Pseudotsuga*, *Larix*, and *Picea* as a series in the reduction of the pollen tube and the passage of the grain from the cone scale to the nucellus.

#### *Female Gametophyte and Embryo.*

As one would expect most of the stages in Gametophyte and Embryo development in *Larix* to be similar to those of other Abietineae already described, only such points will be fully dealt with as are peculiar to *Larix* or are of other special interest.

The first stage found was the megaspore itself. The tetrad formations have been described for *Larix europea* (26) and *Larix sibirica* (14), the former with only three cells in the linear tetrad, the latter with four. The remains

of the other cells of the tetrad were still visible in *Larix leptolepis*, sufficient to demonstrate that the formation was linear; but whether there were three cells or four could not be determined. As would be expected, only one megaspore is formed. On March 23rd the first division was seen. All through April only the typical parietal layer was forming, such appearing even in ovules gathered on April 28th. Once May set in the activity was rapid, so that the only stage obtained on May 5th showed the endosperm so well formed that it was impossible to say how it had grown in. On May 12th, though the endosperm was still far from compact, archegonial development had well begun and was quite normal, a superficial cell dividing to give an inner archegonial cell and an outer neck cell. The rest of May was occupied by the maturing of the whole gametophyte, which, and especially the archegonium, merits perhaps a few words of description.

Plate XVIII, fig. 8, shows the archegonium in longitudinal section. It is relatively long and thin and recalls that of *Pseudotsuga*. Lawson (15), however, referring to a photomicrograph through a complete female gametophyte of *Larix europea* which appears in Thomson's well-known paper on "The Megaspore Membrane" (27), says that of *Larix* seems thicker than that of *Pseudotsuga*. Difficult as it is to see the difference when a comparison is made with Thomson's photograph, a comparison with the fig. on Pl. XVIII, only emphasizes the general similarity of the archegonia of the two genera. The archegonia of *Larix europea* are, however, certainly relatively wider. The archegonia are always five in number (Pl. XVIII, fig. 9). Though the jacket cells are very marked all round the archegonium in fig. 8, the jackets of neighbouring archegonia are almost in contact, as fig. 9 shows. The double layer may be reduced to one, and this even to a thin membrane at times. Lawson reports the same of *Pseudotsuga*, with which *Larix* also agrees in its shallow archegonial chamber. There are one or two tiers of neck cells, though one layer appears more common. The cells of each tier vary from four to eight in number (Pl. XVIII, fig. 10). The cytoplasm at this stage is markedly vacuolar and the nucleus apical. As already reported by Thomson for *L. europea* and *L. americana*, the megaspore membrane, very definite and thick at the bottom, thins out so markedly over the archegonial region that at maturity no trace of it can be seen there. *Pseudotsuga* shows a quite similar condition, and in both the condition is very much more definite than in the other Abietineae so far described. (This is in interesting contrast to *Pseudolarix* (17), in which the megaspore membrane is quite distinct even at the micropylar end of the endosperm.) So that taken all in all a description of the female gametophyte of *Larix leptolepis* might well be a description of that of *Pseudotsuga Douglasii*.

The detailed ingrowth of the endosperm is the one feature still to be determined.

On June 2nd the archegonia were still in the same condition, but by June 9th other activity began. The vacuolated archegonium follows the usual course in becoming densely granular and compact. In the meantime, the ventral canal cell is cut off, and henceforth appears as a shrivelled mass at the top of the archegonium. The female nucleus becomes much larger and stands centrally in the cytoplasm. Neither pollen tube nor any stage of it was found in the ovules of this date.

On June 15th in every cut ovule which had been earlier pollinated, fertilization had been effected. The tube, which is very short, runs perfectly

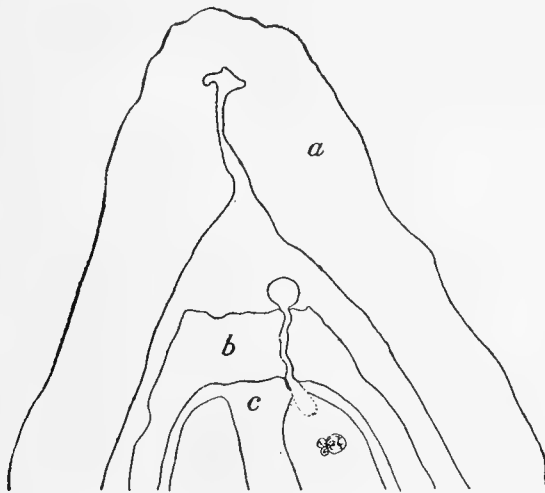


FIG. 5.—*Larix leptolepis*. Longitudinal section of mature ovule at fertilization to show pollen germinating on nucellus *b*. *a*, integument, the micropylar chamber still visible. *c*, endosperm.  $\times 40$ .

straight to the archegonium neck, so that if it appeared at all in the section it appeared as a complete linear channel in the nucellus. It would seem, then, that the time of actual growth of the pollen tube itself must be very short, though this point cannot be sustained till the results from further possible collections are available. The contents of the tube are emptied into the archegonium, and the next stage observed was the very large fusion nucleus still central, with three nuclei very close together in the upper part—presumably the non-functioning male, the tube and stalk cell (Text-fig. 5.) The closed over, upper micropylar chamber is shown. Unfortunately the division of the body cell and the two male nuclei were not seen, so that it cannot be decided whether *Larix* has the typically Abietinean inequality of the male nuclei or not. Nor can Strasburger's (24) statement be verified



that the two male cells are formed in the grain just as the pollen tube begins. In *Pseudotsuga*, as in others, the body cell divides far down in the pollen tube. The details, then, of fertilization need completion, though the process is obviously similar to that in the other Abietineans.

The embryo is formed in the typical fashion, with division of the fusion nucleus into four, their passage to the archegonial base, further division into 8 with wall formation, and so on. Though all the stages were noted, Pl. XVIII, figs. 11, 12, 13, are sufficient to add *Larix* to the list of those genera already shown to have embryo development of the Abietinean type. It is hardly likely that any important variation will appear in the others, not yet demonstrated. In spite of that, such demonstration is much to be desired. As against *Pinus*, only one embryo is usually formed from one fertilization, although on one occasion two embryos were found attached to the one suspensor. Embryonal cells or secondary suspenders were developed. The archegonial base was gradually compacted at the attachment of primary suspensor and rosette to form a deeply staining mass very similar to the "plug" described by Lawson. It was not determined if this were merely a temporary compacting of the archegonial cytoplasm or a mucilage plug as distinct as in *Pseudotsuga*.

All stages up to wall formation at the 8 nuclei stage were found on June 15th. The other stages up to Pl. XVIII, fig. 12, were found on June 23rd, although the stage figured was by far the most common. The fig. 13 was from July 7th, and the rest of that month saw the gradual organization of the great body regions. By mid-August the embryo was mature and the cycle complete.

### III.—THE POSITION OF *LARIX*.

There is one main result appearing from the facts recorded from the study of *Larix leptolepis*, and that is a definite placing of it in its natural systematic position. A study of its stem anatomy had already indicated what that position was; but the few new facts here recorded have clearly fixed it.

The natural position of *Larix* has suffered much at the hands of the systematists. Strasburger (24), in a genealogical tree at the end of his "Coniferen und Gnetaceen," puts together *Larix*, *Pseudolarix*, and *Cedrus*. In Schumann's Lehrbuch (22) *Larix* and *Cedrus* are linked with *Pinus* near, while *Picea* and *Abies* are linked as distinct from the others. Warming (29) puts together *Picea*, *Larix*, *Cedrus*, and *Pinus*, and includes *Tsuga* and *Pseudotsuga* together as sub-genera of *Abies*. Von Wettstein (30) (the recent 1911 edition was not

available) links *Larix*, *Cedrus*, *Pseudolarix*, and *Pinus* as distinct from *Abies*, *Pseudotsuga*, *Picea*, and *Keteleeria*, which are linked. Eichler (6) has *Cedrus*, *Larix*, and *Pseudolarix* together, with *Pinus* near; and *Picea*, *Abies*, and *Tsuga* together, the latter genus including *Pseudotsuga*. Lastly, without exhausting the list, Lotzy (16), who breaks the Abietineae into sub-tribes, includes under one sub-tribe, the Lariceae—called Laricineae on p. 286—*Larix*, *Pseudolarix*, and *Cedrus*. He makes *Picea* and *Tsuga* form the Piceae, while *Pseudotsuga* is bracketed with *Abies* and *Keteleeria* to form the sub-tribe, Sapineae. We have thus differences of opinion to suit almost any taste, though they all definitely agree in separating *Pseudotsuga* from *Larix*.

The anatomists, however, have had a clearer insight, as appears from the well-known contributions of Jeffrey (11) and Penhallow (18). Jeffrey, basing his results on resin canal distribution, divides the Abietineae into the Pineae, including *Pinus*, *Larix*, *Pseudotsuga*, and *Picea*; and the Abietae, including *Abies*, *Cedrus*, *Tsuga*, and *Pseudolarix*. *Pinus*, he considers, is somewhat apart from the rest, while *Picea* and *Pseudotsuga* are very close, with *Larix* not far removed. Penhallow, from data based on almost every other anatomical point as well as resin cells and canals, concludes that *Larix*, *Pseudotsuga*, and *Picea* are very closely allied, with *Pinus* as a near relative. Here, then *Larix* is removed from relation with *Cedrus* or *Pseudolarix*, and put into relation with *Pseudotsuga*, in spite of the marked differences in habit. That such is correct appears from these observations on *Larix*.

For, in addition to the extreme similarity in wood anatomy, which is evident from these and other papers, and which, indeed, is so close that in the fossil condition no satisfactory differentiation can be made between them, the following extra points of agreement must be emphasized as existing between *Larix* and *Pseudotsuga* as demonstrated in this paper:—

1. Wingless pollen.
2. Large cavities in the microsporophyll apex in both the mature cone and the bud.
3. Gradual transition in female cone from basal vegetative leaves to typical cone bracts.
4. The peculiar pollen-receiving development of the micropylar tube.
5. The very close agreement in the structure of the female gametophyte in both genera.

From which it can be said, in conclusion, that a close natural affinity exists between *Larix* and *Pseudotsuga*; but that there is need for that affinity to be recognized in current systematic classifications.

## SUMMARY.

1. The first section of the paper deals with some points in the anatomy of the microstrobilus of *Larix leptolepis*, but especially with certain peculiarities in pollen grain development.

2. There are very definite sacs in the microsporophyll apex, especially in the bud. From a comparison of similar structures, as well as vegetative buds in other genera, it is claimed that the evidence is in favour of the paired cavities in that apex being homologous with the paired canals of the vegetative leaf and not with abortive sporangia.

3. The normal grain, shed with stalk and generative nucleus already formed, is wingless, large, with two very marked cellulose walls bounding the prothallial cells, and the vestiges of a cellulose wall surrounding the generative nucleus.

4. In development, the first division may be very large—one-third or even one-half of the original cell—due to the obliquity of the first division spindle even through a right angle. In the latter case, very complete double grains are formed; in the former, the resultant divisions are also followed. The whole is very similar to the irregular pollen-grain development in *Picea canadensis*.

5. The capacity for division of prothallial cells is thus not confined to the Araucarians and the Podocarps.

6. In wingless pollen, and in the possession of marked apical cavities in the microsporophyll, especially in the bud, *Larix* and *Pseudotsuga* agree, in marked contrast to the other Abietinean genera.

7. The paper deals with some points in the anatomy of the female strobilus and gametophyte of *Larix leptolepis*.

8. There is a gradual transition from basal vegetative leaves to cone bracts, as in *Pseudotsuga*.

9. The ovule has a micropylar pollen-receiving device similar to *Pseudotsuga*.

10. The female gametophyte develops as in other Abietineae; but the megaspore membrane, very thick below, fades over the top; the archegonia are long and five in number: the neck cells are in one or two layers of four to eight cells; the archegonia may touch so that individual jacket layers may coalesce or fade. It is strikingly similar to the female gametophyte of *Pseudotsuga*.

11. In contradistinction to this genus, only those pollen grains which reach the nucellus develop pollen tubes, and none such were seen till June had well begun.

12. Fertilization is normal, but the relative sizes of the two male nuclei were not determined.

13. The pro-embryo is of the Abietinean type. One embryo is the rule.

14. There is a distinct natural affinity between *Larix* and *Pseudotsuga*. This affinity is not recognized in current systematic classifications.

Finally, I wish to return thanks to Sir Frederick Moore, F.L.S., Royal Botanic Gardens, Dublin, for the use of the Larch-trees in the Gardens; to the Director, Kew Gardens, for the vegetative and cone buds named in the first section of this paper; and to Miss E. J. Leonard, M.Sc., of the Botanical Department, University College, Dublin, for the drawing of the illustrations, except the photo-micrographs.

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EXPLANATION OF PLATES.

PLATE XVII.

All of *Larix leptolepis.*

Figs.

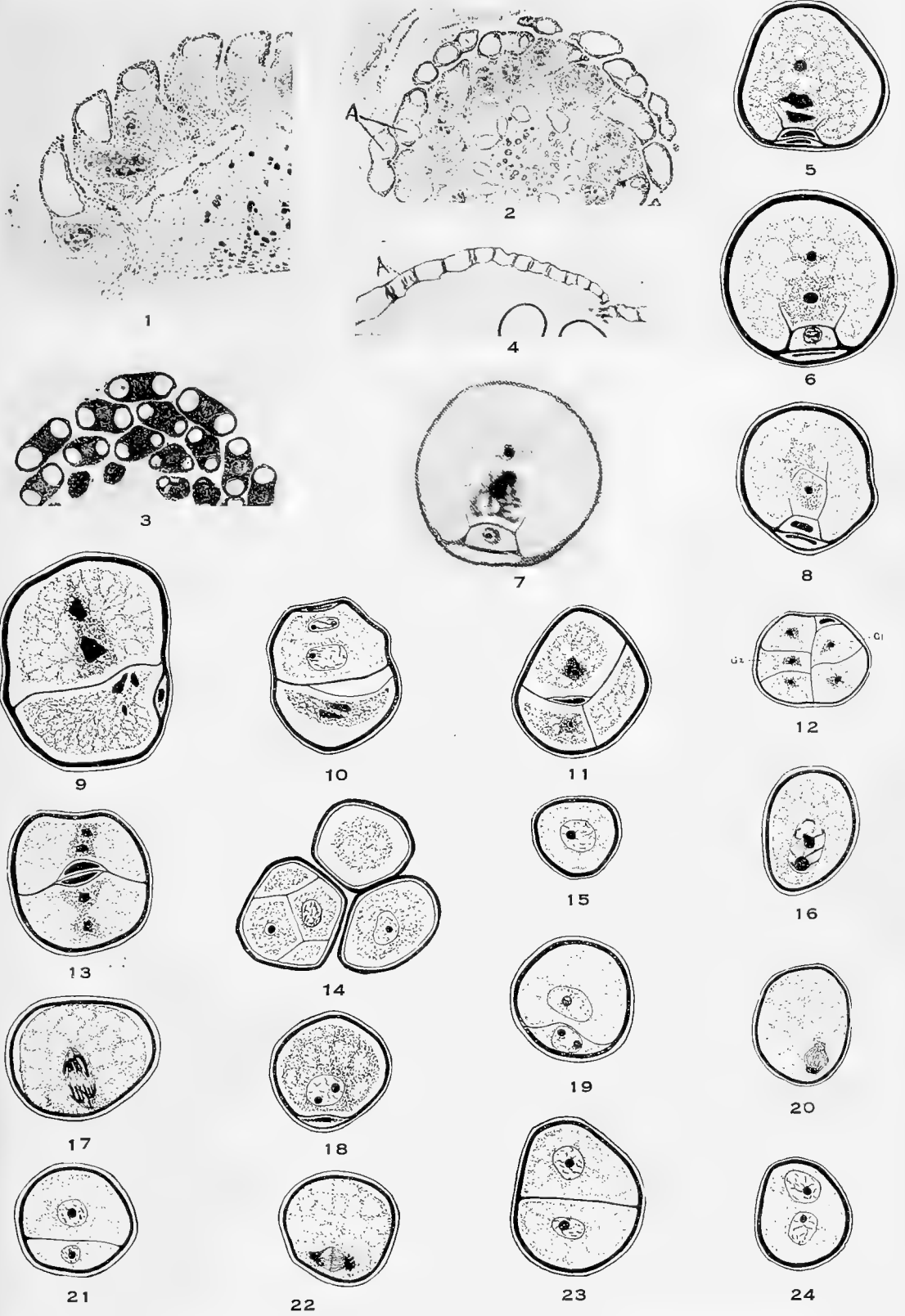
1. L. S. of male bud, showing secretory sacs in microsporophyll knob. ( $\times 35$ .)
2. T. S. of same. A = secretory sacs of microsporophylls below. ( $\times 30$ .)
3. T. S. of vegetative bud, showing secretory canals for comparison with fig. 2A. ( $\times 25$ .)
4. Portion of epidermal wall of microsporangium, showing stomium. ( $\times 50$ .)
- 5, 6, 8. Mature pollen grain. ( $\times 350$  approx.)
7. Photomicrograph of grain drawn in fig. 6. ( $\times 350$  approx.)
- 9–13. Various double grains. ( $\times 350$  approx.)
14. A grain already irregularly divided, though not yet separated from its tetrad fellows. ( $\times 350$  approx.)
15. Grain just rounded after tetrads. ( $\times 350$  approx.)
16. Spireme of first division, to show passive nucleoli. ( $\times 350$  approx.)
- 17, 18. Cutting of first normal prothallial. ( $\times 350$  approx.)
19. Prothallial nucleus returning to resting stage if sufficient cytoplasm. ( $\times 350$  approx.)
- 20, 21. Oblique spindle of first division, cutting off one-third of the primary cell. ( $\times 350$  approx.)
- 22, 23. Spindle at right angles to normal plans, dividing primary cell into two equal ones. ( $\times 350$  approx.)
24. No wall formation at first division, leaving two free nuclei in the cytoplasm. ( $\times 350$  approx.)

PLATE XVIII.

1. Normal second prothallial cell formed. ( $\times 350$  approx.)
2. Second prothallial following a first division, which had cut off one-third the primary cell. ( $\times 350$  approx.)
3. A double pollen grain, with the vestiges of the wall round the generative nucleus appearing in one half. ( $\times 350$  approx.)
4. Normal division in formation of stalk and body cells. ( $\times 350$  approx.)

5. T. S. basal vegetative leaf of female cone, text-fig. 1 (a); latter about one inch long. On April 7. ( $\times 40$ .)
6. T. S. typical bract of same cone: cf. text-fig. 1 (e). ( $\times 24$ ).
7. L. S. ovule, to show micropylar arrangement. One pollen grain is embedded in the hairs. April 7. ( $\times 180$ .)
8. L. S. archegonium. May 27. ( $\times 180$ .)
9. T. S. ovule, to show five archegonia, with coalescing jacket-layers. May 27. ( $\times 40$ .)
10. T. S. top of archegonium, showing four neck-cells. May 27. ( $\times 150$ .)
- 11, 12, 13. Typical stages of embryo formation. June 15, June 23, July 7, respectively. ( $\times 150$ .)

In the fig. 13 the suspensor-like tubes are "embryonal cells."



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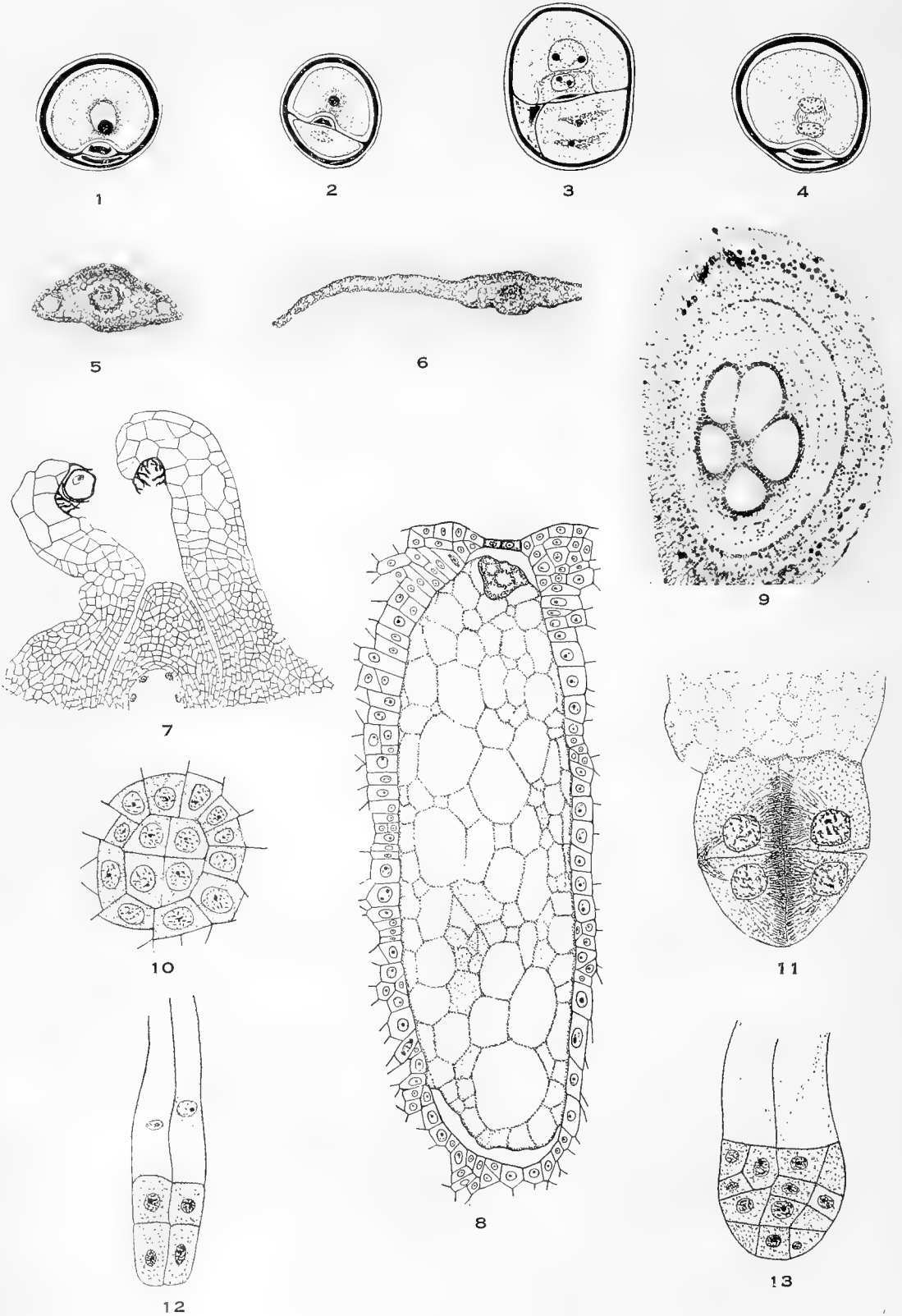
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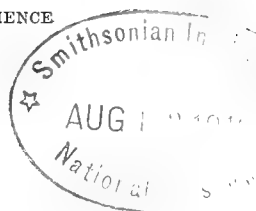
THE INSULATING PROPERTIES OF ERINOID.

BY

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[COMMUNICATED BY PROFESSOR WILLIAM BROWN.]



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## XXIX.

## THE INSULATING PROPERTIES OF ERINOID.

By R. G. ALLEN, B.Sc., LOND.; A.R.C.Sc.I.;

Assistant to the Professor of Applied Physics in the Royal College of  
Science for Ireland, Dublin.

(COMMUNICATED BY PROFESSOR WILLIAM BROWN.)

[Read APRIL 23; published AUGUST 16, 1918.]

THIS paper deals with the results of an investigation of some of the properties, chiefly relating to insulation, of Erinoid<sup>1</sup>—a material of comparatively recent origin, which, among other purposes, is used as an insulator.

A few preliminary tests were made on several samples of erinoid. Thus it was found to have a density 1.34 at ordinary temperature; to soften somewhat when immersed in boiling water for a short time; that when immersed in heated olive oil at a temperature of 200°C. for some minutes and then removed it readily disintegrated into the form of a burnt powder; to be non-inflammable, and apparently unattacked by dilute sulphuric acid of density 1.2 after immersion therein for over a week; to have considerable mechanical strength and be easily machined into various forms.

It was thought desirable, for the sake of comparison, to similarly test under the same conditions as nearly as possible some other insulating material in common use, and the one selected as being perhaps the most representative was red vulcanized fibre, which will generally be referred to as red fibre.

The samples used in this investigation had been previously exposed to air under ordinary conditions in a dry room for several months. Some of these were in the form of short cylindrical tubes, closed at one end, and turned in a lathe. Others were in the sheet form, with unmachined surfaces.

*Absorption and Retention of Water.*

The samples in the form of solid cylinders or plates were first weighed in air,  $W_1$  grammes; immersed in water at ordinary temperature for  $t_1$  hours;

---

<sup>1</sup> This material is a by-product of milk; the process of its manufacture, which is complicated, being partly mechanical and partly chemical. It is extensively used for various purposes in many countries. For further information, see Whitaker, 1918: A New British Industry, p. 820.

weighed again,  $W_2$ ; exposed to air at normal condition for  $t_2$  hours; then finally weighed,  $W_3$ . The total surface  $A$  sq. cms. of the sample was also calculated.

The following results were obtained for three samples of erinoid in the form of short cylindrical rods of diameter about 2.5 cms.

$$A = 66 \text{ sq. cms.}, t_1 = 73 \text{ hours}, t_2 = 25.5 \text{ hours.}$$

| Material.          | $W_1$ . | $W_2$ . | $W_3$ . | $x$ . | $y$ . |
|--------------------|---------|---------|---------|-------|-------|
| Erinoid, blue, . . | 43.72   | 45.27   | 44.15   | 1.55  | 1.12  |
| „ black, . .       | 46.02   | 48.30   | 46.69   | 2.28  | 1.61  |
| „ red, . .         | 45.05   | 47.88   | 46.21   | 2.83  | 1.67  |

in which  $x = W_2 - W_1$  the water absorbed in 73 hours, and  $y = W_2 - W_3$  the water lost in the succeeding 25.5 hours on exposure to normal air.

The percentage gain in weight due to the absorption of water in 73 hours was therefore  $\frac{100x}{W_1}$ , and the percentage loss of the water absorbed due to air drying for 25.5 hours was  $\frac{100y}{x}$ .

Thus, for the three samples the following values are calculated:—

| Material.          | Percent. gain in weight in 73 hours. | Percent. loss of absorbed water in 25.5 hours. |
|--------------------|--------------------------------------|--|
| Erinoid, blue, . . | 3.55                                 | 72   |
| „ black, . .       | 4.9                                  | 71   |
| „ red, . .         | 6.3                                  | 59   |

Of these, the red variety is the most absorbent and the most retentive of water. The blue, a dark blue, and the black are much more nearly equal in these respects.

To confirm the result that red was more absorbent of water than blue erinoid, a second experiment was made with samples of erinoid in sheet form, each of total surface-area of about 135 sq. cms. The results obtained were:—

| Material.          | $W_1$ | $W_2$ | $x$  | Percent. gain in weight in 65 hours. |
|--------------------|-------|-------|------|--------------------------------------|
| Erinoid, blue, . . | 47.49 | 50.72 | 3.23 | 6.8                                  |
| „ red, . .         | 54.64 | 58.87 | 4.23 | 7.75                                 |

The larger percentage gain in weight for a shorter period of immersion than in the preceding test, is due to the surface-area being nearly double of what it was. That the red variety absorbs more water than the blue is again demonstrated.

Erinoid is not nearly so absorbent as vulcanized fibre as shown by the following results obtained for red erinoid and red fibre. In each sample the total surface-area was about 135 sq. cms.

| Material.           | $W_1$                    | $W_2$ | $W_3$                   | $x$   | $y$  |
|---------------------|--------------------------|-------|-------------------------|-------|------|
| Erinoid, red . . .  | 51.64                    | 58.87 | 55.92                   | 4.23  | 2.95 |
| Fibre, red, . . .   | 69.61                    | 85.14 | 75.35                   | 15.53 | 9.79 |
|                     | Percent. gain in weight. |       | Percent. loss of water. |       |      |
| Erinoid, red, . . . | 7.75 in 65 hours.        |       | 70 in 25.5 hours.       |       |      |
| Fibre, red, . . .   | 22.3 in 72 hours.        |       | 63 ,, ,, ,,             |       |      |

The time of immersion was 65 hours for erinoid and 72 hours for fibre, and the time of drying, exposed to air, 25.5 hours in each case. This drying began at the same time in each case, and the samples were placed near each other to ensure the same drying facilities.

Allowing for the difference of the time of immersion the fibre probably absorbed more than 2.5 times as much water as erinoid, while it was more retentive of its absorbed water.

In this test the erinoid was slightly swollen after immersion in water, but not nearly so much so as the fibre, which increased in its thickness from 1 cm. to 1.4 cm.

The effect on the weight of erinoid by soaking it in different liquids for two weeks has been investigated at the National Physical Laboratory and the results obtained were these:—

| Liquid.                      | Percent. increase of weight. |
|------------------------------|------------------------------|
| Distilled water, . . .       | 18.3                         |
| Sea water, . . . . .         | 19.0                         |
| Dilute sulphuric acid, . . . | 15.3                         |
| Mineral oil, . . . . .       | Loss 0.02                    |
| Castor oil, . . . . .        | Loss 0.35                    |



In the present investigation the effect of the absorption of water by erinoid upon its electrical resistance was also determined for different times of immersion. This was done as follows.

The sample in the form of a short tube closed at one end was immersed in water with a length of one cm. projecting above the surface. Mercury was poured inside the tube to a level of that of the outside water, and thermometers reading to  $0.2^{\circ}\text{C}$ . were placed in the mercury and water.

The resistance between mercury and water through the walls of the sample was measured for different intervals at ordinary temperature. By warming or cooling the bulbs of the thermometers as required and replacing them in the mercury and water, the temperature of the sample could be adjusted to the right value; time being allowed to reach a fairly steady state. This operation was done very carefully to avoid wetting the dry part of the tube. An allowance for the evaporation and absorption of the water was also made when necessary.

The tube was about 6.5 cms. long, of outer diameter 2.5 cms., and inner diameter 1.55 cms. The results obtained for red and black erinoid are given in Table 1, and Fig. 1 gives the curves relating percentage decrease of resistance and time in hours.

TABLE 1.  
Temperature  $18.6^{\circ}\text{C}$ .

| Red Erinoid. |                  |                      | Black Erinoid. |                  |                      |
|--------------|------------------|----------------------|----------------|------------------|----------------------|
| Time Hours.  | Resist. Megohms. | Percentage decrease. | Time Hours.    | Resist. Megohms. | Percentage decrease. |
| 0            | 32               | —                    | 0              | 83               | —                    |
| 1.5          | 28               | 12.5                 | 0.4            | 77               | 7.2                  |
| 22.5         | 16.3             | 49                   | 0.63           | 75               | 9.6                  |
| 31.6         | 14.2             | 55.5                 | 1.5            | 69               | 16.8                 |
| 46           | 12.2             | 62                   | 2.6            | 67               | 19.2                 |
| 51           | 11.2             | 65                   | 8.5            | 59               | 29                   |
| 55           | 10.5             | 67                   | 21             | 49               | 41                   |
| 70           | 8.3              | 74                   | 30             | 44               | 47                   |
| 79           | 7.5              | 76.5                 | 44             | 40               | 52                   |
| 81           | 7.2              | 77.5                 | 53             | 37               | 55                   |
| 99           | 5.3              | 83.5                 | 70             | 33               | 60                   |

Thus the red erinoid has a greater decrease of insulation resistance due to

more absorption of water than the black erinoid excepting at the initial stage, shown by the curves, when the decrease is roughly the same in both cases. The rate of decrease is seen to be comparatively large for the first 8 hours, and much smaller after an immersion of 70 hours.

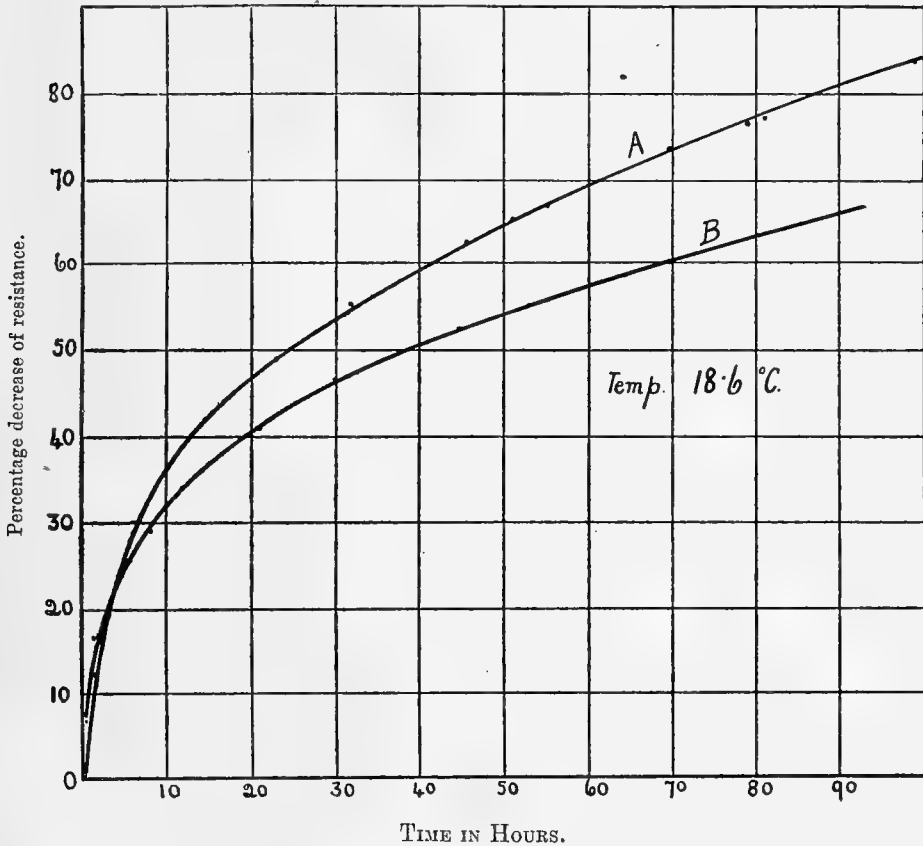


FIG. 1.—Percentage decrease of resistance with time due to absorption of water. Curve *A* is for red erinoid; Curve *B* for black erinoid.

At the end of immersion, the part of the sample tube projecting above the surface of the water was found to be unchanged in dimensions excepting close to the surface of the water where its *outer* diameter had increased to an appreciable degree which extended throughout the immersed length. This swelling was more pronounced in the red than in the black erinoid.

A test was also made on a tube of white erinoid. Its resistance in megohms was found at several different temperatures in the dry state with mercury inside and outside the tube. After immersion in water for 72 hours the tube was taken out, carefully dried by rubbing it with dry cloths for

a few minutes, and its resistance measured as before for the same set of temperatures. The values obtained were as follows:—

| Temp. | Resist.<br>before immersion. | Resist.<br>after immersion. |
|-------|------------------------------|-----------------------------|
| 18·5  | 75                           | 4·2                         |
| 23    | 42                           | 3·4                         |
| 33    | 13                           | 1·5                         |
| 36·5  | 9                            | 1·2                         |

By graphing the values of resistance after immersion against temperature an approximate straight line is obtained. This suggests that the absorbed water is distributed more or less uniformly throughout the material as the graph of the resistance before immersion, against the temperature, is not a straight line.

The change of resistance due to the immersion of erinoid in different liquids for two weeks was found at the National Physical Laboratory to be as follows:—

|                                |                     |
|--------------------------------|---------------------|
| Material unsoaked, . . .       | ohms.<br>20,000,000 |
| Soaked in distilled water, . . | 80,000              |
| „ „ sea water, . . .           | 1,000               |
| „ „ dilute sulphuric acid, .   | 2,000               |
| „ „ mineral oil, . . .         | 2,600,000           |
| „ „ castor oil, . . .          | 5,000,000           |

*Specific insulation resistance of erinoid and fibre at ordinary temperatures.*

The insulation resistance of erinoid and fibre at ordinary temperatures was found for samples in the form of tubes and plates. The tubes were turned in a lathe, but the surfaces of the plates were unprepared in any way. The latter were fitted on one face with a bounding ridge of paraffin wax 3 or 4 cms. in width by 1 or 2 cms. in depth. The other face was placed in contact with mercury in a dish, and the receptacle on the upper face was partly filled with mercury.

In some cases the mercury at the top and bottom of the plate was replaced by water so as to test whether better contact was made between the material and its water electrodes than in the case of mercury.

A test was made on both fibre and erinoid to determine whether the surface leakage between the electrodes of the sample had an appreciable effect on the resistance being measured, and it was found that this effect was negligible.

The results obtained are given in Table 2;  $\sigma$  being the specific resistance in megohms per cm. cube;  $l$  the effective length,  $b$  the breadth, and  $t$  the thickness of the sheet sample in cms.; and  $D_1$  and  $D_2$  the outer and inner diameters of the tubular samples.

TABLE 2.

| 1. Thick plates : mercury electrodes.            |      |       |       |       |          |
|--|------|-------|-------|-------|----------|
| Material.  | $l$  | $b$   | $t$   | Temp. | $\sigma$ |
| Erinoid, white,                                  | 13.8 | 25.2  | 0.62  | 16.3  | 17,000   |
| „ black,   | 13.7 | 25.3  | 0.53  | 16.6  | 26,000   |
| „ blue,  | 8.3  | 14.5  | 0.6   | 17.4  | 18,000   |
| „ red,   | 8.7  | 14.0  | 0.6   | 16.8  | 38,000   |
| <i>Fibre</i> , red,                              | 15.5 | 25.2  | 1.0   | 16.7  | 94       |
| „ red,   | 6.4  | 9.8   | 1.0   | 16.0  | 62       |
| 2. Thin plates : mercury electrodes.             |      |       |       |       |          |
| Erinoid, black,                                  | 5.5  | 10.6  | 0.248 | 16.8  | 65,000   |
| „ black,   | „    | „     | „     | 26    | 15,000   |
| „ blonde,  | 5.4  | 10.6  | 0.26  | 16.7  | 200,000  |
| „ blonde,  | „    | „     | „     | 23    | 72,000   |
| „ brown,   | 5.5  | 10.2  | 0.23  | 24    | 36,800   |
| „ gold,  | 5.5  | 9.8   | 0.24  | 23    | 35,000   |
| 3. Thin plates : water electrodes.               |      |       |       |       |          |
| Erinoid, black,                                  | 5.5  | 10.6  | 0.248 | 17.8  | 20,800   |
| „ brown,   | 5.5  | 10.2  | 0.23  | 18    | 23,600   |
| „ gold,  | 5.5  | 9.8   | 0.24  | 17.8  | 22,500   |
| „ blonde,  | 5.4  | 10.6  | 0.26  | 17.9  | 37,700   |
| 4. Tubes closed at one end : mercury electrodes. |      |       |       |       |          |
| Material.  |      | $D_1$ | $D_2$ | Temp. | $\sigma$ |
| Erinoid, black,                                  | 4.6  | 2.5   | 1.55  | 16    | 4,600    |
| „ red,   | „    | „     | „     | „     | 2,700    |
| „ white,   | „    | „     | „     | „     | 4,900    |
| „ blue,  | „    | „     | „     | „     | 6,000    |
| <i>Fibre</i> , red,                              | „    | „     | „     | „     | 1,800    |

The value given for red fibre is only a rough representation of its specific resistance at ordinary temperature. It may be much less owing to absorption of moisture from the atmosphere, or greater if in a very dry condition. The values given in Section 1 of Table 2 for sheet fibre are much smaller than 1800, which is the mean value of the two tubular samples whose results are given in Tables 10 and 11.

A test was also made with the white and black plates of Section 1 of this table, and the following results obtained :—

| Material.       | A     |          | B     |          | C     |          |
|-----------------|-------|----------|-------|----------|-------|----------|
|                 | Temp. | $\sigma$ | Temp. | $\sigma$ | Temp. | $\sigma$ |
| Erinoid, black, | 16.6  | 26,000   | 16.8  | 15,000   | 16.8  | 11,200   |
| „ white,        | 16.3  | 17,000   | 16.8  | 12,400   | 16.8  | 8,000    |

A is the case in which mercury electrodes were used ; in B the top electrode was water, and the bottom one mercury ; while in C both were water.

It may, therefore, be deduced that the unprepared surface of erinoid gives the sample a greater specific insulation resistance than when machined, as in the case of the tubes ; that the thinner samples have a higher specific resistance than the thicker ones ; that the water electrode gives a closer contact surface than one of mercury ; that the blonde erinoid has a considerably higher specific resistance than the other varieties of erinoid, and this in view of the results of Sections 2 and 3 of Table 2 may be attributed to a much greater skin effect or inferior contact with its mercury electrodes than that possessed by the other samples of erinoid, or to a combination of both causes. Finally, that erinoid has a higher insulation resistance than the red fibre tested.

The insulation resistance of the samples was generally determined by the megger method ; sometimes by the galvanometer method ; and the highest values by the leakage method.<sup>1</sup>

In the latter a mica condenser of capacity two microfarads in parallel with an electrostatic voltmeter was connected across the sample and the arrangement charged with a direct voltage of about 100.

Whenever a test was made with each of the three methods a very close

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<sup>1</sup> These methods are described in detail in *Scient. Proc. Roy. Dubl. Soc.*, vol. xv. (N.S.), No. 27, June, 1918, p. 292.

agreement of results was always found. Thus the results of the leakage test on a sample of black erinoid at 16°C. were found to be

|              |    |    |    |    |    |    |     |
|--------------|----|----|----|----|----|----|-----|
| Seconds, .   | 0  | 15 | 30 | 45 | 60 | 90 | 120 |
| Volts, . . . | 98 | 91 | 85 | 80 | 75 | 66 | 57  |

Exactly the same set of values were obtained when the direction of the charging voltage was reversed.

The leakage of the arrangement itself, that is the condenser and voltmeter, was 0.4 volt in 120 seconds.

From these results

$$R = \frac{120}{2.3 \times 2 \log_{10} \frac{98}{57.4}} = 113 \text{ megohms.}$$

The test was then made by the galvanometer method, using a direct voltage of 134, and the value obtained for  $R$  was 110 megohms. In this experiment the deflection of the galvanometer remained steady for several minutes' observation, and was of the same value when the direction of the applied voltage was reversed.

The agreement between the galvanometer and the megger results was also very close when testing the sample at higher temperatures.

#### *Voltage test of erinoid and fibre.*

Tests were made on a number of samples of erinoid, and also on one of fibre, to determine whether the insulation resistance depended upon the value of the applied voltage or not.

Three similar tubes of white erinoid of different thicknesses were tested, and the results obtained are given in Tables 3 and 4, in which  $E$  is the voltage applied to the sample, and  $D$  the deflection of the galvanometer, which was shunted in the case of the sample tested at 41°C.

TABLE 3.

| White Erinoid 0.53 cm. thick.<br>Temp. 41° C. |          |               | White Erinoid 0.32 cm. thick.<br>Temp. 19.7°C. |          |               |
|---|----------|---------------|--|----------|---------------|
| <i>E</i>                                      | <i>D</i> | $\frac{E}{D}$ | <i>E</i>                                       | <i>D</i> | $\frac{E}{D}$ |
| 95  | 46       | 2.07          | 56.6   | 6.4      | 8.8           |
| 149   | 72       | 2.07          | 109  | 12.5     | 8.7           |
| 280   | 137      | 2.04          | 236  | 27.9     | 8.45          |
| 525   | 253      | 2.07          | 386  | 45.7     | 8.43          |
| 650   | 318      | 2.04          | 516  | 62.0     | 8.3           |
| 802   | 406      | 1.97          | 790  | 100      | 7.9           |

TABLE 4.

*White* erinoid. Thickness, 0.175 cm. Temp. 33.4° C.  
Complete voltage cycle.

| <i>E</i>  | <i>D</i> | $\frac{E}{D}$ | <i>E</i>  | <i>D</i> | $\frac{E}{D}$ | <i>E</i> | <i>D</i> | $\frac{E}{D}$ |
|-----------|----------|---------------|-----------|----------|---------------|----------|----------|---------------|
| 37        | 16.7     | 2.2           | 44        | 19.5     | 2.25          | 55       | 28.5     | 1.93          |
| 141       | 73       | 1.93          | 140       | 76.5     | 1.83          | 139      | 75.5     | 1.84          |
| 278       | 154      | 1.8           | 303       | 174      | 1.74          | 300      | 172      | 1.74          |
| 574       | 348      | 1.66          | 598       | 376      | 1.59          | 596      | 373      | 1.6           |
| 602       | 372      | 1.62          | 303       | 177      | 1.71          |          |          |               |
| 312       | 174      | 1.79          | 140       | 78.5     | 1.78          |          |          |               |
| 140       | 73.5     | 1.91          | 56        | 29       | 1.93          |          |          |               |
| 44        | 18.5     | 2.38          | —         | —        | —             |          |          |               |
| Reversed. |          |               | Reversed. |          |               |          |          |               |

The first set of values in Table 4 was taken for the current going from the outside to the inside of the tubular sample; the current was then reversed and the second set taken; finally the current was again reversed and the third set taken.

The results obtained for red fibre are given in Table 5,

TABLE 5.

*Red fibre.* Sheet form. Thickness, 1 cm.

Temp. 16° C.

|                       |      |      |       |      |       |      |      |
|-----------------------|------|------|-------|------|-------|------|------|
| $E$ , . . .           | 71   | 144  | 313   | 600  | 310   | 144  | 43.5 |
| $D$ , . . .           | 35.5 | 73.5 | 163.5 | 341  | 162.5 | 72.5 | 20   |
| $\frac{E}{D}$ , . . . | 2    | 1.96 | 1.92  | 1.76 | 1.91  | 1.98 | 2.18 |

Immediately after these values were taken, a test was made to ascertain whether any dielectric absorption was present. This was done by passing the current through the sample in the same direction as in the preceding test, namely from the mercury on which the sheet floated, through its thickness, to the mercury on the top surface of the sheet walled round by paraffin wax, and applying a voltage of 590 to the sample for three minutes while noting the deflection  $D$ . The latter was found to remain steady at 330.

This voltage was then suddenly reversed and  $D$  was found to start at 358 then gradually rise to 368 after two minutes and 370 after three minutes. Reversing again the following values were obtained :—

|             |     |     |     |     |     |     |     |     |
|-------------|-----|-----|-----|-----|-----|-----|-----|-----|
| $t$ , . . . | 0   | 1   | 2   | 3   | 5   | 8   | 11  | 12  |
| $D$ , . . . | 375 | 370 | 365 | 359 | 350 | 340 | 339 | 336 |

$t$  being the time in minutes.

Reversing, the value of  $D$  only changed from 368 to 365 in three minutes. The next reversal gave :—

|     |     |     |     |     |   |     |
|-----|-----|-----|-----|-----|---|-----|
| $t$ | 0   | 1   | 2   | 3   | 4 | 5   |
| $D$ | 376 | 374 | 365 | 354 | — | 342 |

and at a final reversal  $D$  only fell from 370 to 367 in four minutes.

Throughout this test the temperature remained steady at 16°C. and the applied voltage at 590.



A similar test was made on a sheet of white erinoid, but there was no variation of  $D$  for a voltage of 590 applied for over three minutes in each direction. In each case the value of  $D$  was 110 divisions.

Thus while fibre showed the presence of dielectric absorption the sample of erinoid did not. This was generally found to be the case for the latter material.

The results given in Tables 3 and 4 are for tubes of erinoid which have been *machined*. A set of tests was made on samples in the form of sheets whose surfaces had not been machined or prepared in any way. The results are given in Table 6.

TABLE 6.

| Material ;<br>Effective dimensions ;<br>Temperature. | $E$  | $D$   | $\frac{E}{D}$ |
|--|------|-------|---------------|
| <i>Blue erinoid</i> , . . . .                        | 42   | 0·8   | 53            |
| 8·3 × 14·5 by 0·6 cm. thick, .                       | 144  | 4·4   | 32·5          |
| 17·4° C., . . . .                                    | 272  | 9·7   | 28            |
| Mercury electrodes, . . .                            | 570  | 26·4  | 21·5          |
| <i>Red erinoid</i> , . . . .                         | 52   | 0·5   | 104           |
| 8·7 × 14 by 0·6 cm. thick, .                         | 142  | 2     | 71            |
| 16·8° C., . . . .                                    | 301  | 6·4   | 47            |
| Mercury electrodes, . . .                            | 590  | 13·5  | 43·5          |
| <i>White erinoid</i> , . . . .                       | 28   | 2     | 14            |
| 13·8 × 25·2 by 0·62 cm. thick, .                     | 141  | 14·5  | 9·7           |
| 16·9° C., . . . .                                    | 299  | 43·5  | 6·9           |
| Mercury electrodes, . . .                            | 590  | 110   | 5·35          |
| <i>White erinoid</i> , . . . .                       | 16   | 9     | 1·78          |
| 13·8 × 25·2 by 0·62 cm. thick, .                     | 140  | 49    | 2·86          |
| 15·8° C., . . . .                                    | 306  | 106·5 | 2·86          |
| <i>Water electrodes</i> , . . . .                    | 600  | 212   | 2·83          |
| <i>Black erinoid</i> , . . . .                       | 39·6 | 1·2   | 33            |
| 14 × 25·6 by 0·53 cm. thick, .                       | 141  | 10·8  | 13            |
| 16·8° C., . . . .                                    | 295  | 32    | 9·2           |
| Mercury electrodes, . . .                            | 588  | 81·5  | 7·2           |

These results, excluding those of the fourth section, are plotted in Fig. 2.

From the results of Tables 3, 4, 5, and 6, and the curves of Fig. 2, the following may be deduced:—

1. The insulation resistance of unmachined fibre is only slightly dependent upon the value of the applied voltage. Table 5.

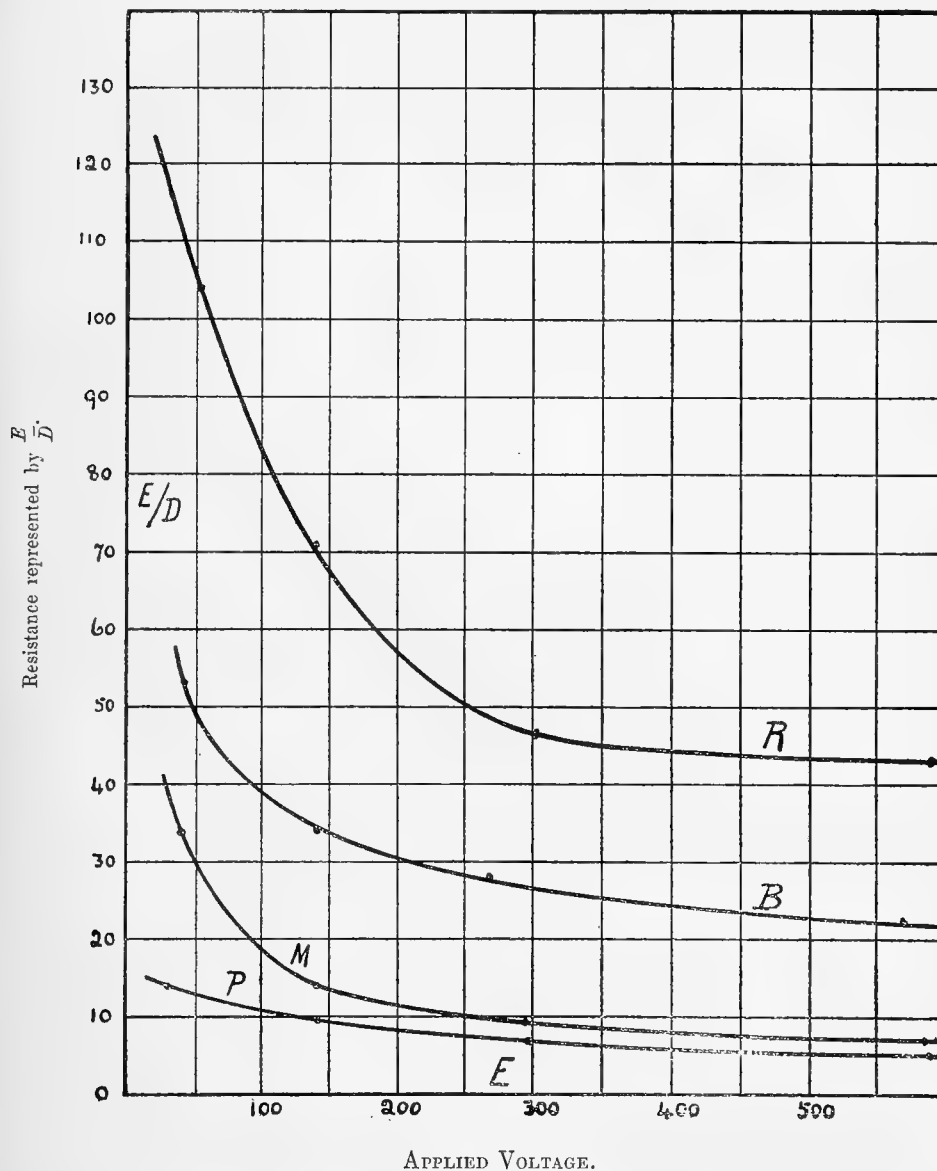


FIG. 2.—Insulation resistance and applied voltage; *R* is for red; *B* for blue; *M* for black; *P* for white erinoid. In these cases the surfaces of the sample were unmachined and mercury electrodes were used.

2. The insulation resistance of unmachined erinoid is *greatly* dependent upon the value of the applied voltage when mercury is used as the electrodes. Table 6 and Fig. 2.

3. When machined, the insulation resistance of erinoid is only slightly dependent upon the value of the applied voltage. Tables 3 and 4.

4. Unmachined erinoid with water electrodes is practically independent of the value of the applied voltage. Table 6.

5. Above a voltage of 500, the insulation resistance of unmachined erinoid with mercury electrodes is roughly independent of the value of the applied voltage. Fig. 2.

This dependence of the value of the resistance of unmachined erinoid upon the value of the voltage thus appears to be very largely a *surface* effect, as it practically disappears when the material is either machined, or its surfaces are in contact with water electrodes.

In conjunction with the preceding deduction it appears from Fig. 2 that increase of voltage improves the contact between electrode and material. This improvement is very rapid at first, but very slow after the voltage has exceeded 500: the voltage of the megger.

The resistance of the sample of unmachined white erinoid, represented by curve *P*, Fig. 2, was found by the megger to be 29.5 megohms at 16.8°C. with mercury electrodes, and 14 megohms with water electrodes. It follows that a much higher voltage than 500 would be required to obtain the same contact effect with mercury as with water electrodes. The latter agreement would, in all probability, never be realized on account of the advantage possessed by the water of becoming absorbed into the skin of the material.

Evershed<sup>1</sup> investigated the change of resistance with voltage for certain porous materials such as paper and cotton cloth, and found that a similar change took place to that shown in Fig. 2. Copper plates were used as electrodes. A theory of this change which depends upon the condensation of moisture in the pores of the sample was given by him.

In the case of erinoid, viewed from such a theory, it would appear that the porosity of the surface of the material is mainly responsible for its change of resistance with applied voltage.

The value of the galvanometer deflection for 600 volts in the case of the white erinoid with water instead of mercury electrodes was 212, which was found to remain constant for over three minutes and was quite independent of the direction of the applied voltage. This showed an absence of dielectric absorption and an unappreciable absorption of the water by the surface of the material during the time stated.

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<sup>1</sup> Journ. Inst. Elec. Eng., vol. lii, 1913, p. 51.

*The specific insulation resistance of erinoid and red fibre at different temperatures.*

The samples in a tubular form closed at one end, with mercury electrodes unless otherwise stated, were heated in a sand bath.

The results obtained for black, red, and white erinoid are given in Tables 7, 8, and 9; and for two samples of red fibre in Tables 10 and 11. The method of entry of these results is used in order to discover whether or not a certain simple relation holds between resistance and absolute temperature.

The thickness of the walls of the tube is given and also the value of  $\sigma$  in terms of  $R$ . Unless otherwise stated the inner diameter of the tube was 1.55 cms. and the effective length, which differed slightly in these samples, corrected for the closed end of the tube was about 4.6 cms.

TABLE 7.

*Black erinoid ; thickness 0.47 cm.*

$$\sigma = 61.3 R.$$

| $t$                     | $T$   | $\frac{I}{T}$         | $\sigma$ | $\text{Log}_{10} \sigma$ |
|-------------------------|-------|-----------------------|----------|--------------------------|
| 16                      | 289   | $34.6 \times 10^{-4}$ | 4,700    | 3.68                     |
| 29                      | 302   | 33.1 ,,               | 910      | 2.96                     |
| 34                      | 307   | 32.5 ,,               | 507      | 2.71                     |
| 44                      | 317   | 31.5 ,,               | 175      | 2.24                     |
| 51                      | 324   | 30.8 ,,               | 80       | 1.9                      |
| 56                      | 329   | 30.4 ,,               | 49       | 1.69                     |
| 64                      | 337   | 29.65 ,,              | 22.5     | 1.35                     |
| 73                      | 346   | 28.9 ,,               | 10.2     | 1.01                     |
| Results two days later. |       |                       |          |                          |
| 22                      | 295   | $33.9 \times 10^{-4}$ | 2,450    | 3.39                     |
| 29.5                    | 302.5 | 33.0 ,,               | 920      | 2.96                     |
| 36                      | 309   | 32.4 ,,               | 410      | 2.61                     |
| 41                      | 314   | 31.8 ,,               | 225      | 2.35                     |
| 47.5                    | 320.5 | 31.2 ,,               | 112      | 2.05                     |
| 56.5                    | 329.5 | 30.3 ,,               | 48       | 1.68                     |
| 65                      | 338   | 29.6 ,,               | 20.5     | 1.31                     |
| 73                      | 346   | 28.9 ,,               | 10.2     | 1.01                     |
| 81.5                    | 354.5 | 28.2 ,,               | 4.9      | 0.69                     |

The results obtained two days later for the same sample agree very closely with those obtained at first, notwithstanding its heating in the previous test.

This shows that the values are representative of the machined sample with mercury electrodes, and in a measure indirectly suggests that it is not appreciably hygroscopic. The same deduction may be made for white erinoid Table 14, p. 352.

TABLE 8.

*Rcd* erinoid; thickness 0.43 cm.

$$\sigma = 66R.$$

| $t$  | $T$   | $\frac{1}{T}$         | $\sigma$ | $\log_{10} \sigma$ |
|------|-------|-----------------------|----------|--------------------|
| 18   | 291   | $34.4 \times 10^{-4}$ | 2,230    | 3.35               |
| 22   | 295   | 33.9 ,,               | 1,320    | 3.12               |
| 25.5 | 298.5 | 33.5 ,,               | 860      | 2.93               |
| 31   | 304   | 32.9 ,,               | 436      | 2.64               |
| 35   | 308   | 32.4 ,,               | 264      | 2.42               |
| 43   | 316   | 31.6 ,,               | 119      | 2.08               |
| 48   | 321   | 31.2 ,,               | 76       | 1.88               |
| 55.5 | 328.5 | 30.4 ,,               | 33       | 1.52               |
| 62   | 335   | 29.8 ,,               | 17.8     | 1.25               |
| 66   | 339   | 29.5 ,,               | 13.2     | 1.12               |
| 70   | 343   | 29.1 ,,               | 8.7      | 0.94               |
| 75.5 | 348.5 | 28.7 ,,               | 6        | 0.78               |

TABLE 9.  
*White erinoid; thickness, 0.53 cm.*  
 $\sigma = 56.8 \text{ R.}$

| $t$  | $T$   | $\frac{1}{T}$         | $\sigma$ | $\text{Log}_{10} \sigma$ |
|------|-------|-----------------------|----------|--------------------------|
| 17.2 | 290.2 | $34.4 \times 10^{-4}$ | 4,130    | 3.62                     |
| 25   | 298   | 33.5 ,,               | 1,690    | 3.23                     |
| 28.5 | 301.5 | 33.1 ,,               | 1,130    | 3.05                     |
| 36.5 | 309.5 | 32.3 ,,               | 450      | 2.65                     |
| 39.5 | 312.5 | 32.0 ,,               | 322      | 2.51                     |
| 41.5 | 314.5 | 31.8 ,,               | 244      | 2.39                     |
| 45.5 | 318.5 | 31.4 ,,               | 164      | 2.22                     |
| 48   | 321   | 31.1 ,,               | 124      | 2.09                     |
| 57.5 | 330.5 | 30.2 ,,               | 49       | 1.69                     |
| 66.5 | 339.5 | 29.4 ,,               | 21       | 1.32                     |
| 70.5 | 343.5 | 29.1 ,,               | 15       | 1.18                     |
| 75   | 348   | 28.7 ,,               | 10.8     | 1.03                     |
| 81.5 | 354.5 | 28.2 ,,               | 5.7      | 0.76                     |

These results for white erinoid are much the same as for the black given in Table 7.

TABLE 10.  
*Red fibre; thickness, 0.5 cm.*  
 $\sigma = 59 \text{ R.}$

| $t$               | $T$   | $\frac{1}{T}$         | $\sigma$ | $\text{Log}_{10} \sigma$ |
|-------------------|-------|-----------------------|----------|--------------------------|
| 22.8              | 295.8 | $33.8 \times 10^{-4}$ | 350      | 2.54                     |
| 25                | 298   | 33.5 ,,               | 307      | 2.49                     |
| 34.5              | 307.5 | 32.5 ,,               | 130      | 2.11                     |
| 40                | 313   | 31.9 ,,               | 86       | 1.93                     |
| 45.5              | 318.5 | 31.3 ,,               | 56       | 1.75                     |
| 51.8              | 324.8 | 30.7 ,,               | 36       | 1.56                     |
| 62.5              | 335.5 | 29.7 ,,               | 18       | 1.26                     |
| 68.5              | 341.5 | 29.2 ,,               | 12.7     | 1.1                      |
| 71.7              | 344.7 | 29.0 ,,               | 10.6     | 1.03                     |
| 79.5              | 352.5 | 28.4 ,,               | 7.4      | 0.87                     |
| Water electrodes. |       |                       |          |                          |
| 37                |       |                       | 39       |                          |
| 42                |       |                       | 29       |                          |
| 51                |       |                       | 19       |                          |

In this test the sample was heated to the highest temperature used, and values obtained for descending temperatures. A few results obtained after water had been substituted for mercury are given. This sample was cut from a sheet of thick red fibre, and turned in a lathe to the tubular form. It was found to be slightly swollen through absorption of water at the end of the second test.

TABLE 11.

*Red fibre*; thickness, 0.31 cm. $\sigma = 72 \text{ R.}$ 

| <i>t.</i>         | <i>T</i> | $\frac{1}{T}$         | $\sigma$ . | $\text{Log}_{10} \sigma$ . |
|-------------------|----------|-----------------------|------------|----------------------------|
| 23                | 296      | $33.8 \times 10^{-4}$ | 2,160      | 3.30                       |
| 25.5              | 298.5    | 33.4 ,,               | 1,510      | 3.18                       |
| 28.5              | 301.5    | 33.1 ,,               | 1,150      | 3.06                       |
| 32                | 305      | 32.7 ,,               | 830        | 2.92                       |
| 36                | 309      | 32.3 ,,               | 520        | 2.72                       |
| 46                | 319      | 31.3 ,,               | 216        | 2.33                       |
| 54                | 327      | 30.5 ,,               | 108        | 2.03                       |
| 65                | 338      | 29.6 ,,               | 48         | 1.68                       |
| 73                | 346      | 28.9 ,,               | 27         | 1.43                       |
| Water electrodes. |          |                       |            |                            |
| 41                |          |                       | 187        |                            |
| 51.5              |          |                       | 93         |                            |
| 57.5              |          |                       | 70         |                            |

This sample was heated just above 70° C., and values for descending temperatures obtained. It was a piece of tubing of inner diameter 1.6 cms.; outer diameter, 2.22 cms.; effective length, 3.7 cms.; and closed at one end with an ebonite stopper. This tube was not machined, but in the condition supplied by the manufacturer, and had previously been stored in a dry room for eight or nine months.

The resistance of this sample is seen to be considerably greater than the preceding one, and the decrease of resistance due to the use of water instead of mercury electrodes is much less.

It has been found by different workers that the value of  $\sigma$  in megohms

per cm. cube for fibre may range from 10 to 10,000, or somewhat higher if the material is very dry.

The value of  $\sigma$  obtained by Curtis<sup>1</sup> for red fibre at 22° C. was 5000. The corresponding value from the results of Table 11 is roughly of the same order.

Rayner<sup>2</sup> gives 100 as the value of  $\sigma$  at 20° C. for red fibre, a result of the same order as the corresponding value in Table 10, or more nearly in agreement with the results obtained for sheet fibre in Table 2.

The degree of dryness of the sample is by far the chief factor governing this large variation in insulation resistance of vulcanized fibre.

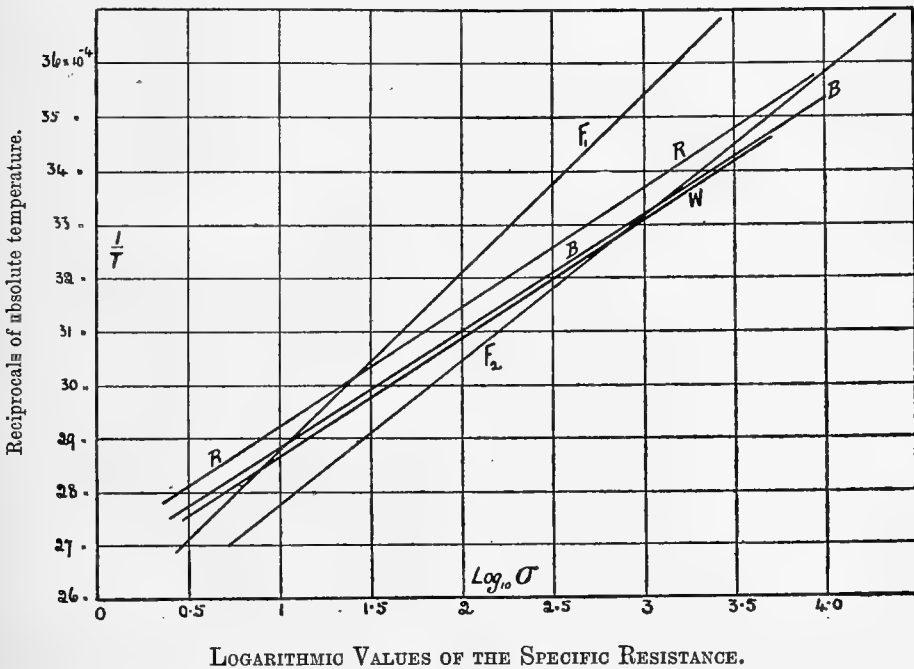


FIG. 3.—The relation between the reciprocal of absolute temperature and the logarithmic value of specific resistance. *B* is drawn for black erinoid; *W* for white erinoid; *R* for red erinoid; *F*<sub>1</sub> and *F*<sub>2</sub> for two different samples of red vulcanized fibre.

The values of  $\frac{1}{T}$  and  $\log_{10} \sigma$  given in Tables 7 to 11 are plotted in Fig. 3 for the samples of erinoid and fibre tested, and the points all lie fairly upon straight lines.

<sup>1</sup> Bulletin of the Bureau of Standards, vol. ii, No. 3, 1915, p. 418, Table 8.

<sup>2</sup> Journ. Inst. Elec. Eng., xxxiv, 1905, p. 620.



In 1908 Rasch and Hinrichsen<sup>1</sup> showed that the relation between insulation resistance and temperature for certain materials including porcelain, glass, and oil was a simple one, namely

$$\log \sigma = \frac{a}{T} + b$$

$a$  and  $b$  being constants for a given material.

The straight lines of Fig. 3 show that this relation is also true for erinoid and red fibre.

The lines for red, white, and black erinoid show by their approximate parallelism that the variation of the resistance of these samples with temperature is similar; but this is not the case with the two different samples of fibre. The insulation resistance of red erinoid is seen to be lower than that of the other varieties of erinoid as shown previously in Section 4 of Table 2.

*Insulation resistance and thickness of sample at different temperatures.*

From the same rod of white erinoid four cylindrical tubes, each closed at one end, were turned in the lathe, and then tested at different temperatures. The results are given in Tables 9, 12, 13, and 14.

TABLE 12.

*White erinoid; thickness, 0.65 cm.*

$\sigma = 42 \text{ R.}$

| $t$  | $T$   | $\frac{1}{T}$         | $\sigma$ | $\log_{10} \sigma$ |
|------|-------|-----------------------|----------|--------------------|
| 21.5 | 294.5 | $33.9 \times 10^{-4}$ | 2,080    | 3.32               |
| 23.5 | 296.5 | 33.7 ,,               | 1,680    | 3.23               |
| 26   | 299   | 33.4 ,,               | 1,260    | 3.10               |
| 34   | 307   | 32.5 ,,               | 464      | 2.68               |
| 38   | 311   | 32.1 ,,               | 295      | 2.47               |
| 50   | 323   | 30.9 ,,               | 84       | 1.93               |
| 59   | 332   | 30.1 ,,               | 34.5     | 1.54               |
| 61.5 | 334.5 | 29.8 ,,               | 27.4     | 1.44               |
| 65   | 338   | 29.6 ,,               | 20.3     | 1.31               |
| 67   | 340   | 29.4 ,,               | 17       | 1.23               |

<sup>1</sup> Zeit. für Elektrochem., vol. xiv, 1908, p. 41.

The internal diameter in this case was 1.3 cms., and the external diameter 2.6 cms. For the following cases the internal diameter was 1.55 cms., and the effective length of the sample tube in every case 4.6 cms.

TABLE 13.

*White erinoid; thickness, 0.32 cm.*

$$\sigma = 80 R.$$

| $t$  | $T$   | $\frac{l}{T}$         | $\sigma$ | $\log_{10} \sigma$ |
|------|-------|-----------------------|----------|--------------------|
| 17.4 | 290.4 | $34.4 \times 10^{-4}$ | 4,880    | 3.69               |
| 20.5 | 293.5 | 34.0 ,,               | 3,200    | 3.51               |
| 25   | 298   | 33.5 ,,               | 1,920    | 3.28               |
| 33   | 306   | 32.7 ,,               | 760      | 2.88               |
| 36   | 309   | 32.3 ,,               | 544      | 2.74               |
| 49.5 | 322.5 | 30.9 ,,               | 119      | 2.08               |
| 65.5 | 338.5 | 29.5 ,,               | 26       | 1.41               |
| 75   | 348   | 28.7 ,,               | 12       | 1.08               |
| 94   | 367   | 27.2 ,,               | 2.94     | 0.47               |
| 108  | 381   | 26.2 ,,               | 1.0      | 0.00               |

This sample was heated up to 110° C. and the values of the three highest temperatures of the table were obtained. It was then allowed to cool, and the next day values were taken for the ascending temperatures up to 65.5° C. given in the table.

In the previous heating the sample was exposed to a temperature of 100 to 110° C. for about one hour, and at the end of the test of the second day was observed to be very slightly discoloured, due to a little burning of the material.

The insulation resistance as judged by the results of the other samples of white erinoid was practically unaltered by exposure to this high temperature.

TABLE 14.  
 White erinoid; Thickness 0.175 cm.  
 $\sigma = 140 \text{ R.}$

| $t$                           | $T$   | $\frac{l}{T}$         | $\sigma$ | $\log_{10} \sigma$ |
|-------------------------------|-------|-----------------------|----------|--------------------|
| 21                            | 294   | $34 \times 10^{-4}$   | 5,300    | 3.72               |
| 26.5                          | 299.5 | 33.4 ,,               | 2,800    | 3.45               |
| 31                            | 304   | 32.9 ,,               | 1,680    | 3.23               |
| 35                            | 308   | 32.4 ,,               | 1,080    | 3.03               |
| 37.5                          | 310.5 | 32.2 ,,               | 770      | 2.89               |
| 40                            | 313   | 31.9 ,,               | 590      | 2.77               |
| 43                            | 316   | 31.6 ,,               | 435      | 2.64               |
| 46                            | 319   | 31.3 ,,               | 309      | 2.49               |
| 49                            | 322   | 31.0 ,,               | 224      | 2.35               |
| 53                            | 326   | 30.7 ,,               | 154      | 2.19               |
| 54                            | 327   | 30.5 ,,               | 123      | 2.09               |
| Values obtained the next day. |       |                       |          |                    |
| 17.8                          | 290.8 | $34.3 \times 10^{-4}$ | 7,700    | 3.89               |
| 20.5                          | 293.5 | 34.0 ,,               | 5,320    | 3.73               |
| 22                            | 295   | 33.8 ,,               | 4,060    | 3.61               |

The results obtained for this sample on the second day agree very well with those found on the first day.

The results of Tables 9, 12, 13, and 14 are plotted in Fig. 4, and the curves show that the thinner the erinoid the higher is its specific resistance. This characteristic is confirmed by the results for unmachined black erinoid in sections 1 and 2 of Table 2—namely,  $\sigma = 65,000$  for a thickness 0.248 cm. at  $16.8^\circ \text{C.}$ , and 26,000 for a thickness 0.53 cm. at  $16.6^\circ \text{C.}$

In the latter case the greater part of the large difference in  $\sigma$  was probably due to some difference in the manufacture of the thin and thick sheets.

This characteristic, also possessed by certain other materials, may be due to a large skin effect, or a large contact resistance between the material and its mercury electrodes, or a combination of both causes.

In the case of the machined white erinoid, in addition to the preceding causes, there may have been a greater drying out in the thinner sample, due to its drilling and turning, and also to its heating in the test.

The inset curves of Fig. 4 support the view of either skin or contact effect,

or a combination of both, but the greater drying out of sample C, already referred to, has apparently had no appreciable effect on the value of  $\sigma$ .

Whatever the causes of this characteristic, the latter becomes less and less pronounced as the temperature increases.

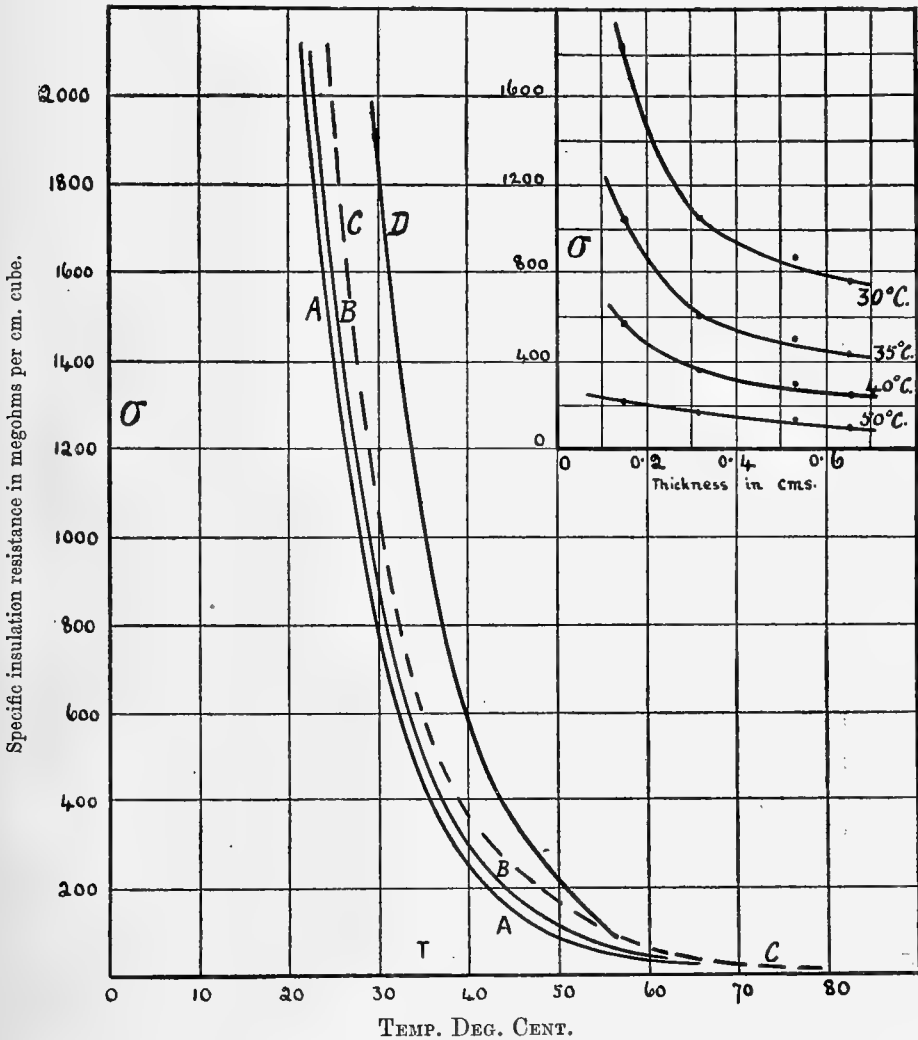


FIG. 4.—The specific insulation resistance of white erinoid at different temperatures and different thicknesses. Curve A is for thickness 0.65 cm.; B, 0.53 cm.; C, 0.32 cm.; D, 0.175 cm.

*Insulation resistance of erinoid at different temperatures for different contact electrodes.*

Erinoid in a tubular form was tested at different temperatures with mercury electrodes, then with graphite, next with water, afterwards air-dried for a short time, and finally tested again with mercury as its electrodes. The results obtained for blue erinoid are given in Table 15.

TABLE 15.

*Blue erinoid*; thickness 0.445 cm.

$\sigma = 64.6 R.$

| Mercury electrodes.  |       |                       |          |                          |
|--|-------|-----------------------|----------|--------------------------|
| $t$  | $T$   | $\frac{1}{T}$         | $\sigma$ | $\text{Log}_{10} \sigma$ |
| 81   | 354   | $28.2 \times 10^{-4}$ | 7.1      | 0.85                     |
| 70   | 343   | 29.1 ,,               | 18.1     | 1.26                     |
| 60   | 333   | 30 ,,                 | 45       | 1.65                     |
| 50.5   | 323.5 | 30.9 ,,               | 116      | 2.06                     |
| 40   | 313   | 31.9 ,,               | 355      | 2.55                     |
| 35   | 308   | 32.4 ,,               | 640      | 2.81                     |
| 30.5   | 303.5 | 32.9 ,,               | 1,100    | 3.04                     |
| 26   | 299   | 33.4 ,,               | 1,940    | 3.29                     |
| Graphite electrodes.   |       |                       |          |                          |
| 45   | 318   | $31.4 \times 10^{-4}$ | 1,290    | 3.11                     |
| 43   | 316   | 31.6 ,,               | 1,740    | 3.24                     |
| 40   | 313   | 31.9 ,,               | 2,500    | 3.40                     |
| Water electrodes.  |       |                       |          |                          |
| 61   | 334   | $29.9 \times 10^{-4}$ | 26       | 1.42                     |
| 54   | 327   | 30.5 ,,               | 45       | 1.65                     |
| 43   | 316   | 31.6 ,,               | 123      | 2.09                     |
| 35   | 308   | 32.4 ,,               | 275      | 2.44                     |
| 30.6   | 303.6 | 32.9 ,,               | 450      | 2.65                     |
| 22.8   | 295.8 | 33.8 ,,               | 1,130    | 3.05                     |
| 20.5   | 293.5 | 34.0 ,,               | 1,490    | 3.17                     |
| Air-dried for $1\frac{1}{4}$ hours; then tested with mercury electrodes. |       |                       |          |                          |
| 76   | 349   | $28.6 \times 10^{-4}$ | 3.4      | 0.53                     |
| 68.5   | 341.5 | 29.2 ,,               | 6.5      | 0.81                     |
| 58   | 331   | 30.2 ,,               | 17.4     | 1.24                     |
| 48   | 321   | 31.1 ,,               | 43.6     | 1.64                     |
| 38.5   | 311.5 | 32.1 ,,               | 116      | 2.06                     |
| 34   | 307   | 32.5 ,,               | 187      | 2.27                     |
| 32   | 305   | 32.7 ,,               | 240      | 2.38                     |

The sample was first heated to just above 80° C. and values obtained for descending temperatures. Graphite in the form of fine flakes was then substituted for the mercury and a few values found. After this, water electrodes were used; care being taken to keep the upper part of the sample which projected above the surface quite dry.

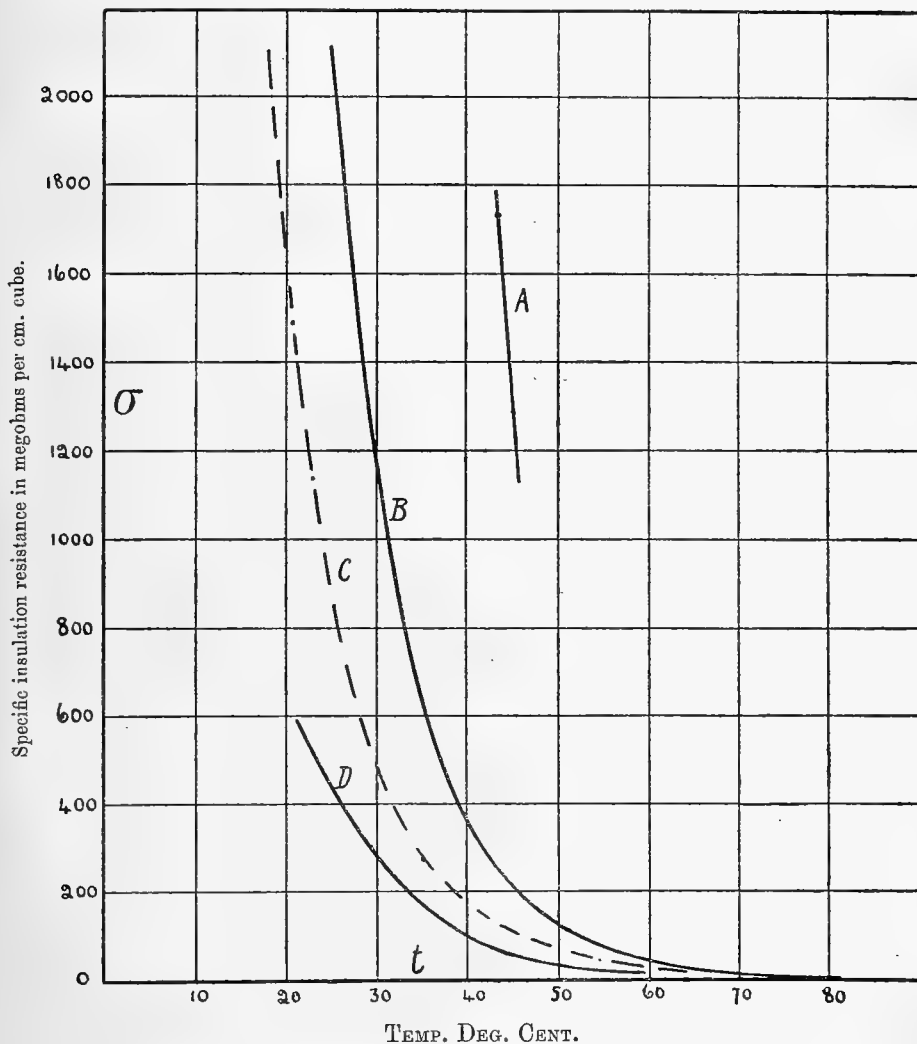


FIG. 5.—The effect on the insulation resistance at different temperatures of blue erinoid, by using various contact electrodes. Curve *A* is for graphite; *B* for mercury; *C* for water; *D* for mercury after 1¼ hour's drying in air at ordinary temperature.

The sample after the latter test was carefully dried with a cloth and allowed to dry in the air of the room for 1¼ hours. With mercury electrodes the sample was then raised to a temperature of about 80° C., and afterwards values were obtained at descending temperatures.

The results of Table 15 are shown plotted in Figs. 5 and 6. These show that the graphite is the worst electrode for making contact with the material.

In the case of line *C*, Fig. 6, the lowest observed contact point was that corresponding to temperature 61°C., Table 15.

At the time the data for this point were obtained, the wetted surfaces of the sample had been penetrated by a film of absorbed water. This film then increased in thickness as the temperature fell, that is, as time proceeded, until the last determination at 20.5°C., was made.

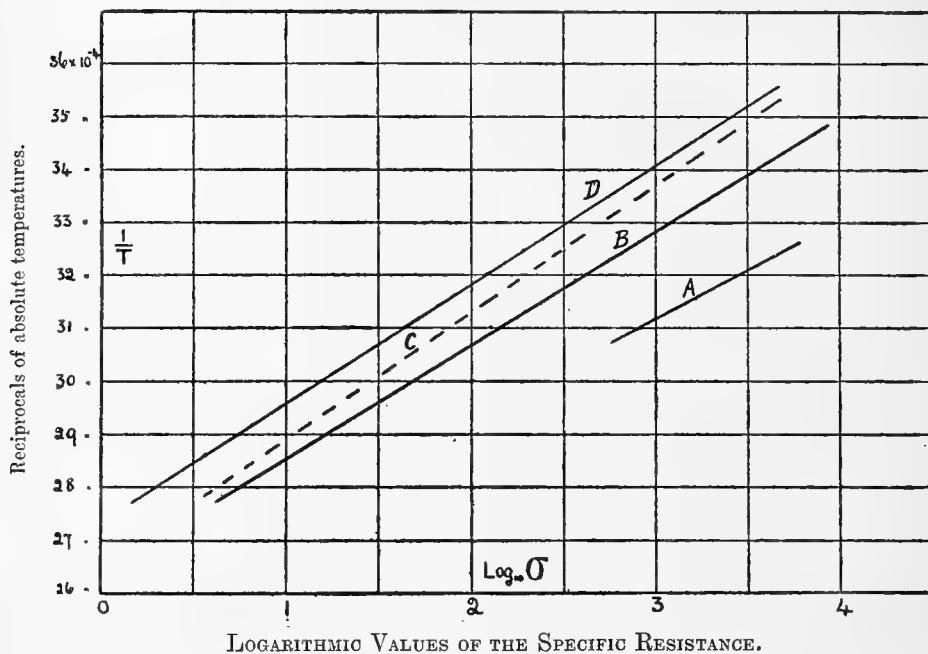


FIG. 6.—The relation between  $\text{Log}_{10} \sigma$  and  $\frac{1}{T}$  for blue erinoid when different electrodes are used.

Curve *A* is for graphite; *B* for mercury; *C* for water; *D* for mercury after 1½ hour's drying in air at ordinary temperature.

It follows, therefore, that the resistance of the sample would in this case have a double decrease as the temperature fell, one due to fall of temperature and which if there were no extra penetration of water, would probably give a straight line approximately parallel to *B*; the other due to the thickening of the film of water reducing the thickness of the unwetted part of the walls of the tube. This explains in a general manner the divergence of line *C* from parallelism with *B*.

A more detailed explanation would involve a knowledge of the rate and degree of uniformity of the water absorption. Dependence would also have to be placed to a slight extent upon the fact, already demonstrated, that decrease of thickness of erinoid is accompanied by increase of resistance.

After the air-drying, the sample with its contained water was heated to just above 80°C., and during this heating it is fair to assume that very little of this water would escape, but would go on penetrating a little farther into the material as time went on. This extra penetration, as shown by the rough parallelism of line *D* with *B* during the time of the last test, is apparently very small.

*The break-down voltage of erinoid and fibre.*

This has been determined for erinoid at the National Physical Laboratory. The electrodes used were two inches in diameter and the sample about two millimetres thick. Tests were made on unsoaked erinoid and on this material after soaking for two weeks in distilled water, mineral oil, and castor oil.

The respective r. m. s. values found for the break-down voltage in these four cases were 13,000 ; 1,500 ; 7,000 ; and 8,000.

The break-down voltage of vulcanized fibre has been investigated by a number of workers, but as this value mainly depends upon the degree of dryness, and partly upon the thickness of the sample, the results given show a very large variation. For a thickness of about two millimetres, and a well-dried sample, the value of the break-down voltage of fibre may, from the results referred to, be somewhere within the range 10,000 to 16,000 ; that is roughly the same as the value for erinoid.

*Summary of deductions.*

1. When dry, erinoid is a good insulator of fairly constant insulation resistance. It is slightly hygroscopic, but not so much so as fibre.

2. Erinoid does not absorb water when in direct contact with it so readily and to such an extent as red fibre, neither is it so retentive of the water absorbed as the latter.

3. When its surface is not machined its resistance greatly depends upon the value of the applied voltage, unless water electrodes are used. This dependence is very slight in the case of unmachined fibre, whether mercury or water electrodes are used. In the case of *machined* erinoid the resistance is almost independent of the voltage.

4. It is practically free from dielectric absorption, but the latter is appreciable in the red fibre.

5. The relation pointed out by Rasch and Hinrichsen between temperature and resistance is true for erinoid and fibre.

6. Of the varieties of erinoid tested, red is the most absorbent of water and generally of the lowest resistance.



7. Erinoid of *blonde* colour has a considerably larger resistance than the other varieties tested: probably due to greater skin or contact resistance.<sup>1</sup>

8. The specific resistance of erinoid diminishes with the thickness of the sample.

9. The break-down voltage of erinoid and fibre is practically the same.

In conclusion, acknowledgment must be made to the Erinoid Company, Lightpill Mills, Stroud, Gloucestershire, for their kindness in giving the material used in these tests and permission to incorporate the results obtained for erinoid at the National Physical Laboratory.

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<sup>1</sup> This was definitely shown, later, by testing *machined* blonde erinoid and finding it had practically the same resistance as black and red erinoid.

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A DISEASE OF FLAX SEEDLINGS CAUSED BY  
A SPECIES OF *COLLETOTRICHUM*, AND  
TRANSMITTED BY INFECTED SEED.

BY

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(PLATES XIX. and XX.)

[*Authors alone are responsible for all opinions expressed in their Communications.*]

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## XXX.

A DISEASE OF FLAX SEEDLINGS CAUSED BY A SPECIES OF  
*COLLETOTRICHUM*, AND TRANSMITTED BY INFECTED SEED.

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(PLATES XIX. AND XX.)

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I.—INTRODUCTORY.

FARMERS in the North of Ireland who cultivate flax complain not infrequently of trouble with the crop (when in the seedling stage) which they describe as "yellowing." Very little attention has, up to the present, been devoted to this trouble from a scientific standpoint ; but it is almost certain that both the nature and causes of this so-called "yellowing" in flax are not in every case the same.

There is one form of "yellowing" in which the seedling plants exhibit a general paleness or yellowing of their normally green parts—a kind of *chlorosis*—and in which search for a parasite as the causative agent has given only negative results. Since this form of "yellowing" can be cured by the application of an artificial manure, rich in potash salts, it is usually supposed that the chlorotic condition is due to potash starvation.

Another form of "yellowing" in flax has been attributed to attacks on the roots of seedlings by *Asterocystis radicis*, a parasite belonging to the Chytridiaceæ.<sup>1</sup> A short note<sup>2</sup> on this matter was published in August, 1900 ;

<sup>1</sup> This organism has also been found in yellowing flax in France (Arnaud G. La Brûlure du Lin. Bull. Soc. Path. Vég. de France I (1) 1914, p. 38), and, according to Arnaud, the *brûlure* attributed by Ladureau in 1880 to Thrips may perhaps in reality have been caused by *Asterocystis*.

<sup>2</sup> Anon. The Yellowing of Flax Plants. Journ. Dept. Agric. and Tech. Inst. for Ireland, vol. i., 1900-01, p. 151.

and in the following year Johnson<sup>1</sup> dealt with this disease, calling it “firing or ‘yellowing.’” Johnson’s description was not based on any extended study of the disease in Ireland, but was derived mainly from Marchal’s<sup>2</sup> account of a disease of young flax plants, which occurs in Flanders, and is known there as *vasbrand* or *brûture*.

It is true that the parasite discovered by Marchal was found (in its resting-spore condition at any rate) in the roots of certain flax seedlings sent from the North of Ireland, taken from a crop affected with “yellowing”; but as to whether this organism is common, or is of serious importance as a cause of “yellowing” in Ireland, we are still largely in the dark.

Johnson appears to have assumed that “yellowing” and “firing” were one and the same disease, attributable to the same cause. We find, however, that although these popular terms are at times used somewhat loosely by farmers, yet, generally speaking, they are applied to widely differing troubles with the flax crop.

The term “firing” is usually employed for a disease of flax plants when they are one half or more than one half grown, not when they are only in the seedling stage. Moreover, “firing” is a term applied chiefly to stem-trouble, whereas the most obvious general feature of “yellowing” is the paleness of the foliage, especially in quite young plants.

Our study of “firing” has not yet progressed far enough to enable us to define it with preciseness, or to state what the cause of it is; and it is, of course, possible that it may be the result of more causes than one. Undoubtedly, however, there is a *Fusarium* disease of flax in this country, which results in damage to the crop, sometimes spoken of as “firing”; but all cases of “firing” cannot be explained as the result of *Fusarium* attack.

The disease to be dealt with in the present paper has nothing in common with “firing,” as usually understood, and it is very different from Marchal’s *brûture*.

Although it was first introduced to our notice as a form of “yellowing,” and although, under certain circumstances, affected plants do turn more or less yellow, we do not think that the term “yellowing” is really appropriate for the disease, and we do not propose to employ it. Popular terms, such as “yellowing” (flax), “yellow-blight,” “curl” (potato), &c., which are applied somewhat indiscriminately to congeries of distinct diseases, should, as far as possible, be avoided. The disease in the present case is often more of the nature of a “damping-off” than of a “yellowing.”

<sup>1</sup> Johnson, T. The “Firing” or “Yellowing” of Flax. Journ. Dept. Agric. and Tech. Inst. for Ireland, vol. i., 1900-01, p. 591.

<sup>2</sup> Marchal, E. Recherches Biologiques sur une Chytridinée Parasite du Lin. Bruxelles 1901.

Our attention was first drawn to it in the early part of the summer of 1916 by Mr. P. T. O'Hare, A.R.C.Sc.I., Instructor in Agriculture in County Antrim. Specimens, showing the same characteristic symptoms in each case, were forwarded by Mr. O'Hare from several farms in that county; and observations made by one of us in the flax-fields in that and the neighbouring counties in the following spring showed that the disease was by no means an uncommon one, and caused in some cases no inconsiderable damage to the young crop.

## II.—SYMPTOMS OF THE DISEASE.

The disease first makes itself evident to the ordinary observer when the seedlings are only an inch or two above ground. The braird, as a whole, or patches of it, presents a more or less sickly and pale appearance, which farmers often wrongly attribute to frost.

When individual diseased seedlings are closely examined it is at once evident that, at least in the early stages, the trouble concerns primarily the cotyledonary leaves. On them rounded, water-soaked areas are present, which may arise anywhere on their surfaces. In a great many cases, however, the diseased areas are intimately associated with the adhering seed-coats, which, particularly in the case of shallow-planted seed, are carried above ground by the cotyledons. As time goes on these water-soaked, dead areas increase in size, and exhibit a more or less distinct circular zonation. The earlier attacked portions of the leaf become dried up, and, finally, the whole leaf is killed. This state of affairs is illustrated in fig. 1, Plate XIX.

Close examination shows that the diseased areas are not confined to the leaves of the seedlings. In very many cases the young stems show small lesions, which, at first sight, might be mistaken for damage resulting from insect attack. These lesions, illustrated in fig. 6, Plate XIX., are sunken, pale areas, which run longitudinally on the stems, and often originate from the base of a previously affected leaf.

Examination with the microscope shows that, in the majority of cases, the epidermis on a diseased area is still intact; and the sinking-in is due merely to the contraction of the dead tissues. Sometimes, however, the contraction is so great that actual rupture of the dead tissues occurs.

It not infrequently happens also, especially at the ground-level, that the lesion completely encircles the young stem. This results in the falling over and ultimate death of the young seedling; and the appearance thus presented strongly resembles the condition often called "damping-off."

More advanced cases of the disease can also be found in which the epidermal and cortical tissues of the stems at or near ground-level have more



or less completely disappeared, leaving the central, woody cylinder bare. In such cases the stem lies more or less parallel with the surface of the ground, but with its younger, positively heliotropic portion directed more or less vertically upwards. Plants affected in this way may remain alive for some little time, but their leaves gradually become yellow, and they die.

If affected seedlings be examined with the microscope, especially after a period of about twenty-four hours' incubation, at room-temperature, in a moist atmosphere, the surface of the diseased areas, both on leaf and stem, are seen to be dotted over with minute fungus pustules (*acervuli*). These consist in the main of aggregations of conidia, and they vary in colour from shell-pink to salmon. From the base of each acervulus arise, not only the short conidiophores, on which the single-celled conidia are borne, but also a number of characteristic long, black, tapering hairs or setae. (See fig. 3, Plate XIX.)

Sections through the diseased tissues show an abundance of fungus mycelium in them, but in no case have any indications of the formation of sclerotia been observed.

The conidia are hyaline, non-septate, rounded at each end, and either cylindrical or slightly fusiform in shape. Each contains a central oil-drop. In breadth they vary but little, measuring usually about  $4\mu$  in this direction. There is, however, considerable variation in their length. The extremes found were  $11\mu$  and  $21\mu$ , whilst the average length of fifty conidia, taken at random, was  $17\mu$ .

The conidiophores are short, unbranched, and hyaline. They arise from a small sub-epidermal aggregation of hyphae, scarcely developed enough to be regarded as a definite stroma, and are compacted together in the form of minute tufts, which break through the epidermis of the host, and protrude to a very short distance beyond it. The conidia are formed only after the epidermis has thus been broken through; and no case has been met with of conidia being borne actually within the host-tissue, as has been described by Atkinson<sup>2</sup> for *Colletotrichum gossypii*.

The setae arise from the same source as the conidiophores. They are dark-brown to black in colour, except at their more or less hyaline, tapering apices. They are usually three-septate, and the basal cell is often somewhat swollen. They vary considerably in length, but, on an average, are  $150\mu$  long and  $4\mu$  broad. Two to ten of them may be present in each

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<sup>1</sup> The colour nomenclature adopted in this paper is based on Ridgway's "Colour Standards and Nomenclature." Washington, 1912.

<sup>2</sup> Atkinson, G. F. Anthracnose of Cotton. Journ. Mycol., vol. vi, 1891, p. 173.

acervulus. No cases either have been observed where setae perform the rôle of conidiophores, such as have been described for *C. gossypii*.

From what has been said it will be evident that the fungus present on the affected flax seedlings belongs to the genus *Colletotrichum*, and in order to study it in more detail, and to ascertain whether it was responsible for the disease, it was isolated, and grown in pure culture, and infection experiments were carried out.

### III.—ISOLATION OF THE FUNGUS AND GROWTH IN PURE CULTURES.

Since the production of conidia on the host plant is abundant, and the conidia are large enough to be located individually under the microscope, it was a comparatively easy matter to get fungus into pure culture.

Conidia-suspensions of suitable dilution were inoculated into tubes of melted wort-gelatine and plated out in the usual way. After the gelatine had solidified, the locations of completely isolated single conidia were marked, and, after germination had occurred, the latter were removed to suitable media slanted in test tubes. Thus each culture emanated from a single conidium.

The fungus grows well on a variety of media, producing an abundance of conidiophores, conidia, and setae. The following are some of the media used:—beef-extract-agar, and -gelatine, wort-gelatine, quaker-oat-agar, potato-stalk-extract-agar, cooked potato, tomato-fruit-extract-agar, green flax-extract-agar and oat-extract-agar. Gelatine media become liquefied slowly when the fungus is cultivated on them.

On beef-extract-agar the growth of the fungus is very meagre, and on beef-extract-gelatine no conidia, setae or appressoria were found. On the other media mentioned it varies in luxuriance with the nature of the medium, but as regards morphological characters the variation of the fungus when grown on the different media is very slight.

In general the *nature of the growth* on these media is at first sparse, and not much raised above the surface. At the outset white, it gradually turns grey and finally becomes almost black, at least in that portion of it at or near the surface of the slant. This uppermost dark layer consists of a matted mass of dark-brown, gnarled and twisted hyphae.

The *submerged mycelium* permeating the medium consists of branched, septate, hyaline, hyphae; where, however, these come into contact with the sides of the test-tube in which the medium is contained, dark, irregular, thick-walled cells are produced, either singly or in chains. They may be terminal or intercalary, and are produced especially in media which are not

particularly rich in nutrient material, such as oat-extract-agar.<sup>1</sup> These cells are to some extent suggestive of chlamydo-spores, but many of them appear to be devoid of contents, and their walls are more irregular in shape and thickness than it is customary to find in chlamydo-spores. Further reference will be made to them later on in this paper. (See fig. 4, Plate XX.)

The *conidia* are developed on and above the surface of the medium in irregular, salmon-coloured masses. They are not, however, so distinctly aggregated together into acervuli as is the case on the living host-plant. Those produced in pure cultures closely resemble those found on the host, and are of about the same size, the average dimensions being  $15.5\mu$  long by  $4\mu$  broad.

The *conidiophores* are, on the average, usually somewhat longer when developed in pure culture than when produced on the host plant. Their length varies very considerably, the extremes being  $16\mu$  and  $60\mu$ . In breadth they measure  $3\mu$ . They are not aggregated together into clusters or tufts but are scattered irregularly over the surface of the medium. They are usually unbranched, but occasionally they are branched in an irregular manner. Rarely, a conidiophore bearing conidia may be produced from a still living cell of a hypha within an adjacent, empty cell, the walls of which therefore form a kind of sheath around the conidiophore and conidia. A case of this kind is illustrated on Plate XX. fig. 6.

The *conidia* are produced in succession at the tips of the conidiophores. Their germination can be observed without difficulty in hanging drops or in cover-glass films. A germ-tube is produced as a rule from each end of the conidium, and, after this has occurred, a transverse wall usually arises in the middle of the conidium.

The *setae*, in pure cultures, arise from the submerged colourless mycelium. They are similar to those already described, and vary from  $150\mu$  to  $250\mu$  in length. They are  $3\mu$  in breadth, being but slightly thicker than the mycelium from which they spring. (See fig. 5, Plate XX.)

*Development of appressoria.*—The following details are based on observations made of the germination and subsequent development of a conidium on a cover-glass film of oat-extract-agar. A germ tube was produced from each end of the conidium, as usual. These germ tubes soon became branched and thus developed into mycelium. At about this time a transverse wall was formed in the original conidium. After two days, terminal, dark-brown thick-walled cells were produced on the mycelium, having irregular outlines,

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<sup>1</sup> This contains only the cold water soluble extract of ground Quaker Oats. See Sci. Proc. Roy. Dublin Soc., vol. xiii., no. 36, 1913, p. 578.

and each having a minute round pit or perforation of the wall. Frequently there developed from these dark cells new hyaline hyphae, while at times the dark cells reproduced themselves; and thus an irregular chain of them was formed. With the exception of the terminal cell of each chain which retained its protoplasmic contents, these dark cells appeared to be devoid of contents. (See Plate XX. fig. 2.)

Although somewhat suggestive of chlamydospores, we are of the opinion that these dark cells are really to be regarded as of the nature of *appressoria* or organs of attachment similar to those described by Hasselbring<sup>1</sup> for other species of fungi. True appressoria are certainly produced by this fungus, for they have been observed by us on the surface of the stems of diseased flax seedlings raised from seed which, prior to sowing, had purposely been sprayed with water containing conidia of the fungus in suspension. When the seedlings showed the disease on their cotyledons they were watered with a fine rose from above, and the newly developed conidia were thus washed from the infected leaves on to the hypocotyledonary stems. The conidia germinated on the stems, each producing a very short and slender germ tube, from which a dark cell with thickened wall and characteristic pit or perforation immediately arose. This cell remained firmly attached to the surface of the stem, and from it there grew out a delicate hypha which penetrated the epidermis of the host. (See Plate XX. fig. 3.) The penetrating hypha was very constricted at the point of passage through the wall of the host cell, but became considerably enlarged as soon as the interior of the cell was reached.

#### IV.—PROOF OF PATHOGENICITY.

In order to find out whether the fungus was capable of producing the disease in healthy flax seedlings the following infection experiment was carried out:—

Two lots of flax seed, of two hundred each, were sown in pots of soil. A good crop of perfectly healthy seedlings was produced in each case.

When the cotyledons were fully developed and the succeeding leaves were beginning to appear, the seedlings in one of the pots were sprayed with a suspension of conidia (from a pure culture) in sterile water. The other lot of seedlings was sprayed with sterile water alone. Both pots were then covered with bell-jars and kept in the greenhouse.

After two days several of the cotyledons of the seedlings sprayed with the conidia-suspension showed rounded, water-soaked areas, whilst no such spots were observable on the control seedlings sprayed with sterile water only.

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<sup>1</sup> Hasselbring, H. The Appressoria of the Anthracoses, *Bot. Gazette.* vol. xlii., 1906, p. 135.

The bell-jars were removed, and subsequently the water-soaked areas became brown and more or less dried up. Ultimately almost every cotyledon of the artificially infected seedlings became attacked and eventually died. Microscopic examination of the diseased cotyledons and stems showed the presence of the fungus (*Colletotrichum*) in abundance. From these diseased seedlings the fungus was re-isolated in pure culture without any difficulty, and was proved, by comparative cultures, to be identical with that used for inoculation purposes.

The control seedlings remained perfectly healthy; and the experiment clearly proves that the fungus is pathogenic to flax.

#### V.—PREVIOUS STUDIES OF COLLETOTRICHUM DISEASES OF FLAX.

It was not until our pure-culture and infection work had been completed that we became aware that a *Colletotrichum* disease of flax had already been noted as occurring in the United States of America. It appears that H. L. Bolley, in 1903,<sup>1</sup> first stated that a species of *Colletotrichum* was very destructive to young flax plants.

In 1910 this author published a brief description of a disease which he called "Flax Canker," and which he regarded as being caused by a species of *Colletotrichum*, to which he gave the name *C. lini* Bolley.<sup>2</sup> The description is altogether too fragmentary to enable us to state whether Bolley's "Flax Canker" is identical with our *Colletotrichum* disease. In the case of "Canker" the characters of the disease emphasized are the attacks on the stems (usually at ground-level), and the breaking off of the stems at this point as if eaten by insects. Bolley states that: "The general life history simulates that of the wilt fungi, but it is more distinctly an *internal seed disease*,<sup>3</sup> and the formaldehyde treatment is not so effective as against wilt . . ."

A somewhat more extended and illustrated account of "Flax Canker" was published by Bolley<sup>4</sup> two years later; but the description is of a popular character, and nothing is said of the parasite which causes the disease. Emphasis is, however, again laid on the detection of the disease through the shrunken or concave seeds, and it is maintained that the chief source of transmission of the disease to new areas is to be found in *internally* infected seeds.

<sup>1</sup> Bull., No. 55. N. Dakota Agric. Coll. Fargo, 1903.

<sup>2</sup> Bolley, H. L. Seed Disinfection and Crop Production. Bull., No. 87 N. Dakota Agric. Coll. Expt. Station, 1910, p. 144.

<sup>3</sup> Present authors' italics.

<sup>4</sup> Bolley, H. L. Flax Canker, N. Dakota Agric. Expt. Station. Press Bull., No. 52, 1912.

It is stated that "such seeds are often diseased on the interior, the young seed leaves already bearing cankers or sore spots before the seeds germinate." In our *Colletotrichum* disease we have not found a single case of attack of any part of the embryo within the seed, and in this very important respect our disease differs from Bolley's "Canker."

In reply to our enquiry for information as to the description of *Colletotrichum lini* Professor Bolley was good enough to state that as he did not consider himself to be a systematist he had refrained from describing the fungus, leaving that to be done by others. This apparently has never been done, and we are, therefore, in the unfortunate position of not being able to compare our fungus with that believed by Bolley to be the cause of "Canker."

In 1915 Schoevers<sup>1</sup> published an account of a flax disease in Holland which he ascribed provisionally to the attacks of a species of *Colletotrichum* which Mr. Bolley informs us represents, in his opinion, the same organism as he had observed in America.

Schoevers' account of the disease is based upon specimens forwarded to him from Friesland; and apparently he had not personally seen the disease as it occurs in the field. He calls attention to sunken patches on the young stems below the surface of the ground, but yet above the neck of the root; to the browning and death of some of the lower leaves of the seedlings, and to the fact that he found a fungus on all the affected plants, belonging, apparently, to the genus *Colletotrichum*. He thinks that this *Colletotrichum* is perhaps related to, or identical with, a species of *Gloeosporium* found by him on the seed-bolls of flax from Sexbierum.

Schoevers gives a careful description of the *Colletotrichum* observed by him, and his account of the disease is illustrated with four figures. The account is, however, evidently a preliminary one, and this is perhaps the reason why no species-name is given to the fungus. The fungus was not isolated in pure culture, and no infection experiments were made. The disease appears to be rather rare in Holland, and Schoevers' note upon it was published apparently with a view to calling the attention of inspectors and others to it, in order that on some future occasion a more thorough investigation of it might be made. We think it quite possible that our *Colletotrichum* disease may be the same as that described by Schoevers in his preliminary communication.

With the exception of the incomplete and preliminary accounts of the two authors just mentioned we have not been able to discover in phytopathological literature anything bearing on flax diseases resembling the one which we have been studying.

<sup>1</sup> Schoevers, T. A. C. Voorloopige Mededeeling over eene nog onbekende, wellicht niet ongevaarlijke ziekte van het vlas. Tijdsch. over Plantenziekten, xxi., 1915, p. 100.

With regard to the question of a possible connexion between *Colletotrichum* and *Gloeosporium* on flax we may say that we have also found a species of *Gloeosporium* on more or less fully grown flax plants, particularly when such plants are suffering from what has been termed "browning" in this country. Whether the *Gloeosporium* is the cause of this "browning" or not we are not yet in a position to say. We have, however, isolated the fungus, and grown it in pure cultures side by side with our *Colletotrichum*, and we are quite convinced that the two fungi are totally distinct. The general mode of growth and appearance of the cultures are different. Moreover, in our cultures setae were *always* produced by the *Colletotrichum*, and *never* by the *Gloeosporium*.

In Holland *Gloeosporium Lini* has been described<sup>1</sup> as having a *Colletotrichum* stage, and as being the cause of a flax disease; but this fungus appears to be different from ours, and the disease caused by it is evidently not the same.

#### VI.—DESCRIPTION OF THE CAUSATIVE PARASITE.

Descriptions of a considerable number of species of *Colletotrichum* have been published from time to time, but we have not been able to identify the species which causes this disease of flax seedlings with any of those hitherto described.

It may be identical with the species already described (but not named) by Schoevers, and it is just possible that it may be Bolley's *C. lini*. Since, however, no description of this latter species has been published, the name cannot be regarded as valid.

In the circumstances we have decided to treat our fungus as a new species, and to describe it as follows:—

#### *Colletotrichum linicolum* nov. spec.

Acervulis sparsis subepidermicis erumpentibus carnis; conidiis hyalinis continuis oblongis vel cylindricis vel sub-fusiformibus apicibus obtusis 1-guttulatis  $17\mu \times 4\mu$ ; basidiis fasciculatis brevissimis simplicibus hyalinis ex parvulis subepidermicis pulvillis ortis; setulis simplicibus erectis 3-septatis atro-fuliginis acuminatis apicibus hyalinis  $150\mu \times 4\mu$ ; appressoriis atrofulgineis.

*Hab.* in foliis stirpibus seminisque vivis *Lini usitatissimi* in Hibernia.

No perithecia, pycnidia, resting spores or reproductive bodies other than

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<sup>1</sup> Jaarverslag, 1915. Phytopathologisch Laboratorium "Willie Commelin Scholten." Amsterdam, 1916.

conidia have been observed, either on the host or in pure cultures, and no evidence has been obtained suggesting a connexion between this species and *Gloeosporium* or *Glomerella*.

#### VII.—TRANSMISSION OF THE DISEASE.

The observations made on diseased seedlings in the early stages of attack, to which allusion has already been made (see p. 361), suggested that the disease might be transmitted by the agency of the seed.

In order to settle this point, two lots of seed of one hundred each were taken from a sample part of which, when previously sown, had given rise to a certain number of diseased plants.

These two lots of seed were sown in very carefully sterilized soil contained in sterilized pots, and, after sowing, the pots were kept covered with glass bell-jars in order to eliminate possible contamination of the seedlings from air-borne sources. The seedlings which developed were kept under very close scrutiny, and up to the seventeenth day after sowing no traces of attack were discernible. On the next day, however, five seedlings with the first signs of disease on them were discovered in one of the pots and two in the other. These affected seedlings and others which appeared later were removed from the pots as carefully as possible as soon as they were recognized, this being done each day up to the twenty-first after sowing. At that time twenty-four had been removed from one of the pots and twelve from the other.

After the twenty-first day the diseased seedlings, as they appeared, were not removed; and at the end of the twenty-fifth day, when the experiment was concluded, ninety-three had been produced in the first pot and eighty-nine in the second. The rapid increase of the disease during the last three days was probably due, to some extent, to secondary infection. Indeed, it is possible that before the twenty-first day some cases of secondary infection may have occurred. For, although the diseased seedlings were removed as carefully as possible, it cannot be maintained that all chance of secondary infection was excluded during the process, especially seeing that the seedlings were in rather close proximity to one another in the pots.

The result of the experiment shows quite clearly that the disease emanates from the seed; and further experiments of the same kind both with sterilized and ordinary soil have confirmed this view.

In the present paper we have purposely confined our attention to the attacks of the fungus on seedling flax; but we may state here that it also attacks the leaves and stems of the mature plant. Indeed, acervuli bearing abundant conidia have been found on the outer surface of the "seed-bolls" (fruit). During rippling and de-seeding it would not be difficult for the seeds,



as they are threshed out of the bolls, to become contaminated with conidia. Further, if the seed were at all damp, the mucilaginous nature of the outer wall of its epidermis would, no doubt, assist in causing the conidia to adhere to it. It was thought that this might possibly be the way in which the seed carried the fungus, and it was therefore decided to contaminate seed with conidia artificially, and to find out whether such seed, when sown, would give rise to diseased seedlings.

In the first experiment a quantity of flax-seed was divided into two portions. One of these was steeped for one minute in sterile water, and was then allowed to become air-dry. The other portion was steeped for a similar period in sterile water containing *Colletotricum* conidia in suspension, prepared by agitating diseased seedlings in the water. After these artificially contaminated seeds had become air-dry, both lots were sown in pots of soil which were covered with bell-jars and placed in a greenhouse.

At the end of ten days a good crop of seedlings had arisen in each pot. The seedlings produced from the contaminated seed were in many cases diseased, the fungus being identified with the microscope and found attacking both the cotyledons and the stems of the seedlings. The seedlings derived from the seeds steeped in sterile water showed no trace either of disease or fungus.

A second experiment of a similar kind was then undertaken. The conidia used for preparing the steeping medium were, however, in this case derived from a pure culture. The result was similar to the previous one. The contaminated seed gave rise to diseased seedlings, while the "control" seed produced nothing but healthy plants. (See fig. 2, Plate XIX.) From the diseased seedlings in this experiment *Colletotrichum linicolium* was re-isolated in pure culture by the usual methods.

This experiment was repeated, a different sample of flax-seed being used. One hundred artificially contaminated seeds gave rise to ninety-seven seedlings, seventy-eight of which were found to be diseased on the twentieth day after sowing. In this case, however, out of the ninety-seven seedlings also produced by the non-contaminated (control) seed, ten were found to be diseased. This result was unexpected, and led us to suspect that the sample of seed used in the experiment was already naturally contaminated with the fungus; and this was proved to be the case subsequently.

In the next experiment, the seed used was first proved to be free from natural contamination by sowing it and ascertaining that it produced nothing but healthy seedlings.

Four lots of this clean seed, of one hundred seeds each, were counted out and steeped for one minute in a suspension of conidia (from a pure culture)

in sterile water. The four lots of seeds were then sown in separate pots at varying depths below the surface of the soil. This was done in order to ascertain whether there would be any correlation between the incidence of disease and the carrying above ground of the seed-coats. The deeper the seeds were sown, the less chance there was of the seed-coats being carried up.

The results of the experiment are summarized in the following table:—

| Depth of sowing. | No. of plants produced. | No. carrying seed-coats aloft. | No. of Plants diseased. |
|------------------|-------------------------|--------------------------------|-------------------------|
| 0.25 inch, .     | 97                      | 64                             | 52                      |
| 0.5 ,, .         | 97                      | 12                             | 10                      |
| 1 ,, .           | 78                      | 1                              | 3                       |
| 2 inches, .      | 88                      | 0                              | 1                       |

It is clear that there is a close correlation between the carrying up of the seed-coats and infection with the disease, but it is also clear that such carrying up of the seed-coats *is not absolutely necessary* for infection, for in three cases infection occurred, although the seed-coats remained in the soil; and further cases of this kind have been noted from time to time with naturally infected seed.

The foregoing experiments show clearly that the disease can be transmitted by conidia adhering to the seed; but they are, of course, open to the objection that the artificially contaminated seed was sown very soon after having been prepared, and it does not therefore follow that this is the actual mode of transmission which occurs in nature.

Attempts were next made to discover conidia adhering to the seeds in naturally infected samples, that is in those which gave rise to a certain proportion of diseased seedlings when sown. Portions of the samples were thoroughly shaken up with water and the washings examined with the microscope (as is done for certain cereal smuts), but no conidia were found. Further trials were made and the washings centrifuged, but with no positive result. Examination of the mucilage also revealed no conidia.

Attention was then directed more closely to the external appearance of the seeds composing naturally infected samples. No seeds with lesions or acervuli were found. In the case of one sample a good many seeds were present in which the cuticle of the epidermis of the seed-coat was evidently more or less ruptured. Fifty seeds of this kind were sown in moist sterilized silver sand. In eight days twenty-eight seedlings had been produced; and no others appeared subsequently. The cotyledons of these seedlings, as they

emerged, were subjected to minute scrutiny. On one cotyledon of each of four seedlings small, reddish spots were observed at a very early period. These spots, however, did not increase in size, and no fungus appeared on any of them. Eventually the cotyledons were sectioned and examined microscopically. It was found that the redness was due to the presence of anthocyan in certain of the cells, but they were apparently quite healthy, and no fungus hyphae were associated with them.

On the ninth day a small water-soaked area was observed on one of the cotyledons of a fifth seedling which up to that time had shown no sign whatever of discolouration or of fungus attack of any kind. Microscopic examination showed that this was a case of *Colletotrichum* attack. This was the only seedling out of the twenty-eight which showed any disease. The evidence in this case pointed clearly to the fact that the cotyledon was not already affected whilst within the seed, and infection must have been subsequent to germination. In spite of careful search we have in no single instance obtained the slightest evidence in favour of the view that the embryo is already infected while still within the seed; and we are of opinion that seedling infection is from an external source, and occurs during the course of, or subsequent to, germination.

The next step taken was to examine one by one the individual seeds in a naturally infected sample. This was done by placing each seed in a drop of water on a microscope slide and allowing the seed to swell. The mucilaginous epidermis of the seed-coat was then examined carefully. Nothing was found in the first few seeds examined, but it was soon discovered that *in some of the seeds fungus mycelium in considerable amount was present in the cells of the epidermis*. (See fig. 4, Plate XIX., and fig. 7, Plate XX.)

This mycelium was very similar in all the cases in which it was found. It was septate and hyaline; and in one case appressoria were found, similar to those already described (see p. 364), which at once strongly suggested that it might be that of *Colletotrichum*. Some of the cells of the hyphae were empty, but many of them retained their protoplasmic contents and presented every appearance of being still alive.

After a little practice it was found comparatively easy to pick out with the naked eye seeds containing mycelium. Such seeds have a dull appearance, and are often somewhat dark in colour and slightly roughish on the surface owing to the partial absence of the cuticle. Probably this last-named feature explains why such seeds were found to swell up, when placed in water, more rapidly than the normal-looking seeds, the absence of cuticle facilitating the rapid imbibition of water by the remainder of the cell wall.

The amount of mycelium present varied considerably from seed to seed,

but it was found that every infected seed could not with certainty be picked out from a sample by naked-eye examination or even with the help of a strong lens. Thus, one hundred seeds which showed none of the above-mentioned characteristics, but appeared to be absolutely normal and healthy, were selected from an infected sample and sown in moist sterilized silver sand. Fifteen of these gave rise to diseased seedlings, suggesting that in all probability a small amount of mycelium was present in their seed-coats, but not enough to make the seed appear in any way abnormal.

As is well known, the flax seed-coat consists of several layers of cells. The innermost layer, abutting on the endosperm, is the pigment layer. Next to this comes a layer of compressed, empty, thin-walled cells, which is followed by a layer of thick-walled sclerenchymatous fibres; and this is succeeded by a layer, one or two cells thick, of squarish parenchymatous elements. The outermost layer of all—the epidermis—is composed of cells, the outer walls of which absorb water readily and become much swollen when wetted, giving to soaked flax seed its mucilaginous character. A distinct cuticle is present on the outer surface of these walls.

Sections cut through dry infected seeds, when mounted in water, present the appearance shown in fig. 4, Plate XIX., and fig. 7, Plate XX. It will be observed that the mycelium is found only in the cells of the epidermis, and we have not been able to discover cases of penetration into any of the other layers of the seed-coat or into the endosperm or the embryo itself. Hence, although infection of the seed in the case of this disease is, strictly speaking, internal, it is only skin-deep. The embryo, within the seed, is free from infection.

It was next necessary to ascertain for certain whether the mycelium present in the epidermis of infected seeds was alive or not.

For this purpose a sample known to contain infected seeds was taken, and from it eight seeds were selected, each of which contained mycelium in its epidermis, this being determined by preliminary microscopic examination. A further lot of eight seeds was selected from the same sample, in which microscopic examination failed to reveal the presence of mycelium. The infected and non-infected lots of seed (as they may be called) were placed on moist filter paper in Petri dishes and kept in an incubator at 20° C. In three days all the seeds in both lots had germinated, and on the surface of six of the infected seeds *Colletotrichum* was present and bearing conidia. No fungus growth was present on the seed-coats of the eight non-infected seeds. Two days later the experiment was concluded. It was then found that seven of the non-infected seeds were free from fungus, while on the eighth there was a trace of *Penicillium* but none of *Colletotrichum*. Of the two infected seeds which had not developed *Colletotrichum* on the third day

one showed a slight development of *Alternaria* and the other no fungus growth. It is clear that in one case, at least, the mycelium originally present in the epidermis was dead. The experiment shows that although the mycelium of the epidermis of the infected flax seeds may not in every instance be alive, yet it is so in the majority of cases.

In another experiment twenty seeds, each found by microscopical examination to have mycelium in its epidermis, and twenty others, in which mycelium could not be found, were sown in moist, sterilized silver sand. The twenty non-infected seeds produced the same number of seedlings, of which fifteen bore their seed-coats aloft. Examination of the mucilage of these seed-coats (which was done by carefully removing a little of it without removing the seed-coats themselves) showed no trace of any fungus; and all of the seedlings remained free from disease up to the end of the experiment. From the infected seed eighteen seedlings were produced, thirteen of which carried their seed-coats on the cotyledons. In each of the thirteen cases *Colletotrichum*, bearing conidia, was found on the seed-coats, which were left *in situ*. All of these thirteen seedlings subsequently became infected with the disease, as also did four others of those derived from the infected seed which did not carry up their seed-coats. At the conclusion of the experiment, which lasted a fortnight, the seventeen infected seedlings were all dead. One, free from the disease, remained alive. This plant may have escaped infection by chance, or the mycelium in its seed-coat may have been dead from the start.

These two experiments practically prove that not only is the mycelium in the epidermis of the infected seed in most cases alive, but also that it is that of the *Colletotrichum* which causes the disease.

Further proof of these two important points was obtained from the following experiments:—Seeds containing the mycelium were soaked in sterile water until they became mucilaginous. A small portion of the mucilage was carefully removed to an oat-extract-agar film on the lower surface of a cover-glass, which was then placed over a cavity on a microscope slide, and subsequently vaselined around its edges. The preparation was examined at frequent intervals, and on the second day it was found that the hyphae in the mucilage had begun to grow. Growth continued and increased for some days, and on the ninth day the characteristic dark cells (appressoria) and conidia of *Colletotrichum* were produced.

This result was confirmed by another experiment, in which small portions of the mucilage, containing mycelium, were placed on slants of oat-extract-agar in test-tubes. Growth in this case was more rapid than on the film; and *Colletotrichum* conidia were produced within seven days.

The film culture mentioned above was opened, and small portions of the growth (consisting of both mycelium and conidia) were carefully transferred to the cotyledons of four healthy seedlings derived from seeds from a non-infected sample, which, to make assurance doubly sure, had been disinfected with formaldehyde solution previous to sowing. They were sown in sterile sand, and protected from aerial contamination. After fourteen days all four seedlings were diseased. Four similar seedlings were used as a control, and had drops of sterile water placed on their cotyledons instead of portions of the film culture. They remained perfectly healthy. The experiment was repeated, the cotyledons of ten healthy seedlings being inoculated from the growth of the film. The result was as before; in three days all ten seedlings had contracted the disease.

Finally, small portions of the mucilage, taken direct from seeds containing mycelium, were placed on the cotyledons of five healthy seedlings specially grown under aseptic conditions, as in the previous trials. As a control, portions of mucilage from a seed containing no mycelium were placed on the cotyledons of five similar seedlings. In the latter no disease developed; but all the five seedlings inoculated with the mycelium-containing mucilage became diseased within a fortnight. This experiment was also repeated, ten further healthy seedlings being inoculated as before. In four days all of them had become diseased.

Summarizing all these results, it is clear that the mycelium present in the epidermis of infected seeds is, in the majority of cases, living, retains its infective power, and is that of *Colletotrichum linicolum*. The infection of the crop undoubtedly occurs by means of this hibernating mycelium present in the epidermis of the seeds.

The precise method by which the seedlings become infected from the seed has not yet been determined; but no evidence could be found to support the view that the fungus reached the embryo by passing *through* the seed-coat. It may possibly be the case that during germination or afterwards the mycelium grows from the mucilaginous epidermis of the seed, and passes directly into the seedling, causing infection wherever the mucilage may happen to come in contact with it. When the seed-coats are carried above ground, this is most frequently on one or both cotyledons.

We are inclined to think, however, that infection is probably indirect, and that it takes place from conidia, which are produced by the hibernating mycelium, and which subsequently come into contact with some part of the seedling, where the production of germ tubes would take place, and penetration would occur. The production of such conidia has been observed on the surface of infected seed-coats, when carried above ground by the cotyledons,

considerably before the latter show signs of infection. Rain or dew would easily enable such conidia to be carried downwards, both to the cotyledons and the stems of the seedlings. Further, it has been observed that if mucilage from the infected seeds be placed on the cotyledons of healthy seedlings, conidia are developed from the mycelium some considerable time before the cotyledons show signs of infection. The matter is an interesting one biologically, and may be of some significance from the practical point of view. For, if infection occurs only through conidia, it might be possible to prevent their development (by suitable treatment of the seed) until the seed-coats had been thrown off, whereas the more drastic treatment which would probably be necessary to kill the hibernating mycelium might have an injurious effect on the seedling, or even kill the seed itself.

#### VIII.—CONTROL OF THE DISEASE.

Since the disease is transmitted through infected seed, the obvious<sup>1</sup> control measures that suggest themselves are:—

- (1) Prevention of seed infection, and, failing that,
- (2) Disinfection of infected seed.

We have not yet had an opportunity of ascertaining the exact way in which the seed becomes infected under natural circumstances. It has already been stated that *Colletotrichum linicolum* attacks the seed-bolls; and it is possible that its mycelium passes through the tissues of the fruit-wall, and thus reaches the surfaces of the seeds and infects them. This is apparently what occurs with the allied species, *C. Lindemuthianum* (the cause of bean-anthraxnose), although in this case the fungus passes through not only the fruit-wall but also through the seed-coat, and thus infects the embryo.

On the other hand, it may be, as has also already been suggested, that the seeds become contaminated with conidia which, under favourable conditions of moisture, germinate and send their germ-tubes into the epidermis of the seed-coat, there to develop into the hibernating mycelium. It was proved by experiment that infection of the seed by this latter means is at any rate

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<sup>1</sup> The close connexion between the incidence of infection and the carrying above ground of the seed-coats on the cotyledons has already been emphasized, and it is conceivable that the disease could be obviated by deep sowing. But it has been shown that a proportion of seedlings become diseased even when the seed-coats are not carried up, and these would under favourable conditions act as centres for subsequent infection of neighbouring plants. Further, deep sowing retards germination and lessens the vigour of the resulting seedlings, which is a serious disadvantage; and in Ireland flax-seed is always sown broadcast and is only lightly harrowed in. Hence deep sowing cannot be looked upon as a suitable means of controlling the disease.

possible. Twenty seeds from a disease-free sample were placed on moist filter paper in a Petri dish, and each seed was inoculated with a few conidia from a pure culture of *C. linicolum*. Germination of the conidia took place, and in some cases appressoria were developed. In a number of cases penetration of the germ-tubes into and development of mycelium within the epidermis occurred. Twenty other seeds from the same sample, not inoculated with conidia, but otherwise treated similarly, served as a control, and remained free from mycelium.

To prevent the seed from becoming infected would entail the prevention of the spread of the fungus over the crop. Whether anything of value could be accomplished in this direction by spraying during the growing season is a problem which we have not yet approached, but is one which may be kept in view for investigation when opportunity serves.

Disinfection of infected seed would appear to be of more practical importance under present circumstances, if it could be accomplished thoroughly without difficulty and without injury to the seed.

Before proceeding to any method of seed disinfection in practice, it would be essential first of all to ascertain whether a sample of the seed proposed to be sown contained any seeds infected with the disease. Diagnosis is not a difficult matter, and it could be carried out at any Seed Testing Station having a competent phytopathologist on the staff. The period required for each test would not be longer than the ten days required for a germination test of a sample of flax seed; and the two tests could run concurrently. Where, however, as at the Irish Seed Testing Station, the number of samples of flax seed received for testing runs into some thousands in a season—and that a short one—it would be a very considerable undertaking, requiring an increased staff technically trained to cope with the work.

Examination of seeds for pathological purposes is already carried out at the Irish Station in the case of some cereal diseases and also of celery seed; and as the number of plant diseases definitely proved to be transmitted by seed is now a considerable one, this aspect of the work of a properly staffed seed-testing station is likely to come into more prominence as time goes on. There is no doubt that large, but certainly avoidable, losses are occasioned annually in agricultural crops by the use for sowing of seed carrying disease with it.

Our first trials at seed disinfection with flax were started before it had been clearly demonstrated that the source of infection lay in hibernating mycelium contained within the epidermis of the seed-coat. They were based rather upon the idea of killing any conidia which might be adhering to the surface of the seed. In any case, however, disinfecting agents which killed



the conidia might also be expected to kill the resting mycelium, although, perhaps, not quite so readily or completely.

Two experiments were first carried out with seed which had previously been proved to be free from the disease. Some of the seed was artificially contaminated with conidia of *Colletotrichum* derived from a pure culture, while some of it was not thus contaminated and served as a control. The contaminated seed after drying was disinfected either by spraying with dilute solutions of formaldehyde, or by steeping it for short periods in such solutions; and, after drying, it was sown.

It is not necessary to record here the full details of these experiments, but the results may be summarized briefly. The uncontaminated (control) seeds produced healthy seedlings only in all cases. The contaminated but not disinfected seeds in one case produced eighty per cent., and in the other forty per cent. of diseased seedlings. Spraying the contaminated seeds before sowing with dilute formaldehyde solution by means of an atomiser reduced the incidence of disease from eighty per cent. to fifteen per cent. Steeping contaminated seed in dilute formaldehyde solution completely suppressed the disease in seven trials, and, in the only other one made, reduced it from eighty per cent. to two per cent. Where the seed was steeped in weak solutions for short periods (two to three minutes) there was no adverse effect on the germination of the seed or the development of the seedlings; but where the steeping was prolonged (six to ten minutes) the effect was to reduce the germination very markedly (in one case from 97 per cent. to 59 per cent.); and the seedlings which appeared were in many cases seriously injured by the treatment. It was clear that soaking flax seed for several minutes even in weak formaldehyde solutions would not be a practicable method of disinfection of the seed owing to the bad effects mentioned. The best results were obtained when the time of steeping was two minutes and the strength of solution 1:400 or 1:300 of forty per cent. formalin in water.

The next trial was made with naturally infected seed. This, when sown untreated, produced twenty-four diseased and seventy healthy seedlings. When steeped before sowing for two minutes in formalin, 1:400 and 1:300, the disinfected seed gave rise to ninety-three and ninety-four seedlings respectively, amongst which there was only one diseased seedling in each case. In this trial, therefore, the germination of the seed was not interfered with at all, and the disease was reduced to a minimum, although not completely eliminated.

This result, although extremely gratifying, cannot be regarded as entirely satisfactory, for, if even a comparatively small number of infected seedlings

were scattered through the crop in a field, each would probably serve as a centre from which the disease would radiate during the growing season, provided the weather conditions were favourable for the spread of the fungus.

The experiment was repeated, and alongside of it another one was carried out in which hydrogen peroxide (20 vols.) was used as the disinfectant. The strength of formalin used was one part (40 per cent.) in four hundred of water. After steeping, the one hundred seeds used in all cases were allowed to become air-dry before sowing. The pots and soil used were carefully sterilized, and the former were kept under bell-jars during the experiment, which lasted for twenty-one days. Two controls, consisting of one hundred untreated seeds in each case, were used, and the disease appeared first in these, namely, twelve days after the sowing of the seed. The seedlings were very closely examined each day (except on the sixteenth), and any showing the disease were carefully removed at once. The results are summarized in the following table:—

| Treatment.                            | No. of Plants. | No. of diseased seedlings recorded each day. |      |      |      |      |      |      |      |      | Total. |
|---------------------------------------|----------------|--|------|------|------|------|------|------|------|------|--------|
|                                       |                | 12th   | 13th | 14th | 15th | 17th | 18th | 19th | 20th | 21st |        |
| None (Control).                       | 100            | 3  | 7    | 4    | 3    | 8    | 1    | 4    | 1    | 0    | 31     |
| Steeped in formalin 40% 1:400         | 2 mins.        | 94   | 0    | 0    | 0    | 0    | 1    | 1    | 0    | 0    | 2      |
|                                       | 4 "            | 93   | 0    | 0    | 0    | 0    | 1    | 1    | 0    | 0    | 2      |
|                                       | 6 "            | 85   | 0    | 0    | 0    | 0    | 0    | 1    | 1    | 0    | 2      |
|                                       | 8 "            | 81   | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0      |
|                                       | 10 "           | 88   | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0      |
| None (Control).                       | 94             | 6  | 7    | 6    | 9    | 3    | 2    | 2    | 4    | 1    | 40     |
| Steeped in hydrogen peroxide 20 vols. | 2 mins.        | 99   | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0      |
|                                       | 4 "            | 95   | 0    | 1    | 2    | 0    | 2    | 2    | 0    | 0    | 8      |
|                                       | 6 "            | 90   | 0    | 2    | 0    | 0    | 2    | 3    | 1    | 0    | 8      |
|                                       | 8 "            | 97   | 0    | 0    | 0    | 0    | 0    | 2    | 0    | 0    | 2      |
|                                       | 10 "           | 90   | 0    | 0    | 0    | 0    | 0    | 1    | 0    | 0    | 1      |

As in the previous experiments, steeping the infected seed in weak formaldehyde solution for several minutes totally eliminated the disease, but depressed the germination percentage and resulted in the production of injured seedlings. Steeping for a shorter period greatly reduced the disease, but did not totally eliminate it. It had a less serious effect on the total germination, and caused only a very slight retardation in growth of the seedlings.

It was probably only by chance that no diseased seedlings appeared from the seed steeped for two minutes in hydrogen peroxide. Steeping for several minutes in this solution did not entirely eliminate the disease, but reduced it to small limits and had practically no adverse effect on germination. It was particularly noted that the use of hydrogen peroxide had no deleterious effect on the development of the seedlings.

Of the two disinfectants, formalin would be the cheaper, but hydrogen peroxide would be safer and equally efficient, if allowed to act for a considerable time. Neither of these two solutions is, however, perfectly satisfactory; and, in fact, any solution in which water is the solvent is disadvantageous for treating flax-seed, owing to the caking together of the seeds which is bound to occur more or less, and the difficulty of drying them again satisfactorily and without injury.<sup>1</sup>

In view of this difficulty, an attempt was made to disinfect the seed with liquids other than watery solutions. For this purpose, infected seed was steeped for half a minute in methylated spirit, allowed to dry, and then sown in sterilized soil. This treatment did not in any way impair the germination of the seed or injure the seedlings arising from it, but it had no effect whatever in suppressing the disease. Probably the time of steeping was so short that neither the interior of the seed nor the dormant mycelium in its epidermis was reached by the spirit.

Trials were also made with two proprietary fluids, sold for treating seed grain, primarily for the purpose of preventing the depredations of birds, but for which it has also sometimes been claimed that they are effective in preventing "smut" and "bunt." These liquids are of a more or less oily character, and appear to be coal-tar products. Steeping infected flax-seeds for one minute in these liquids, however, did not give satisfactory results. The seedlings produced were somewhat retarded in growth; their cotyledons were scorched by coming into contact with the seed-coats, while there was little or no reduction in the number of seedlings which became diseased.

In another experiment seeds were coated with the moist precipitate produced by mixing solutions of copper sulphate and washing soda, as is done in the preparation of potato-spraying mixture. There was no ill effect on germination or on the resulting seedlings. The percentage of diseased seedlings was considerably reduced, but not to the vanishing point.

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<sup>1</sup> In some parts of the United States of America it is regarded as absolutely essential to disinfect flax-seed before sowing, to ward off attacks of "wilt" (*Fusarium*). It is recommended to throw a fine misty spray of formaldehyde solution (1 lb. to each 40 gallons (U.S.A.) of water) over the seed, this being meanwhile shovelled and raked over. Half a gallon of solution is sufficient for a bushel of seed.

Finally, the idea of first very slightly moistening the seed with a misty spray of water and then drying it off at once by mixing a dry fungicidal powder with the seed was acted upon.

The powders used were—(1) the dried precipitate produced when a solution of copper sulphate is acted on by milk of lime, and (2) a finely ground mixture of copper sulphate crystals and dry sodium carbonate. Both of these powders are sold commercially for preparing potato-spraying mixtures, although such preparations have been proved to be less efficacious in warding off the potato blight than freshly prepared Bordeaux and Burgundy mixtures.

The results of the treatment were very encouraging. With the dried precipitate mentioned, the percentage of diseased seedlings arising from the treated seed was only two, whereas in the case of the same seed untreated it was thirty-five. Treatment with the mixture of copper sulphate and sodium carbonate gave even better results, for in this case not a single diseased seedling appeared during the experiment, which lasted for three weeks, a period which experience has shown is much more than ample for the appearance of primary infection.<sup>1</sup>

It is perhaps needless to say that all the attempts at seed disinfection dealt with in the present paper were carried out on a small scale; and it is not claimed that any one of them would necessarily be practicable under field conditions. Nevertheless we consider that sufficient has been done to show that, working along the lines indicated, there is a good prospect that further trials, on a more extended scale, would result in the working out of a method of treating flax-seed infected with the *Colletotrichum* disease, which could be used in actual practice, and which would, if persevered with, ultimately lead to the disappearance of this malady from our flax fields.

#### IX.—DISTRIBUTION OF THE DISEASE.

It has already been pointed out that a *Colletotrichum* disease of flax occurs in the United States of America. It appears to be especially prevalent in the State of North Dakota, where Bolley studied it. It is, however, not certain that Bolley's disease is identical with that described in the present communication, for we have been unable to discover any signs of internal attack upon the embryo while within the seed, as Bolley did.

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<sup>1</sup> While the present paper was passing through the press the results of further seed-disinfection trials became available. Sulphur was found to be quite useless as a disinfecting agent for this disease. Dry infected seed exposed for two hours to moist formaldehyde gas was almost, but not quite completely, disinfected; and no adverse effect on the germination of the seed or the development of the seedlings was observable. Exposure for four and six hours was scarcely more effective in killing the hibernating mycelium, and caused severe injury to the seed.

It is more than likely that the disease described by Schoevers is identical with that described by us, and it is to be hoped that further research on the disease in Holland will throw more light on this point.

At the Department's seed-testing station in Dublin large numbers of samples of flax-seed from various parts of the world are tested annually; and since the *Colletotrichum* disease is transmitted through the seed, we decided to investigate representative samples of flax-seed from widely different sources, to ascertain whether any of them carried the disease.

For this purpose seed from various countries was sown in pots of sterilized soil, and the seedlings carefully watched for the appearance of the disease. In this way seedlings affected with it have been grown from seed coming from Russia, Holland, Canada, and Japan. Hibernating mycelium of *Colletotrichum linicolum*, which produced conidia on incubation, has also been found in seeds from samples coming from the United States of America.

We have no reason to doubt the authenticity of the sources of origin of the samples of seed tested; but, of course, we are not personally able to vouch for their accuracy, since they were not forwarded direct to us for the purpose of the investigation. It is, however, to say the least, exceedingly probable that the disease described by us occurs, not alone in Ireland, but also in the other countries named. It would not be surprising if further research should show that it exists more or less wherever flax is cultivated.

#### X.—SUMMARY.

The present communication deals with a disease of flax seedlings which was reported as a case of "yellowing," but for which this designation is not regarded as being particularly appropriate.

The symptoms of the disease are described in detail, chief amongst them being the development of spots on the leaves and lesions on the stems leading, in many cases, to the death of the seedlings by a process resembling "damping off."

A species of *Colletotrichum* was found associated with the disease. This fungus was isolated and grown in pure culture; and infection experiments were carried out which proved it to be the cause of the malady.

The disease to some extent resembles the so-called "Flax Canker" attributed to *Colletotrichum lini* in the United States of America. It resembles more closely a disease ascribed to an unnamed species of *Colletotrichum* in Holland.

The fungus, proved to be the cause of the disease, is described as a new species under the name *Colletotrichum linicolum*.

It was discovered that mycelium of the fungus hibernates within the cells of the epidermis of the seed-coat, and it was proved that this was the source from which the disease was transmitted, the seedlings becoming infected during or subsequent to germination.

Transmission of the disease by infected seeds can to some considerable extent be overcome by sowing the seed deeply so that, on germination, the seed-coats are kept below ground, but this is scarcely a practicable method of control.

Disinfection of infected seed with formalin and with hydrogen peroxide reduces the number of seedlings to a marked degree, but does not completely eliminate the disease. Treating slightly moistened infected seed with a mixture of finely powdered copper sulphate crystals and dry sodium carbonate suppressed the disease entirely.

Flax-seed from Russia, Holland, Canada, the United States of America, and Japan has been found to give rise to diseased seedlings, and it is believed that the disease is widespread over the globe.

#### XI.—EXPLANATION OF PLATES.

##### PLATE XIX.

Fig.

1. Four flax seedlings naturally affected with the *Colletotrichum* disease.

From the one on the extreme left, one cotyledon has already fallen off, while the other one and the cotyledons of the three remaining seedlings are severely attacked. A few of the older lower leaves of the seedlings are also affected. The constricted areas on the hypocotyledonary stems are points of attack by the fungus. (Slightly reduced.)

2. Young flax seedlings photographed from above, showing the disease on their cotyledons. In the cases of the middle seedling in the upper row, and the right hand one in the lower row, the seed-coat is still adhering to one cotyledon. These seedlings were raised from healthy seed, artificially contaminated with conidia of *Colletotrichum linicolum*. (Natural size.)

3. Portion of the superficial tissues scraped from a naturally infected hypocotyledonary stem, showing the acervuli and setae of the fungus. ( $\times 60$ .)

4. Section through portion of the endosperm and seed-coat of an infected flax-seed mounted in water, and not stained, showing hyphae of *C. linicolum* in the much-swollen epidermal cells. ( $\times 200$ .)

Fig.

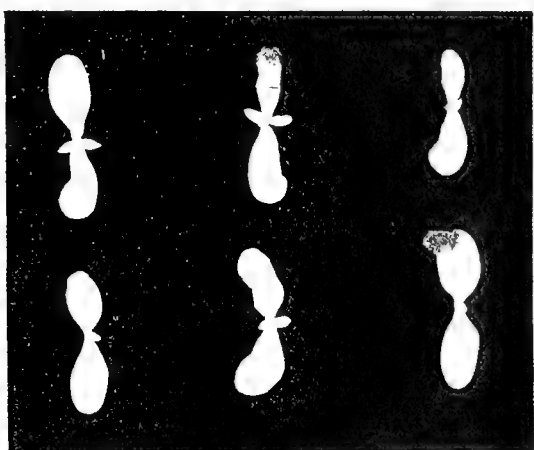
5. Treatment of naturally infected seed with formalin. In each pot one hundred seeds were sown. Those in the left-hand pot were steeped for two minutes in 40 per cent. formalin 1:400, and gave rise to ninety healthy, and three diseased, seedlings. Those sown in the right-hand pot were not treated, and gave rise to one healthy plant and ninety-three diseased plants, most of which were completely dead at the time of photographing.
6. Portions of the hypocotyledonary stems of three flax seedlings, derived from artificially infected seed, showing lesions of *Colletotrichum linicolum* on their surfaces. (Slightly reduced.)

## PLATE XX.

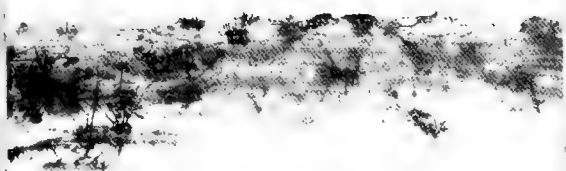
1. Ripe conidia and germinating conidia of *Colletotrichum linicolum* from a pure culture. ( $\times 730$ .)
2. The growth from a single conidium on an oat-extract-agar film after five days, showing the production of conidiophores and conidia, and the development of appressoria. ( $\times 510$ .)
3. A conidium which has germinated on the surface of a flax stem. An appressorium was first produced, and from its lower surface a delicate hypha penetrated into the epidermal cell as shown. ( $\times 730$ .)
4. Appressoria developed from mycelium in contact with the sides of a test-tube in a three weeks' old pure culture of *C. linicolum* on oat-extract-agar. ( $\times 730$ .)
5. Setae of the fungus; on the left from a naturally infected leaf, on the right from a pure culture. ( $\times 510$ .)
6. Conidiophore and conidia formed within an empty cell of a hypha. ( $\times 510$ .)
7. Portion of section through the endosperm and seed-coat of an infected flax-seed showing hyphae of *C. linicolum* in the swollen epidermis. ( $\times 510$ .)



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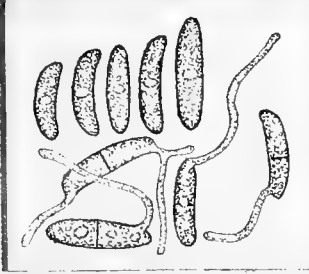
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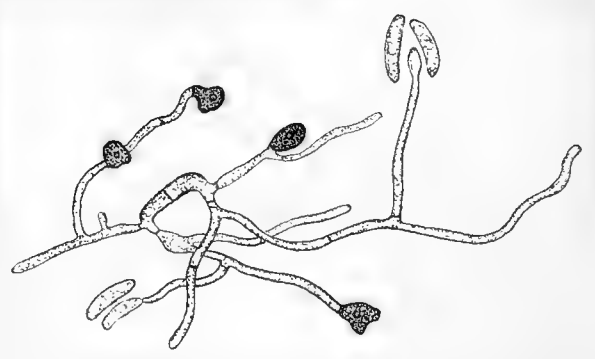
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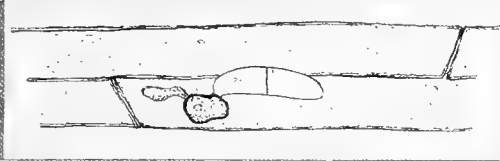




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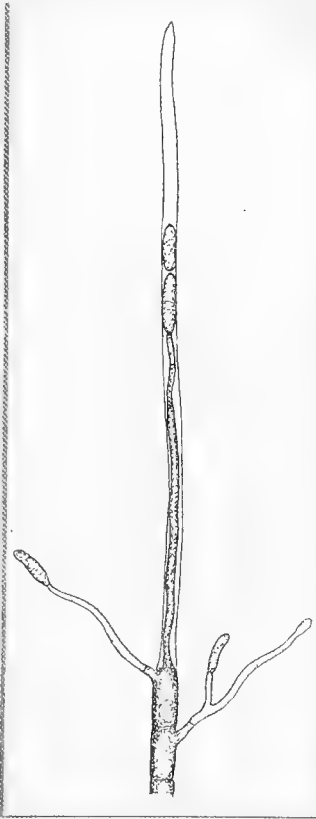
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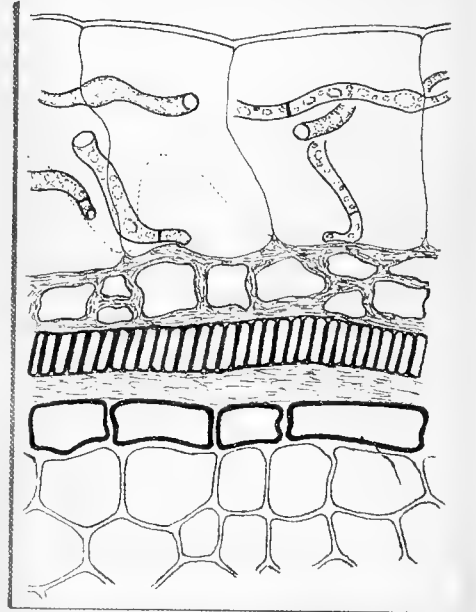
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## SCIENTIFIC PROCEEDINGS.

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THE  
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ROYAL DUBLIN SOCIETY.

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THE DETERMINATION OF THE RATE OF  
SOLUTION OF ATMOSPHERIC NITROGEN  
AND OXYGEN BY WATER.

PART I.

BY

W. E. ADENEY, D.Sc., A.R.C.Sc.I., F.I.C.,

ACTING PROFESSOR OF CHEMISTRY IN THE ROYAL COLLEGE OF SCIENCE FOR IRELAND,

AND

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RESEARCH STUDENT.

(PLATE XXI.)



[*Authors alone are responsible for all opinions expressed in their Communications.*]

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1918.

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## XXXI.

THE DETERMINATION OF THE RATE OF SOLUTION OF  
ATMOSPHERIC NITROGEN AND OXYGEN BY WATER.

## PART I.

BY W. E. ADENEY, D.Sc., A.R.C.Sc.I., F.I.C.,

Acting Professor of Chemistry in the Royal College of Science for Ireland ;

AND

H. G. BECKER, A.R.C.Sc.I.,  
Research Student.

(PLATE XXI.)

[Read MAY 28 ; published AUGUST 14, 1918.]

It has been commonly assumed that a quiescent body of water, when exposed to the air, after being wholly or partially deprived of its full air-content from any cause, becomes re-saturated with nitrogen and oxygen by two distinct processes—(1) a rapid process of solution by the surface layer of as much of the gases as possible, under the prevailing conditions ; and (2) an extremely slow process of diffusion of the dissolved gases through the mass of the water below the surface layer.<sup>1</sup>

One of the authors some years ago communicated to this Society, in a paper entitled "Unrecognized Factors in the Transmission of Gases through Water,"<sup>2</sup> the results of some preliminary experiments, which showed that, as nitrogen and oxygen are dissolved at the exposed surface of a quiescent body of re-aerated water, the dissolved gases do not remain concentrated in the surface layer, but are gravitationally drawn downwards through the lower layers of the water with comparative rapidity ; and that this downward "streaming" process, as Huefner<sup>3</sup> had termed it, must be regarded as of great practical importance in such public health questions as the protection of water-ways from the danger of fouling by sewage matter ; and in industrial processes, such as brewing ; and of such magnitude that the effects of ordinary diffusion may, in comparison, be entirely neglected.

<sup>1</sup> See "Solutions," by Ostwald, p. 10.

<sup>2</sup> Trans. Roy. Dubl. Soc., 1914 ; also Phil. Mag., March, 1905.

<sup>3</sup> Ann. Phys. Chem. (11), vol. ix, pp. 134-168. 1897.



A large number of additional experiments on this subject has since been made by the same author, from time to time, during intervals of leisure from professional and official work; and the results have showed that the rate at which water, when deprived of its usual air-content, dissolves and absorbs the gases of the atmosphere, is a problem which involves so many variable factors that its determination experimentally is by no means so simple a matter as might at first appear. Amongst the factors referred to are—the humidity of the air and the initial air-content, salinity, temperature, and depth of the water. Some of these factors had, to some extent at least, already been studied.<sup>1</sup> But before publishing the results obtained it was thought desirable to make a careful experimental investigation of the question of the rate of solution of atmospheric gases by the exposed surface-layer of a quiescent body of de-aerated water, apart from that of the rate at which the gases “stream” downwards through the lower layer of the water.

It is proposed to describe in this communication the results of a research which we have carried out with this object in view.

Experiments were in the first instance directed towards carefully studying the influence of the thickness of a layer of de-aerated water upon the rate at which it becomes re-aerated, with a view to obtaining data by means of which the factor of depth of water could be eliminated, when considering the question of the rate of solution by the surface-layer of the water.

With a view to obtaining a sufficiently extended series of observations in any one experiment, under constant conditions, or, in other words, within as short a time as possible, it was intended to estimate the oxygen only in the water under examination by a colorimetric method. A number of preliminary experiments was made with certain organic dyestuffs, including methylene blue, indigo, and indigo carmine, after reduction with suitable re-agents, but the results obtained were not encouraging. Alkaline pyrogallol was also tried, but with like results.

On the whole, it was concluded that no very simple method of estimating oxygen in this way could be devised which could be relied upon to give results of the accuracy required in the investigation.

Letts' method of estimating oxygen with ferrous sulphate was then tried, and gave good results, when the water examined was nearly saturated with the gas; but the exposure of the water to the air during manipulation introduced errors, which could not be regarded as negligible, when the analyses were made during the earlier stages of re-aeration.

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<sup>1</sup> J. H. Coste has given a valuable notice and bibliography of the published work on the Absorption of Atmospheric Gases by Water in his two communications on the subject to the *Journal of the Society of Chemical Industry*, vol. xxxvi, p. 846, and vol. xxxvii, p. 170.

Since these methods proved inapplicable, it only remained to make the analyses by means of an extraction pump and eudiometer in the usual way. This method had also the advantage of affording a check on the estimation of oxygen, since the determination of the dissolved nitrogen and carbon dioxide could be included with but little additional labour.

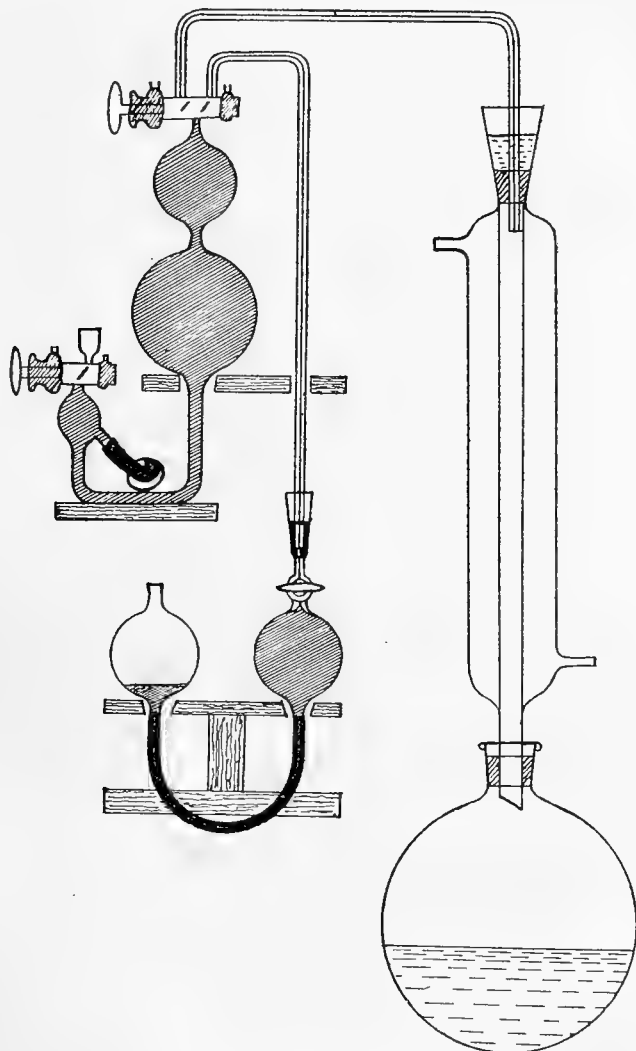


FIG. 1.—Mercury Pump and Storage Pipette.

The apparatus employed was a modification of the form described by one of the authors in the Supplementary Volume VI to the Fifth Report of the Royal Commission on Sewage Disposal, p. 96.<sup>1</sup> It consists of a mercury pump

<sup>1</sup> See also Proceedings Roy. Dubl. Soc., 1890, p. 542.

and an eudiometer, as shown in figs. 1 and 2. The pump was prepared for use by placing in the laboratory flask a small amount of water, acidulated with sulphuric acid, and boiling this until the steam had driven most of the air out of the flask. The flask was then raised, and the cork well forced into the neck so as to make a vacuum-tight joint, this being ensured by placing a little mercury in the annular space above the cork. The mercury pump was then worked until no air could be detected after a full stroke of the pump,

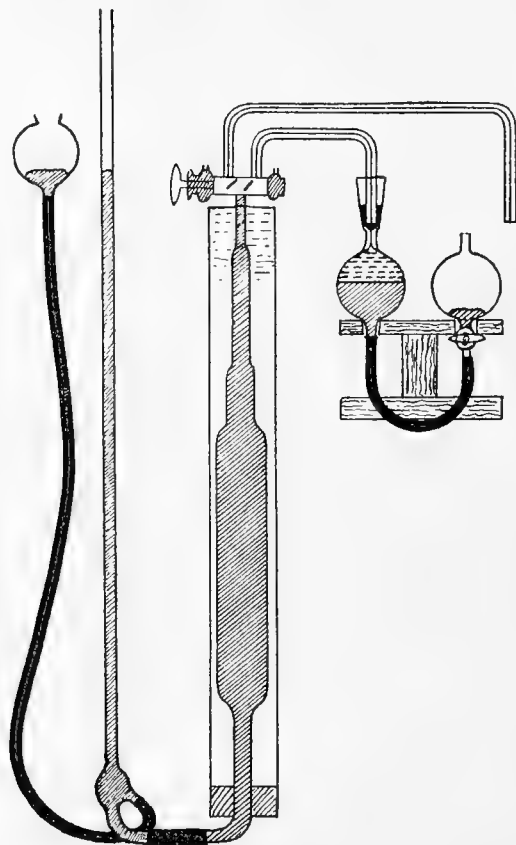


FIG. 2.—Eudiometer and Reagent Pipette.

the water in the laboratory flask being kept boiling all the time, and cold water running through the condenser.

The water to be examined was then drawn into the pump through the second capillary, the volume being noted by means of two marks on the narrow necks of the bulbs, one at 50 cc., and the second at 250 cc.

A short length of thick-walled rubber tubing, one end of which had been rounded by melting its edges in a bunsen flame, was slipped over the end of

the capillary, and all traces of air expelled from the rounded end of the rubber by repeatedly drawing water in and out of the capillary.

The gas pipette, which is shown in position in fig. 1, was provided with a conical tube, which allowed a gas-tight joint being made when pressed up against the rubber-tipped capillary. The gases could then be extracted from the water in the laboratory flask and stored in the gas pipette by boiling the water and drawing the gases over into the pump, and thence expelling them into the pipette, by operating the mercury reservoir of the pump. Any excess of water which distilled over was returned to the laboratory flask. When the gases were completely extracted and stored in the gas pipette, the latter was removed and attached to the eudiometer, shown in fig. 2, by a similar joint, and the gases drawn over and measured at reduced pressure. The absorption pipettes were of similar construction to the gas pipette, and were attached to the other capillary of the eudiometer.

A number of tubes of 40 mms. internal diameter and of three different lengths were used to expose the water to be tested. The lengths of the tubes were 12 cms., 22 cms., and 32 cms., while the columns of water experimented with were about 2 cms. shorter in each case.

The water used was freed from air and from mineral and organic impurities by distillation in vacuo, the tap water being boiled at about 30° C. in a large glass flask, and the distillate collected in a glass receiver of about 4 litres capacity. In this way a large volume of purified water was obtained, with an average air-content of less than 1 cc. of total gases per litre. Each tube was filled by syphoning the water from the bottle into it, and allowing a fair quantity to overflow at the top. The tube was then quickly closed by inserting a rubber stopper, provided with a glass stopcock, without leaving any air-bubbles entrapped, and the tube was placed in a thermostat until the contents attained the desired temperature, before exposing the surface of the water to the air.

If, as is commonly assumed, the surface layer of the water rapidly takes up as much of the gas as is possible under the prevailing conditions, and the dissolved gases only diffuse downwards through the mass of the water with extreme slowness, the air-content of the water in the shallow tubes should have been nearly as great as that of the water in the deep tubes, since the lower layers should receive but little dissolved gas in the time during which experiments were carried on.

When a series of tubes were analysed, however, after exposing them to the air for like periods of time, but too short to ensure complete saturation, it was found that the air-content of the water in them varied approximately in proportion to the depth of the water-column employed. Thus the tube con-

taining 300 cc. of water in each case contained very nearly three times the amount of the dissolved gases contained in the tubes holding 100 cc. of water. Obviously, if any concentration had taken place in the surface layers of the columns of water, this should not have been observed.

The rate of absorption of air by the water in these tubes proved, however, to be so very slow that it was not possible to obtain a complete set of observations under constant conditions. The length of exposure varied from one hour to 144 hours, and even after six days' exposure, complete saturation was not reached. In addition, it was found that the variations of atmospheric conditions during these long periods of exposure exercised a very considerable influence on the rate of solution, causing irregularities in the air-content which could not be corrected for.

In order to overcome this difficulty, it was thought advisable to provide each tube with an enclosed atmosphere that could be kept at least at a uniform temperature and uniform state of humidity during the course of the experiments. For this purpose a modification of the constant-pressure apparatus, that was used by one of the authors to measure the absorption of oxygen by polluted waters,<sup>1</sup> was employed.

The rate of absorption in these tubes was much the same as before, but the conditions affecting the atmosphere above the water-surfaces were under control. Thus some of the tubes were wholly immersed in the thermostat to the level of the corks; while others were only immersed to the same level as the water surface inside them. In the one case, therefore, the air in the tube was kept at the same temperature as the water, and evaporation from the surface was reduced to a minimum; while, in the other case, the air was exposed to all the fluctuations of temperature of the laboratory, and considerable evaporation and condensation took place. There was a marked difference in the rate of absorption under these different conditions, it being much greater in the tubes liable to fluctuation of temperature.

In order to shorten the time during which it was necessary to keep the tubes under observation, they were only half filled and laid on their sides, so as to expose a greater area of water-surface—equal to the longitudinal section of the tube—and a considerably reduced thickness of water to be saturated.

The area of surface was in this way increased from about 12 square centimetres to about 120 square centimetres, and the thickness decreased to a maximum of about 2 centimetres, and, further, the actual volume of water used was only half the previous amount. Under these conditions the aera-

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<sup>1</sup> Supplementary Volume VI, Fifth Report, Royal Commission on Sewage Disposal, pp. 438-441.

tion took place in a much shorter time, and it was found possible to saturate the water in about twenty-four hours.

This modification in the method of employing the tubes brought the series of observations under better control, and more concordant results were obtained; nevertheless the observations showed some irregularity, which, though small, could not be regarded as negligible. Attempts were, therefore, made to work out an entirely new method of experimenting, and to devise some method by which the water could be uniformly mixed during aeration, and still preserve an unbroken water-air surface.

One of the simplest means of effecting this seemed at first to be to pass a known volume of air, in a slow and uniform stream of bubbles, through a given thickness of water, in an observed time, and to determine the amount of air dissolved during that time. Experiments carried out in this way yielded results which afforded a remarkably uniform curve; but attempts to gain an accurate estimate of the water-air surface exposed proved unsuccessful, owing to the variation in the size and shape of the bubbles, as well as to the irregularity of the paths they took in ascending the water.

With a view to bringing the method under better control, efforts were made to direct the course of the bubbles into a straight line, and it was found that the conditions prevailing, when a large bubble is allowed to ascend a narrow tube filled with water, were almost exactly those sought. In this case, the surface tension keeps the water-air surface unbroken during its passage up the tube, and since the bubble occupies nearly the whole cross-section of the tube, the water is exposed to the air in an extremely thin layer; while the upward movement of the bubble produces a very perfect local mixing of the water.

Since the bubble tends to assume a simple geometrical form, the calculation of the area exposed, from measurements, is rendered comparatively simple, provided that the measurement of length is made when the bubble is in motion. In practice this was achieved by taking an instantaneous photograph of the bubble with a glass metre scale placed alongside of it, in the same focal plane.

Some difficulty was at first experienced in getting the edges of the meniscus well defined; but this difficulty was finally surmounted by colouring the water slightly with eosin, and taking the photograph by transmitted light from a powerful arc-lamp.

After some trials, it was found that the simplest method of measuring the amount of absorption of air, after each excursion of the bubble, was by measuring the loss of pressure exerted by the bubble.

The form of apparatus finally adopted is shown in fig. 3. It consists of

an inner tube, about 1 metre long, and 1 cm. bore. Into each end of the tube a rubber stopper is fitted. The lower stopper carries a small capillary stopcock, and the upper one, a two-way stopcock, with capillary tubes. One limb of this tap was cut off short, and inserted in the stopper. Of the two other limbs one was left straight, and cut off short, while the other was bent over until parallel with the long tube, and a length of fairly wide capillary tubing was fused on to it. The lower end of this tube was connected by rubber tubing with the movable limb of the manometer, which was also provided with a stopcock, to prevent the liquid spilling when inverted. This manometer was filled with water, coloured with a little methylene blue.

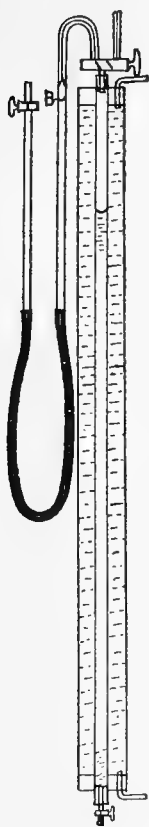


FIG. 3.

The long tube was completely surrounded by an outer jacket, held in place by rubber stoppers, which were provided with inlet and outlet tubes for a current of water.

A mark B was made on the manometer tube to which the level of the meniscus was always brought when taking a reading, and the volume of the space between this mark and the stopcock was measured by filling with mercury and weighing the mercury. This small volume involved a constant correction, which had to be applied to the observed manometer readings in order to get the true pressure in the tube.

If  $p'$  = loss in pressure in bubble,  
 $p_1$  = loss in pressure measured on manometer,  
 $v$  = volume of capillary,  
 $V$  = volume of bubble,

then  $p'$  and  $p_1$  are connected by the formula

$$p' = p_1 \left( 1 + \frac{v}{V} \right).$$

The experimental tube was filled with the air-free water by exhausting it as completely as possible by means of a water-pump, and then attaching it to the vessel containing the air-free water. By opening the connecting tap, and allowing air to flow into the vessel containing the supply of distilled water, the tube was filled, almost completely, without allowing the water to come into contact with air. The small bubble left at the top was removed by taking out the rubber stopper, and quickly filling up the space with air-free water from a pipette, and allowing it to overflow. The cork was then

replaced, and the tap closed, thus leaving the tube completely filled with water.

The tube was then clamped vertically, and the lower stopcock connected with a standard burette by means of pressure tubing full of water. The level of the burette having been read, both stopcocks of the tube were opened, and the water was allowed to flow from the tube into the burette until the correct volume of water (15 cc. in most cases) had flowed out. All the taps were then closed, and the pressure in the bubble adjusted to that of atmospheric by repeatedly turning the two-way tap so as to connect the bubble alternately with the atmosphere and the manometer.

The tube was then swung steadily round a central axis, so as to invert it, and allow the bubble to form without splashing; when the bubble reached the inverted end of the tube, the latter was returned to its first position, and on the bubble reaching the top, the pressure in it was measured by opening connexion with the manometer. The time taken by the bubble to traverse the tube was measured in every case, and found to be practically constant, at eighteen seconds for a double journey.

The air in the bubble was renewed after each observation by taking out the stopper and inserting a tube connected with a filter-pump, which drew a current of air through the space. The stopper was marked, so that it could be always inserted in the same position.

As the water approached saturation and the readings of the manometer got smaller, the number of inversions between each reading was increased gradually from two up to ten. The readings were continued until after ten inversions the manometer showed no distinct movement; and the water in the tube was then drawn into the pump and analyzed for dissolved gases.

Considerable difficulty was at first experienced in getting an experiment done at an absolutely constant temperature, owing to the fact that the temperature of the laboratory varied considerably, and, when the tap-water was tested, it was also found to be subject to rapid and relatively large variations in temperature.

The difficulty was overcome by making the manometric observations in a room the temperature of which was not subject to serious fluctuations. A supply of water at steady temperature was secured by setting up in this room a large thick-walled wooden vat capable of holding about sixty gallons, and filling this with tap-water, the day before it was required for use, thus allowing it to attain a steady temperature overnight. During the course of an experiment, the water was allowed to syphon over through the water-jacket of the apparatus continually. In this way it was found possible to keep the temperature of the tube constant within  $0.1^{\circ}$  C. during an experiment.



The length of the bubble while in motion was measured by taking a number of instantaneous photographs of it while it travelled up the tube. A millimetre scale engraved on glass was placed in the same focal plane as the centre of the tube, and an image of this scale appeared alongside the bubble on the plate.

On comparing this scale with a standard millimetre scale, it was found to be considerably in error, and means were adopted to correct for this.

By the use of a micrometer eyepiece in the microscope the length of the bubble was read off on the scale photographed on the plate. The two points corresponding to these readings were found on the actual scale, and the distance between them read by means of the standard millimetre scale and the micrometer. In this way all errors due to the inaccuracy of the scale used were eliminated. The mean of a series of observations was taken as the true length of the bubble.

Plate XXI is a photograph of the bubble while in motion, and shows the form it assumes while moving up the tube.

Experiments were made with three classes of water, namely, water distilled in vacuo, tap-water from the Dublin Vartry supply, and sea-water. In each case, two experiments were made under conditions as similar to each other as possible, though it was unavoidable that the atmospheric pressure and the temperature varied a little.

The manometer readings were in all cases converted to volumes at N. T. P., and these included all the gases absorbed from the atmosphere during the experiment. The effect of the CO<sub>2</sub> in the air is scarcely appreciable in the case of the distilled water and of the sea-water. But in the case of the Vartry water, the manometer observations indicate a greater absorption of gases than in the case of the distilled water. The analyses of the gases extracted in the two cases show that this increased absorption was due to the formation of carbon dioxide in minute quantities in the Vartry water, and to the consequent fixation of an equivalent volume of dissolved oxygen during the experiment—a result, it may be assumed, due to slight oxidation of the humus in the Vartry water. This water contains decided quantities of peaty matter.<sup>1</sup>

The actual experimental results obtained, in the case of distilled water, tap-water, and sea-water, are recorded in Tables 1, 2, and 3.

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<sup>1</sup> See the Experiments on the fermentative properties of humus in water, by one of the authors. *Trans. Roy. Dubl. Soc.*, 1895, pp. 593-615; and 1897, pp. 269-281.

TABLE 1.—*Details of Experiments with Distilled Water.*

Volume of water in experimental tube = 94 cc.

Area of air-bubble = 56.34 sq. cm.

Volume of water around bubble = 3.10 cc.

*Experiment No. 12.* Temp. of water 11.4° C., Bar. 762.0 mm.

| Time in minutes. | Manometer readings cms. | Vol. of gases at N.T.P. |                | Mean value of "w." | Rate of solution in cc. per minute. |
|------------------|-------------------------|-------------------------|----------------|--------------------|-------------------------------------|
|                  |                         | absorbed cc.*           | contained cc.* |                    |                                     |
| 0                | 0                       | 0                       |                |                    |                                     |
| 0.3              | 13.00                   | 0.181                   | 0.181          | 0.090              | 0.603                               |
| 0.6              | 12.2                    | 0.170                   | 0.351          | 0.266              | 0.567                               |
| 0.9              | 11.30                   | 0.157                   | 0.508          | 0.429              | 0.524                               |
| 1.2              | 9.85                    | 0.137                   | 0.645          | 0.576              | 0.457                               |
| 1.5              | 8.80                    | 0.123                   | 0.768          | 0.706              | 0.410                               |
| 1.8              | 8.20                    | 0.114                   | 0.882          | 0.825              | 0.380                               |
| 2.1              | 7.46                    | 0.104                   | 0.986          | 0.934              | 0.346                               |
| 2.4              | 7.15                    | 0.099                   | 1.085          | 1.035              | 0.330                               |
| 3.0              | 11.90                   | 0.166                   | 1.251          | 1.168              | 0.277                               |
| 3.6              | 10.20                   | 0.142                   | 1.393          | 1.322              | 0.236                               |
| 4.2              | 8.70                    | 0.121                   | 1.514          | 1.453              | 0.202                               |
| 4.8              | 6.95                    | 0.097                   | 1.611          | 1.562              | 0.162                               |
| 5.4              | 5.70                    | 0.079                   | 1.690          | 1.650              | 0.132                               |
| 6.0              | 4.66                    | 0.065                   | 1.755          | 1.722              | 0.108                               |
| 6.6              | 3.74                    | 0.052                   | 1.807          | 1.781              | 0.087                               |
| 7.2              | 2.08                    | 0.039                   | 1.846          | 1.826              | 0.065                               |
| 7.8              | 2.28                    | 0.032                   | 1.878          | 1.862              | 0.053                               |
| 8.7              | 3.10                    | 0.043                   | 1.921          | 1.899              | 0.048                               |
| 9.6              | 2.90                    | 0.040                   | 1.961          | 1.941              | 0.044                               |
| 10.5             | 1.97                    | 0.027                   | 1.988          | 1.974              | 0.030                               |
| 11.7             | 2.08                    | 0.029                   | 2.017          | 2.002              | 0.024                               |
| 13.2             | 1.35                    | 0.019                   | 2.036          | 2.026              | 0.013                               |
| 15.0             | 1.20                    | 0.017                   | 2.053          | 2.044              | 0.009                               |
| 17.4             | 1.04                    | 0.014                   | 2.067          | 2.060              | 0.006                               |
| 19.4             | 0.415                   | 0.006                   | 2.073          | 2.070              | 0.002                               |
| 24.9             | 0.100                   | 0.001                   | 2.074          | 2.073              | 0.001                               |

*Experiment No. 13.* Temp. of water 11.3° C., Bar. 771 mm.

|      |       |       |       |       |        |
|------|-------|-------|-------|-------|--------|
| 0    | 0     | 0     |       |       |        |
| 0.3  | 14.00 | 0.195 | 0.195 | 0.097 | 0.650  |
| 0.6  | 12.60 | 0.175 | 0.370 | 0.282 | 0.583  |
| 0.9  | 11.70 | 0.163 | 0.533 | 0.452 | 0.543  |
| 1.2  | 10.80 | 0.152 | 0.685 | 0.609 | 0.506  |
| 1.5  | 9.45  | 0.131 | 0.816 | 0.750 | 0.433  |
| 1.8  | 8.70  | 0.121 | 0.937 | 0.876 | 0.406  |
| 2.1  | 7.80  | 0.108 | 1.045 | 0.991 | 0.360  |
| 2.4  | 7.25  | 0.101 | 1.146 | 1.090 | 0.333  |
| 2.7  | 6.75  | 0.094 | 1.240 | 1.193 | 0.310  |
| 3.0  | 6.10  | 0.085 | 1.325 | 1.282 | 0.283  |
| 3.6  | 9.85  | 0.137 | 1.462 | 1.393 | 0.228  |
| 4.2  | 7.90  | 0.110 | 1.572 | 1.517 | 0.183  |
| 4.8  | 6.64  | 0.092 | 1.664 | 1.618 | 0.153  |
| 5.4  | 5.70  | 0.079 | 1.743 | 1.703 | 0.131  |
| 6.0  | 4.56  | 0.063 | 1.806 | 1.774 | 0.105  |
| 6.6  | 4.25  | 0.059 | 1.865 | 1.835 | 0.098  |
| 7.2  | 3.52  | 0.049 | 1.914 | 1.889 | 0.081  |
| 8.1  | 3.63  | 0.050 | 1.964 | 1.939 | 0.054  |
| 9.0  | 2.60  | 0.036 | 2.000 | 1.982 | 0.040  |
| 9.9  | 2.08  | 0.029 | 2.029 | 2.014 | 0.032  |
| 10.8 | 1.86  | 0.026 | 2.055 | 2.042 | 0.029  |
| 11.7 | 1.35  | 0.019 | 2.074 | 2.064 | 0.020  |
| 12.9 | 1.24  | 0.017 | 2.091 | 2.082 | 0.014  |
| 14.4 | 1.00  | 0.014 | 2.105 | 2.098 | 0.0096 |
| 15.9 | 1.35  | 0.019 | 2.124 | 2.114 | 0.012  |
| 17.4 | 0.52  | 0.007 | 2.131 | 2.127 | 0.004  |

\* The figures in this column = manometer readings  $\times$  the factor 0.01393.

TABLE 2.—Details of Experiments with the Dublin Tap-water.  
 Experiment No. 14. Temp. of water 12·6° C., Bar. 771·6 mm.

| Time in minutes. | Manometer readings cms. | Vol. of gases at N.T.P. |               | Mean value of "w." | Rate of solution in cc. per minute. |
|------------------|-------------------------|-------------------------|---------------|--------------------|-------------------------------------|
|                  |                         | absorbed cc.            | contained cc. |                    |                                     |
| 0                | 0                       | 0                       |               |                    |                                     |
| 0·3              | 13·50                   | 0·188                   | 0·188         | 0·094              | 0·626                               |
| 0·6              | 12·40                   | 0·172                   | 0·360         | 0·274              | 0·573                               |
| 0·9              | 11·80                   | 0·164                   | 0·524         | 0·442              | 0·546                               |
| 1·2              | 10·40                   | 0·145                   | 0·669         | 0·596              | 0·483                               |
| 1·5              | 9·80                    | 0·136                   | 0·805         | 0·737              | 0·453                               |
| 1·8              | 8·90                    | 0·124                   | 0·929         | 0·867              | 0·410                               |
| 2·1              | 8·00                    | 0·112                   | 1·041         | 0·985              | 0·373                               |
| 2·4              | 7·15                    | 0·099                   | 1·140         | 1·090              | 0·330                               |
| 2·7              | 6·75                    | 0·093                   | 1·233         | 1·186              | 0·310                               |
| 3·0              | 5·80                    | 0·081                   | 1·314         | 1·272              | 0·270                               |
| 3·3              | 5·40                    | 0·075                   | 1·389         | 1·350              | 0·250                               |
| 3·6              | 4·97                    | 0·069                   | 1·458         | 1·425              | 0·230                               |
| 3·9              | 4·66                    | 0·065                   | 1·523         | 1·490              | 0·216                               |
| 4·5              | 7·35                    | 0·102                   | 1·625         | 1·575              | 0·170                               |
| 5·1              | 6·32                    | 0·088                   | 1·713         | 1·665              | 0·147                               |
| 5·7              | 5·70                    | 0·079                   | 1·792         | 1·750              | 0·133                               |
| 6·3              | 4·15                    | 0·058                   | 1·850         | 1·820              | 0·097                               |
| 6·9              | 3·73                    | 0·050                   | 1·900         | 1·875              | 0·083                               |
| 7·5              | 3·10                    | 0·043                   | 1·943         | 1·920              | 0·070                               |
| 8·1              | 2·60                    | 0·036                   | 1·979         | 1·960              | 0·060                               |
| 9·0              | 3·22                    | 0·045                   | 2·024         | 2·000              | 0·047                               |
| 9·9              | 2·56                    | 0·035                   | 2·059         | 2·041              | 0·038                               |
| 10·8             | 2·40                    | 0·033                   | 2·092         | 2·075              | 0·037                               |
| 11·7             | 1·14                    | 0·016                   | 2·108         | 2·100              | 0·017                               |
| 13·2             | 1·55                    | 0·021                   | 2·129         | 2·118              | 0·013                               |
| 14·7             | 1·04                    | 0·014                   | 2·143         | 2·136              | 0·010                               |
| 16·2             | 0·41                    | 0·006                   | 2·149         | 2·146              | 0·004                               |
| 18·6             | 1·04                    | 0·0145                  | 2·163         | 2·156              | 0·007                               |
| 21·0             | 0·52                    | 0·007                   | 2·170         | 2·166              | 0·003                               |
| 24·0             | 0·31                    | 0·004                   | 2·174         | 2·172              | 0·002                               |
| 27·0             | 0·21                    | 0·003                   | 2·177         | 2·175              | 0·001                               |

Experiment No. 15. Temp. of water 12·1° C., Bar. 768·8 mm.

|      |       |       |       |       |        |
|------|-------|-------|-------|-------|--------|
| 0    | 0     | 0     |       |       |        |
| 0·3  | 14·20 | 0·198 | 0·198 | 0·099 | 0·660  |
| 0·6  | 13·10 | 0·182 | 0·380 | 0·289 | 0·606  |
| 0·9  | 11·80 | 0·164 | 0·544 | 0·462 | 0·546  |
| 1·2  | 10·30 | 0·143 | 0·687 | 0·615 | 0·477  |
| 1·5  | 9·34  | 0·130 | 0·816 | 0·751 | 0·433  |
| 1·8  | 8·30  | 0·115 | 0·932 | 0·874 | 0·383  |
| 2·1  | 8·20  | 0·114 | 1·046 | 0·989 | 0·380  |
| 2·4  | 7·05  | 0·098 | 1·143 | 1·095 | 0·320  |
| 2·7  | 5·90  | 0·082 | 1·228 | 1·185 | 0·273  |
| 3·0  | 5·80  | 0·081 | 1·310 | 1·269 | 0·266  |
| 3·3  | 5·30  | 0·074 | 1·384 | 1·345 | 0·246  |
| 3·6  | 4·67  | 0·065 | 1·450 | 1·415 | 0·216  |
| 4·2  | 8·30  | 0·115 | 1·564 | 1·505 | 0·190  |
| 4·8  | 7·36  | 0·102 | 1·666 | 1·610 | 0·170  |
| 5·4  | 5·90  | 0·082 | 1·748 | 1·700 | 0·136  |
| 6·0  | 4·87  | 0·068 | 1·816 | 1·770 | 0·113  |
| 6·6  | 3·74  | 0·052 | 1·868 | 1·837 | 0·085  |
| 7·2  | 3·11  | 0·043 | 1·911 | 1·887 | 0·073  |
| 7·8  | 2·60  | 0·036 | 1·947 | 1·925 | 0·060  |
| 8·7  | 3·11  | 0·043 | 1·990 | 1·965 | 0·049  |
| 9·6  | 2·60  | 0·036 | 2·026 | 2·005 | 0·040  |
| 10·5 | 1·66  | 0·022 | 2·048 | 2·032 | 0·025  |
| 11·4 | 1·04  | 0·014 | 2·062 | 2·052 | 0·015  |
| 12·6 | 1·04  | 0·014 | 2·076 | 2·070 | 0·012  |
| 14·1 | 1·04  | 0·014 | 2·090 | 2·085 | 0·010  |
| 15·4 | 0·83  | 0·011 | 2·101 | 2·095 | 0·006  |
| 17·7 | 0·52  | 0·007 | 2·108 | 2·105 | 0·004  |
| 20·1 | 0·41  | 0·006 | 2·114 | 2·111 | 0·0024 |
| 23·1 | 0·30  | 0·004 | 2·118 | 2·116 | 0·0014 |
| 26·1 | 0·20  | 0·003 | 2·121 | 2·119 | 0·0010 |
| 32·1 | 0·10  | 0·001 | 2·122 | 2·121 | 0·0001 |

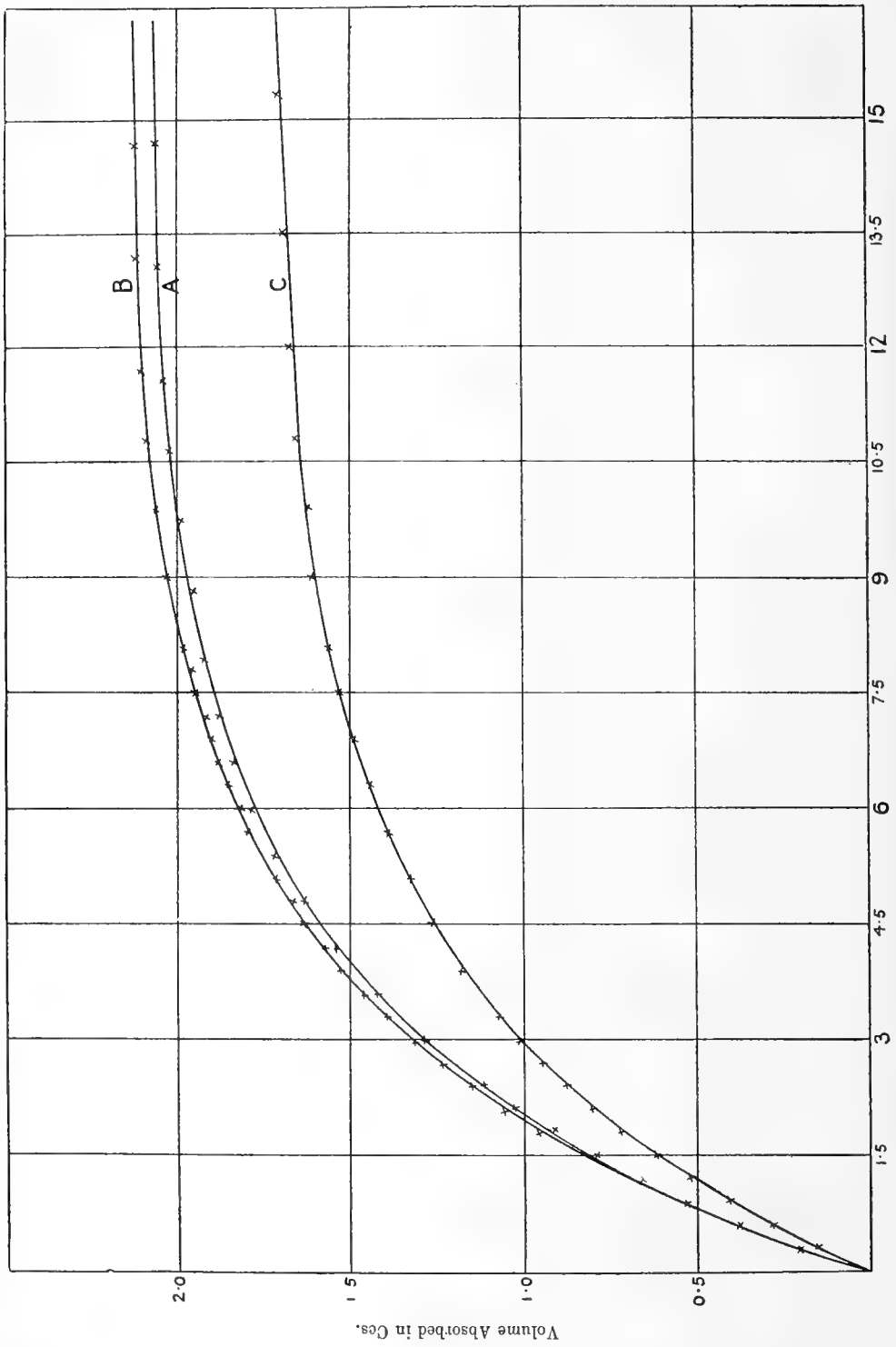
TABLE 3.—*Details of Experiments with Sea-water.*

*Experiment No. 16.* Temp. of water 11·8° C., Bar. 767·8 mm.

| Time in minutes. | Manometer readings cms. | Vol. of gases at N.T.P. |               | Mean value of "w." | Rate of solution in cc. per minute. |
|------------------|-------------------------|-------------------------|---------------|--------------------|-------------------------------------|
|                  |                         | absorbed cc.            | contained cc. |                    |                                     |
| 0                | 0                       | 0                       |               |                    |                                     |
| 0·3              | 10·70                   | 0·149                   | 0·149         | 0·074              | 0·496                               |
| 0·6              | 9·65                    | 0·134                   | 0·283         | 0·216              | 0·460                               |
| 0·9              | 8·80                    | 0·122                   | 0·405         | 0·344              | 0·406                               |
| 1·2              | 8·10                    | 0·112                   | 0·517         | 0·461              | 0·373                               |
| 1·5              | 7·60                    | 0·106                   | 0·623         | 0·520              | 0·353                               |
| 1·8              | 6·85                    | 0·095                   | 0·718         | 0·670              | 0·316                               |
| 2·1              | 5·90                    | 0·082                   | 0·800         | 0·759              | 0·276                               |
| 2·4              | 5·70                    | 0·079                   | 0·880         | 0·840              | 0·266                               |
| 2·7              | 4·87                    | 0·068                   | 0·947         | 0·913              | 0·226                               |
| 3·0              | 4·56                    | 0·063                   | 1·010         | 0·978              | 0·210                               |
| 3·3              | 4·15                    | 0·058                   | 1·068         | 1·04               | 0·193                               |
| 3·8              | 7·67                    | 0·107                   | 1·175         | 1·121              | 0·171                               |
| 4·5              | 6·10                    | 0·085                   | 1·260         | 1·217              | 0·141                               |
| 5·1              | 4·76                    | 0·066                   | 1·326         | 1·293              | 0·110                               |
| 5·7              | 4·45                    | 0·062                   | 1·388         | 1·357              | 0·103                               |
| 6·3              | 4·05                    | 0·056                   | 1·444         | 1·416              | 0·093                               |
| 6·9              | 3·32                    | 0·046                   | 1·490         | 1·467              | 0·076                               |
| 7·5              | 2·70                    | 0·038                   | 1·528         | 1·509              | 0·063                               |
| 8·1              | 2·08                    | 0·029                   | 1·557         | 1·542              | 0·048                               |
| 9·0              | 3·11                    | 0·043                   | 1·600         | 1·578              | 0·048                               |
| 9·9              | 1·97                    | 0·027                   | 1·627         | 1·613              | 0·030                               |
| 10·8             | 1·55                    | 0·021                   | 1·648         | 1·637              | 0·023                               |
| 12·0             | 1·45                    | 0·020                   | 1·668         | 1·658              | 0·017                               |
| 13·5             | 1·66                    | 0·023                   | 1·691         | 1·679              | 0·015                               |
| 15·3             | 1·04                    | 0·014                   | 1·705         | 1·693              | 0·008                               |
| 17·4             | 0·93                    | 0·013                   | 1·718         | 1·711              | 0·0064                              |
| 19·8             | 1·14                    | 0·016                   | 1·734         | 1·726              | 0·006                               |
| 22·2             | 0·31                    | 0·004                   | 1·738         | 1·736              | 0·0016                              |
| 24·6             | 0·20                    | 0·003                   | 1·741         | 1·739              | 0·0012                              |
| 27·6             | 0·31                    | 0·004                   | 1·745         | 1·743              | 0·0011                              |
| 30·6             | 0·21                    | 0·003                   | 1·748         | 1·746              | 0·0010                              |

*Experiment No. 17.* Temp. of water 12·3° C., Bar. 758·6 mm.

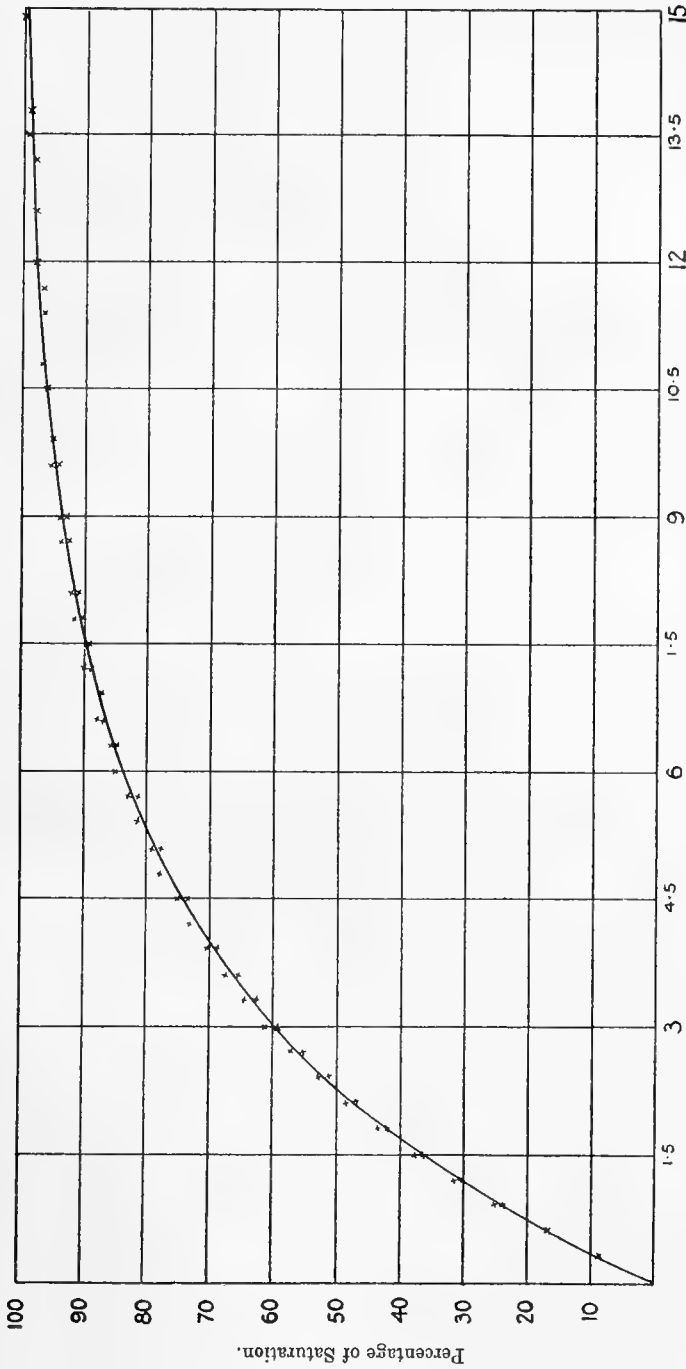
|      |       |       |       |       |       |
|------|-------|-------|-------|-------|-------|
| 0    | 0     | 0     |       |       |       |
| 0·3  | 10·37 | 0·144 | 0·144 | 0·072 | 0·480 |
| 0·6  | 9·65  | 0·134 | 0·278 | 0·211 | 0·466 |
| 0·9  | 8·92  | 0·124 | 0·402 | 0·340 | 0·413 |
| 1·2  | 8·10  | 0·113 | 0·515 | 0·459 | 0·376 |
| 1·5  | 7·26  | 0·102 | 0·616 | 0·565 | 0·336 |
| 1·8  | 6·95  | 0·095 | 0·712 | 0·664 | 0·323 |
| 2·1  | 6·12  | 0·085 | 0·797 | 0·754 | 0·283 |
| 2·4  | 5·18  | 0·072 | 0·869 | 0·833 | 0·240 |
| 2·7  | 5·08  | 0·071 | 0·940 | 0·904 | 0·236 |
| 3·0  | 4·66  | 0·065 | 1·005 | 0·972 | 0·216 |
| 3·3  | 4·03  | 0·056 | 1·061 | 1·030 | 0·186 |
| 3·6  | 3·94  | 0·055 | 1·116 | 1·086 | 0·180 |
| 3·9  | 3·63  | 0·051 | 1·167 | 1·139 | 0·170 |
| 4·5  | 6·22  | 0·086 | 1·253 | 1·208 | 0·143 |
| 5·1  | 5·08  | 0·071 | 1·324 | 1·286 | 0·118 |
| 5·7  | 4·57  | 0·063 | 1·387 | 1·353 | 0·105 |
| 6·3  | 3·73  | 0·052 | 1·439 | 1·410 | 0·086 |
| 6·9  | 3·11  | 0·043 | 1·482 | 1·457 | 0·071 |
| 7·5  | 2·60  | 0·036 | 1·518 | 1·497 | 0·060 |
| 8·1  | 2·28  | 0·032 | 1·550 | 1·531 | 0·051 |
| 8·7  | 1·87  | 0·026 | 1·576 | 1·560 | 0·043 |
| 9·6  | 1·87  | 0·026 | 1·602 | 1·585 | 0·030 |
| 10·5 | 1·35  | 0·019 | 1·621 | 1·608 | 0·020 |
| 11·4 | 1·24  | 0·017 | 1·638 | 1·625 | 0·018 |
| 12·6 | 1·87  | 0·026 | 1·664 | 1·646 | 0·021 |
| 13·8 | 1·35  | 0·019 | 1·683 | 1·668 | 0·015 |
| 15·3 | 1·35  | 0·019 | 1·702 | 1·685 | 0·012 |
| 16·8 | 2·18  | 0·030 | 1·732 | 1·717 | 0·020 |
| 18·3 | 1·45  | 0·020 | 1·752 | 1·742 | 0·013 |
| 19·8 | 0·62  | 0·008 | 1·760 | 1·756 | 0·007 |
| 21·3 | 0·83  | 0·011 | 1·771 | 1·765 | 0·006 |
| 22·8 | 0·31  | 0·004 | 1·775 | 1·773 | 0·002 |



Curves, showing the Absorption of Air by De-aerated water. A = Distilled water, B = Vartry water, C = Sea-water.

FIG. 4.

When the values of the absorptions, given in column 4 of the tables, are plotted against the time, a smooth curve is obtained in each case. The curves



Curve, showing the rate of Re-aeration in Percentages of Saturation.  
FIG. 5.

representing the behaviour of distilled water and tap-water are very closely

alike, while that representing sea-water is widely different (see fig. 4). This difference is evidently due to a difference in the saturation value, for when the experimental results are expressed as percentages of saturation, the curves from the different experiments are almost coincident, as shown in fig. 5.

The results of the experiments show that the bubble of air in passing up the tube continually exposed fresh water-surface to the air, and at the same time kept the water mixed. In order to confirm this view, a test experiment was made with a tube 5 feet long. This was filled in the ordinary way, and the inversions carried out, until the air-content was about 60-70 per cent. of saturation. The water in the tube was then drawn into the pump in two equal portions, each of which was analysed separately. One of the analyses represents the air-content of the water in the upper half of the tube, and the other that in the lower half.

|                 | Upper half.      | Lower half.      |
|-----------------|------------------|------------------|
| CO <sub>2</sub> | 0·099 cc.        | 0·075 cc.        |
| O <sub>2</sub>  | 0·235 cc.        | 0·247 cc.        |
| N <sub>2</sub>  | 0·442 cc.        | 0·466 cc.        |
| Totals,         | <u>0·776 cc.</u> | <u>0·788 cc.</u> |

These figures show that the difference in air-content between any one portion of the water in the tube and any other is not appreciable on analysis; hence the assumption that the water is well mixed seems to be a reasonable one.

In order to keep a check on the manometer readings, the air-content of the water was determined after each experiment by boiling out in vacuo and measuring the gases, using the apparatus described above. A comparison of the results obtained by the different methods is given in Table 4.

The area of the surface of the bubble was calculated from the measurements of its length when at rest and in motion and the known internal diameter of the tube.

The volume of the bubble was 15 cc. Its length when in motion was 16·04 cms. and when at rest 13·30 cms. The diameter of the tube was 1·20 cms.; hence its sectional area was 1·13 sq. cm.

The total volume of the water supported around the bubble was the amount which collected when the bubble burst, i.e., = (16·04 - 13·3) 1·13 cc. = 3·10 cc.

This volume is made up of the portion round the hemispherical cap of the bubble and the cylindrical shell below.

TABLE 4.—*Comparison of Results of Analysis of the Dissolved Gases with Manometer Observations.*

| No. of Experiment. | Temperature. | Volume of gases absorbed |             | Analyses of gases dissolved |                 |            | Saturation values (Dittmar). |                  |
|--------------------|--------------|--------------------------|-------------|-----------------------------|-----------------|------------|------------------------------|------------------|
|                    |              | from Addition.           | from Graph. | Oxygen + Nitrogen.          | Carbon Dioxide. | Total.     |                              |                  |
| —                  | —            | —                        | —           | ·022 cc.                    | ·028 cc.        | ·050 cc.*  | —                            | —                |
| 12                 | 11·4 C.      | 2·076 cc.                | 2·060 cc.   | 2·039 cc.                   | ·034 cc.        | 2·073 cc.  | 2·137                        | Distilled water. |
| 13                 | 11·3 C.      | 2·136 cc.                | 2·115 cc.   | 2·134 cc.                   | ·101 cc.        | 2·235 cc.  | 2·142                        |                  |
| 14                 | 12·6 C.      | 2·177 cc.                | 2·130 cc.   | 2·007 cc.                   | ·368 cc.        | 2·375 cc.  | 2·079                        | Vartry water.    |
| 15                 | 12·1 C.      | 2·121 cc.                | 2·100 cc.   | 1·932 cc.                   | ·375 cc.        | 2·307 cc.  | 2·106                        |                  |
| —                  | —            | —                        | —           | 0·015 cc.                   | 3·984 cc.       | 3·999 cc.* | —                            | —                |
| 16                 | 11·8 C.      | 1·750 cc.                | 1·700 cc.   | 1·632 cc.                   | 4·179 cc.       | 5·811 cc.  | 1·717                        | Sea-water.       |
| 17                 | 12·3 C.      | 1·776 cc.                | 1·700 cc.   | 1·634 cc.                   | 4·119 cc.       | 5·753 cc.  | 1·700                        |                  |

\* These figures give the initial air-contents in the case of distilled water and sea-water respectively.

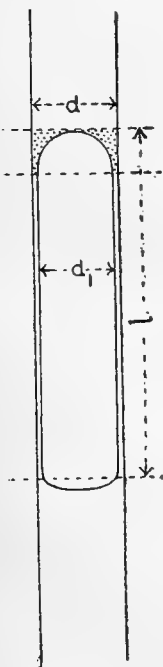


FIG. 6.

The volume shown dotted in the diagram (fig. 6) is equal to

$$\left( \pi \frac{d^2}{4} \right) \frac{d_1}{2} - \frac{2}{3} \pi \frac{d_1^3}{8} = \pi \left( \frac{d^2 d_1}{8} - \frac{d_1^3}{12} \right)$$

and the volume of the cylindrical shell is

$$= \pi \left( \frac{d^2 - d_1^2}{4} \right) \left( l - \frac{d_1}{2} \right)$$

$$\therefore \pi \left\{ \left( \frac{d^2 d_1}{8} - \frac{d_1^3}{12} \right) + \left( \frac{d^2 - d_1^2}{4} \right) \left( l - \frac{d_1}{2} \right) \right\} = 3·10 \text{ ccs.}$$

$$d_1^3 - 6 l d_1^2 + 6 l d^2 = ·984 \times 24,$$

$$d_1^3 - 96·2 d_1^2 + 114·93 = 0.$$

By trial it was found that the value of  $d_1$  which very nearly satisfied this equation was  $d_1 = 1·0993$  cms. Having found the internal diameter of the bubble, it was comparatively simple to calculate the surface area. This is made up of the top hemispherical area + cylindrical area + base area :

$$\begin{aligned} \text{i.e., } & 2\pi \frac{d_1^2}{4} + \pi d_1 \left( l - \frac{d_1}{2} \right) + \pi \frac{d_1^2}{4} \\ & = \pi d_1 \left( l + \frac{d_1}{4} \right) \\ & = 1·0993 \times 3·1416 (16·04 + 0·2748) \\ & = 56·344 \text{ sq. cms.} \end{aligned}$$



Hence the area of water air-surface was 56.34 sq. cms.

When a gas is dissolving in a liquid, we may assume that the rate of passage of the gas into the liquid is proportional to the partial pressure of the gas and the area of liquid exposed. Hence:—

Rate of passage of gas into liquid =  $S.A.p.$ , where  $p$  = partial pressure of gas,  $A$  = area of surface, and  $S$  = rate of solution for unit area.

As solution goes on, the gas in the upper layers of the water escapes into the air, and the rate of its escape is proportional to the amount of gas in solution; hence if  $w$  = weight of gas per cc. in upper layer, then the rate of escape of gas from liquid =  $f.w.A$ . This gives us as the net rate of solution— $S.A.p. - f.w.A.$ ; and when equilibrium is reached, i.e., at saturation,  $S.A.p. = f.w.A.$  or  $Sp = fw$ .

The value of " $w$ " is generally unknown, since the gas diffuses rapidly from the surface layer of the liquid and the exact gas-content is uncertain. If we keep the liquid mixed, we render  $A$  the area uncertain in general. But if a method of mixing the liquid which would leave  $A$  still determinate is possible, then we can calculate the rate of solution for a given area, assuming that the gas remains at constant density. These conditions are complied with in the case of a cylindrical bubble moving up a narrow tube.

If  $V$  = volume of liquid, and  $\rho$  = density of the gas (assumed constant), the rate of solution is:—

$$\frac{dVw}{dt} = SA\rho - fwA$$

$$= SAk\rho - fwA$$

$$\therefore \frac{dw}{dt} = \frac{SA}{V} k\rho - fw \frac{A}{V},$$

$$\text{which} = a - bw \dots \dots \dots (1) \text{ when } a = \frac{SA}{V} k\rho \text{ and } b = f \frac{A}{V},$$

$$= -b \left( w - \frac{a}{b} \right)$$

$$w - \frac{a}{b} = Ce^{-bt} \quad w = 0 \text{ when } t = 0 \text{ hence } c = -\frac{a}{b}$$

$$\therefore w = \frac{a}{b} (1 - e^{-bt}) \quad \text{when } t = \infty, w = \frac{a}{b} \text{ the saturation value.}$$

Equation (1) shows that plotting the values of  $\frac{dw}{dt}$  against  $w$  should give a straight line, and when the actual observations are plotted in this way, a straight-line graph results (fig. 7).

From the graph of  $\frac{dw}{dt}$  against  $w$ , we can obtain the initial rate of solution into air-free water.

In the diagram (fig. 8), the intercept  $OA$  gives the total amount of air absorbed which agrees closely with that calculated from direct observations.

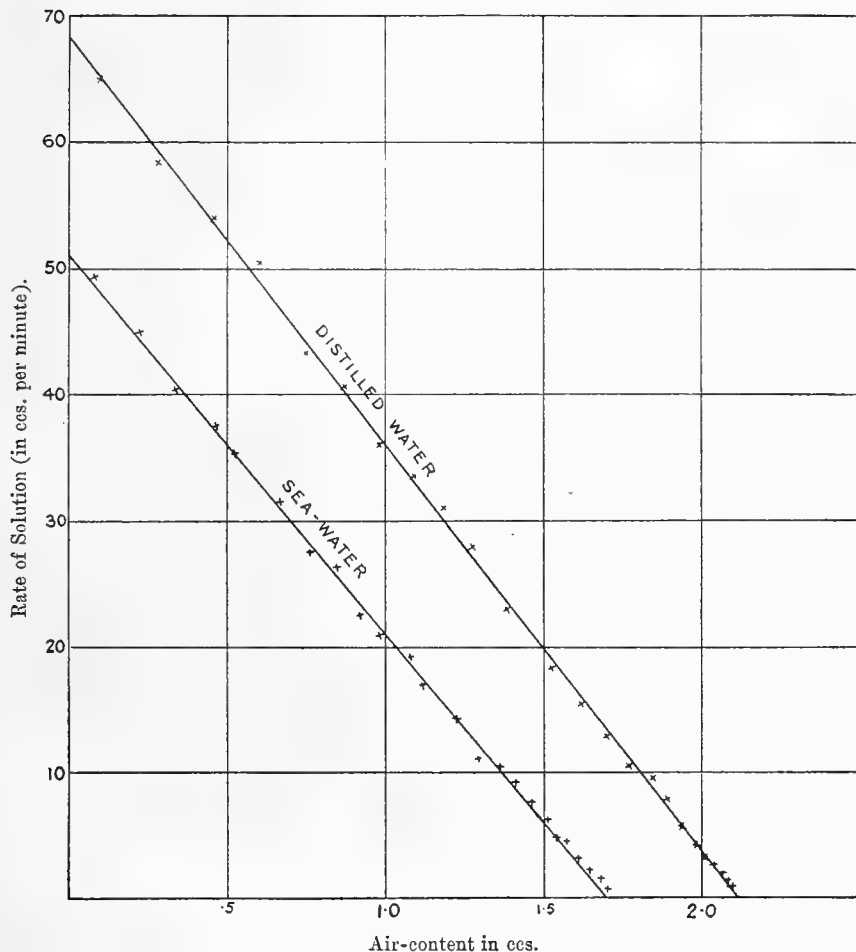


FIG. 7.

The intercept  $OB$  gives the initial rate of solution at the beginning of the experiment. To obtain the actual rate of solution into air-free water, we must continue the line  $AB$  back to meet an ordinate through  $C$ , where  $OC$  is the quantity of air in solution initially. Then  $CD$  represents the initial rate of solution into air-free water.

The table shows the results of the experiments treated in this way.

| No. of Experiment. | Values of "a."   |                                     | Values of "b." |
|--------------------|------------------|-------------------------------------|----------------|
|                    | In ces. per min. | In per cent. of Saturation per min. |                |
| 12                 | ·645             | 31·3                                | ·313           |
| 13                 | ·675             | 31·9                                | ·319           |
| 14                 | ·685             | 32·2                                | ·322           |
| 15                 | ·687             | 32·7                                | ·327           |
| 16                 | ·510             | 30·0                                | ·300           |
| 17                 | ·510             | 30·0                                | ·300           |

Taking the mean of the results in the case of sea-water and distilled water, we arrive at the formula  $\frac{dw}{dt} = 30\cdot8 - \cdot308w$ , which gives the rate of re-aeration, in percentages of saturation per minute, for an exposed area of 56 sq. cms.

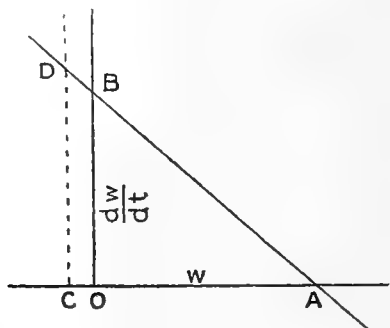


FIG. 8.

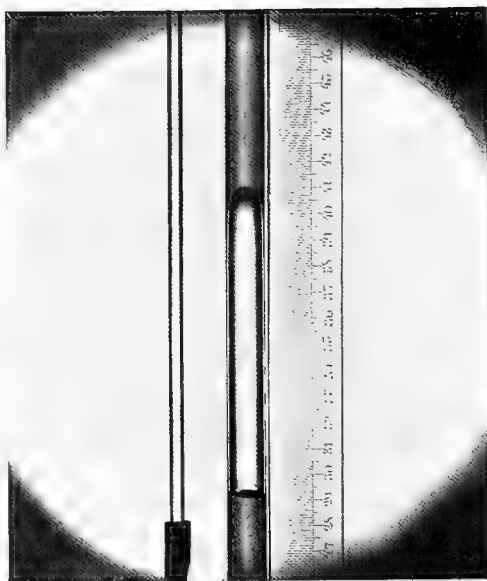
These figures represent the mean effect over the area exposed.

Experiments are being made with bubbles of various sizes, and it is proposed to deal with these in a further communication.

The authors desire, in conclusion, to express their indebtedness to Dr. Hackett, Lecturer in Physics in this College, for the advice and assistance that he has generously given them in the mathematical treatment of the subject of this communication.

CHEMICAL DEPARTMENT,

ROYAL COLLEGE OF SCIENCE FOR IRELAND.



PHOTOGRAPH OF BUBBLE IN MOTION UP THE TUBE.



## SCIENTIFIC PROCEEDINGS.

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THE ABSORPTION OF WATER BY VULCANIZED  
FIBRE AND ERINOID ON EXPOSURE TO MOIST  
AIR, AND THE CONSEQUENT CHANGE OF  
ELECTRICAL RESISTANCE.

BY

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[COMMUNICATED BY PROFESSOR WILLIAM BROWN.]



[*Authors alone are responsible for all opinions expressed in their Communications.*]

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## XXXII.

## THE ABSORPTION OF WATER BY VULCANIZED FIBRE AND ERINOID ON EXPOSURE TO MOIST AIR, AND THE CONSEQUENT CHANGE OF ELECTRICAL RESISTANCE.

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(COMMUNICATED BY PROFESSOR WILLIAM BROWN.)

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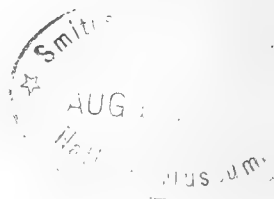
THE absorption of moisture by erinoid and fibre when directly immersed in water for a certain time, and the electrical resistances of these materials in their ordinary physical states at different temperatures, have already been investigated by the author.<sup>1</sup> The present paper deals with the absorption of water by fibre and erinoid when exposed to moist air, and the consequent change in their electrical resistances after different times of exposure.

*The absorption of water with time of exposure.*

Samples of fibre and erinoid were first well dried in an air-oven and afterwards weighed. They were then immersed in nearly saturated air for a certain time, and weighed at intervals. The arrangement used for producing the moist air consisted of a large glass vessel, containing water to the depth of about two inches and fitted with an air-tight lid. A narrow glass platform was fixed well above the surface of the water, and upon it was placed a wet and dry bulb thermometer. The samples were suspended in the air close to the hygrometer. This air was not quite saturated, but the

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<sup>1</sup> Scient. Proc. Roy. Dubl. Soc., 1918, vol. xv. (N.S.), No. 29, p. 331.



quantity of moisture present, as indicated by the hygrometer, was approximately constant throughout each test.

Three plates, one of red fibre, a second of red erinoid, and a third of blue erinoid, were first tested. These were of equal size, 5.5 by 5.95 by 0.5 cm., and their surfaces were prepared in the same way. The surface of each plate exposed to the moist air was therefore 77 sq. cms.

After the samples were heated for 144 hours at 70° C. in an air-oven they were weighed, and the respective weights for red erinoid, blue erinoid, and red fibre were found to be 26.95, 25.72, and 26.3 grammes.

They were then immersed together in moist air, and taken out at intervals, and weighed. During the test the two thermometers of the hygrometer indicated a nearly constant difference of 0.3 C., and the reading of the dry bulb thermometer varied only between 18° C. and 19° C.

The results which were obtained are given in Table 1, and the corresponding graphs in Fig. 1.

TABLE 1.

| Time.<br>Hours. | Grammes of water absorbed. |               |            |
|-----------------|----------------------------|---------------|------------|
|                 | Red erinoid.               | Blue erinoid. | Red fibre. |
| 22.6            | 0.25                       | 0.21          | 0.59       |
| 46.1            | 0.39                       | 0.34          | 1.02       |
| 69.9            | 0.52                       | 0.45          | 1.40       |
| 103.2           | 0.64                       | 0.55          | 1.793      |
| 167.4           | 0.87                       | 0.76          | 2.56       |
| 239             | 1.025                      | 0.90          | 2.9        |
| 333             | 1.24                       | 1.095         | 3.155      |
| 407             | 1.43                       | 1.26          | 3.42       |

Table 1 and Fig. 1 show that red fibre is much more hygroscopic than erinoid, and red erinoid somewhat more so than blue erinoid. Red erinoid was also previously found to absorb more water, when *directly* immersed in it, than other varieties of erinoid.<sup>1</sup> From Fig. 1 and the initial weights, previously given, of the samples, it follows that the percentage gain in

<sup>1</sup> Scient. Proc. Roy. Dubl. Soc., 1918, vol. xv. (N.S.), No. 29, p. 332.

weight after 400 hours' immersion in nearly saturated air was respectively 12.8, 5.2, and 4.8 for red fibre, red erinoid, and blue erinoid.

It is also seen from the curves<sup>1</sup> that the power of absorption is by no means exhausted after 400 hours' immersion, and gradually a much higher percentage increase of weight will be attained as time proceeds.

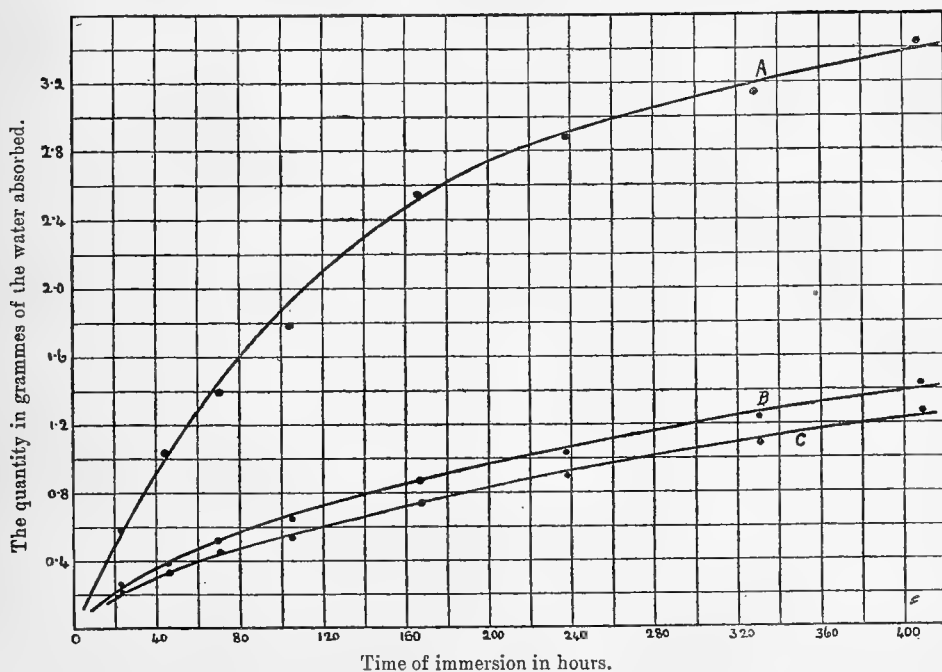


FIG. 1.

The relation between the quantity of water absorbed from moist air and the time of immersion therein.

Curve *A* is for red fibre, *B* for red erinoid, and *C* for blue erinoid.

The samples are of sheet form.

Three samples in the form of tubes, each closed at one end, were similarly tested, after having been dried for fourteen days at 70° C. The humidity of the moist air was practically the same as in the preceding test. The results

<sup>1</sup> The relation between  $x$  the grammes of water absorbed, and  $T$  the time of absorption in hours, for the range of the experiment, will be found to be roughly represented by  $x = kT^{0.6}$ ,  $k$  being 0.04 for red erinoid, 0.034 for blue erinoid, and 0.103 for red fibre. This equation is not quite so representative for fibre as for erinoid, and this is probably due to the greater sensitiveness of the former material to any small change in the degree of humidity of the air-bath.

which were obtained are given in Table 2, and the corresponding graphs in Fig. 2.

TABLE 2.

| Black erinoid. $W = 44.89$ grammes. $A = 155$ sq. cms. |      |      |      |      |      |      |      |
|--|------|------|------|------|------|------|------|
| Time,  | 8.5  | 23.7 | 96   | 142  | 263  | 336  |      |
| $x$ ,  | 0.21 | 0.4  | 0.95 | 1.15 | 1.66 | 2.02 |      |
| Red erinoid. $W = 44.61$ grammes. $A = 155$ sq. cms.   |      |      |      |      |      |      |      |
| Time,  | 6.5  | 20.2 | 95   | 213  | 328  |      |      |
| $x$ ,  | 0.18 | 0.37 | 0.94 | 1.5  | 2.12 |      |      |
| Red fibre. $W = 106.82$ grammes. $A = 275$ sq. cms.    |      |      |      |      |      |      |      |
| Time,  | 9.4  | 27.1 | 45   | 66   | 88   | 114  | 159  |
| $x$ ,  | 0.97 | 2.5  | 4.0  | 5.5  | 6.9  | 8.2  | 9.94 |

$W$  is the initial weight after drying,  $A$  the surface area of the sample exposed to the moist air, and  $x$  the quantity of absorbed water in grammes. The time of exposure is given in hours.

As the superficial area of the fibre-tube is much larger than that of either of the erinoid tubes, the quantity of water absorbed by it will be correspondingly greater. Curve  $A$ , Fig. 2, is therefore much higher than it would be if its area was 155 instead of 275 sq. cms.

On comparing the results of the plate sample of fibre with that of the tubular sample of the same material, for a given time of immersion, it will be found that the ratio of the respective quantities of water absorbed is roughly constant. Thus, from the curves of Figs. 1 and 2, it follows that this ratio for 40 hours' immersion is 3.9; for 80 hours' immersion 4; and for 160 hours' immersion also 4. The forms of the two absorption-curves are therefore practically the same. The ratio of the exposed surfaces of the two samples, namely,  $\frac{275}{77} = 3.6$ , is somewhat smaller than the preceding ratio.

The corresponding ratio of the quantities of absorbed water in the case of the tubular and plate samples of red erinoid is not quite so constant, and

is smaller than the ratio of the areas. This divergence of erinoid from the case of fibre is probably due to different processes being employed in the manufacture of the plate and tubular forms.

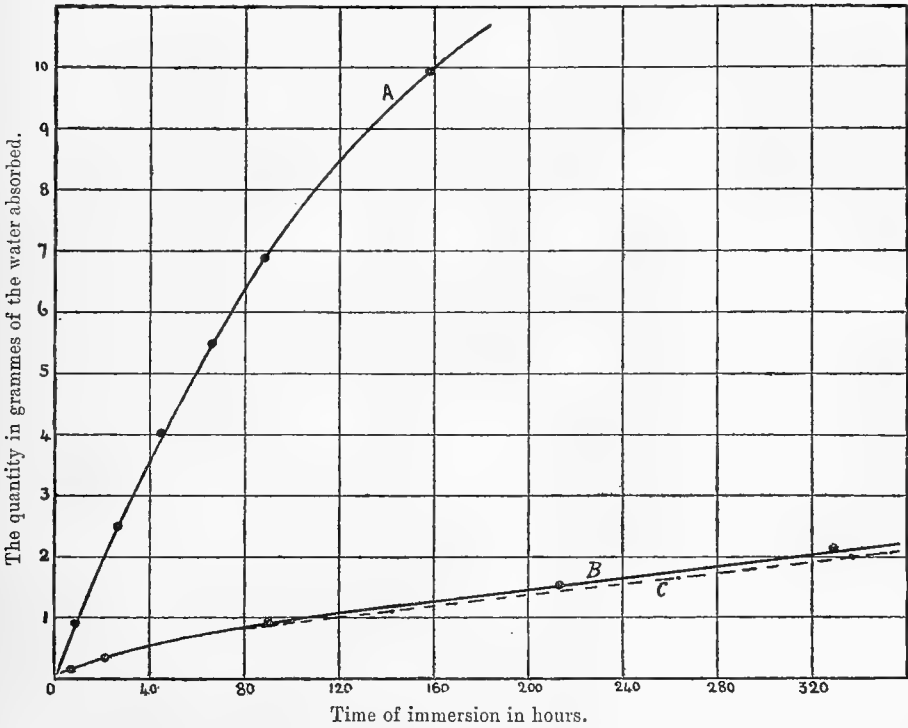


FIG. 2.  
Absorption of water and time of immersion in moist air.  
Curve *A* is for red fibre, *B* for red erinoid, and *C* for black erinoid.  
The samples are of tubular form.

*Change of electrical resistance due to the water absorbed by fibre and erinoid from moist air.*

The sample, in the form of a tube closed at one end, was thoroughly dried by heating for fourteen days in an air-oven at 70° C. Its electrical resistance was then measured, and directly afterwards the sample was placed in nearly saturated air for a certain time, and its resistance again determined. This was repeated for a number of succeeding intervals.

The readings of the two thermometers of the hygrometer were roughly constant through all the following tests, the average difference between them being 0.4° C., and the average temperature indicated by the dry bulb thermometer 18.5° C.

A set of resistances for different temperatures was measured after each interval of immersion in the moist air. During the test a slight loss of

absorbed water took place, but this, on weighing, was found to be practically negligible.

On testing, it was determined that there was no appreciable creepage over the tops of the walls of the sample, and the resistance was independent of the applied voltage: two essential conditions for representative measurement of insulation resistance. The former was shown to be the case by measuring the resistance of the tube for a given level of the mercury contact-surfaces, and then changing this level and again measuring the resistance. The specific resistance calculated for different levels was found to be very nearly constant. The voltage test up to 500 was performed by the galvanometer and the voltmeter method.

Each set of resistances for different temperatures, measured after an interval of immersion in moist air, was tabulated as in Tables 3 and 4. These two tables are typical of each of the twenty-seven sets obtained; Table 3 being for black vulcanized fibre after 63 hours' immersion in moist air, and Table 4 for red erinoid after 6.5 hours' immersion.

TABLE 3.

| $t$ | $T$ | $\frac{I}{T}$         | $R$ | $\text{Log}_{10} R$ |
|-----|-----|-----------------------|-----|---------------------|
| 33  | 306 | $32.7 \times 10^{-4}$ | 640 | 2.81                |
| 40  | 313 | 31.9 ,,               | 290 | 2.46                |
| 48  | 321 | 31.1 ,,               | 127 | 2.10                |
| 57  | 330 | 30.3 ,,               | 59  | 1.77                |
| 64  | 337 | 29.7 ,,               | 26  | 1.42                |

TABLE 4.

| $t$ | $T$ | $\frac{I}{T}$       | $R$   | $\text{log}_{10} R$ |
|-----|-----|---------------------|-------|---------------------|
| 39  | 312 | $32 \times 10^{-4}$ | 4,100 | 3.61                |
| 45  | 318 | 31.4 ,,             | 2,100 | 3.32                |
| 55  | 328 | 30.5 ,,             | 720   | 2.86                |
| 64  | 337 | 29.6 ,,             | 240   | 2.38                |
| 69  | 342 | 29.2 ,,             | 150   | 2.18                |

$t$  being the temperature in degrees centigrade,  $T$  the absolute temperature, and  $R$  the resistance of the sample in megohms.

Rasch and Hinrichsen and others have found for certain materials, that the graph of the reciprocal of absolute temperature and the logarithm of resistance is a straight line.<sup>1</sup> The former workers showed it was followed by such substances as porcelain, glass, oil, water, and ice. The same result was previously found, by the author, for both erinoid and fibre in their ordinary physical states.<sup>2</sup> It would seem that this relation is generally followed by insulating materials.

In the present investigation the same relation between  $\frac{1}{T}$  and  $\text{Log. } R$  was found to be followed by both fibre and erinoid in every case, whatever the quantity of water absorbed. This is an important result, for it gives strong support to the theory, propounded by Evershed, that electricity is conducted through an insulating material by means of an internal system of water-films.<sup>3</sup>

Straight-line graphs, twenty-seven in number, were drawn according to the data of tables such as 3 and 4, and from them the resistances at 30° C., 40° C., and 50° C. were obtained for each stage of immersion in the moist air.

The resistance was measured by means of the leakage method, using an electrostatic voltmeter and mica condenser in parallel with the sample.<sup>4</sup> In some cases the megger was used. The results obtained for blonde erinoid for different times of immersion in moist air are given in Table 5.

TABLE 5.  
Blonde erinoid ; thickness 0.38 cm.

| Hours. | Specific resistance in megohms per cm. cube. |           |           |
|--------|--|-----------|-----------|
|        | 30° C.                                       | 40° C.    | 50° C.    |
| 0      | 17,800,000                                   | 6,800,000 | 2,750,000 |
| 19.3   | 6,800,000                                    | 1,960,000 | 660,000   |
| 42     | 4,900,000                                    | 1,180,000 | 340,000   |
| 62.5   | 2,560,000                                    | 690,000   | 230,000   |
| 118    | 1,960,000                                    | 490,000   | 148,000   |
| 187    | 1,120,000                                    | 310,000   | 96,000    |
| 271    | 710,000                                      | 196,000   | 62,000    |
| 514    | 107,000                                      | 30,300    | 9,800     |
| 677    | 45,000                                       | 8,500     | 1,960     |

<sup>1</sup> *Zeit. Elektrochem.*, Bd. xiv, 1908, p. 41.

<sup>2</sup> *Scient. Proc. Roy. Dub. Soc.*, 1918, vol. xv. (N.S.), No. 29, p. 350.

<sup>3</sup> *Journ. Inst. Elec. Eng.*, vol. lli, 1913, No. 224, p. 51.

<sup>4</sup> For the arrangement used, see *Scient. Proc. Roy. Dub. Soc.*, 1918, vol. xv. (N.S.), No. 27, p. 292.



In this case the initial weight of the sample was 44.04 grammes, and the final weight, after 677 hours' immersion, 47.1 grammes, thus giving a percentage increase in weight of 6.9. The area of the surface in contact with the moist air was 155 sq. cms., and the specific resistance was 170 times the resistance measured in megohms.

The rapid decrease of resistance as more and more water was absorbed is clearly shown by Table 5. This decrease for a given stage in the absorption is probably caused chiefly by the continued penetration of the water absorbed at earlier stages, and to a lesser extent by the water being absorbed during the stage under consideration.

Similar results were obtained for a tube of black fibre, and these are given in Table 6.

TABLE 6.

Black fibre; thickness, 0.6 cm.

| Hours. | Specific resistance in megohms per cm. cube. |            |           |
|--------|--|------------|-----------|
|        | 30° C.                                       | 40° C.     | 50° C.    |
| 0      | 42,600,000                                   | 12,000,000 | 3,360,000 |
| 20.7   | 5,360,000                                    | 1,500,000  | 510,000   |
| 44     | 355,000                                      | 112,000    | 39,000    |
| 63     | 107,000                                      | 34,000     | 12,000    |
| 84.5   | 15,000                                       | 4,800      | 1,560     |

The initial weight, after drying, was 79.3 grammes, and the weight after 180 hours' immersion in moist air was 85 grammes, thus giving a percentage increase in weight of 7.2. The area of the surface in contact with the moist air was 178 sq. cms., and the specific resistance was 120 times the resistance measured in megohms.

In this case the decrease of resistance with time of exposure is much greater than in the case of erinoid. This is mainly due to the fibre being very much more hygroscopic than erinoid.

More complete results were obtained for tubes of red erinoid and red fibre. These are given in Tables 7 and 8.

TABLE 7.

Red erinoid; thickness, 0.39 cm.

| Hours. | $x$   | $P$  | Specific resistance in megohms per cm. cube. |           |         |
|--------|-------|------|--|-----------|---------|
|        |       |      | 30° C.                                       | 40° C.    | 50° C.  |
| 0      | 0     | —    | 9,900,000                                    | 2,600,000 | 750,000 |
| 6.5    | 0.18  | 0.40 | 2,300,000                                    | 630,000   | 190,000 |
| 20     | 0.345 | 0.77 | 1,200,000                                    | 336,000   | 104,000 |
| 83     | 0.88  | 1.97 | 490,000                                      | 120,000   | 33,000  |
| 185    | 1.37  | 3.07 | 213,000                                      | 56,000    | 15,800  |
| 300    | 1.94  | 4.35 | 147,000                                      | 34,500    | 9,200   |

The initial weight, after drying, was 44.61 grammes, the area of the surface in contact with the moist air 155 sq. cms., and the specific resistance 165 times the resistance measured in megohms.

$P$  is the percentage gain in weight, and  $x$  the number of grammes of water absorbed at the end of each interval of immersion in moist air.

TABLE 8.

Red fibre; thickness, 0.65 cm.

| Hours. | $x$  | $P$  | Specific resistance in megohms per cm. cube. |         |         |
|--------|------|------|--|---------|---------|
|        |      |      | 30° C.                                       | 40° C.  | 50° C.  |
| 0      | 0    | —    | 2,150,000                                    | 650,000 | 205,000 |
| 9.4    | 0.97 | 0.91 | 980,000                                      | 310,000 | 112,000 |
| 25     | 2.46 | 2.30 | 515,000                                      | 142,000 | 41,000  |
| 43     | 3.82 | 3.58 | 11,600                                       | 4,300   | 1,740   |
| 63     | 5.30 | 4.95 | 730  | 326     | 163     |
| 82     | 6.49 | 6.08 | 109  | 65      | 49      |
| 102    | 7.69 | 7.20 | 21   | 13      | 8       |

The initial weight of this sample was 106.82 grammes, the area in contact with the moist air 275 sq. cms., and the specific resistance 163 times the resistance measured in megohms.

Tables 7 and 8 show the great decrease of resistance in fibre<sup>1</sup> and erinoid with increase in the quantity of water absorbed. The decrease is enormous in the case of fibre between the absorption of 2.46 and 5.3 grammes of water. This suggests that a rapid penetration of the liquid across the thickness of the material was taking place at that stage in the absorption.

In conclusion, the results of this investigation are :—

1. Vulcanized fibre is much more hygroscopic than erinoid.
2. After having been thoroughly dried, and then exposed to moist air, the electrical resistance of both fibre and erinoid, especially the former, rapidly decreases as time of exposure continues. Thus the decrease of specific resistance of a sample of red vulcanized fibre after 82 hours' immersion in nearly saturated air, was from  $2.2 \times 10^6$  to 109 megohms per cm. cube; and for a sample of red erinoid, after 83 hours' immersion, from  $9.9 \times 10^6$  to  $0.49 \times 10^6$  megohms per cm. cube, a very much smaller percentage decrease than that of the former material.
3. Whatever the quantity of absorbed water in the sample, the same simple relation between temperature and resistance was found to be followed by fibre and erinoid. This gives strong support to the theory that electricity is conducted through insulating materials by the vehicle of water-films.

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<sup>1</sup> For the range of absorption given in Table 8, beginning at 25 hours, the resistance of the red fibre at 30° C. will be found to be approximately proportional to  $x^{-8.7}$ . The corresponding index of  $x$  for the red erinoid is very roughly -1.2.

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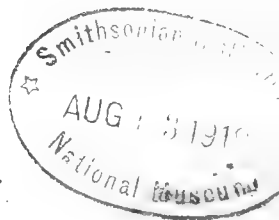
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THE TWIST AND MAGNETIZATION OF A STEEL  
TUBE IN A SPIRAL MAGNETIC FIELD.

BY

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[*Authors alone are responsible for all opinions expressed in their Communications.*]

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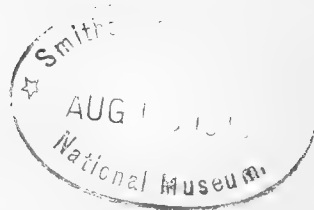
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## XXXIII.

## THE TWIST AND MAGNETIZATION OF A STEEL TUBE IN A SPIRAL MAGNETIC FIELD.

BY F. E. HACKETT, M.A., PH.D.,

Lecturer in Physics, Royal College of Science, Dublin.

[Read JUNE 25; published OCTOBER 28, 1918.]

THE investigation of the behaviour of the ferromagnetic metals under varying conditions of magnetic and mechanical stress carried out by Professor Brown and described in a series of communications to the Royal Dublin Society has shown that a number of simple relations exist between the applied stress, the magnetic field, and the linear dimensions of the wires examined which suggest a simple theoretical relation between them. Before seeking for such a relation the effects produced by the magnetic field alone require correlation.

The connexion between the Joule effect (the change of length of iron, nickel, or cobalt in a magnetic field) and the Wiedemann effect (the twist of an iron, cobalt, or nickel wire in a magnetic field when a current is passing through it) was long ago pointed out by Maxwell, but only in a very general way. It is obvious that the current passing through a wire produces a circular magnetic field. It might be expected, then, that the Wiedemann effect is merely another aspect of the Joule effect due to the combination of the circular magnetic field with the longitudinal field. This view of the phenomenon suggests the experiment of studying the Wiedemann effect in steel tubes, producing the circular field by a current along an insulated wire coinciding with the axis of the tube. This experiment has been carried out by S. R. Williams,<sup>1</sup> who has made an extensive study of this subject, but not under conditions which would reveal experimentally the connexion between the two effects. The tubes used were of very small diameter, and may be described as hollow wires. The thickness of the tube was thus very large in comparison with the radius. It was thought worth while to repeat the

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<sup>1</sup> S. R. Williams, *Phys. Rev.*, Mar. 1911.



experiment, using tubes which more nearly correspond to the ideal cylindrical shell, such as the tubing used in the frames of bicycles.

This paper gives an account of an extended investigation into the Wiedemann effect, using such a steel tube 5.94 mm. mean radius, 0.87 mm. in thickness, and 95.1 cm. in length. The first problem which presented itself was the measurement of the twist which would be produced in such a tube under the available magnetic fields. We may state at once that it has been found possible to measure a twist of the order of one second of arc, and to investigate the Wiedemann effect over a sufficiently wide range of magnetic fields to demonstrate a simple relation to the Joule effect indicated by mathematical theory.

#### THE TWIST OF A STEEL TUBE IN SPIRAL MAGNETIC FIELD.

*Theory of the Wiedemann effect.*—We shall first consider the theory of the effect, as this explains the special experimental conditions which have to be complied with. Consider a thin cylindrical magnetic shell whose axis coincides with the axis of  $z$  drawn downwards. Let  $S$  be a spiral magnetic field whose axis coincides with the axis of  $z$ . This field produces a strain consisting of an elongation  $\epsilon_1$  along the lines of force, and a contraction  $\epsilon_2$  normal to the lines of force. This elementary strain produces a twist of the cylindrical shell ( $\theta$ ) and an elongation along its length. Applying the usual transformation of axes of the theory of elasticity, we obtain finally

$$\theta = (\epsilon_1 + \epsilon_2) \sin 2\alpha \, l/r.$$

This equation has been given by Knott<sup>1</sup> in his investigation of the Wiedemann effect in steel and nickel wires with a slightly different notation. Here  $l$  = length of the tube,  $r$  = its mean radius,  $\epsilon_1$  the elongation per unit length parallel to the resultant field  $S$ ,  $\epsilon_2$  the transverse contraction per unit length. The resultant field  $S$  acting on the tube is a spiral made up of the longitudinal field  $H$  and the circular field  $F$ , where the pitch-angle  $\alpha$  is given by the equation  $\tan \alpha = H/F$ . The mathematical theory requires us to keep  $S$  constant while varying  $H/F$ . Under these conditions

$$\theta \propto \sin 2\alpha.$$

The observations given below show a satisfactory concordance with this relation.

*Hysteresis effects.*—As is well known, magnetic hysteresis presents great difficulties in the examination of this phenomenon. We have not only to

<sup>1</sup> Knott, *Trans. Roy. Soc., Edin.*, vol. xxxv, p. 388.

overcome hysteresis with respect to the intensity of the applied field, but also with respect to its direction. It is quite obvious that the spiral field  $S$  will not produce similar intensities of magnetization if produced by circular and magnetic fields applied successively. Theoretically the spiral field should be allowed to grow to its full value, keeping the pitch-angle constant, that is, the ratio  $H/F$  should be constant. This is feasible by combining the circuits producing the circular and magnetic fields so that they are both made simultaneously. This method has been used in the later stages of the investigation, but in practice it is not so simple as another process which was first adopted, and which is described in connexion with the actual observations.

*Magnetizing Solenoid.*—These experiments were rendered possible by the use of a specially large magnetizing solenoid designed by Professor Brown, for the use of which the author of this paper is greatly indebted to him. Its length over all is 121 cm., and the magnetizing coil is divided into six sections, each of which is wound so as to give a magnetizing field of 12.21 c.g.s. units per ampere. The field inside the coil is uniform within 10 cm. of the ends, giving a uniform field over 100 cm. The external diameter of the windings is 7.62 cm. and the internal diameter is 2.54 cm. The internal space is provided with a jacket for heating or cooling as may be required. The whole is mounted vertically in a strong wooden frame, 170 cm. high and 58 cm. wide. Each end of the steel tube was brazed to a short length of brass tubing which reduced its free length to 91 cm. The upper length was clamped in a nut rigidly attached to the wooden frame in which the solenoid was mounted, so that the steel tube was entirely within the uniform field of the solenoid. The lower length projecting below the solenoid carried the mirror reflecting the beam of light whose deflection measured the twist. An insulated copper wire passed down the steel tube, and was fixed centrally by ebonite plugs, to carry the current which produced the circular field.

*Measurement of twist.*—The difficulty of getting a beam of light to give a clear, definite image on a scale at a sufficient distance away, to measure the small deflections to be expected, was surmounted by utilizing the collimator of a spectroscope. The image of a Nernst filament was focussed on the slit, and the collimator adjusted to give an image on a glass scale at a distance of 1325 cm. When the slit was narrowed sufficiently, the image was traversed by diffraction bands approximately 0.1 mm. in width. The position of one of these bands was read by a low-power ocular, and readings could be made with ease to 0.1 mm., which corresponds to a twist of 3.77 micro-radians.

*Magnetizing circuits.*—In the final arrangement three sections of the solenoid were used to give the longitudinal field, another section to compensate the vertical component of the Earth's field, and two others for the demagnetizing circuit.

*Demagnetization.*—This was carried out by reversing the direct current from a 20-volt storage battery by reversal with a hand commutator at the rate of one reversal per second, reducing the current at a uniform rate, the whole process occupying two minutes and a half. This is the method recommended by Burrows.<sup>1</sup> Recently Smith<sup>2</sup> has drawn attention to the fact that even this rate may be too great for complete demagnetization; but in the present set of experiments the rate of one cycle per second proved to be ample, as shown either by tests with the magnetometer or observations on the Wiedemann effect.

*Elimination of Hysteresis.*—The elimination of hysteresis in magnitude and direction under a spiral field in the first series of observations was accomplished by the method used by Steinhaus and Gumlich<sup>3</sup> in their experiments on the magnetization of iron in the absence of hysteresis. A given magnetic field was applied to the solenoid, and an additional longitudinal field of one cycle per second was applied and gradually decreased to zero. This has been shown to give an  $I$ - $H$  curve similar to the hysteresis-free curve given by tapping soft iron, and bearing a similar relation to the hysteresis loop.<sup>4</sup>

This type of magnetization has been termed anhysteretic, which usage will be adopted in this paper. The process is a symmetrical one when applied to a simple longitudinal field, but it is not so symmetrical when superimposed on a spiral field. However, it is easy to demonstrate that it gives here also the required result. It has long been known that the Wiedemann effect gives a hysteresis loop if the longitudinal field is kept constant and the circular field (or current passing along the central wire) is varied.

A hysteresis loop obtained in this manner is shown in fig. 1, using a longitudinal field of 8 units, and varying the circular field between  $-15$  and  $+15$  e.g.s. units. The anhysteretic curve was obtained by setting the circular and longitudinal fields, and then superimposing on these fields a longitudinal field which was slowly decreased to zero, with reversals at the rate of one

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<sup>1</sup> Burrows, Bull. Bureau of Stand., vol. iv, p. 205, 1908.

<sup>2</sup> Smith, Phys. Rev., Sept., 1917.

<sup>3</sup> Steinhaus and Gumlich, Ber. d. Deut. Phys. Ges. 17, 369, 1915.

<sup>4</sup> Ewing, Magnetic Induction, pp. 116 and 322.

per second, giving the broken line shown. The position of this curve shows that the process eliminates hysteresis, since it lies symmetrically in the hysteresis loop. In fact, the process is so complete that it is a matter of indifference in what order the observations are taken, or how the circular and longitudinal fields are applied. The final reading is always the same. The

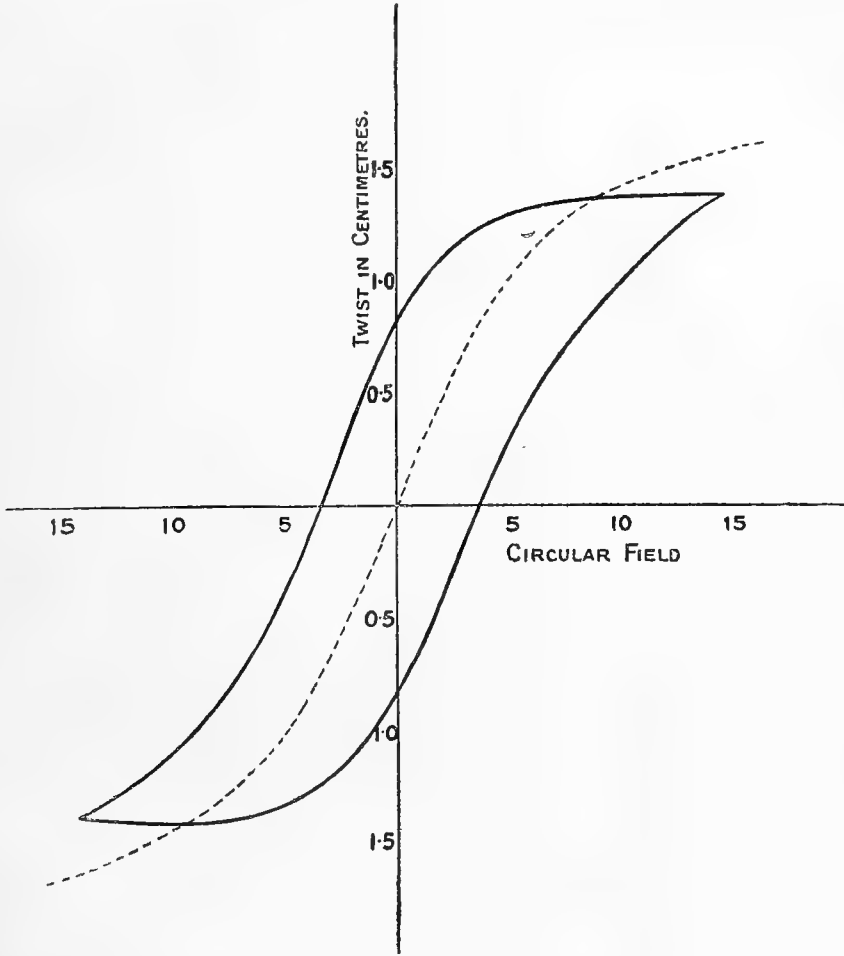


FIG. 1.

previous magnetic history is completely wiped out. We conclude that the axis of magnetization is by this process brought into coincidence with the direction of the resultant field.

*Test of the theory.*—This method of anhysterization gives us a means of testing the above formula for the twist in the following manner:—A given

value of the spiral field  $S'$  was chosen, and the longitudinal applied field  $H'$  and the applied circular field  $F'$  were set so as to give this value of  $S'$  for a given value of the pitch-angle  $\alpha$  where  $\tan \alpha = H'/F'$ . The notations  $S'$  and  $H'$  are used here to denote the *applied* magnetic fields, postponing the question of their relation to the *actual* fields  $S$  and  $H$  until we consider the demagnetizing effects of the ends in the later sections of the paper. The process of anhysterization was carried out and the deflection read. This method should produce the same intensity of magnetization along the resultant spiral field while  $\alpha$  alone varies, thus complying with the mathematical conditions provided the tube is magnetically isotropic. The observations were taken according to the scheme given in Table I, which also gives the observations for  $S' = 14$ . It is easily seen that the deflections vary as  $\sin 2\alpha$ .

TABLE I.

Twist of a steel tube in a resultant spiral magnetic field  $S' = 14$  for varying pitch-angle  $\alpha$ .

$$\text{Applied longitudinal field} = S' \sin \alpha.$$

$$\text{Applied circular field} = S' \cos \alpha.$$

$$\text{Current in amperes in central wire} = 3S' \cos \alpha.$$

| Sin $2\alpha$ . | 1.0  | 0.8  |      | 0.6  |      | 0.4  |      | 0.2  |     |
|-----------------|------|------|------|------|------|------|------|------|-----|
| $\alpha$        | 45°0 | 63°3 | 26°3 | 71°3 | 18°3 | 78°1 | 11°5 | 84°1 | 5°5 |
| twist mm.       | 15.8 | 12.7 | 12.1 | 9.2  | 9.8  | 5.8  | 5.8  | —    | 2.8 |

The process of anhysterization causes a slight disturbance of the zero of the mirror, owing to the to-and-fro vibration which accompanies the application of the alternating magnetic field, so that a reading of the zero had to be taken after each observation. This, of course, requires the complete demagnetization of the tube by the method already described. The shift of the zero due to this cause was very slight, usually of the order 0.1 to 0.2 mm. A very striking feature of the twist is its absolutely dead-beat quality, the diffraction band moving immediately to its new position on the application of the magnetic fields. The results for a series of observations for spiral fields  $S' = 14, 20, 30, 40,$  and  $60$  c.g.s. units are shown in fig. 2. A complete set

of observations could not be taken for the higher fields, as the circular current was limited to 60 amperes.

Inspection of the graphs demonstrates that the linear relation required holds approximately within the region under investigation. As we increase the intensity of the resultant field the graph becomes slightly curved. This

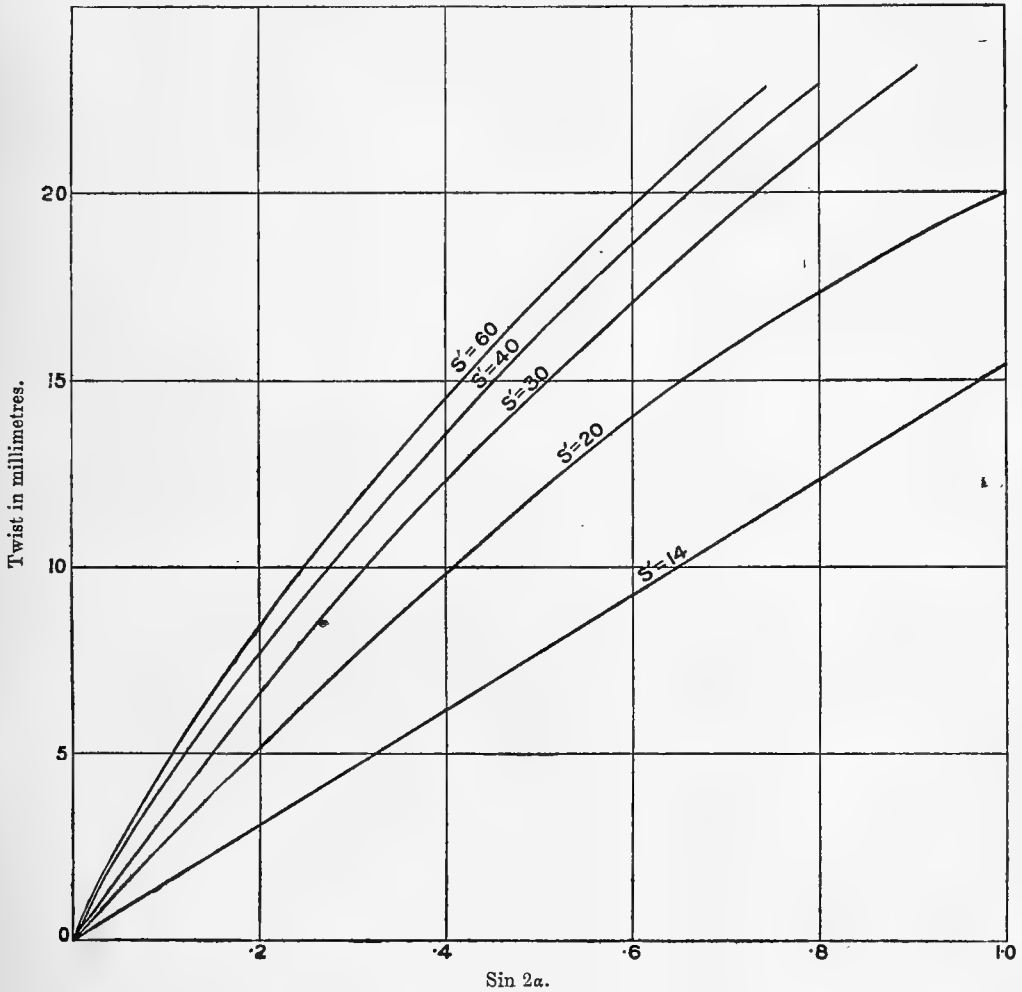


FIG. 2.

suggests some minor departures from the ideal conditions of magnetization postulated by the theoretical investigation. We require, therefore, to examine the actual state of magnetization of the tube under these special conditions. The results of the investigation are given in the second section of the paper.

## THE MAGNETIZATION OF A STEEL TUBE IN A SPIRAL MAGNETIC FIELD.

*Influence of the demagnetizing factor.*—Experiments on magnetic phenomena which have to be performed with linear rods are subject to the grave disadvantage that the magnetization at the ends sets up an opposing field to the applied force, so that neither the resulting field nor the magnetization can be uniform. This effect may have an important influence on the twist in the spiral magnetic field, and may be the cause of the departure from the linear law shown in fig. 2. This can only be demonstrated by showing that the linear law holds strictly if a correction is introduced for the magnetization of the ends, which is usually done by means of the demagnetizing factor  $N$ , approximately constant, where  $H' - NI = H$ , the average magnetizing force existing in the iron and referring the values of  $I$  to  $H$  instead of  $H'$ .

Unfortunately there are no reliable data regarding the demagnetization effects in a steel tube, and special methods had to be devised to evaluate this constant from observations on the magnetization. The values of  $I$  for different values of a longitudinal field  $H'$  and a spiral field  $S'$  are therefore required.

*Magnetometer measurements.*—The measurement of the intensity was carried out in the usual way by the one-pole magnetometer method. A complexity is introduced by the fact that the spiral field is produced, in part, by the current through the central wire in the steel tube. The magnetic field due to the current is, of course, parallel to and varies the magnitude but not the direction of the control field at the magnetometer. This, however, merely requires a determination of the value of the control field in each observation by means of an auxiliary coil in series with a calibrated millimeter. The whole series of measurements was affected by small variations in the zero, due to the neighbourhood of magnetic material, which had to be eliminated by the method of taking observations, before a consistent series could be obtained. The most troublesome effect was in the variation of the vertical component of the earth's field due to extraneous magnetic material consequent on the variety of magnetic fields to which it was subjected. The current in the compensating coil had, therefore, to be varied accordingly. The range of variation was about 0.05 c.g.s. units.

The only other point which may be noticed is the determination of the equivalent position of the poles of the steel tube. Ewing states that the position in which the deflection is a maximum may be taken as the position in which the magnetometer and one pole are in the same horizontal plane. This is only approximate. The difference in the present observations amounted

to 1 per cent. In fact, this maximum can be used to determine the equivalent position of the poles, assuming that the change of intensity of the magnetic field at the magnetometer near the maximum is due to poles localized at two points symmetrically placed with reference to the ends of the bar. The position of these equivalent poles was thus found to be 4.0 cm. from the ends, and the distance between them 87.1 cm.

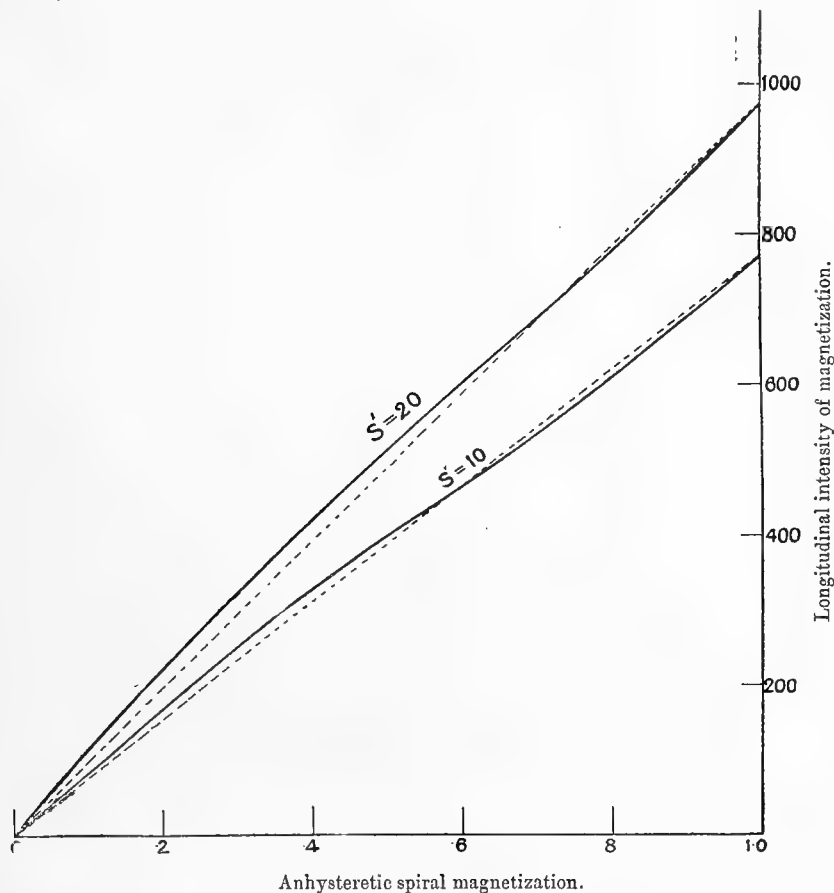


FIG. 3.

*Anhyseretic spiral magnetization.*—As the intensity of magnetization measured is only the longitudinal component  $I_{l\alpha}$  of the total intensity  $I_s'$  in applied spiral field  $S'$  with pitch-angle  $\alpha$ , we should expect to find

$$I_{l\alpha} = I_s' \sin \alpha,$$

if the following assumptions hold:—(1) That the applied spiral field ( $\alpha$ ) gives a magnetization parallel to its own direction; (2) produces exactly the same



magnetization at each pitch-angle which requires the susceptibility to be the same in all directions: (2) that the demagnetizing effect can be neglected. The deviations from this result give some information on the relative importance of these factors.

The results for anhysteretic spiral magnetization are shown in the two graphs of fig. 3 for  $S' = 10$  and  $S' = 20$ . In these observations a spiral field is applied given by  $H' = S' \sin \alpha$  and  $F' = S' \cos \alpha$ ; and the tube is then subjected to the diminishing alternating field, as in the case of the twist, while under the influence of this spiral field. It will be seen that the graph follows very closely the broken line  $y = I_L \sin \alpha$  where  $I_L$  is the intensity of magnetization when the pitch-angle of the spiral field becomes equal to  $90^\circ$ , that is, for a simple longitudinal field of the same strength as the spiral field. It has a curious lack of symmetry lying above this line for values  $0^\circ$ – $45^\circ$ , and below it for values  $45^\circ$ – $90^\circ$ , of which it has not been possible to give an explanation.

The applied alternating field superposes a longitudinal oscillation on the steady spiral field. This oscillation is asymmetric about the final rest-point, either from the point of view of magnitude or direction, except for small or large pitch-angles. Again, the problem is complicated by the demagnetizing factor, whose influence it is difficult to follow out in the present instance. In fact, the investigation of the anhysteretic spiral magnetization can only be regarded as showing that the experimental conditions give approximately a constant intensity of magnetization, as required by the theory of the twist given in this paper, subject, however, to some small disturbing effects, which cannot be separated in the complex method which is used to give anhysteretic magnetization.

*Initial spiral magnetization.*—At this stage it became necessary to return to the second method of getting spiral magnetization, viz., to arrange for the circular and longitudinal fields to grow up from zero simultaneously, so that the lines of magnetic force formed a spiral of constant pitch-angle, in which the intensity increased from zero to the required value. This would magnetize the tube everywhere in lines inclined at an angle  $\alpha$  to its axis. This type of magnetization may be termed the “initial” spiral magnetization. Here also we should have

$$I_{\alpha} = I_s' \sin \alpha,$$

using the same notation, provided the same set of assumptions hold. Of these it may be remarked that (1*a*) is satisfied by the method of obtaining the spiral field. We can evaluate to a certain extent the influence of (2), which will allow us to deduce the effect of (1*b*).

Experimentally, we can make the two fields develop simultaneously by shunting the solenoid across a short section of the circuit carrying the current in the central wire. This current was controlled by a wire-resistance frame, with Fleming anti-inductive coils, arranged in parallel, as in a lamp resistance. The solenoid was in parallel with one of these coils, which was permanently in the circuit. Owing, however, to the self-induction of the solenoid, absolute simultaneity in the growth of the currents in each branch cannot be secured. The circular magnetic field will develop a little more rapidly than the longitudinal field. This effect will prevent (1 *a*) from being completely satisfied.

The results obtained by this method are shown in fig. 4. The theoretical linear relation is approximately satisfied, though apparently not quite so completely as in the case of anhysteretic spiral magnetization. But it is possible to assign a reason for the deviation observed by taking account of the demagnetizing factor.

Let  $I_a$  = longitudinal intensity for the applied spiral field  $S'$  at pitch-angle  $\alpha$ .

$I_L$  = longitudinal intensity for longitudinal field  $S'$ .

$\partial H'$  = average demagnetizing force.

$S' - \partial S'$  = net resultant spiral field.

$$\left(\frac{\partial I}{\partial H'}\right)_{H'=S'} = K.$$

Then

$$H = H' - NI.$$

$$\frac{\partial I}{\partial H'} = \frac{\partial I}{\partial H} \left[1 - N \frac{\partial I}{\partial H'}\right].$$

$$\frac{\partial I}{\partial H} = K(1 + NK) = K \text{ approx.}$$

The demagnetizing force  $\partial H'$  arises from the longitudinal magnetization, and may be written  $NI_a$ , where  $N$  is of the order  $10^{-3}$ . The following relations can be easily written down from a diagram of the applied and resultant fields:—

$$\partial S' = \partial H' \sin \alpha,$$

$$\partial H' = NI_a,$$

$$I_a = I_L \sin \alpha \text{ (approx. from graph fig. 4),}$$

$$\partial H' = NI_L \sin \alpha.$$

The resulting intensity  $I_a$  for the resultant field  $S' - \partial S'$  for any pitch-angle  $\alpha$ , assuming a constant susceptibility at all angles, is given by

$$\begin{aligned} I_a &= I_L + K[S' - \partial S' - (S' - NI_L)] \\ &= I_L [1 + KN \cos^2 \alpha]. \end{aligned}$$

The component intensity is given by

$$I_{l\alpha} = I_{\alpha} \frac{H' - \partial H'}{S' - \partial S'} = I_L (1 + KN \cos^2 \alpha) \frac{S' - \partial S' / \sin^2 \alpha}{S' - \partial S'} \sin \alpha.$$

$$\begin{aligned} I_{l\alpha} &= I_L \sin \alpha \left[ 1 + N \cos^2 \alpha \left( K - \frac{I_L}{S' - NI_L \sin^2 \alpha} \right) \right] \\ &= I_L \sin \alpha [1 + N \cos^2 \alpha (K - I_L/S')] \text{ approx.} \end{aligned}$$

The shape of the curve of initial magnetization shows that

$$K - \frac{I_L}{S'}$$

is negative, and writing it  $-A$  we have

$$I_L \sin \alpha - I_{l\alpha} = ANI_L \sin \alpha \cos^2 \alpha,$$

which gives a maximum at  $\sin \alpha = 0.576$ .

It may be seen that the graphs in fig. 4 correspond generally to the theory. The deviations for the spiral fields  $S' = 10$  and  $S' = 20$  from the broken lines representing  $y = I_L \sin \alpha$  follow the variations in  $\sin \alpha \cos^2 \alpha$ , giving a maximum near  $\sin \alpha = 0.6$  excepting at the ends where the deviations are larger than are to be expected from the theory.

The analysis, however, is important in showing how the demagnetizing effect may be corrected. We have hitherto obtained a spiral field  $S'$  by applying fields

$$\begin{aligned} H' &= S' \sin \alpha, \\ F &= S' \cos \alpha. \end{aligned}$$

The field  $H'$  is, however, diminished by the demagnetizing force by

$$NI_{l\alpha} = NI_L \sin \alpha \text{ approx.,}$$

so that the actual spiral field  $S$  is somewhat less than  $S'$ . To obtain a net spiral field  $S$  we have to apply a circular field  $F = S \cos \alpha$  and a longitudinal field

$$H' = S \sin \alpha + NI_L \sin \alpha = (S + s) \sin \alpha,$$

where  $s$  is a quantity to be determined from a knowledge of the demagnetizing factor.

*Correction for the demagnetizing effect.*—It will be shown later in the paper that  $s = 2.5$  compensates for the distorting effect of the demagnetizing effect in the study of the twist of a spiral field  $S = 10$ , especially in the neighbourhood of the pitch-angle  $45^\circ$ . The curve marked  $S = 10$ , fig. 4, shows how the longitudinal intensity varies for the fields;

$$F = 10 \cos \alpha, \quad H = (10 + 2.5) \sin \alpha,$$

which, on this theory, should give a resultant field  $S = 10$ . It is seen that the linear relation with  $\sin a$  is closely followed for the interval  $0.7 > \sin a < 1.0$ . The deviations increase as the pitch-angle diminishes. This is evidently not due to the demagnetizing effect. Experiment shows that the longitudinal magnetization remains too small, even if the correction term is greatly increased. We have reached the limit of the correction for the demagnetizing factor, and we shall have to explain this result by a failure in the other

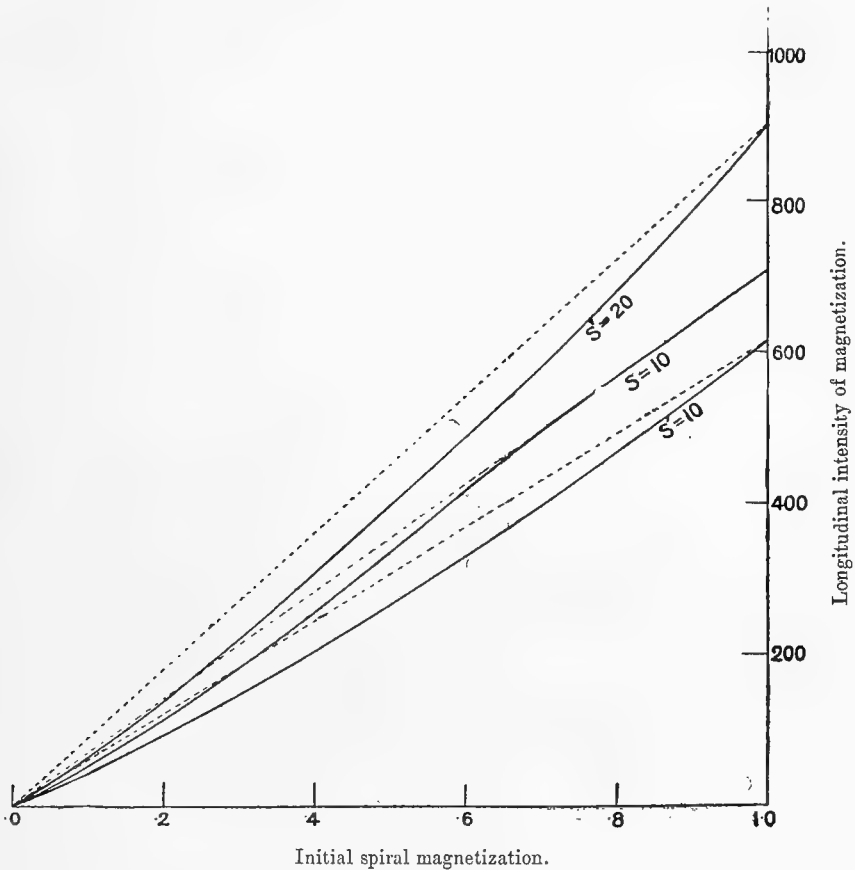


FIG. 4.

assumptions. Either (1) the susceptibility is not the same in all directions, or (2) the condition of simultaneity is not satisfied, and the circular component grows up appreciably more rapidly than the longitudinal component of the field.

Experiments show that the first alternative gives a sufficient explanation. All the above observations were on left-hand spiral magnetization. On reversing the circular field the values of the twist for right-hand spiral

magnetization were found to be appreciably higher than the corresponding values for the left-hand series, showing that the susceptibility was greater for these directions. One example may be given. For an applied spiral field of 20 units, at a pitch-angle of  $\sin \alpha = 0.2$ , the longitudinal intensity of magnetization was 138 for the left-hand spiral, and 230 for the right-hand spiral. Similar observations have been made by Williams in his investigations on wires. A limit is, therefore, reached. It is not possible to place all the observations in a theoretical framework, based on constant susceptibility in all directions for a given field. The variations are not serious, being less than 5 per cent. throughout most of the range examined, except in the extreme case quoted above. If we wish to obtain exact concordance between theory and experiment, we shall have to operate in a region where the susceptibility is approximately constant, which seems to be the case from  $45^\circ$  to  $90^\circ$ , corresponding to a range of  $\sin \alpha$  to 0.7 to 1.0, and  $\sin 2\alpha$  from 1.0 to 0.0.

*Determination of the demagnetizing factor.*—It has already been pointed out that there are no reliable experimental data for the demagnetizing factor of steel tubes. Grotrian<sup>1</sup> arrived at the conclusion that it was the same as that of a cylinder of equal diameter. Du Bois,<sup>2</sup> from observations on bundles of wires, concluded that it was equal to the factor for a circular cylinder of the same sectional area. The demagnetizing factor depends on the ratio of the length/diameter, and from the values given by Schuddemagen, Grotrian's theory gives  $N \times 10^3 = 2-2.5$ , while the theory of Du Bois gives  $N \times 10^3 = 7-7.7$ . It may be stated that neither theory is true, and that the true value of  $N$  lies nearer the mean of these values. The easiest method to demonstrate this is to make use of the property of the anhysteretic curve of magnetization obtained by superimposing a diminishing alternating field, as explained in the earlier part of this paper. It was shown by Steinhaus and Gumlich that the anhysteretic curve has an infinite slope at the origin. The curve obtained from the steel tube has a finite slope, due to the demagnetizing factor. The curve has to be sheared back by measuring the magnetic field from the line  $H = NI$ . If the sheared curve is to have an infinite slope at the origin, the line  $H = NI$  must be a tangent to the experimental curve at the origin. The equation of the experimental curve for very small fields, therefore, gives the value of  $N$ . It is found that the equation of the curve at the origin is  $H = 0.033I$  for magnetic fields  $< 0.2$  c. g. s. units. As the deflections observed were very small, larger values of  $H$  ranging from 0.2 to 0.6 c. g. s. units were

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<sup>1</sup> Grotrian, *Ann der Physik*, vol. 52, 1892; vol. 54, 1894.

<sup>2</sup> Du Bois, *Magnetic Circuit*.

used, giving a line for which  $\delta H / \delta I = 0.40$ . These values rule out definitely the theory of Du Bois and Grotrian. The demagnetizing factor for a steel tube is approximately the mean of the factors for a solid cylinder of equal radius and a cylinder of equal sectional area.

CONCLUSION.

The results of the investigation on magnetization have shown that the ideal conditions required for the experimental proof of the theoretical formula for the twist cannot be completely satisfied for all values of the pitch-angle. As we have seen, the introduction of the demagnetizing factor makes a closer approach to these conditions; but then the variations in susceptibility become apparent. It is not therefore surprising that it was not found possible to demonstrate the variation of the twist with  $\sin 2\alpha$  for a constant spiral magnetic field for all angles and intensity more exactly than is shown in fig. 2. A limited success was, however, attained with field of low intensity,  $S = 10$ , which is interesting, as it gave an independent determination of the demagnetizing factor. It has been shown that a spiral field whose components are  $H = (S + s) \sin \alpha$ , and  $F = S \cos \alpha$ , should give a net resultant field  $S$ , if a suitable value of  $s$  be selected.

A value of  $s = 1.65$  was taken for  $S = 10$ , giving  $H = (10 + 1.65) \sin \alpha$  and  $F = 10 \cos \alpha$ . The twist was observed for various pitch-angles in the neighbourhood of  $45^\circ$ , when both fields were applied simultaneously, as in the measurement of the "initial" spiral magnetization. The maximum twist occurred for a pitch-angle of  $47.5^\circ$ . It was inferred from this result that a set of fields given by  $H = (10 + 2.5) \sin \alpha$  and  $F = 10 \cos \alpha$  would bring the maximum to  $45^\circ$ . The observations obtained are given in Table II, and it will be seen how closely they follow the  $\sin 2\alpha$ -law in the neighbourhood of the maximum.

TABLE II.

Twist of a Steel Tube for a Spiral Field  $S = 10$ .  
Circular and longitudinal fields applied simultaneously.

|                     |            |              |            |              |              |
|---------------------|------------|--------------|------------|--------------|--------------|
| Sin $2\alpha$ , . . | 0.9        | 0.95         | 1.0        | 0.95         | 0.9          |
| Sin $\alpha$ , . .  | 0.53       | 0.586        | 0.707      | 0.81         | 0.85         |
| $\alpha$ , . . .    | $32^\circ$ | $35.9^\circ$ | $45^\circ$ | $54.1^\circ$ | $57.9^\circ$ |
| Twist in mm.        | 8.1        | 8.3          | 9.1        | 8.45         | 8.0          |

Comparison with the spiral curve for magnetization for the same fields, given in fig. 4, marked  $S = 10$ , shows that the twist is symmetrical, even over the

region where the linear variation of magnetization with  $\sin \alpha$  begins to fail. It must be admitted that this is a stringent test of the formula, though the same symmetry with stronger fields in neighbourhood of  $45^\circ$  was not obtainable, even over a smaller angular range. This is explained, however, by the variation in susceptibility with direction, noticed in the observations on magnetization, becoming more important with stronger fields.

The value of  $s = 2.5$  gives a second value for the demagnetizing factor, since we have  $NI_L = s = 2.5$ , and from fig. 4,  $I_L = 710$ , giving  $N = 3.5 \times 10^{-3}$ , which is in satisfactory agreement with the value  $3.3 \times 10^{-3}$ , obtained from the observations on anhysteretic spiral magnetization, thus confirming the validity of this method of correcting for the demagnetizing factor in experiments on spiral magnetization, since the latter value was obtained from observations on longitudinal magnetization alone.

#### SUMMARY.

Observations have been made on the Wiedemann effect in a steel tube in which the twist is produced by a combination of circular and longitudinal fields, which gave a spiral field whose axis coincided with the axis of the tube. The intensity of the field was kept constant, while the pitch-angle of the spiral was varied. It is shown that the twist varies as the sine of twice the pitch-angle, thus verifying a formula given by Knott in 1888.

The longitudinal magnetization of the tube was examined under the same type of spiral field, and was shown to vary approximately as the sine of the pitch-angle. Deviations from this law were shown to be due to the demagnetizing effects of the ends, and in a lesser degree to the fact that the tube is not magnetically isotropic.

Two methods, which show a satisfactory agreement with each other, are given for obtaining the demagnetizing factor for a steel tube.

The author has much pleasure in expressing his obligations to Professor Brown, for the use of the solenoid described in this paper. The initial stages of the work owe much to the assistance of Mr. O'Callaghan, A.R.C.Sc.I.; and Mr. Moore, A.R.C.Sc.I., materially contributed to its progress by a series of tedious magnetic measurements.

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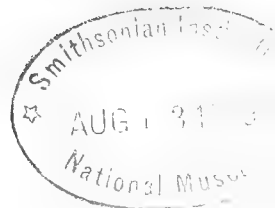
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MAHOGANY, AND THE RECOGNITION OF SOME  
OF THE DIFFERENT KINDS BY THEIR MICRO-  
SCOPIC CHARACTERISTICS.

BY

HENRY H. DIXON; Sc.D., F.R.S.,  
UNIVERSITY PROFESSOR OF BOTANY, TRINITY COLLEGE, DUBLIN.



(PLATES XXII.—XLIV.)

[*Authors alone are responsible for all opinions expressed in their Communications.*]

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## XXXIV.

MAHOGANY, AND THE RECOGNITION OF SOME OF THE  
DIFFERENT KINDS BY THEIR MICROSCOPIC CHARACTERISTICS.

BY HENRY H. DIXON, Sc.D., F.R.S.,  
University Professor of Botany, Trinity College, Dublin.

(PLATES XXII.-XLIV.)

[Read APRIL 23; published DECEMBER 7, 1918.]

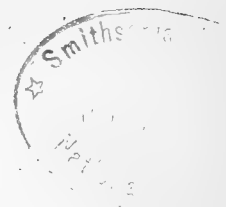
## DEFINITION OF MAHOGANY.

As a rule the general or trade names of timbers are applied to the woods yielded by one species, or at most by one genus, of tree. Even with this limitation it is found that often the physical properties of the timber, designated by any one name, may be inconveniently variable, depending as they do in part on the conditions under which the tree has grown. This variability of physical characters is often associated with variations in structure, or variations of structure which do not involve other physical differences may occur, so that accurate description and identification are rendered difficult.

In the case of mahogany, however, no such limitations have been observed, and the mahogany of commerce is well known to be derived from many different genera and species of trees. Furthermore, as we might expect, in these cases, too, the varying conditions under which the different trees grow impose many modifications on the properties of their timbers, and consequently there is extreme latitude for variety of appearance, of physical properties, and of minute structure in the woods classed as mahoganies.

Some idea of the number of woods connoted by this name may be obtained from C. D. Mell's paper (10), where he lists some sixty-seven species of trees as supplying timbers whose characteristics sufficiently coincide with the popular idea of mahogany to be marketed as that wood. It is certain that his list might be added to from our present knowledge, and may well be further largely increased as the properties of unexamined timbers are ascertained. In this present piece of work, which must be regarded as only preliminary, I have had the opportunity of examining the wood of only about forty species of trees which yield mahogany.

Only in a few cases has it been possible to obtain reliable records of the identification of the tree supplying the timber; usually in commercial samples



the only record available is the port of origin, and often this even is not ascertainable. Naturally this uncertainty as to species greatly increases the difficulty of constructing any scheme for identification, for it is often hard, or impossible, to determine whether differences in characters are to be interpreted as differences existing between individuals of the same species, or as characteristics of different species. Where it was impossible to ascertain the name of the tree, the commercial or trade name of the timber has been used; and as much certainty as to specific and individual characteristics has been obtained as possible, by the examination of a number of specimens of the same wood where opportunity allowed.

As a considerable time must elapse before anything like a complete collection of mahoganies can be examined, and as there appears to be an immediate need for some method of identifying the more common kinds, I have put together descriptions and illustrations of the structure of the mahoganies which up to the present have been available to me, in the hope that they may be useful as a means of identification, and that they may serve as a beginning of an examination of a more extensive list of woods.

In colour the mahoganies vary from almost white to dark brown, sometimes of tawny, sometimes of rose, and sometimes of ashen grey tinge. They are sometimes dense and sometimes light, having a specific gravity ranging from 0·87 to 0·34. In hardness they are variable, and may take a good polish on the end grain or they may be so soft as to be easily marked by the finger-nail.

With regard to structural differences, we find some mahoganies with almost typical year-rings, others quite without them; in some the denser region of the growth-zone is produced by the reduction in size and numbers of the vessels ("ring-porous"), in others the greater density is due to the increase in thickness of the wall of the fibrous elements of the wood and the reduction of their lumen. In this latter case the dense tissue is hard and horny, and cuts with a polish, and so in a cross-cut the dense zones, which are polished, contrast very strongly with the less dense and softer tissue which is not polished, and a very marked zonation is produced. This zonation may coincide with a zonation of the vessels in the less dense or soft zone, or it may be apparently independent of the distribution of the vessels. Many mahoganies do not show this form of zonation at all.

What is true of the larger structures, such as annual rings, pore-rings, and growth-zones, is equally true of the less conspicuous and more minute structures. Thus the size of the pores is very various; the largest in Lumbayao and Cape Lopez mahoganies may have a diameter of 0·45 mm. or 0·50 mm.; while in Turiballi, some Cuban, and other West Indian mahoganies

the maximum diametric measurement is 0.15 mm.—0.12 mm. The medullary rays are also of very different sizes in different mahoganies, and may average 1.5 mm. in height: *e.g.*, in Lumbayao (Pl. XLIV., fig. 133), to 0.35 mm., *e.g.*, in some West Indian. Also the number of cells forming the thickness of the medullary rays may be very different. For instance, in Guatemalan (Pl. XXVIII., fig. 41) the rays are usually but a single cell in thickness, while in African mahoganies they are often seven cells thick, and may be eight or even nine (Pls. XXX.—XXXII., figs. 50, 56, 63).

These structural differences have led to rather confusing and contradictory statements as to the anatomical characteristics of "mahogany." Gamble (8), in a description of mahogany, says:—"Annual rings marked by a continuous line of pores, with few or no pores in the autumn wood." Stone, commenting on this statement, remarks:—"A continuous pore-ring can only be found in the so-called cedars, and then only in the light and softer kinds, such as Mexican cedar, and they have invariably pores scattered throughout the autumn or late wood (*i.e.* the outside of the annual ring)." In contradiction to this view, both Marshall Ward (20) and Boulger (2) classify mahogany with the ring-porous woods; but the latter states:—"The vessels in the summer wood [are] but little smaller than those in the spring wood." There is no doubt that in many mahoganies the vessels are uniformly scattered over the whole cross section, while in others they are grouped in zones. We may even find this variation in different samples of wood coming from the same species, *e.g.*, *Svietenia mahagoni* L. (Pl. I, figs. 1 and 4) has uniformly scattered vessels; in fig. 4 the vessels are grouped in zones, leaving the intervening regions almost free from vessels.

Such differences in the different woods classed as mahogany might be multiplied, and it might seem that either the name mahogany ought to be abandoned altogether and distinct names given to the different timbers now classed under it, or it should be restricted, as Mell (10) suggests, in its use to the wood to which it was originally applied, *i.e.* to the timber derived from *Svietenia mahagoni* and possibly also from *S. macrophylla*. But the abandonment of a term so widely used is quite impracticable; and its restriction to the timber of the tree from which mahogany was first obtained is also not feasible, for, according to Stone (16), it is even uncertain if any of the timbers now on the market come from *Svietenia mahagoni* L., and certainly most of them do not. Another course is to so define the term "mahogany" as to include most, if not all, the timbers at present recognized under that name in commerce, and at the same time exclude as far as possible similar woods which, differing demonstrably from the "true" or original mahogany, are not generally considered to be mahoganies.

This last course is the one naturally essayed by each person who has to deal with mahoganies, and more or less accurate working definitions on these lines have been arrived at.

J. C. Taylor, in *Veneers*, Indianapolis, quoted in the "Timber Trades Journal," July, 1917, furnishes an example of a trade description of mahogany: "There is much difference in texture as well as much difference in appearance between various woods classed as mahogany. There are really just two strong points of value to mahogany. One is the beauty of its appearance, distinguished by various shades of reddish colour and many different figurings. The other point of value is that it seasons readily, and is but little disposed to shrink or warp. To the general public, and for that matter to the majority of wood-workers, mahogany is a reddish wood, and generally with some figure, and often with distinct figure, and fairly characteristic texture, and valued in proportion to the appeal in the figure appearing."

But such a definition as the preceding is evidently not sufficiently exclusive, for according to it we should have to receive as mahogany any piece of sound wood of a reddish colour, and displaying some figure; and in such a category a vast number of timbers would be included which no one would for a moment regard as any kind of mahogany. Evidently such a definition must be considerably narrowed.

In the first place, reddish colour is essential in a wood which is to be considered a mahogany. Reddish colour, of varying tints, is characteristic of the true or original mahogany derived from *Swietenia mahagoni*, and is, as is well known, a character generally sought for in mahogany, so that it will be right to include this character in a definition of the wood. This will lead to the exclusion of several white and yellowish woods which have been styled mahoganies, without any defined or substantial resemblance to the original mahogany in physical properties or in minute structure.

The presence of figure is emphasized in most of the diagnoses of the original mahogany: cf. that of Chaloner and Fleming (3), Boulger (2), &c, and is generally demanded, as Taylor's (19) description, quoted above, shows, in wood purchased as mahogany. Furthermore, any extended examination of samples of woods emanating from commercial sources as mahoganies impresses on one the feeling that this is an important characteristic of the wood.

In those mahoganies where year-rings or any form of zonation is present, figure is of course very noticeable on tangential surfaces, and it is often enhanced by the presence of laminae of parenchyma (or soft tissue) in certain regions of the zones. These laminae may be light when the cells of the soft

tissue are empty, or they may be dark, approaching black, when spaces in these laminae are filled with dark deposit. As these laminae form somewhat irregular cylindrical layers in the wood, in tangential sections they appear as irregular linear or thin band-like markings.

But in all woods recognized as mahoganies, even those devoid of year-rings and the parenchymatous laminae just mentioned, the most striking and beautiful feature of the figuring is the wonderful play of light and shade over a polished longitudinal surface of the wood. This is generally most noticeable on radial surfaces (quarter cuts). When viewed from any one point the radial surface appears to be made up of alternate bands of light and dark, which not infrequently grade longitudinally and transversely into one another. When the piece of wood is turned end for end, or the observer changes his point of view, the bands which were light become dark and *vice versa*. On tangential surfaces the play of light and shade is not always so contrasted, but yet adds very materially to the beauty of the figure. This characteristic, which is called "roe" or "royness," is described by Chaloner and Fleming (3) in West Indian mahogany, but appears to receive little attention as a diagnostic of mahogany from more recent writers.

Examination into the cause of this effect shows that it is due to the reflection of the light from the fibres of the wood. These are not all strictly parallel to one another in the wood, but are laid down in zones or layers, the fibres of one zone being inclined more or less to those of the adjacent zones. The longitudinal trend of the fibres and vessels in these zones follows a somewhat undulatory course, so that the reflection of the light from a given zone may alter gradually on any surface. The orientation of the fibres and vessels in any zone may be observed to change gradually in a more or less neutral region separating the zones. Sometimes the transition is comparatively abrupt.

The inclination or crossing of the fibres of the different zones is also responsible for another general characteristic of mahogany. A longitudinal surface, when planed, tends to become smooth and rough in alternate bands. This effect again is more marked on surfaces the more they approximate to radial sections. It is also very noticeable on other surfaces where the normal longitudinal run of the fibres has been disturbed by the contortion of the tree or the emergence of a branch. The effect is due to the fact that the zones of fibres pointing obliquely out of the surface, in the direction of motion of the plane, cut smoothly, while the zones of those dipping inwards remain rough. This feature is usually described by wood-workers as a difficulty in "cleaning."

The characteristic orientation of the fibres of the different zones, crossing



one another in the manner described, is further responsible for the resistance of mahoganies to splitting, and also secures for it comparative immunity to shakes and warping. Evidently owing to it a split or shake starting from cleavage or shrinkage is directed in the zone in which it originates across the direction of the fibres of the adjacent zones, and so its spread is prevented. In a similar way the shrinkages of the different zones tend to nullify one another, and so warping is reduced to a minimum. Thus by the peculiar orientation of the fibres nature has produced in mahogany a substance with properties similar to a "multiply" of other woods. When a radial cleavage is effected the two surfaces produced have the form of a series of interlocking ridges and grooves—a fact which gives a radial split surface of mahogany a most characteristic appearance.

Seeing, then, that this peculiarity in the arrangement of the elements of the wood is fundamental to several of those properties which are generally regarded as characteristic of mahogany, viz., figure, play of light, texture, strength, and durability, it should certainly be required of any timber which claims to be mahogany, and it is surprising that hitherto it has not been utilized diagnostically.

With regard to the microscopic structure of the woods classed as mahoganies, it will be found that the following characters are almost always observable, and it will be convenient to exclude the few woods which do not possess them from the mahoganies:—

In the cross-section the vessels are scattered, occurring singly or in small groups of less than ten, which are for the most part in radial series. The parenchyma is in the form of tangential sheets, cells scattered through the fibres or in contact with the walls of the vessels; but the soft tissue never forms thick layers of circumvasal parenchyma. The medullary rays are fine, and fairly uniform in size; *i.e.*, they are rarely 2 mm. high, and usually considerably under 1 mm. in height. They vary from one to nine cells across. The comparative uniformity and fineness of the rays cause a fine uniform undulation in the fibres threading their way among them, which is apparently largely responsible for the satin-like lustre of mahogany.

These structural characteristics would exclude the following woods described subsequently:—Panama mahogany, *Mimusops globosa* (Bullet-wood); *Lysiloma sabicu* (Sabicu); *Pterocarpus indicus* (Indian Padouk); *Chlorophora excelsa* (Iroko wood); *Pterocarpus soyauxi* (African Padouk).

We may, then, define as mahogany all red or red-brown timbers in which the fibres of the adjacent layers cross each other obliquely, and so give rise to a play of light and shade on longitudinal surfaces ("roe"), greatly emphasizing and enhancing the figure. This causes the wood to be difficult to

clean," and confers on it a freedom from splitting and warping. In addition a mahogany should have scattered vessels, isolated or in small, mostly radial, groups; the parenchyma round the vessels should be narrow and inconspicuous, while the medullary rays are on the average well under 2 mm. in height, and are not more than nine cells thick, except occasionally where the uniform grain of the wood is locally disturbed.

In other respects the woods classed as mahoganies have very varied properties; *e.g.*, with regard to density, hardness, presence or absence of year-rings, pore-rings, size and contents of vessels, distribution of parenchyma, structure and size (within the limits above mentioned) of rays, &c. These and other characteristics, however, may be used as diagnostic characters of the different kinds of mahogany.

#### IDENTIFICATION OF THE DIFFERENT KINDS OF MAHOGANY.

In a general way the colour of the freshly cut wood may be helpful as a diagnostic. Thus freshly cut Cuban mahogany is rose brown, while St. Domingo is characterized by true brown, approaching the tint of burnt sienna; but the difficulty of accurately describing small differences in colour, and the colour variations, in samples of the same wood render this property of little use in descriptive distinctions between the several mahoganies. The same criticism applies to the extract. Specific gravity and hardness are also useful; but we must be alive to the fact that considerable variations are often met with in these properties, even in the same woods; *e.g.*, Cuba mahogany (*Swietenia mahagoni*) has been found to vary in sp. gr. between 0.73 and 0.84, while the so-called "Spanish," West Indian, and St. Domingo (all probably from *Swietenia mahagoni*) have been found to have densities ranging from 0.82 to 0.68. The variation is still greater in the woods of *S. macrophylla* (Honduras, Tabasco mahoganies, and Baywood), in which the density ranges from 0.61 down to 0.43. Where, however, distinction is to be made between two specimens of widely different specific gravity the characteristic is useful; but it is rarely applicable as a distinguishing feature between two samples otherwise generally resembling one another.

As a general rule microscopic measurements are only satisfactory when large differences characterize different woods; for small or even considerable differences may be found in different specimens of the same wood, or even in the same piece. Thus the diameter of the large vessels may easily vary 30 per cent. or 40 per cent. in any wood, and the limits of the vertical heights of the large medullary rays may be even more extended. Similar variations in other woods are instanced by Bailey (1). There is less variation if we take the maximum diameter attained by the vessels in each sample

of a species; and the mean height of ray given by the average of 5 or 10 rays of greatest width, taken at random, is sometimes a useful characteristic. For example, the maximum diameter of the vessels of Lumbayao (Pl. XLIV., fig. 133) and Cape Lopez (Pl. XXXVII., fig. 91) mahoganies is 0.45 mm. and 0.50 mm., respectively, and gives us a safe distinguishing characteristic when we are comparing them with the Khayas or Swietenias, in which, so far as my experience goes, the diameters are never greater than 0.25 mm. and 0.32 mm., respectively. Turiballi (Pl. XXVII., fig. 34) may be instanced as a wood characterized by very small vessels, their maximum diameter being no more than 0.12 mm. [For the sake of comparison in the following descriptions the measurement of the diameter is taken in a tangential direction, and the maximum tangential diameter (M.T.D.) of the vessels is recorded for each specimen examined.] Similarly, the average height of the 3-4 ply medullary rays of Lumbayao is 1.5 mm. (Pl. XLIV., fig. 134), and this characteristic readily distinguishes this wood from that of the Swietenias (Pl. XXII., figs. 2, 5, Pl. XXXIII., fig. 68), where the average height of the rays does not appear to exceed 0.65 mm.

Sometimes the medullary rays seem to occupy a large proportion of the tangential section; again in other woods but a small proportion of the total area of the section is composed of the section of the rays. This leads to a very different appearance in the tangential section of the two woods, which is difficult to convey in description. To estimate the proportional area occupied by the rays in the section would be tedious and impracticable where quickness in identification is demanded; so in the following descriptions the total width of the rays traversed by a horizontal line 2 mm. long in a tangential section is given. Sometimes this figure is of use in identification, *e.g.*, the total width of the rays in 2 mm. is usually about 0.50 mm. for Tabasco or Honduras mahogany (Pl. XXIII., fig. 8), while in Colombian (Pl. XXV., fig. 23), Guatemalan (Pl. XXVIII., fig. 41), and Gaboon (Pl. XXXV., fig. 80) it does not exceed 0.25 mm. But, on the other hand, great variations in this figure are found for some woods, *e.g.*, in Cuba it has been found to vary from 0.79 mm. to 0.50 mm., these being averages taken in different samples of this wood. Even in different parts of the same sample great differences may be found, especially in figured specimens, when the grain of the timber is disturbed by the proximity of a branch, *e.g.*, *Khaya*, sp., Pl. XXXII., figs. 62 and 63. These sections were cut from opposite faces of a block just 1 cm. across.

Numerical characters are also useful when the differences are great, but they cannot be relied on as a rule where the two numbers approximate. This is true for such characters as the number of rays seen in a given area of tangential section, or the number of vessels in a given area of cross-section.

The number of cells forming the thickness of the medullary rays is often a very useful diagnostic. For example, I have not found that rays 7 cells thick occur in any West Indian or American mahogany, while such rays are not uncommon in the Khayas of Africa. But, on the other hand, considerable variation may be found in the number of cells forming the thickness of the rays in Cuban mahogany. Immediately round the pith the rays are seldom more than 3 cells thick (3-ply); at some little distance from it, they are usually 4- or 5-ply. Some Cuban mahogany retains the embryonic condition much later than others (Pl. XXII, figs. 2 and 5). Also where the grain is locally disturbed by the proximity of branches abnormally thick rays may be found.

The presence and absence of structural features are, perhaps, the most satisfactory diagnostic characters.

Foremost amongst these is the presence or absence of tangential laminae of parenchyma (soft tissue) in the wood. The arrangement of this tissue calls for a brief special notice.

The parenchyma of the wood may be divided into three different categories according to its distribution, viz.:—(1) *Scattered* among the fibres and tracheids, as may be well seen in some of the soft and light cedars and mahoganies, e.g. in *Cedrela odorata* (Havana cedar) (Pl. XXIII., fig. 10) and Cape Lopez mahogany (Pl. XXXVII., fig. 91). (2) *Circumvasal* surrounding the vessels and in contact with them (Pl. XXXVI., fig. 88, Pl. XLII., fig. 124, Pl. XLIII., fig. 130). (3) *Laminar*, forming thin sheets extending in a tangential, or irregularly tangential, manner between the other wood elements. These parenchymatous laminae are characteristic of the Swietenias and other West Indian and some African mahoganies (Pl. XXII., fig. 1, Pl. XXV., fig. 22, Pl. XXX., fig. 49, Pl. XXXIII., fig. 67, Pl. XXXIV., fig. 73).

Where the parenchyma is distributed circumvasally it forms a thin layer, mostly one cell thick and often interrupted, coating the vessels, and in cross-sections is usually quite inconspicuous. In some cases at places round the vessels it may be a few cells thick, and extend out among the surrounding tissues in a tangential direction. But in none of the true mahoganies (Swietenias) or those woods generally recognized as mahoganies does it form a thick coating to the vessels, and a smooth cross-cut of the wood is readily distinguished by lens examination from a section of those in which a thick coating of circumvasal parenchyma marks out the vessels among the fibres with a light and mealy-looking margin of soft tissue, giving the section a very different appearance. For this reason it is advisable not to reckon such timbers as Iroko wood (*Chlorophora excelsa*) and Locust (*Hymenoc courbaril* L.) &c., as mahoganies.

The laminar parenchyma exhibits a great deal of variation in its development in the mahoganies. Sometimes the laminae are thin (1 or 2 cells

thick), *e.g.*, in Colombian mahogany (*Cariniana pyriformis* (Pl. XXV., fig. 22), or they may attain 8 to 10 cells in thickness, *e.g.*, Sapeli (Pl. XXXIII., fig. 67), *Khaya senegalensis* (Pl. XXX., fig. 49), *Swietenia mahagoni* (Pl. XXII., fig. 1), &c. Sometimes the laminae viewed on cross-sections form curves uniformly convex on the outside, sometimes there are salients on these curves, and sometimes concavities. The cells of the laminae are usually empty, but sometimes are filled with dark contents. In Colombian mahogany about one-third of the thin-walled parenchymatous cells of the laminae are filled with opaque contents, and a very striking appearance is presented. Sometimes a copious deposit is laid down between the cells of the laminae, and accumulates in special intercellular lacunae. These lacunae are cylindrical, with their longitudinal axis parallel to the vessels of the wood, and may be very close to, or even in contact with, one another tangentially. Such laminae, with their intercellular lacunae, give rise to dark lines in cross and radial sections and in tangential sections to irregular bands, bordered or fringed on each side by the light-coloured layers of the laminae. The cells adjoining the lacunae are flattened and regularly arranged (Pl. XXX., fig. 49, Pl. XXXVIII., fig. 97, Pl. XXXIX., fig. 108). These markings often greatly emphasize the figure of the wood.

The spacing of the laminae is also various, and sometimes affords an important diagnostic. Thus the laminae may be spaced fairly uniformly and closely (0.2 mm. to 0.5 mm. apart), as in Colombian mahogany (Pl. XXV., fig. 22), where they remind one of the similar structures in the walnuts and hickories. This is also the rule in Guatemalan (fig. 40) and Sapeli (figs. 67 and 70) mahoganies, *Dysoxylon lessertianum* (fig. 109), &c. Again, the laminae may be quite irregularly spaced, but moderately distant from one another (0.5 mm. to 25 mm.). This is usual in *Swietenia mahagoni*, *S. macrophylla*, and *Cedrela odorata* (Pl. XXII., fig. 1, Pl. XXIII., figs. 7, 10). In some mahoganies (*Khaya* spp. and Gaboon mahoganies) the laminar parenchyma may be absent over great thicknesses of the wood, and appears to be distributed quite irregularly. British Guiana or Demerara mahogany (*Carapa guianensis*) presents the peculiar case that in some specimens moderately spaced laminae are visible, while in others they cannot be made out with careful lens examination. Possibly here we have to do with two species of *Carapa* (Pl. XXIV., figs. 13 and 16).

The laminae are usually quite independent of one another right round the circuit of the wood, but they occasionally run into and join up with one another. Again, they sometimes appear quite independent of the vessels, and they may traverse the denser region of the growth-zones or be situated in the less dense. Sometimes they seem to connect the vessels (or circumvasal parenchyma) tangentially, and sometimes they mark the limit of the growth-zones. In some woods the parenchymatous laminae are crowded more closely

in the outer part of the growth-zone, and are more widely spaced towards its inner boundary. This arrangement produces a strange reversal of what is usually found in an annual ring, where the denser tissue forms the outer part of each ring. Here the inner region of the ring is denser, and each growth-zone (year-ring) becomes less dense on the outside owing to the greater admixture of parenchyma in that region. Entandrophragma spp. furnish examples of this phenomenon. Sometimes the laminae have no great extension in a tangential direction, and form vertical straps of tissue, more or less narrow, instead of sheets of tissue (Pl. XL., fig. 112).

The contents of the vessels may also be used for purposes of identification. Most mahoganies have a dark crimson or black substance more or less completely filling a number of the vessels; others, such as Cuban, "Spanish," and St. Domingo, often have a large number of the vessels filled with a white substance; in many others a few vessels contain a similar substance. This appears to be an amorphous deposit of calcium carbonate, as it is soluble in acetic acid with an evolution of gas. In Cuban mahogany, especially near the pith, some of the vessels contain a translucent substance, tinged yellowish-green. Then again the vessels of some mahoganies contain tyloses, *e.g.* Cape Lopez (Pl. XXXVII., fig. 91); Colombian; Guatemalan (Pl. XXVIII., fig. 40); Turiballi (Pl. XXVII., fig. 36); "Cedrana" (Pl. XXIX., fig. 43); Panama mahogany (Pl. XXIX., fig. 46); Gaboon (Pl. XXXV., fig. 79), &c., while the greater number are free from them. It should be noted that some writers (10) call all deposits in the vessels tyloses, but it is better to retain the name for the cellular ingrowths from the wood parenchyma cells into the vessels, as it was originally used.

The cells of the rays and of the circumvasal parenchyma may be empty or filled with contents. In the heart-wood this may be a valuable diagnostic, but in the sap-wood this feature would evidently largely depend on the conditions of metabolism in the tree, and should not be used in diagnosis. Further the presence or absence of crystals in the marginal cells of the rays seems a feature variable in the same wood, and does not consequently appear suitable for distinguishing different woods. In a few mahoganies linear series of crystals are found in septate fibres, and this feature seems to form a constant characteristic of some woods, *e.g.* Colombian mahogany.

The degree of uniformity in size of the rays seen in tangential section is often of great value in distinguishing various kinds of mahoganies. Generally speaking, there is no great disparity in the size of the rays of mahogany, such as there is, for example, in Oaks and Beeches. Turiballi may be mentioned as an exception to this general rule. It has occasional giant rays scattered widely among the smaller ones which form the vast majority. In this case the giant rays may be 0.75 mm. high and 0.20 mm. wide, while the average

dimensions of the others are 0.35 mm. by 0.016 mm. With this exception the rays of mahoganies vary from 2 mm. in height downwards. The proportions, however, of different sizes within these limits may be very different. Thus in the Khayas the number of small rays approximates to the number of large rays (Pl. XXX., fig. 50, Pl. XXXI., figs. 56, 59, Pl. XXXII., figs. 62, 63), while in the Swietenias (Pl. XXII., figs. 2, 5, 6, Pl. XXIII., fig. 8) the number of larger rays greatly predominates over that of the smaller ones. In the former consequently the rays, seen in a tangential section, appear of irregular sizes, while in the latter they seem much more uniform in size.

The marginal cells of the rays of different mahoganies present differences of diagnostic value. Often in radial sections they appear roughly pentagonal, in tangential sections triangular, and usually much deeper and wider, and less extended in a radial direction than the middle cells of the rays (Pl. XXIII., fig. 9, Pl. XXIV., fig. 18, Pl. XXXII., fig. 66), which are narrow cylinders or prisms with their axes in a radial direction. On the other hand, the marginal cells of Colombian mahogany (Pl. XXV., fig. 24), *Pterocarpus* (Pl. XXXV., fig. 84, Pl. XL, fig. 114), and of *Entandrophragma* (Pl. XXXIII., fig. 72) and others can scarcely be distinguished in shape from the middle cells of the rays. Where the marginal cells are larger and well differentiated from the middle cells they appear in the cross-section as radial series of large parenchymatous cells, and give the section a very characteristic appearance. Sometimes (*e.g.* Khaya, Pl. XXX., fig. 50) a proportion of the large rays have margins several cells deep but only one cell thick. In tangential sections this gives a striking appearance which reminds one of the same shaped rays (rat-tailed) in Walnut. Generally the walls of the marginal cells are no thicker than those of the middle cells; but in Gaboon mahogany they are strongly thickened and pitted and in radial section approximate to rectangles or rhomboids. Guatemalan mahogany also has marginal cells of this shape (Pl. XXVIII., fig. 42). The walls of the middle cells are seldom very thick, but in some of the dense woods they are sufficiently thickened to render the lumen seen in tangential section rounded and so contrast with the angular outline of the middle cells of other wood viewed from the same aspect. Observation of this point is sometimes useful.

Apparently little reliance can be placed on the presence or absence of septa in the fibres. Thus they occur in some specimens of "Spanish" and Cuban mahoganies, but cannot be detected in others. The same appears to be the case with certain African woods otherwise similar to one another. In certain mahoganies they form a striking feature, *e.g.* in *Carapa guianensis* (Pl. XXIV., figs. 14, 17) and *Aucoumea klaineana* (Pl. XXXV., fig. 80).

The presence or absence of pore-rings, annual rings, and zonation of the fibres has already been commented upon.





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|-----|---|---|----|
| 3.  | { | C.S. largely composed of thick-walled fibres with lumen almost obliterated and of parenchyma in conspicuous groups or lines, but not usually extending tangentially across more than 4 rays,..... | 4  |
|     | { | Fibrous elements of wood usually with open lumina ; parenchymatous laminae where present extending across many rays,.....   | 8  |
| 4.  | { | Some rays 6-, 7-, and 8-ply,.....   | 5  |
|     | { | Few or no rays more than 5-ply,.....  | 6  |
| 5.  | { | Wood between rays formed of alternate layers of fibres and parenchyma of approximately equal thickness.<br>41. "Eng. Teak." <i>Dipterocarpus tuberculatus</i> .                                   |    |
|     | { | Fibrous layers of wood much thicker than parenchymatous.<br>43. "Yang."   |    |
| 6.  | { | Over 40 groups of vessels in 2 mm. field C.S. and over 40 rays in 2 mm. field T.S. 32. "Moabi."   |    |
|     | { | Less than 40 groups of vessels in 2 mm. field C.S. and less than 40 rays in 2 mm. field T.S., .....   | 7  |
| 7.  | { | Parenchymatous elements approximately equal to fibrous in C.S. 40. <i>Shorea robusta</i> .  |    |
|     | { | Fibrous elements greatly predominate in C.S. 42. "Camphor wood."<br><i>Dryobalanops aromatica</i> ?   |    |
| 8.  | { | Circumvasal parenchyma conspicuous, often extended into narrow tangential laminae, .....  | 9  |
|     | { | Circumvasal parenchyma inconspicuous,.....  | 12 |
| 9.  | { | Vessels with tyloses. 30. <i>Chlorophora excelsa</i> .  |    |
|     | { | Vessels without tyloses, .....  | 10 |
| 10. | { | Rays often 4- and 5-ply. 8. <i>Hymenoclea courbaril</i> .   |    |
|     | { | Rays 1- and 2-ply, .....  | 11 |
| 11. | { | Rays empty, uniform in height 5-8 cells. 37. <i>Pterocarpus indicus</i> .<br>28. <i>Pterocarpus sp.</i>   |    |
|     | { | Rays filled, irregular in height 2-18 cells. 9. <i>Lysiloma sabicu</i> .  |    |
| 12. | { | Vessels without tyloses, .....  | 13 |
|     | { | Vessels with tyloses,.....  | 35 |
| 13. | { | Some rays 3-, 4-, or 5-ply or more.....   | 14 |
|     | { | Rays 1- or 2-ply,.....  | 33 |
| 14. | { | Rays frequently 6- and 7-ply,.....  | 15 |
|     | { | Rays seldom or never 6- and 7-ply,.....   | 18 |

|     |   |  |     |   |    |
|-----|---|--|-----|---|----|
| 15. | { | More than 60 rays in 2 mm. field T.S.  | 19. | <i>Khaya sp.</i>                            |    |
|     |   | Less than 60 rays in 2 mm. field T.S.,.....  |     |   | 16 |
| 16. | { | Average height of rays about 1·10 mm.  | 18. | <i>Khaya sp.</i> (Axim).                    |    |
|     |   | Average height of rays about 0·70 mm. or less,.....  |     |   | 17 |
| 17. | { | 30-50 rays in 2 mm field T.S.  | 17. | <i>Khaya senegalensis.</i>                  |    |
|     |   | Less than 30 rays in 2 mm. field T.S.  | 16. | <i>Khaya anthotheca.</i>                    |    |
| 18. | { | Parenchymatous laminae frequent (1 or 2 in 10 mm.),.....                                     |     |   | 19 |
|     |   | Parenchymatous laminae rare or absent, .....   |     |   | 31 |
| 19. | { | Parenchymatous laminae distinct, 4 or more cells thick,.....                                 |     |   | 20 |
|     |   | Parenchymatous laminae indistinct and thin, .....  |     |   | 29 |
| 20. | { | Parenchymatous laminae about 5·0 mm. or more apart, .....                                    |     |   | 21 |
|     |   | Parenchymatous laminae close in outer regions of growth-zones,<br>1 mm. or less apart,.....  |     |   | 27 |
| 21. | { | Circumvasal parenchyma spreading tangentially.   | 24. | "African walnut."                           |    |
|     |   | Circumvasal parenchyma not spreading tangentially,.....                                      |     |   | 22 |
| 22. | { | Margin of rays indistinct.   | 6.  | <i>Protium altissimum.</i>                  |    |
|     |   | Margin of rays distinct,.....  |     |   | 23 |
| 23. | { | Vessels distinctly grouped in zones. ("Ring Porous.") Ray cells<br>bulging into fibres,..... |     | <i>Cedrela,</i>                             | 24 |
|     |   | Vessels indistinctly zoned. Ray cells not bulging,.....                                      |     | <i>Swietenia,</i>                           | 26 |
| 24. | { | Rays 1-, 2-, and 3-ply.  | 35. | <i>Cedrela serrata.</i>                     |    |
|     |   | Rays 1-, 2-, 3-, 4-, 5-ply, .....  |     |   | 25 |
| 25. | { | Circumvasal parenchyma 3-6 cells thick. Some scattered paren-<br>chyma.                      | 3.  | <i>C. odorata</i>                           |    |
|     |   | Circumvasal parenchyma inconspicuous. Little or no scattered<br>parenchyma.                  | 33. | <i>C. toona.</i>                            |    |
| 26. | { | Average height of rays less than 0·45 mm.  | 1.  | <i>S. mahagoni.</i>                         |    |
|     |   | Average height of rays more than 0·45 mm.  | 2.  | <i>S. macrophylla.</i>                      |    |
| 27. | { | Rays blunt in T.S., mostly 4-ply,  | 22. | <i>Entandrophragma</i><br><i>candollei.</i> |    |
|     |   | Rays acute in T.S., seldom 4-ply, .....  |     |   | 28 |
| 28. | { | Parenchymatous laminae undulating in C.S.  | 20. | <i>Entandrophragma utile.</i>               |    |
|     |   | Parenchymatous laminae not undulating in C.S.  | 21. | <i>E. excelsum.</i>                         |    |

|     |   |   |    |
|-----|---|---|----|
| 29. | } | Circumvasal parenchyma sometimes marked and spreading tangentially. <b>26.</b> "African cedar."   |    |
|     |   | Circumvasal parenchyma thin and inconspicuous, not spreading tangentially, .....  | 30 |
| 30. | } | Average height of rays about 0.5 mm. Maximum rising to 0.9 mm. 35-40 rays in 2 mm. field T.S. <b>4.</b> <i>Carapa guianensis</i> .              |    |
|     |   | Average height of rays about 0.8 mm. Maximum rising to 1.5 mm. about 25 rays in 2 mm. field T.S. <b>39.</b> "Red Serayah."                      |    |
| 31. | } | Circumvasal parenchyma forming a complete thin dark sheath round the vessels. M.T.D. = 0.45 mm.-0.50 mm. <b>44.</b> <i>Tarrietia javanica</i> . |    |
|     |   | Circumvasal parenchyma usually incomplete. M.T.D. less than 0.30 mm., .....   | 32 |
| 32. | } | Rays occasionally 5-ply; average height = 1.0 mm.; 20 or less in 2 mm. field T.S. <b>12.</b> "Dalli."   |    |
|     |   | Rays never 5-ply; average height less than 0.9 mm.; 25 or more in 2 mm. field T.S. <b>5.</b> <i>Carapa</i> sp. (Demerara).                      |    |
| 33. | } | Parenchymatous laminae present, .....   | 34 |
|     |   | Parenchymatous laminae absent or rare. <b>45.</b> <i>Acacia koa</i> .   |    |
| 34. | } | Rays 100 or more in 2 mm. field T.S. <b>29.</b> <i>Trichilia emetica</i> .  |    |
|     |   | Rays about 50 or 60 in 2 mm. field T.S. <b>36.</b> <i>Dysoxylon lessertianum</i> .  |    |
| 35. | } | Some rays 4-ply, .....  | 36 |
|     |   | Rays rarely if ever 4-ply, .....  | 38 |
| 36. | } | Average height of rays about 0.30 mm. <b>38.</b> "Thitka" <i>Pentace burmanica</i> ?  |    |
|     |   | Average height of rays 0.6 mm. or more, .....   | 37 |
| 37. | } | Parenchymatous laminae rare or absent. Much scattered parenchyma. <b>27.</b> "Cape Lopez."  |    |
|     |   | Parenchymatous laminae close but interrupted. Scattered parenchyma insignificant. <b>14.</b> "Cedrana."   |    |
| 38. | } | Parenchymatous laminae rare or absent, .....  | 39 |
|     |   | Parenchymatous laminae close (0.2 mm. or less apart). <b>7.</b> <i>Cariniana pyriformis</i> .   |    |
| 39. | } | Fibres thick-walled, lumen often obliterated. <b>11.</b> "Turiballi."   |    |
|     |   | Fibres thin-walled, .....   | 40 |
| 40. | } | Circumvasal parenchyma inconspicuous. <b>23.</b> <i>Aucoumca klaineana</i> .  |    |
|     |   | Circumvasal parenchyma 4-10 cells thick. <b>15.</b> "Panama mahogany"   |    |

WESTERN MAHOGANIES.

- |                                   |                               |
|-----------------------------------|-------------------------------|
| 1. <i>Swietenia mahagoni</i> .    | 9. <i>Lysiloma sabicu</i> .   |
| 2. <i>Swietenia macrophylla</i> . | 10. <i>Mimusops globosa</i> . |
| 3. <i>Cedrela odorata</i> .       | 11. "Turiballi."              |
| 4. <i>Carapa guianensis</i> .     | 12. "Dalli."                  |
| 5. <i>Carapa</i> sp.              | 13. "Guatemalan mahogany."    |
| 6. <i>Protium altissimum</i> .    | 14. "Cedrana."                |
| 7. <i>Cariniana pyriformis</i> .  | 15. "Panama mahogany."        |
| 8. <i>Hymenoclea courbaril</i> .  |                               |

1. *Swietenia mahagoni*.

No. 78 from commercial source, labelled "St. Domingo mahogany."

No. 81 " " " " "Cuban mahogany."

No. 156 " the Colonial and Indian collections of the Imperial Institute, London, labelled "Cuban mahogany."

No. 48 from commercial source, labelled "Cuban mahogany." Pl. XXII, figs. 1, 2, and 3.

No. 45 from commercial source, labelled "Cuban mahogany." Pl. XXII, fig. 5.

No. 79 from old house.

No. 80 " old Dublin escritoire.

No. 53 " commercial source, labelled "Spanish mahogany."

No. 55 " " " "

Microscopic preparation by Norman.

Preparation by Nördlinger, labelled "Swietenia mahagoni."

Small branch from Trinity College Herbarium, labelled "Swietenia mahagoni Linn., Haiti, 1842." Pl. XXII, fig. 4.

Dark red or rosy brown; lustrous and roey. Vessels indistinctly zoned, with black or white contents. Parenchymatous laminae 1.5 mm-15.0 mm. apart. Sp. gr = 0.84-0.68.

**C.S.**—Vessels mostly isolated, or in small groups, M.T.D. = 0.15 mm.-0.34 mm., 12-40 in 2-mm. field, often filled with dark contents, and frequently with white (calcium carbonate).—Fibres moderately thick-walled. Lumen not obliterated.—Circumvasal parenchyma, seldom more than 1 cell thick, inconspicuous; laminar parenchyma 1-12 cells thick, sometimes containing intercellular spaces, containing dark substance, in tangential series.

**T.S.**—Rays usually of uniform size and regularly arranged, sides bowed, 35-70 in 2-mm. field. Total width of rays in 2 mm. = 0.40 mm.-0.80 mm. Average height = 0.33 mm.-0.48 mm. Average width = 0.035 mm.-0.09 mm.

Rays, 1-, 2-, 3-, 4-, 5-ply. In some cases 5-ply and even 4-ply rays are absent. Margin, 1 or 2 cells deep, sometimes with crystals; distinct from the inner cells, which are usually considerably smaller.

**R.S.**—Fibres septate or non-septate, frequently bent at nearly right angles, in contact with margin of rays.—Cells of ray-margins iso-diametrical or elongated horizontally, rarely elongated vertically, often containing crystals.

## 2. *Swietenia macrophylla*.

No. 49 from commercial source, labelled "Baywood."

No. 82 " " " " "Honduras mahogany, Belize."

No. 87 " " " " "Tabasco mahogany." Pl. XXIII,  
figs. 7, 8, and 9.

No. 88 from commercial source, labelled "Tabasco mahogany."

No. 89 " " " " "Tabasco mahogany, Laguna de Terminos."

No. 213 from commercial source, labelled "Colombian mahogany."

Red brown to golden brown; lustrous and roey. Fibres may be zoned in dense and more open layers. Vessels sometimes zoned, often with black contents, occasionally with white (calcium carbonate) contents. Parenchymatous laminae 1 mm.–10 mm. apart. Sp. gr. = 0·65–0·43.

**C.S.**—Vessels isolated or in small groups, M.T.D. = 0·20 mm.–0·34 mm., 5–30 groups in 2-mm. field.—Fibres thin or moderately thick-walled.—Circum-vascular parenchyma inconspicuous. Parenchymatous laminae 3–8 cells thick. Scattered parenchyma absent or rare.

**T.S.**—Rays fairly uniform in size, sides slightly bowed, finely tapered, 35–48 in 2-mm. field. Total width in 2 mm. = 0·40–0·50 mm. Height of rays (average) = 0·45 mm.–0·60 mm. (5–30 cells). Average width = 0·030 mm.–0·056 mm. (1-), 2-, 3-, 4-, 5-ply. Margin 1 or 2 cells deep, occasionally with crystals. Middle cells angular and thin-walled.

**R.S.**—Fibres septate, often bent at rays. Margin cells of rays square or oblong, horizontal or vertical.

**NOTE.**—No. 155 from the Colonial and Indian collections of the Imperial Institute, London, labelled "Nicaragua, Nicaraguan mahogany." (Pl. XXII., fig. 6), and No. 233 from commercial source, labelled "Costa Rica mahogany" are possibly from a different species of *Swietenia*. They differ from above principally in having mostly non-septate fibres, and the rays seen in tangential section have approximately parallel sides, and are abruptly tapered.

3. *Cedrela odorata*.

No. 56 from commercial source, labelled "Havana cedar."

No. 191 from Havana cigar-box. Pl. XXIII., figs. 10, 11, 12.

Pink brown to greyish pink; lustrous, not roey. Fibres and large vessels distinctly zoned. Vessels often with dark contents. Parenchymatous laminae, sometimes with continuous dark deposit, 2–15 mm. apart. Rays pink or orange pink, contrasting with brown fibres. Sp. gr. = 0.45–0.50.

**C.S.**—Vessels isolated or in small groups. M. T. D. = 0.45, 5–15 groups in 2-mm. field, often with dark contents.—Fibres thin-walled, radially compressed in tangential zones.—Circumvasal parenchyma 4–6 cells thick, laminar parenchyma 2–6 cells thick, sometimes with intercellular spaces filled with deposit; scattered parenchyma abundant.

**T.S.**—Rays fairly uniform in size, sides somewhat distorted and bowed, 40–50 in 2-mm. field. Margin acute, blunted or even bifurcated. Total width of rays in 2 mm., 0.50–0.60 mm. Average height = 0.30–0.50 mm., 2–30 cells. Average width = 0.04–0.06 mm. 1-, 2-, 3-, 4-, 5-ply. Margin of 1 or 2 cells, acute or blunt, or even bifurcated, often with crystals. Middle cells often bulging into fibres.—Parenchyma forming numerous short linear series of about 8 cells, often containing crystals.

**R.S.**—Fibres non-septate.—Ray margins of isodiametrical or horizontally elongated cells. Crystals frequent.—Parenchyma conspicuous.

4. *Carapa guianensis*.

No. 160 from the Colonial and Indian Collections of the Imperial Institute, London, labelled "*British Guiana*. B. G. Mahogany or Crabwood (*Carapa guianensis*)."

No. 162 from the Botanic Gardens, Georgetown, Demerara, labelled "*British Guiana mahogany, Carapa guianensis* Aubl." Pl. XXIV., figs. 13, 14, and 15.

Pinkish brown, lustrous, and roey. Vessels distinctly or indistinctly zoned. Occasionally a very porous zone occurs, often with black and sometimes white contents. Fibres brown, rays orange pink. Parenchymatous laminae fine, 0.3 mm.–25.0 mm. apart. Sp. gr. = 0.62–0.70.

**C.S.**—Vessels isolated or in small groups. M. T. D. = 0.21 mm. 10–25 groups in 2-mm. field. With black or light contents.—Fibres thick-walled, sometimes radially compressed in narrow tangential zones.—Circumvasal parenchyma 1 or 2 cells thick, often with dark contents. Laminar parenchyma 2–4 cells thick, empty.—Rays with dark contents.

**T.S.**—Rays irregular in size, acute, and gradually tapering; 30–40 in 2 mm. field. Total width of rays in 2 mm. = 0.30–0.40 mm. Average height = 0.52 mm., rising to 0.92 mm. Width about 0.03–0.04 mm. 1-, 2-, 3-, 4-ply. Margin 1–5 cells deep, usually empty. Middle cells thick-walled, often with contents.—Fibres with conspicuous septa.

**R.S.**—Marginal cells of rays rectangular, square or oblong. In latter case often vertical.

##### 5. *Carapa* sp.

No. 83 from commercial source, labelled “Demerara mahogany.” Pl. XXIV, figs. 16, 17, and 18.

No. 216 from commercial source, labelled “Demerara mahogany.”

Warm brown, with irregular dark and light streaks and zones, lustrous, roey. Hard, polishes on end grain. Vessels indistinctly zoned, avoiding dark zones. Parenchymatous laminae fine, inconspicuous, irregularly spaced; occasionally thick, and breaking up into a number of fine ones. Sp. gr. = 0.80–0.66.

**C.S.**—Vessels isolated or in small groups of 2–5. M. T. D. = 0.25 mm. 6–14 groups in 2-mm. field, often with dark contents.—Fibres thick-walled.—Parenchyma circumvasal distinct by reason of dark contents, 1 cell thick; laminar parenchyma empty, inconspicuous, rare; 1–4 cells thick.—Rays conspicuous, often with dark contents.

**T.S.**—Rays irregular in size and arrangement, tapering gradually; about 30 or 35 in 2-mm. field. Total width in 2 mm. = 0.36 mm.–0.42 mm. Average height = 0.75 (1.30–0.07) mm., 4–60 cells. Width = 0.05 (0.02–0.08) 1-, 2-, 3-, 4-ply.—Marginal cells triangular; middle cells small, often with dark contents.—Isolated wood parenchyma fibres often adjoining rays. Fibres with frequent and often conspicuous septa, 1–6 between rays.

**R.S.**—Marginal cells of rays square or vertically oblong, with rounded lumina; middle cells horizontal.

NOTE.—Possibly this wood and the previous one correspond to “Lowland” and “Highland Crabwood.” Stone and Freeman (17) regard these two as varieties of the same species.

##### 6. *Protium altissimum*.

No. 164, from Botanic Gardens, Georgetown, Demerara, labelled “Cedar (*Protium altissimum*, Marsh).” Pl. XXV., figs. 19, 20, 21.

Warm brown, lustrous, roey; vessels indistinctly zoned, often with black glistening contents, scattered or in small groups. Parenchymatous laminae

in vascular zone, 3 mm.-5 mm. apart, distinct. Sometimes with continuous deposit. Sp. gr. = 0.35-0.50.

**C.S.**—Vessels scattered, or in small radial groups, circular, M.T.D. = 0.32 mm. 4-12, groups in 2-mm. field. Contents black.—Fibres thin-walled, radially compressed, often rectangular in vascular zones adjoining parenchymatous laminae, often with contents—Parenchyma circumvasal 1 or 2 cells thick, empty; lamellar parenchyma adjoining band of compressed fibres in vascular zone, 3 or 4 cells thick; scattered parenchyma among the fibres.—Rays often with granular contents.

**T.S.**—Rays regular in size, acute with bowed sides, 35-40 in 2 mm. field; total width in 2 mm. = 0.30 mm. Height = 0.37 mm. up to 0.52 mm. Width = 0.048. 1-, 2-, 3-, (4-) ply. Margin inconspicuous, empty, somewhat bulging. Middle cells thin-walled, often with parietal contents.

**R.S.**—Fibres non-septate; tapered ends filled.—Scattered spindle-shaped linear groups of wood parenchyma among fibres.

#### 7. *Cariniana pyriformis.*

No. 146, from commercial source, marked "Mahogany" (Pl. XXV., figs. 22, 23, 24).

Lustrous, roey. Grey-pink brown. Fibres zoned; vessels zoned, close where fibres are less dense. Parenchymatous laminae very fine, close (about 0.15 mm. apart), wavy. Rays very fine. Sp. gr. = 0.69.

**C.S.**—Vessels tangentially compressed, scattered, M.T.D. = 0.28 mm., about 7 groups in 2-mm. field, often with tyloses.—Fibres thick-walled, very regular, 2-16 between rays.—Circumvasal parenchyma, with contents; lamellar, also with contents, one or 2 cells thick, and 0.16-0.15 mm. apart.—Rays filled.

**T.S.**—Rays fairly uniform, sides bowed or parallel, very finely acute, about 50 in 2-mm. field, total width of rays in 2 mm. = 0.20 mm. Height = 0.50 mm. up to 0.80 mm., 6-31 cells. Width = 0.04, 1-, 2-, 3-ply. Margin not defined, acute. Middle cells rounded, thick-walled, with contents.—Fibres sometimes divided into cubic crystalliferous cells.

**R.S.**—Fibres non-septate.—Crystalliferous series in contact with parenchymatous lamellae.—Parenchymatous lamella very marked, composed of vert. series of rectangular cells.

NOTE.—This wood agrees closely with Sudworth and Mell's (18) description of "Colombian mahogany," *Cariniana pyriformis* Miers.



8. *Hymenocœa courbaril*.

No. 166, from Botanic Gardens, Georgetown, Demerara, labelled "Locust (*Hymenocœa courbaril*, L)." Pl. XXVI., figs. 25, 26, 27.

Pink brown, lustrous, not roey; vessels zoned, contents rare. Fibres zoned, dense zones alternating with less dense. Parenchymatous laminae, 0·5 mm.-3·0 mm. apart, avoiding vascular zones; sometimes two laminae between the vascular zones. Sp. gr. = 0·95.

**C.S.**—Vessels circular, scattered or in small radial groups, M.T.D. = 0·30 mm.; 5-7 groups in 2-mm. field; contents granular, dirty.—Fibres thick-walled, very thick in zones, often with contents.—Circumvasal parenchyma, 1-4 cells thick, spreading tangentially; lamellar 3-4 cells thick, both empty.—Rays empty.

**T.S.**—Rays irregular in size, acute, sides irregularly bowed, 30-35 in 2-mm. field; total width in 2 mm. = 0·30 mm. Height = 0·65 mm. up to 0·96 mm. Width = 0·056 mm. 1-, 2-, 3-, 4-, 5-, 6-ply. Margin inconspicuous, empty. Middle cells thin-walled, empty.

**R.S.**—Fibres non-septate, often with contents.

**NOTE.**—The thick coating of circumvasal parenchyma of the vessels excludes this wood from those properly called mahogany.

9. *Lysiloma sabicu*.

No. 282 from Royal Botanic Gardens, Kew, labelled "Sabicu, *Lysiloma sabicu*, Cuba. Received from the Admiralty, 1855." Pl. XXVI., figs. 28, 29, 30.

Very dark brown, dull, vessels often distinctly zoned; wood very hard, distinctly roey. Irregular and undulating discontinuous parenchymatous laminae connecting the adjacent vessels tangentially, and in vessel free zones; 0·25 mm.-0·5 mm. apart. Rays very fine.

**C.S.**—Vessels tangentially compressed; scattered or in radial groups of two ("divided"); often with dark or translucent deposit. M.T.D. = 0·20 mm., 10-18 in 2-mm. field.—Fibres very thick-walled; speck like lumen filled with black deposit, 1-6 between rays.—Circumvasal parenchyma 1-5 cells thick, filled with dark substance and conspicuous, spreading tangentially and connecting adjacent vessels. Laminae 1-10 cells thick, usually filled with dark deposit; scattered parenchyma occasional among fibres also filled.—Rays with dark deposit.

**T.S.**—Rays irregular in size and arrangement. About 200 in 2-mm. field.

Total width in 2 mm. = 0.40 mm. Height = 0.40-0.50 mm., 2-18 cells. Width = 0.01-0.02, 1-, (2-) ply. Margin undefined; cells oval with black contents.

**R.S.**—Ray cells short, rectangular pitted.—Fibres non-septate.

Cp. note to 8.

#### 10. *Mimusops globosa*.

No. 163 from the Botanic Gardens, Georgetown, Demerara, labelled "Bullet Tree (*Mimusops globosa*, Gaertn)." Pl. XXVII, figs. 31, 32, 33.

Pink brown, dull, not roey. Vessels not zoned, in narrow radial groups, straight, or somewhat sinuous, opaque among translucent dark fibres. Parenchymatous laminae very fine and close, 5-7 to 1 mm.; occasional zones where they are more sparse. Rays very fine and inconspicuous. Sp. gr = 0.9-1.0.

**C.S.**—Vessels distorted or angular, in radial groups of 2-10, M.T.D. = 0.08 mm.; 25-30 groups in 2-mm. field; empty.—Fibres very thick-walled, lumen almost obliterated.—Circumvasal parenchyma inconspicuous; laminar 1-2 cells thick, empty or filled.—Rays empty or filled.

**T.S.**—Rays irregular in height, acute, straight, about 100-120 in 2-mm. field. Total width in 2.0 mm. = 0.35 mm. Height = 1.0 mm.-0.05 mm. Width = 0.008-0.024 mm., 1-, 2-ply. Margin 1-8 cells deep, rays often rat-tailed, filled. Middle cells small, filled.

**R.S.**—Parenchyma in regular vertical series of elongate rectangular cells, filled or empty.—Rays with margin of erect rectangular thick-walled pitted cells, and sometimes with a fringe or inner margin of square similarly thickened cells. Inner cells procumbent, also thickened; all usually filled and dark. Pits very distinct.—Fibres non-septate.

**NOTE.**—This wood is listed by Mell among the woods called "mahogany." However, the samples I have seen of it do not display the play of light characteristic of mahogany, and its microscopic structure diverges very much from that of *Swietenia mahagoni*.

#### 11. *Turiballi*.

No. 188. Specimen from Dublin National Museum, labelled "Turiballi, Uriballi or Eurebally, or Guiana mahogany." Pl. XXVII, figs. 34, 35, 36.

Rosy brown, lustrous, roey; fibres distinctly zoned; vessels not zoned, with occasional white or black deposit. Parenchymatous laminae absent. Rays fine. Sp. gr. = 0.85.

**C.S.**—Vessels rounded, scattered, M.T.D. = 0.12 mm., about 35 groups

in 2 mm. field, often with tyloses.—Fibres very thick-walled.—Parenchyma circumvasal only, with dark contents.—Rays with contents. Occasional broad rays many cells across.

**T.S.**—Rays uniform (except for occasional giant rays), acute, about 100 in 2-mm. field. Total width of rays in 2 mm. = 0·34 mm. Height = 0·35 mm., width = 0·016 mm., 1-, 2-ply. Margin 1-5 cells deep, acute, often with crystals. Middle cells thick-walled, often with contents. Giant rays with bowed sides, many cells across, with dark contents in middle cells, a circular curve or even a space.

**R.S.**—Fibres fine, septate.—Marginal cells of rays tall, thick-walled.

### 12. *Dalli.*

No. 169, from the Botanic Gardens, Georgetown, Demerara, labelled "Dalli." Pl. XXVIII, figs. 37, 38, 39.

Pink brown, lustrous, not roey, vessels indistinctly zoned, contents small, dark or dirty white. Dense and light zones of fibres. Parenchymatous laminae absent in 15 mm. Sp. gr. = 0·5.

**C.S.**—Vessels circular, scattered or in small radial groups. M.T.D. = 0·23 mm. 10-15 groups in 2-mm. field. Contents parietal, dark.—Fibres thin-walled, empty.—Parenchyma circumvasal, narrow, sometimes with parietal contents.—Rays with parietal contents.

**T.S.**—Rays irregular in size, acute, sides irregular and sinuous, about 15-20 in 2-mm. field. Total width in 2 mm. = 0·30 mm. Height = 1·13 mm. (0·67-1·80). Width = 0·050. (1-,) 2-, 3-, 4-, (5-) ply. Margin 1—several cells deep, empty. Middle cells thin-walled, small, with parietal contents.—Parenchyma in short columns, 1 cell across. Cells square.

**R.S.**—Fibres conspicuously septate.—Margin of rays of oblong, vertical or horizontal, or of square cells.

### 13. *Guatemala Mahogany.*

No. 84, from commercial source, labelled "Guatemala mahogany." Pl. XXVIII, figs. 40, 41, 42.

No. 217, from commercial source, labelled "Guatemala mahogany."

No. 60, from commercial source, labelled "Padouk."

Warm brown, dull, not roey (?), with indistinct dark zones. Hard, polishes on end grain. Vessels indistinctly zoned, forming oblique or sinuous radiating series. Parenchymatous laminae fine, irregular, often interrupted; about 1 mm. to 0·25 mm. apart. Sp. gr. = 0·74-0·62.

**C.S.**—Vessels somewhat tangentially compressed, isolated or in radially oblique or radially sinuous groups, with parenchyma between the vessels of

each group. M.T.D. = 0.26 mm. 12–20 in 2 mm. field. Occasional tyloses.—Fibres thick-walled and regular.—Circumvasal parenchyma often filling up spaces between individual vessels; laminae 1–4 cells thick, discontinuous, anastomosing, and splitting, often with contents. Rays distinct, with contents.

**T.S.**—Rays irregular in height and arrangement, about 110–150 in 2-mm. field. Total width in 2-mm. = 0.26 mm. Height = 0.20 mm. (0.02–0.56 mm.). 1–18 cells. Width 0.01–0.02 mm. 1–2 ply. Margin distinct. Rays with occasional contents.—Fibres non-septate; 2–5 between rays.

**R.S.**—Marginal cells not always vertically elongated, sometimes rhomboid, often with thick, pitted walls.

NOTE.—The rows of vessels in echelon suggest that this wood is derived from one of the Sapotaceae or Guttiferae. Possibly it is from a species of *Calophyllum*.

#### 14. *Cedrana*.

No. 234 from commercial source, marked "Cedrana from Para." Pl. XXIX., figs. 43, 44, 45.

Light rose-brown, almost flesh-coloured, lustrous and roey, with occasional dark zones. Close interrupted parenchymatous laminae connecting vessels tangentially about 0.3–0.5 mm. apart. Sp. gr. = 0.57.

**C.S.**—Vessels slightly compressed, isolated, occasionally in pairs. M.T.D. = 0.38 mm. 3–6 in 1-mm. field. Tyloses (not lignified) frequent, forming a lining to vessels, and not extending to middle.—Fibres thin-walled, 4–18 between rays.—Circumvasal parenchyma narrow, distinct, with dark contents; laminar in short tangential plates extending laterally from vessels 1–10 cells thick, often appearing to connect adjacent vessels tangentially.—Rays distinct, fairly dark.

**T.S.**—Rays irregular in size and arrangement. Thick, 3–5-ply and thin, 1-ply. About 12 thick and 37 thin rays in 2-mm. field. Total width in 2 mm. = 0.34 mm. Height of 3–5-ply rays = 0.30–0.70–1.50 mm. 8–50 cells. Width = 0.60 mm. 3-, 4-, 5-ply. Height of 1-ply rays = 0.10 mm. – 0.08 mm. 1–13 cells. Width of 1–2-ply rays = 0.04–0.06–0.08 mm.

**T.S.**—Margin of 3–5-ply rays distinct, often many cells deep and "rat-tailed." Contents small, parietal.

**R.S.**—Marginal cells square or oblong, vertical or horizontal.

#### 15. *Panama Mahogany*.

No. 232 from commercial source. Pl. XXIX., figs. 46, 47, 48.

Yellow ochre, lustrous with shaded brown streaks, indistinct zones. Roey. Vessels scattered, surrounded with yellow margin which is deepest in

tangential direction. Parenchymatous laminae absent in thickness of 70 mm. Sp. gr. = 0.58.

**C.S.**—Vessels rounded, isolated, or in small groups of 2 or 3 “divided.” M.T.D. = 0.30 mm. 4-7 in 2-mm. field. All filled with tyloses.—Fibres thin-walled, 2-10 between rays.—Circumvasal parenchyma radially 1-3 cells thick, tangentially 4-10 cells thick.—Rays distinct.

**T.S.**—Rays fairly uniform in size, irregularly distributed, about 55 in 2-mm. field. Total width in 2 mm. = 0.48 mm. Height = 0.10-0.40-0.65 mm., 2-16 cells. Width = 0.02-0.06 mm., 1-, 2-, 3-ply. Margin indistinct, rays often invaded by a single fibre. Crystals in cells frequent.—Fibres septate.

**R.S.**—Ray margins partially of vertical cells.

#### AFRICAN MAHOGANIES.

- |  |                                  |
|--|----------------------------------|
| 16. <i>Khaya anthotheca</i> .          | 25. “African walnut.”            |
| 17. <i>Khaya senegalensis</i> .        | 26. “African cedar.”             |
| 18. <i>Khaya</i> sp.                   | 27. “Cape Lopez mahogany.”       |
| 19. <i>Khaya</i> sp.                   | 28. <i>Pterocarpus</i> sp.       |
| 20. <i>Entandrophragma utile</i> .     | 29. <i>Trichilia emetica</i> .   |
| 21. <i>Entandrophragma excelsum</i> .  | 30. <i>Chlorophora excelsa</i> . |
| 22. <i>Entandrophragma candollei</i> . | 31. <i>Baillonella djava</i> .   |
| 23. <i>Aucoumea klaineana</i> .        | 32. “Moabi.”                     |
| 24. “African walnut.”                  |                                  |

The African mahoganies most usually met with in commerce appear to be furnished principally by three genera, viz.: *Khaya* (Meliaceae), *Entandrophragma* (Meliaceae), and *Aucoumea* (Burseraceae).

The woods of these three genera which I have examined are easily distinguished from one another by the following microscopic characteristics:—

*Khaya*, A. Juss. Also called African, Assinee, Axim, Benin, Bonamba, Gambia, Gold Coast, Grand Bassam, Lagos, Nigerian, Ombega, Sekondi, Zamingila mahogany.

**C.S.**—Parenchymatous laminae absent, or rare and occasional. Scattered parenchyma rarely noticeable. Circumvasal parenchyma inconspicuous, usually discontinuous, and not more than one cell thick. Vessels often with dark deposit. There are no tyloses. Fibres moderately thick-walled and polygonal.

**T.S.**—Rays 1-7-ply. Margin often several cells deep. Fringe-cells often

two or three times as tall as inner marginal cells; acute, and often with crystals. Inner cells small, with rounded or angular lumina.

**R.S.**—Marginal cells of rays square, or polygonal and isodiametrical. Fringe formed of palisade-like cells.

*Entandrophragma* C. DC. Also called *Pseudocedrela* (Sprague (15)), African, and *Sapeli* (or *Sapele*) mahogany.

**C.S.**—Parenchymatous laminae close, 3 mm.—0.5 mm. or less apart; usually more crowded in outer region of growth zones, sometimes forming undulating discontinuous lines.—Circumvasal parenchyma often 3 or 4 cells thick, and spreading tangentially.—Vessels isolated, or in radial pairs. Small groups rare.—Fibres moderately thick, polygonal.

**T.S.**—Rays 1-4-ply. Margin 1 cell thick, triangular, often inconspicuous. Inner cells of small diameter usually fairly thick-walled.

**R.S.**—Marginal cells of rays square or horizontal oblongs, not palisade-like.

*Aucoumea* Pierre. Also called Gaboon mahogany and Okoumie Wood.

**C.S.**—Parenchymatous laminae rare or absent.—Circumvasal parenchyma narrow, often filled.—Vessels isolated, in radial pairs or in small radial groups, sometimes with tyloses.—Fibres thin-walled, nearly rectangular, with tangential walls parallel, forming alternate zones of dense and more open tissue (in which the lumina are reduced and enlarged respectively) gradually passing into each other.

**T.S.**—Rays 1-, 2-, 3-ply. Margin, 1 cell deep.

**R.S.**—Margin of rays 1 cell deep. Cells palisade-like, often rhomboid. Walls often thick and pitted. All cells usually with transparent colourless concretions and sometimes with dark deposit.

The specimens of woods furnished by *Khaya* spp. may be distinguished into four types, according to their microscopic structure:—

Type I—*Khaya anthotheca*.—Occasional parenchymatous laminae, sometimes forming thick layers. No scattered parenchyma. Rays about 25 in a 2-mm. field T.S. Average height of 5-6-ply rays = 0.70, rising to 1.0 mm. Width of 5-6-ply rays about 0.084 mm. Pl. XXX., figs. 52, 53.

Type II—*Khaya senegalensis*.—Parenchymatous laminae rare. No scattered parenchyma. Rays 30-50 in 2-mm. field T.S. Average height of 5-, 6-ply rays = 0.45, rising to 0.70 mm., rarely 1 mm. Width = 0.05-0.10 mm. Pls. XXX., XXXI., and XXXII., figs. 49, 50, 51, 55, 56, 57, 64, 65, 66.

Type III—*Khaya* sp. ? (Axim).—Parenchymatous laminae rare. No scattered parenchyma. Rays 40 in 2-mm. field T.S. Average height of

5- and 6-ply rays = 1.1 mm., rising to 2.0 mm. Width = 0.08. Pl. XXXI., figs. 58, 59, 60.

Type IV—*Khaya* sp.?—Parenchymatous laminae occasional. Scattered parenchyma conspicuous, adhering to rays, and extending in tangential plates. Rays 90-100 in 2-mm. field T.S. Average height = 0.50 mm. Width = 0.06. Pl. XXXII., figs. 61, 62, 63.

#### 16. *Khaya anthotheca* (Type I.).

No. 149. Small specimen of sapwood, with bark, from Royal Botanic Gardens, Kew, labelled "*Khaya anthotheca* C. DC., Uganda, 1906. Coll. M. J. Dawe." Case No. 149. Light greyish brown in transverse section, and lustrous in radial and tangential section; vessels and rays distinct, latter reddish. Broad parenchymatous laminae, about 0.5 cm. apart. Vessels grouped in zones. Roey. Pl. XXX., figs. 52, 53.

**C.S.**—Vessels circular, M.T.D. = 0.35 mm., radially grouped, some in tangential contact; about 15-20 groups in 2-mm. field. Empty.—Fibres thin-walled.—Parenchyma circumvasal and in thick laminae.—Rays with dark contents.

**T.S.**—Rays irregular; sides bowed, sigmoid; about 25 in 2-mm. field; total width in 2 mm. 0.67. Height 0.70 mm. up to 1 mm. Width = 0.084 mm. (1-) 2-, 3-, 4-, 5-, 6-, 7-ply. Margin of several cells deep, often with crystals. Palisade-like fringe. Middle cells smaller, rounded, often with dark contents

NOTE.—This species, according to Mell (10), furnishes white mahogany.

#### 17. *Khaya senegalensis* (Type II.).

This type comprises the wood derived from *Khaya senegalensis*; A. Juss., and possibly that from other species, which resemble that species in microscopic structure. The following samples were examined:—

No. 150, from the Royal Gardens, Kew, labelled "Gambia mahogany, *Khaya senegalensis* A. Juss. Gambia. 1890. Coll. Sir G. Carter."

No. 40, from National Museum, Dublin, labelled "*Khaya senegalensis*. Benin. J. Jackson, Esq., Kew." Pl. XXX., figs. 49, 50, 51.

No. 314, from the Conservator of Forests, Central Circle, Nigeria, labelled "*Khaya senegalensis*."

No. 315, from the Conservator of Forests, Central Circle, Nigeria, labelled "*Khaya grandis*."

No. 316, from the Conservator of Forests, Central Circle, Nigeria, labelled "*Khaya punchii*."

No. 311, from commercial source, labelled "Benin mahogany (probably)."

No. 286, from commercial source, labelled "Assinee mahogany, figured."

No. 309, from commercial source, labelled "Assinee mahogany (probably)."

No. 310, from commercial source, labelled "Axim mahogany (probably)."

No. 288, from commercial source, labelled "Bonamba, from port of Duala, Cameroons."

No. 159, from the Colonial and Indian Collections of the Imperial Institute, London, labelled "Ivory Coast. Grand Bassam mahogany."

No. 75, from commercial source, labelled "African mahogany. Grand Bassam (French Congo)."

No. 301, from commercial source, labelled "African mahogany, shipped from Grand Bassam (Ivory Coast) West Africa."

No. 157, from the Colonial and Indian Collections of the Imperial Institute, London, labelled "*Nigeria*. Lagos mahogany."

No. 287, from commercial source, labelled "Lagos mahogany, from the port of Lagos, Southern Nigeria."

No. 302, from commercial source, labelled "Lagos mahogany, shipped from Koko, Nigeria."

No. 303, from commercial source, labelled "Lagos mahogany, shipped from Koko, Nigeria."

No. 312, from commercial source, labelled "Lagos mahogany (probably)."

No. 313, from commercial source, labelled "Lagos mahogany (probably)."

No. 158, from the Colonial and Indian Collections of the Imperial Institute, London, labelled "*Gold Coast*. Sekondi mahogany."

No. 285, from commercial source, labelled "Zamingila or Ombeqa." Pl. XXXI, figs. 55, 56, 57.

No. 69, from commercial source, labelled "African mahogany."

No. 70, from commercial source, labelled "African mahogany."

No. 71, from commercial source, labelled "African mahogany." Pl. XXXII, figs. 64, 65, 66.

No. 72, from commercial source, labelled "African mahogany."

No. 77, from commercial source, labelled "African mahogany."

No. 148, from commercial source, labelled "Mahogany."

Colour varies from dark brown to golden brown. Smooth cross-section shows scattered vessels, sometimes indistinctly zoned, isolated or in radial groups of two or three, often with dark contents. Fibres on cross-section sometimes indistinctly zoned and darker than rays, which vary from pink to orange.

Parenchymatous laminae absent or occasional, sometimes forming a dark line owing to dark deposit contained in them.

Sp. gr. = about 0.50. Varies from 0.44-0.59.



**C.S.**—Vessels circular or tangentially compressed, isolated or in small groups usually of 2 or 3 radially disposed. M.T.D = 0·20–0·30 mm. 4–17 groups in 2-mm. field. Often with dark contents.—Fibres thin to moderately thick-walled, polygonal.—Circumvasal parenchyma narrow, usually 1 cell thick and discontinuous. Laminar parenchyma rare or absent, sometimes with deposit of dark gum-like substance in intercellular spaces, and forming a dark tangential band across section (Pl. XXX., fig. 49).—Rays distinct, sometimes noticeable owing to dark deposit in cells. The fringes of the rays are often conspicuous as single radial series of larger cells.

**T.S.**—Fibres rarely non-septate.—Rays irregular in size and arrangement, sides bowed, 30–50 in 2-mm. field. Average height of 6-ply rays = 0·45–0·70 mm. Maximum height = 1·1 mm. Width of 6-ply rays = 0·05–0·10 mm. Rays 1-, 2-, 3-, 4-, 5-, 6-, 7-ply, rarely 10-ply. Margin distinct, often with crystals in cells.

**R.S.**—Margin of rays of square or isodiametrical polygonal cells and fringe of palisade cells.

**NOTE.**—With the small number of authentically named specimens it has been found impossible to distinguish with certainty between the species *Khaya senegalensis*, *K. grandis*, and *K. panchii*. The rays of *K. panchii* are often 1 mm. high, their marginal cells frequently contain crystals, and often the rays are covered on the sides as well as on margin by a sheath of large cells. In *K. grandis* and in *K. senegalensis* this lateral sheath is absent, and the rays seldom attain heights of 0·6 mm. and 0·8 mm. respectively. Crystals in the marginal cells are frequent in *K. grandis* and rare in *K. senegalensis*. The extract from these two is much paler than that from *K. panchii*.

#### 18. *Khaya*, sp. ? (Type III.).

No. 76, from commercial source, marked "African mahogany; Axim." Pl. XXXI, figs. 58, 59, 60.

Lustrous, dark rose brown, roey, alternate dense (dark), and open zones grade into one another. Vessels sparser in dense zones. Vessels with dark contents. No parenchymatous laminae in 9 cm. Rays pink. Sp. gr. = 0·53.

**C.S.**—Vessels tangentially compressed, scattered, M.T.D. = 0·25, 10–14 groups in 2-mm. field, with dark contents. Circumvasal parenchyma with open lumina.—Fibres thin-walled, often with contents adjacent to rays.—Rays usually empty.

**T.S.**—Fibres non-septate.—Rays irregular, bowed, finely pointed, about 40 in 2-mm. field, total width of rays in 2 mm. = 0·44 mm. Height = 1·10 up to 2·00 mm. Width = 0·077. 1-, 2-, 3-, 4-, 5-, 6-, 7-ply. Margin often several cells deep, crystals occasional. Middle cells small, angular, mostly empty.

19. *Khaya*, sp. ? (Type IV.).

No. 41. Richly figured specimen, dark brown, from commercial source, labelled "African mahogany."

Longitudinal surface lustrous and roey. Cross-sections zoned dark and light, with irregularly and often widely spaced parenchymatous laminae, sometimes occupied with dark deposit. Pl. XXXII., figs. 61, 62, 63.

Sp. gr. = 0.76.

**C.S.**—Vessels scattered, indistinctly zoned. M.T.D. = 0.14 mm. About 10 groups in 2-mm. field, often with dark contents.—Fibres thick-walled. Circumvasal parenchyma often thick, spreading irregularly, and usually filled with dark deposit. Parenchymatous laminae thick, widely and irregularly spaced. Scattered parenchyma in places abundant, and tending to adhere to rays and to form narrow, irregular laminae. All parenchyma filled with dark deposit.—Rays with dark contents.

**T.S.**—Fibres septate.—Rays irregular in size and arrangement, 80–100 in 2-mm. field. Total width in 2 mm. = 0.56 mm. Average height of 6-ply rays = 0.50 mm. Width = 0.06 mm. Rays 1-, 2-, 3-, 4-, 5-, 6-, 7-ply, many 8–9 or 10-ply in places. Margin of rays several tiers deep. All cells of rays may be blocked with dark contents.

**R.S.**—Marginal cells of rays square or isodiametrical and polygonal. Palisade fringe. Inner cells with rectangular walls.

## ENTANDROPHRAGMA.

The microscopic structure of the woods presumably furnished by species of *Entandrophragma*, which have come under my observation, seem to divide these woods into three types:—

Type I.—*Entandrophragma utile* with undulating parenchymatous laminae 1–4 cells thick, 4–10 groups of vessels in 2 mm. field. The height of the rays averages 0.50 mm., and there are about 35 rays in 2 mm. field in tangential sections. Rays mostly 2- and 3-ply. Pl. XXXIII., figs. 70, 71, 72.

Type II.—*Entandrophragma excelsum* has flat parenchymatous laminae 2–10 cells thick, about 20–30 groups of vessels in 2 mm. field of cross-sections. The height of the rays averages between 0.30 mm. and 0.40 mm., and there are about 50 rays in a 2-mm. field in tangential sections. Rays mostly 2- and 3-ply. Pl. XXXIII., figs. 67, 68, 69.

Type III.—*Entandrophragma candollei*—(Scented Sapele Mahogany) has flat and undulating parenchymatous laminae 2–10 cells thick, about 20–30 vessels in 2-mm. field of cross-sections. The height of the rays averages between 0.45 mm. to 0.55 mm., and there are about 30–35 rays in 2 mm. field of tangential sections. Rays mostly 4-ply. Pl. XXXIV., figs. 73, 74, 75.

20. *Entandrophragma utile* (Type I.).

No. 153. Small specimen of sap-wood from the Royal Gardens, Kew, marked "*Pseudocedrela utilis* Dawe and Sprague, Uganda, 1906. Coll. M. T. Dawe." Pl. XXXIII., figs. 70, 71, 72.

Lustrous, pinkish-buff. Roey. Parenchymatous laminae close and ochre-coloured, discontinuous and splitting. Rays ochre-coloured.

**C.S.**—Vessels scattered, tangentially compressed. M.T.D. = 0.26, 4–10 groups in 2-mm. field.—Fibres thin-walled.—Parenchyma, circumvasal 1- or 2-celled thick, with contents; also forming wavy laminae 1–4 cells thick with contents, and continued radially along rays.—Rays with contents.

**T.S.**—Rays regular, with parallel sides, about 35 in 2-mm. field; total width in 2 mm. = 0.36 mm. Height = 0.50, width = 0.049 (1-), 2-, 3-, (4-) ply. Margin indistinct, without crystals. Middle cells same size as margin, often with contents.—Wood parenchyma cells in laminae, and adjoining rays often with crystals.

**R.S.**—Fibres septate.

21. *Entandrophragma excelsum* (Type II.).

No. 152, from Royal Gardens, Kew, labelled "*Pseudocedrela excelsa*, Dawe and Sprague, Uganda, 1905. Coll. M. T. Dawe." Pl. XXXIII, figs. 67, 68, 69.

No. 186, from propeller of aeroplane.

No. 187, from propeller of aeroplane.

No. 58, from commercial source, labelled "African Mahogany."

Colour brown to rose-brown, lustrous and roey. Parenchymatous laminae 0.2 mm.–0.5 mm. apart in outer region of growth-zone, more sparse within. They are continuous and flat in the outer, somewhat undulating and discontinuous in the inner region of the zone. The laminae and the rays are rose or orange pink. There is an abrupt transition from one growth-zone to next. Vessels often contain dark, very rarely white, deposit.

Sp. gr. about 0.56.

**C.S.**—Vessels isolated or in small groups (radial and tangential). M.T.D. = 0.23 mm. 20–30 groups in 2-mm. field. Occasional dark contents, rarely white.—Fibres thick-walled.—Circumvasal parenchyma 1–3 cells thick. Laminar parenchyma 2–10 cells thick, often with dark contents. There is rarely a continuous band of intercellular spaces in these laminae with dark deposit.—Parenchyma sometimes spreads radially along rays. Rays with dark contents.

**T.S.**—Rays regular in size, sides bowed about 50–55 in 2-mm. field; total width of rays in 2 mm. = 0.33 mm. Height of rays = 0.30 mm.–0.40 mm.

Width = 0.05. (1-), 2-, 3-, 4-ply. In some specimens 4-ply rays are rare. Margin of one cell, distinct, often with crystals. Middle cells of rays often moderately thick-walled, with contents.—Parenchyma often applied to rays; many cells contain crystals.

**R.S.**—Fibres septate or non-septate.

**NOTE.**—Probably in this type there are at least two species. Nos. 152 and 58 have rays which appear more bowed, and the cells more bulged in T.S. than are those of Nos. 186 and 187.

Specimen 58 includes the pith and a considerable thickness of the wood. It was observed that T.S. made near the pith exhibited as many as 80 rays in 2-mm. field.

## 22. *Entandrophragma candollei* (Type III.).

No. 317, from the Conservator of Forests, Central Circle, Nigeria, labelled "*Entandrophragma candollei* or scented mahogany."

No. 74, from commercial source, labelled "African mahogany, Sapele, slightly scented." Pl. XXXIV., figs. 73, 74, 75.

No. 221, from commercial source, labelled "African mahogany, Sapele, with dapple."

No. 300, from commercial source, labelled "Sapele mahogany, shipped from Sapele, Nigeria."

Rich red brown, lustrous and roey. Rays and parenchymatous laminae pink brown. Scented. Parenchymatous laminae 0.3 mm.—3.0 mm. apart; close in outer region, and spaced widely in inner region of growth-zones. Vessels rare in inner region of growth-zones. Sp. gr. = 0.56–0.74.

**C.S.**—Vessels isolated, or in small groups of 2–4. M.T.D. = 0.24 mm., 30–40 in 2-mm. field. Occasionally with dark contents.—Fibres thick-walled. Circumvasal parenchyma 1–3 cells thick, distinct; spreading irregularly from vessels. Laminal parenchyma 2–10 cells thick, occasionally with contents. Scattered parenchyma occasionally adjoining rays.—Rays conspicuous, usually with contents.

**T.S.**—Rays fairly uniform in size and in irregular oblique series, 30–35 in 2-mm. field. Total width in 2 mm. = 0.30–0.72 mm. Height (average) = 0.45–0.50 mm., 15–25 cells. Width = 0.05–0.08 mm., (1-), 2-, 3-, 4-, (5-, 6-) ply. Margin distinct, with crystals. Middle cells often with contents. Parenchyma sometimes with crystals, especially in contact with rays.

**R.S.**—Fibres septate.

**NOTE.**—Mell (10) states that Sapeli mahogany is derived from *Entandrophragma candollei*, Harms. No. 74 seems probably a species distinct from

Nos. 221 and 300. Its rays are more uniform in size, being composed of about 15 tiers of cells, while the rays of the other two are on the average about 25 cells high. The width of the rays of the former is about 0·08 mm., and of the latter about 0·05 mm.

### 23. *Aucoumea klaineana*.

No. 42, from commercial source, labelled "Gaboon mahogany."

No. 66, from commercial source, labelled "Gaboon mahogany."

No. 67, from commercial source, labelled "Gaboon mahogany."

Pl. XXXV., figs. 79, 80, 81.

No. 68, from commercial source, labelled "Gaboon mahogany."

No. 283, from commercial source, labelled "Okoumie, known in European markets as Gaboon mahogany."

No. 284, from commercial source, labelled "Zamingila or Ombega"; but certainly quite unlike in structure the wood usually called by those names, which is a species of *Khaya* (cf. No. 285, Pl. XXXI., figs. 55, 56, 57), and closely similar to the foregoing samples, from which it differs only in the greater number of vessels seen in cross-sections (viz., as many as 50 per 2 mm. field), and having a density above the average (viz., sp. gr. = 0·50). The naming shows that dense and fairly dark samples of the wood of *Aucoumea klaineana* may easily be mistaken for that of *Khaya* sp., unless microscopic structure is observed.

No. 307, from commercial source, labelled "Gaboon mahogany; Cameroons."

No. 308, from commercial source, labelled "Gaboon mahogany; Cameroons."

Colour varies from pale flesh-colour to red brown or pink brown. The longitudinal surfaces are lustrous and roey. The cross-cut is horny or semi-translucent, often exhibiting dark and light bands alternating. The transition from dark to light may be abrupt on either side, or, more usually, the inside of each growth-zone is light, and grows denser gradually towards the outside. The beginning of the next zone is marked by an abrupt transition from dense to light wood. The vessels are usually scattered uniformly, and do not avoid the dense zones. Sometimes an indistinct zoning of the vessels is also found (e.g., No. 284). Again, all zoning both of vessels and fibres may be absent. There are usually no parenchymatous laminae to be seen over wide distances. The rays are fine and paler pink than the adjoining tissues, sinuous and threading their way between the vessels. Sp. gr. = 0·34-0·50.

C.S.—Vessels isolated or in small groups, usually somewhat tangentially compressed, M.T.D. = 0·18-0·31 mm., 5-20 groups in 2-mm. field. (Rarely,

e.g. No. 284, with 50 groups in 2-mm. field.) Often with tyloses.—Fibres thin-walled, nearly rectangular, with tangential walls parallel, forming alternate bands of dense and of more open tissue. Circumvasal parenchyma 1 cell thick, often with contents.—Rays narrow, often dark.

**T.S.**—Rays of varying sizes, irregularly arranged 35–40 in 2-mm. field. Total width in 2 mm = 0.16–0.20 mm. Height of rays on average = 0.30–0.42 mm. Width about 0.04 mm. Rays 1-, 2-, (3-) ply. Margin distinct, acute, without crystals, but there is usually a globular concretion in each cell, and often a dark deposit. The inner cells are somewhat smaller, often filled with dark substance or containing a globular concretion.

**R.S.**—Fibres are septate.—Marginal cells of rays often palisade-like, rectangular, or rhomboidal, often with thick pitted cell-walls, and containing globular concretions and sometimes dark deposit.

**NOTE.**—As will be seen from the naming of the foregoing samples, the term “Gaboon mahogany” is very generally applied to the wood of *Aucoumea klaineana* Pierre. The term “okumé” or “okoumie” seems more generally used on the Continent; and De Wildeman in “Plantes Utiles du Congo,” quoted by Howard (9), states that okumé is produced by *Boswellia klaineana*. Pierre (13) in his description of the species *A. klaineana* states the plant is called Aucoume, near Libreville. “Libreville mahogany” is another name for this wood in the market.

“Gaboon mahogany” is used in a different sense by Mell (10), who states it is yielded by *Entandrophragma pierrei* Chevalier

Famechon (5) distinguishes between Okoumie and Gaboon mahogany. This latter, he says, is yielded by *Sarcocephales diderrichii* (*Sarcocephalus diderrichii* Wildem.). It has a ruddy yellow tint, with red brown veins. Its density is 0.64 in the dry state.

#### 24. *African walnut* (Type I.).

No. 219, from commercial source, labelled “African walnut.”

Olive brown, lustrous, zoned light and dark, with occasional black layers formed by deposit between cells of parenchymatous laminae; distinctly roey. Parenchymatous laminae, usually widely and irregularly spaced (0.5 to more than 3.0 cm. apart), often with black deposit in intercellular spaces. Sp. gr. = 0.64.

**C.S.**—Vessels rounded, isolated or in small (2–10) radial groups. **M.T.D.** = 0.20 mm., 12–30 in 2-mm. field; often with dark contents.—Fibres thick-walled, regular, 6–20 between rays.—Circumvasal parenchyma often

spreading tangentially; laminae irregularly spaced, about 30 cells thick; with schizogenous spaces filled with dark deposit. Rays conspicuous.

**T.S.**—Rays fairly uniform in size, irregularly spaced, 30–35 in 2-mm. field. Total width in 2 mm. = 0·36 mm. Height = 0·12–0·40–0·53 mm., 6–25 cells. Width = 0·02–0·05–0·07 mm., (1–2-), 3-, 4-, 5-ply. Margin sometimes distinct; both margin and middle cells often with contents.—Fibres non-septate.

**R.S.**—Margin rarely distinct.—Chambered fibres, with vertical series of crystals, frequent.

### 25. *African "Walnut."* (Type II.)

No. 190, Piece of heartwood, from propeller of aeroplane. Pl. XXXVIII, figs. 97, 98, 99.

Ochre brown, lustrous. Roey. Zones with close and with sparse parenchymatous laminae alternating with one another. Vessels also zoned, more numerous where the parenchymatous laminae are close. Frequent tangential series of intercellular spaces, filled with black deposit; vessels with black deposit. Sp. gr. = 0·51.

**C.S.**—Vessels compressed tangentially, scattered; M.T.D. = 0·25 mm.; about 25 groups in 2-mm. field, with contents.—Fibres thick-walled. Circumvasal parenchyma spreads tangentially to form laminae, which often develop intercellular spaces in tangential series, filled with dark secretion, and extends radially along rays. Rays with dark contents.

**T.S.**—Rays irregular, sides bowed, about 35 in 2-mm. field, total width of rays in 2 mm. = 0·29 mm. Height = 0·46 mm. up to 0·64 mm. Width = 0·040 mm. 1-, 2-, 3-, 4-ply. Margin indistinct, no crystals. Middle cells small, rounded, sometimes with contents. Crystals in vertical series in transversely divided fibres.

**R.S.**—Fibres non-septate.

NOTE.—Neither this nor No. 219 resembles the wood of any species of true walnut (*Juglans*) examined, and it may be inferred that the trade-name of "African walnut" is given to them owing to their olive-brown colour. No. 219 is easily distinguished from No. 190 by the sparse and irregular parenchymatous laminae. According to Rouget (14) wood furnished by *Coula edulis* Bn. (Olacaceae), and by some species of the genus *Vitex* (Verbenaceae), is exported from Gaboon under the name of walnut.

### 26. *African "Cedar."*

No. 43, from commercial source, labelled "African cedar." No record of port of export. Pl. XXX., fig. 54.

Brown and lustrous. Roey. Parenchymatous laminae thin, indistinct, finer than rays, irregularly spaced; 2 mm.—30 mm. or more apart. Vessels aggregated in pore-zones, with black deposit. Rays pink. Sp. gr. = 0.59.

**C.S.**—Vessels tangentially compressed, scattered, M.T.D. = 0.24 mm., about 10 groups in 2-mm. field; with occasional black contents.—Fibres thick-walled.—Circumvasal parenchyma, 2–4 cells thick spreading tangentially, but not forming many laminae, sometimes with contents.—Rays with contents.

**T.S.**—Rays irregular, sides parallel or bowed, 30 in 2-mm field; total width of rays in 2 mm. = 0.44 mm. Height = 0.60 mm. up to 1.0 mm. Width 0.070 mm. 1-, 2-, 3-, 4-, 5-ply. Margin sometimes indistinct, often with contents. No crystals. Middle cells rounded, with contents.

**R.S.**—Fibres non-septate.

27. *Cape Lopez Mahogany.*

No. 154, from the Colonial and Indian Collections of the Imperial Institute, London, marked "French Congo. Cape Lopez mahogany." Pl. XXXVII., figs. 91, 92, 93.

Warm brown; slightly lustrous; roey. Vessels distinctly zoned and large, oval, subdivided; no deposit, but containing a cork-like substance (tyloses). Rays pink. Parenchymatous laminae absent. Sp. gr. = 0.51.

**C.S.**—Vessels circular, scattered. M.T.D. = 0.50 mm. 2–6 groups in 2-mm. field, with tyloses.—Fibres thick-walled, sometimes radially compressed in a zone.—Parenchyma scattered among fibres, and circumvasal, occasionally with dark contents, sometimes compressed radially with fibres.—Rays with dark contents, which are often drawn away from walls.

**T.S.**—Rays irregular; sides undulating; 22–26 in 2-mm. field; total width of rays in 2 mm. = 0.80 mm. Height = 0.90 up to 2.00 mm. Width = 0.10, up to 0.20 mm. 1-, 2-, 3-, 4-, 5-ply. Margin none; cells angular, bulging, with contents drawn away from walls.

**R.S.**—Fibres non-septate, in linear longitudinal series, regularly alternating with parenchyma.

28. *Pterocarpus* sp.

No. 215, from commercial source, labelled "African padouk." Pl. XXXV., figs. 82, 83, 84.

No. 290, from commercial source, labelled "African padouk, Coral wood, or Red wood."

No. 145, from commercial source, labelled "Bullet wood."

Crimson, not lustrous nor roey, with dark streaks; hard, polishes on end grain. Vessels indistinctly zoned. Narrow zones (about 1 mm. wide), almost free from vessels. Parenchymatous laminae distinct, fairly evenly



spaced; 0·5–0·2 mm. apart, except in vessel-free zones, where they are absent. In cross-section branching and anastomosing. Sp. gr. = 0·75.

**C.S.**—Vessels round, isolated, or in small groups of 2–4. M. T. D. 0·22 mm. 1–8 in 2-mm. field. Contents rare. Always adjoined by laminar parenchyma.—Fibres thick-walled.—Parenchyma circumvasal; laminae often enlarging round vessels, 3–10 cells thick.—Rays fine, inconspicuous.

**T.S.**—Rays uniform, in regular oblique series; about 240 in 2-mm. field. Total width in 2 mm. = 0·40 mm. Height = 0·15 mm. (0·01–0·19 mm.), 1–4–10 cells; width = 0·01; 1–2-ply. Margin not differentiated, cells often with transparent aggregated contents. Radial intercellular spaces at cell angles.—Fibres non-septate, 1–6 between rays.—Cells of laminar parenchyma with oblique or horizontal walls.

**R.S.**—Laminar parenchyma 1–10 cells thick; terminal walls of cells horizontal.—Ray-cells all similar.—Occasional septate fibres with series of 4–8 crystals.

NOTE.—This African padouk is very similar to the sample of Andaman padouk, *Pterocarpus indicus*, described later; but the parenchymatous laminae are thicker and more conspicuous, and seem often to contain the vessels. Rouget (14) states that Coral wood or Red wood is supplied by *Pterocarpus soyauxi* Taub. Boulger (2) refers African padouk to *P. erinaceus* Poir, and to *P. angolensis*.

### 29. *Trichilia emetica*.

No. 238 from Royal Botanic Gardens, Kew, labelled "*Trichilia emetica*, S. Trop. Africa." Pl. XXXIV., figs. 76, 77, 78.

Pale buff, slightly lustrous; roey. Vessels indistinctly zoned, connected tangentially by short, wavy bridges of parenchyma. Occasional dark, continuous layer of parenchyma.

**C.S.**—Vessels slightly compressed tangentially, scattered or in groups, mostly radial of 2–8, usually with tails of tracheids and fibres extending radially from them. M. T. D. = 0·14 mm. 30–40 groups in 2-mm. field.—Fibres with moderately thick walls, 2–6 between rays.—Circumvasal parenchyma distinct, 1–4 cells thick, extending obliquely tangentially to meet circumvasal parenchyma of adjacent vessels.—Rays distinct; contents transparent.

**T.S.**—Rays irregular in size and arrangement, about 150 in 2-mm. field. Total width in 2 mm. = 0·60 mm. Height = 0·12–0·30–0·64 mm.; 5–30 cells. Width = 0·01–0·05 mm.; 1-, 2-ply. Margin indistinct; cells usually with parietal contents.—Wood parenchyma cells rectangular.

**R.S.**—Wood parenchyma cells rectangular.—Fibres non-septate.

30. *Chlorophora excelsa*.

No. 151, from Royal Gardens, Kew, labelled "*Chlorophora excelsa* Benth. Uganda, 1905; Coll. M. J. Dawe." Pl. XXXVI, figs. 88, 89, 90.

Ochre-brown, dull, roey, hard. Vessels not zoned. Fibres in C. S. brown. Parenchymatous laminae buff-yellow, thick and undulating, connecting and surrounding vessels; also occasional thin laminae, straight, about 3 mm. apart, not specially connecting vessels. Rays buff and distinct.

**C.S.**—Vessels tangentially compressed, isolated, or in small radial groups, "divided."—M. T. D. = 0·27 mm. 6–10 in 2-mm. field; with tyloses.—Fibres thick-walled, irregular; 3–20 between rays.—Circumvasal parenchyma conspicuous, spreading tangentially into thick undulating laminae devoid of dark contents; about 10 cells thick; laminar parenchyma about 6 or 8 cells thick, radially compressed.—Rays conspicuous, without dark contents.

**T.S.**—Rays irregular in size and arrangement, sides bowed; about 65 in 2-mm. field. Total width in 2 mm. = 0·44 mm. Height = 0·07–0·32–0·55 mm.; 4–30 cells. Width = 0·01–0·07 mm. 1-, 2-, 3-, 4-, 5-, 6-, 7-, 8-ply. Margin distinct, usually 1 large cell deep, often with crystal. Middle cells thick-walled with small round lumen. No dark contents.—Fibres non-septate, 3–12 between rays.

**R.S.**—Parenchyma rectangular.—Fibres non-septate.—Ray margins with conspicuous row of crystals.

**NOTE.**—The ochre-brown colour and lack of lustre, together with the presence of massive circumvasal parenchyma, distinguish this wood from other commercial mahoganies. It is included here, as it is often listed among the African mahoganies or mahogany substitutes.

31. *Baillonella djava*.

No. 289, from commercial source, labelled "African Pear tree, Duka or Douka = *Baillonella djava* Pierre, also called Indouka and Manioka. Natural Order Sapotaceae." Pl. XXXVI., figs. 85, 86, 87.

Red-brown, no zonation apparent in small sample. No parenchymatous laminae visible, lustrous, without roe. Sp. gr. 0·76.

**C.S.**—Vessels slightly compressed tangentially in radial groups or in indistinct echelons of 4–6. M.T.D. 0·18 mm. About 20 groups in 2-mm. field. With tyloses.—Fibres thick-walled, polygonal, compressed radially in occasional tangential zones.—Circumvasal parenchyma indistinct. Parenchymatous laminae 1 cell thick, about 0·15–0·20 mm. apart, sometimes with dark deposit.—Rays conspicuous, narrow, with dark contents often appearing to end at parenchymatous lamina or zone of compressed fibres.

**T.S.**—Rays irregular in size and arrangement. About 53 in 2-mm. field. Total width in 2 mm. = 0·56 mm. Height = 0·47 mm. (15 cells), width = 0·045 mm., 1-2-ply. Margin distinct, often of several tiers of cells, often with concretion in cells. Inner cells narrow. Cells of margin and others often filled.—Fibres 2-5 between rays.

**R.S.**—Margin of square cells, fringe of palisade often with concretion. Inner cells radially elongate, often filled.—Fibres non-septate, 4-25 between parenchymatous laminae.—Parenchymatous laminae 1 cell thick. Cells usually with concretion, otherwise empty.

### 32. *Moabi*.

No. 291, from commercial source, labelled "Moabi." Pl. XXXVII, figs. 94, 95, 96.

Red-brown, with narrow, dense zones alternating with wider vascular zones, each pair 2-4 mm. wide. Very fine parenchymatous laminae about 0·2 mm. apart. Wood roey and lustrous. Sp. gr. = 0·76.

**C.S.**—Vessels compressed tangentially, very close, single or in radial groups of 2 or 3. M.T.D. = 0·19 mm. About 50 groups in 2-mm. field. With tyloses.—Fibres forming tangential zones 2-10 thick, thick-walled, lumen almost obliterated, 2-7 between rays.—Parenchymatous laminae irregular and sinuous, 1-5 cells thick; cells sometimes filled. No circumvasal parenchyma. Rays conspicuous, filled, bent round vessels.

**T.S.**—Rays irregular in size and arrangement; about 65 in 2-mm. field. Total width in 2 mm. = 0·64 mm. Height = 0·40 mm. 12-15 cells. Width = 0·045 mm. 1-, 2-, 3-ply. Margin distinct of 4 or 5 layers, 1 cell thick; cells square and often filled and with concretion. Inner cells small and rounded, often filled.

**R.S.**—Margin of rays of cells with thick pitted walls, the outermost forming a fringe of somewhat rhomboidal palisade cells.—Parenchyma and fibres conspicuous, latter non-septate.

### ASIATIC AND AUSTRALASIAN MAHOGANIES.

- |                                     |                                 |
|-------------------------------------|---------------------------------|
| 33. <i>Cedrela toona</i> .          | 40. <i>Shorea robusta</i> .     |
| 34. <i>Cedrela australis</i> .      | 41. "Eng teak."                 |
| 35. <i>Cedrela serrata</i> .        | 42. "Camphor wood."             |
| 36. <i>Dysoxylon lessertianum</i> . | 43. "Yang."                     |
| 37. <i>Pterocarpus indicus</i> .    | 44. <i>Tarrietia javanica</i> . |
| 38. "East Indian mahogany."         | 45. <i>Acacia koa</i> ,         |
| 39. "Red Serayah."                  |                                 |

33. *Cedrela toona*.

No. 239, from Royal Botanic Gardens, Kew, labelled "Cedrela toona Roxb., Simla, Punjab. Section cut from India Forest Department specimen marked H 8 (see 'A Manual of Indian Timbers,' Gamble, 1902, p. 159)." Pl. XXXVIII., figs. 100, 101, 102.

Dark red brown, lustrous, roey. Vessels distinctly zoned. Zones with large vessels, separated by usually wider zones, composed of denser tissue, with a few vessels scattered in them. Dense zones of very uneven thickness, sometimes almost disappearing, so that the vascular zones approach one another and run together. Parenchymatous laminae, usually in vascular zones, sometimes in dense zones, and then with black deposit. Rays distinct and lighter red than rest of wood.

**C.S.**—Vessels compressed tangentially, isolated, or in radial groups of 2 or 3, often showing perforated end wall; M.T.D. = 0.30 mm., 4–12 in 2-mm. field; empty.—Fibres thin to moderately thick-walled; 6–23 between rays.—Circumvasal parenchyma narrow; laminar parenchyma narrow, 3 or 4 cells thick on inside of vascular zone, occasionally in dense zone with schizogenous spaces filled with dark deposit.—Rays distinct, almost empty.

**T.S.**—Rays irregular in size and arrangement, sides bowed; about 40 in 2-mm. field. Total width in 2 mm. = 0.44 mm. Height = 0.05–0.43–0.60 mm., 3–25 cells. Width = 0.02–0.08–0.10 mm.; 1-, 2-, 3-, 4-, 5-ply. Margin often distinct; outline of middle cells rounded, often bulging into fibres.—Fibres septate.

**R.S.**—Ray cells short and rectangular, angles filled with deposit; marginal cells nearly square or pentagonal.—Circumvasal parenchyma of rectangular cells, angles often filled with deposit.—Segments of vessels often as short as or shorter than diameter.—Fibres septate.

34. *Cedrela australis*.

No. 196, from the Museum of Economic Forestry, Sydney, N.S.W., marked "Red Cedar, *Cedrela australis* F. v. M." Plate XXXIX., figs. 103, 104, 105.

Rose brown, lustrous, not (?) roey. Large vessels in zones, occasionally with white contents; dark contents also occasional. Parenchymatous laminae 1 mm.–4 mm. apart; in contact with the zones of large vessels. Sp. gr. = 0.49.

**C.S.**—Vessels round, scattered, or in small radial groups; M.T.D. = 0.32 mm., 10–20 groups in 2-mm. field, occasionally filled with dark contents.—Fibres thin-walled, radially compressed in dense part of growth-zone.—Parenchyma circumvasal, inconspicuous, and in tangential laminae 3–5 cells thick, empty.—Rays empty.

**T.S.**—Rays irregular, sides bowed, 35–40 in 2-mm. field. Total width in 2 mm. = 0·34 mm. Height = 0·43 mm., 5–15–21 cells. Width = 0·056 mm., 1-, 2-, 3-, 4-, 5-ply. Margin, usually bulging and triangular, often indistinct, empty, often blunt and distorted. Middle cells thin-walled, bulging, usually empty.

**R.S.**—Margin truncated triangles, distinct. Fibres non-septate.

**NOTE.**—According to the Index Kewensis (6) *C. australis* F. v. **M.** is a synonym of *C. toona* Roxb.

Moll and Janssonius (11) describe the wood of *Cedrelu febrifuga*, which, according to Index Kewensis, is a synonym of *C. toona* Roxb., and consequently a synonym of above. The wood investigated by these authors had rays 2-, 3-, and 4-ply, about 15 cells high. So far as the two specimens (Nos. 239 and 196) here described are concerned, the chief difference seems to be that No. 239 has fibres with considerably thicker walls than those of No. 196.

### 35. *Cedrela serrata*.

No. 240, from Royal Botanic Gardens, Kew, labelled "*Cedrela serrata* Royle, Satan, Chamba, 5000 feet. Section cut from India Forest Department, marked H 782. (See 'A Manual of Indian Timbers,' Gamble, 1902, p. 160.)" Pl. XXXIX., figs. 106, 107, 108.

Rose-brown, lustrous and roey, with light sap-wood, about 12 mm. thick. Vessels zoned; zones of large vessels separated by somewhat wider zones composed of dense tissue, with a few small vessels scattered in it. Longitudinal surfaces distinctly roey. Vessels and rays distinct.

**C.S.**—Vessels rounded, isolated, or in radial groups of 2 or 3 large vessels, occurring in narrow zones containing 2–4; smaller vessels scattered among fibres. M.T.D. = 0·32 mm.; 17–24 in 2-mm. field. Some vessels with dark contents.—Fibres thin-walled on inside, moderately thick-walled on outside of growth-zone; 3–24 between rays.—Circumvasal parenchyma narrow, laminae occasional on outside of growth-zone, about 10 cells thick, sometimes with schizogenous spaces filled with dark deposit.—Rays distinct.

**T.S.**—Rays irregular in size and arrangement, sides almost parallel, finely tapered, about 55 in 2-mm. field. Total width in 2 mm. = 0·22 mm. Height = 0·07–0·30–0·45 mm. 2–18 cells. Width = 0·01–0·04 mm., 1-2-3-ply. Margin of ten distinct, pointed or blunt. Outline of middle cells rounded and somewhat bulging into fibres.

**R.S.**—Ray cells short and rounded, marginal ones square, angles filled with deposit.—Circumvasal parenchyma rectangular, angles filled with deposit;

filaments of parenchyma often traverse schizogenous spaces obliquely.—Fibres non-septate.

36. *Dysoxylon lessertianum*.

No. 197, from the Museum of Economic Forestry, Sydney, N.S.W., marked "Rosewood, *Dysoxylon Lessertianum* (*Fraserianum*), Benth." Pl. XI., figs. 109, 110, 111.

Rose-brown, with slight purple tinge, not lustrous, roey; scented (resembling sandal wood and cedar oil). Vessels scattered, without contents. Parenchymatous laminae close, about 0.3 mm. apart; thick and undulating enclosing vessels. Sp. gr. = 0.77.

**C.S.**—Vessels round, scattered, or in small radial groups; larger vessels in middle of group, tailing off into smaller ones radially. 15–25 groups in 2-mm. field. M.T.D. = 0.20 mm.; occasional dark contents.—Fibres thick-walled.—Laminar parenchyma undulating, often merging into circumvasal, 3–8 cells thick; occasionally with dark contents.—Rays with dark contents.

**T.S.**—Rays irregular, sides parallel, acute, about 55 in 2-mm. field. Total width in 2 mm. = 0.30 mm. Height = 1.0–0.1 mm. Width 0.028 mm. 1–2-ply. Margin not differentiated. Ray cells thick-walled, with dark contents.—Fibres septate, with deposit on septa.—Lenticular thickenings covered with greenish deposit on oblique vascular septa.

**R.S.**—Fibres septate.

37. *Pterocarpus indicus*.

No. 214, from commercial source, labelled "Andaman Padouk." Pl. XL., figs. 112, 113, 114.

Crimson, streaked with black, lustrous, not roey, hard, polishes on end grain. Vessels distinctly zoned, dark and light zones of fibres. Parenchymatous laminae fine but distinct, discontinuous, undulating. 0.5–0.2 mm. apart, closer in the dense zones. Laminae sometimes anastomose. Storeyed structure of wood conspicuous. Sp. gr. = 0.75.

**C.S.**—Vessels round, isolated or in groups of 2 or 3. M.T.D. = 0.28 mm. 4–10 groups in 2-mm. field. Occasional contents.—Fibres thick-, or moderately thick-walled, 3–6 between rays.—Circumvasal parenchyma inconspicuous; laminar parenchyma undulating; 2–3–4 cells thick.—Rays fine, empty.

**T.S.**—Rays uniform, in regular oblique series; about 200 in 2-mm. field; total width in 2 mm. = 0.46 mm. Height = 0.11 mm. (0.11–0.12 mm.); 5–8 cells. Width = 0.15–0.20; 1-, 2-ply. Margin not differentiated. Cells empty, or with transparent aggregated contents; radial intercellular spaces.—Fibres non-septate, 3–6 between rays.—Laminar parenchyma with oblique or horizontal walls.

**R.S.**—Laminar parenchyma 2-3-4 cells thick; with end-walls horizontal.—Ray-cells all similar. Wood parenchyma fibres with vertical series of 6-12 crystals frequent.

**NOTE.**—This sample agrees with Moll and Janssonius' (*loc. cit.*, vol. iii. pp. 64 ff.) description of wood of *Pterocarpus indicus*; but the laminar parenchyma seems less abundant: *cf.* 28.

### 38. *East Indian Mahogany.*

No. 211, from commercial source, labelled "East Indian Mahogany also called 'Thitka.'" Pl. XLI, figs. 115, 116, 117.

Pink-brown, lustrous and roey, with distinct growth-zones. Vessels small, uniformly scattered; fibres zoned. Parenchymatous laminae not visible on cut surface. Rays straight, fine, storeyed. Sp. gr. = 0.76.

**C.S.**—Vessels tangentially compressed, scattered, singly and in radial groups of 2 or 3. M.T.D. = 0.20 mm. 30 groups in 2-mm. field. With tyloses.—Fibres thick-walled.—Circumvasal parenchyma, narrow and discontinuous; scattered parenchyma often grouping into laminae of 1 cell thick connecting adjacent rays, usually empty, separated by 1-4 fibres. Occasional narrow zones, without parenchyma.—Rays narrow, often filled; separated by 4-12 fibres.

**T.S.**—Rays uniform, in oblique series; 70-80 in 2-mm. field; total width in 2 mm. = 0.44 mm. Height = 0.12-0.30-0.70 mm.; 10-16 cells; width 0.01-0.04 mm.; 2-, 3-, 4-ply. Margin 1 cell deep, usually empty. Inner cells often filled.

**R.S.**—Parenchyma of oblong rectangular cells, usually empty. Marginal cells of rays square.

**NOTE.**—Thitka (*Pentace burmanica*, Kurz) has, according to Boulger (2), moderately broad, wavy rays, and consequently can hardly be this wood. Thitka is described by Foxworthy (7) as light and soft.

### 39. *Red Serayah.*

No. 229, from commercial source, labelled "Red Serayah or Borneo cedar." Pl. XLI, figs. 118, 119, 120.

Warm brown, indistinctly zoned in light and dark, slightly lustrous, not roey. Parenchymatous laminae inconspicuous, 0.5-5.0 mm. apart. Sp. gr. = 0.44.

**C.S.**—Vessels round, isolated or in small groups of 2-6; M.T.D. = 0.20 mm.; 7-9 groups in 2-mm. field, often with dark contents.—Fibres thick-walled, zones with reduced lumina and thicker walls adjoining parenchymatous

laminae; 5-21 between rays.—Circumvasal parenchyma narrow, often with dark contents; laminae 1-3 cells thick, inconspicuous. Rays conspicuous, dark.

**T.S.**—Rays irregular in size and arrangement, about 25 in 2-mm. field; total width in 2 mm. = 0.41 mm. Height = 0.10-0.80-1.54 mm., 2-50 cells; width = 0.02-0.05 mm.; 1-, 2-, 3-ply. Margin distinct, cells high, triangular, often several cells deep. Frequent deposit in all ray-cells.—Fibres septate.

**R.S.**—Marginal cells square or vertical rectangles.

NOTE.—Foxworthy (7) says Serayah is derived from *Hopea* or *Shorea* spp.

40. *Shorea robusta.*

No. 194, in School of Botany, Trinity College, Dublin, without record of origin, labelled "Shorea robusta, Sal." Pl. XLII., figs. 121, 122, 123.

Pale brown, dull and roey; vessels scattered, close, with mealy margin in C.S. In T. and R. sections, with glistening light contents (tyloses). Occasional narrow zones of dense fibres, almost free from vessels. Parenchymatous laminae very close, thin, and often narrow in tangential direction; irregular, about 0.2 mm. apart. Sp. gr., 0.87.

**C.S.**—Vessels circular, scattered, seldom in contact with one another. M.T.D. = 0.20 mm., 24 in 2-mm. field. With tyloses.—Fibres very thick-walled. Lumen obliterated.—Circumvasal parenchyma 2-3 cells thick, spreading tangentially into laminae, 1-10 cells thick; empty.—Rays filled.

**T.S.**—Vessels packed with tyloses. Rays irregular in size, acute, sides irregular and sinuous, about 30 in 2-mm. field. Total width in 2 mm. = 0.43 mm. Height = 0.93 mm. (0.45-2.00 mm.). Width = 0.056 mm. 1, (2-) 3-, 4-ply. Margin indistinct. Inner cells thick-walled, filled.

**R.S.**—Fibres non-septate. Occasional vertical rows of crystals.

NOTE.—Foxworthy (6) states rays are mostly 4 cells wide.

41. *Eng. Teak.*

No. 117, from commercial source, labelled "Eng. Teak." Pl. XLIII., figs. 124, 125, 126.

Brown, with narrow (1 mm. thick) layers of dense and dark-brown tissues. Vessels usually filled with buff, mealy substance (tyloses) or black deposit, or more seldom with white substance, avoiding dense layers. Sticky resinous substance exudes from vessels in hot weather. No parenchymatous laminae visible. Sp. gr. = 0.87.



**C.S.**—Vessels somewhat compressed tangentially, isolated. M.T.D. = 0.29 mm. About 30 in 2-mm. field. Usually filled with tyloses and dark deposit. Fibres thick-walled, with much reduced lumina in irregular patches, 6–24 fibres in radial thickness, and of greater extension in a tangential direction. Parenchyma also in irregular patches, sometimes surrounding vessels and extending considerably in a tangential direction, or sometimes forming narrow incomplete circumvasal sheaths. Cells of parenchyma and fibres form fairly regular radial series. Some cells of parenchyma contain dark deposit. Rays conspicuous, with dark contents, often markedly deflected by vessels, of two sizes, 2 or 3 small rays between large ones.

**T.S.**—Rays irregular in size and arrangement, roughly of two grades, wide and narrow. About 5 wide and 33 narrow in 2-mm. field. Total width in 2 mm. = 0.64 mm. Height of large rays = 1.15 mm., of small rays 0.40 mm., 45–2 cells. Width of large rays = 0.12–0.15 mm. Rays 1-, 2-, 3-, 4-, 5-, 6-, 7-, 8-ply. Margin indistinct, marginal cells of large rays, and all of the cells of small rays somewhat larger than inner cells of large rays. All cells filled.—Fibres pitted, 2–4 between rays.

**R.S.**—Marginal cells square or even palisade-like. Inner cells radially elongate. Cells of small rays resemble marginal cells.

NOTE.—This wood agrees with that of *Dipterocarpus tuberculatus* in many particulars, as given by Gamble (8).

#### 42. *Camphor wood.*

No. 237, from commercial source, labelled “Camphor wood.” Pl. XLIII., figs. 127, 128, 129.

Rose-brown, dull, with indistinct, close, dark, and light zones; about 6–8 in 10 mm. Hard; end grain cuts with polish. Scented, roey. Narrow, discontinuous laminae very close. Distinct parenchymatous laminae occasional; 1 in 55 mm. Sp. gr. = 0.87.

**C.S.**—Vessels rounded, isolated, or in pairs. M. T. D. = 0.25 mm.; about 20 in 2-mm. field. Large tyloses, each filling the lumen of a vessel, frequent. Fibres thick-walled, lumen usually obliterated, pitted. 6–20 between rays.—Circumvasal parenchyma thin; often short, tangential laminae traversing the groups of fibres between the rays. 1 cell thick, radially.—Rays conspicuous, dark.

**T.S.**—Rays irregular in size and arrangement; about 30 in 2-mm. field. Total width in 2 mm. = 0.63 mm. Height = 0.08–1.0–2.0 mm.; 2–80 cells. Width = 0.02–0.06–0.08 mm. 1-, 2-, 3-, 4-, 5-ply. Margin usually distinct, often many cells deep; 1 cell thick. All ray-cells usually with parietal contents.—Wood parenchyma cells rectangular.

**R.S.**—Ray marginal cells square or oblong, vertical.—Frequent parenchymatous laminae, 1 cell thick.—Fibres non-septate.

NOTE.—This wood agrees closely in structure with that of the Dipterocarpeae, and is possibly the wood of *Dryobalanops aromatica* Gaertn. f.

#### 43. *Yang.*

No. 218, from commercial source, labelled. "Yang, or bastard teak from Moulmein." Pl. XLIII., figs. 130, 131, 132.

Warm brown, with indistinct dark zones in which the vessels are scarcer; distinctly roey and lustrous. Vessels with mealy margin. Parenchymatous laminae fine, discontinuous, light; 0.5–2.0 mm. apart. Sp. gr. = 0.70.

**C.S.**—Vessels somewhat compressed tangentially, isolated or in groups of two. M. T. D. = 0.26 mm.; about 14 in 2-mm. field; occasional tyloses.—Fibres thick-walled, lumen often obliterated.—Circumvasal parenchyma often conspicuous; small amount of scattered parenchyma. Laminar parenchyma 3–10 cells thick, forming short plates in a tangential direction, chiefly in connexion with the small vessels.—Rays conspicuous, with dark contents.

**T.S.**—Rays irregular in size and arrangement, roughly of two grades, wide and narrow; 25–30 in 2-mm. field. Total width in 2-mm. field = 0.43 mm. Height = 0.90 mm. (0.20–1.50 mm.); 10–60 cells. Width = 0.01–0.07–0.10 mm. 1-, 2-, 3-, 4-, 5-, 6-, 7-, 8-, 9-ply. Margin distinct, often of many cells; middle cells with small lumen, often with contents.—Fibres non-septate, 1–10 between rays.

**R.S.**—Marginal cells of rays square or triangular, with thick pitted walls.

NOTE.—This wood is not the bastard teak of Boulger (2), which is derived from *Pterocarpus marsupium* Roxb. The latter, according to Gamble (8), has very fine rays: cf. figs. 82 and 112.

The wood resembles that of Shorea, and may well be one of the Dipterocarpeae. Its structure agrees with Gamble's description of *D. tuberculatus*, except in the absence of resin.

#### 44. *Tarrietia javanica.*

No. 85, from commercial source, marked "Philippine mahogany, Lum-bayao." Pl. XLIV., figs. 133, 134, 135.

Dark rose-brown and lustrous, not roey. Fibres distinctly zoned, vessels avoiding dense zones. Vessels large and very evident on radial and tangential faces. Contents black or occasionally white. No parenchymatous laminae.

Rays dark-red brown, very marked on radial face, contrasting strongly with silky fibres, tall Sp. gr. = 0·65.

**C.S.**—Vessels circular, scattered. M.T.D. = 0·45 mm.; 5–10 in 2-mm. field, often with dark contents.—Fibres in dense zones thick-walled.—Circumvasal parenchyma forming a dark margin 1–3 cells thick round vessels. Contents dark.—Rays filled with dark contents.

**T.S.**—Rays irregular, sides parallel, acute, 20–30 in 2-mm. field. Total width of rays in 2 mm. = 0·46 mm. Height = 1·56 mm. Width = 0·10 mm. 1-, 2-, 3-, 4-ply. Margin not always distinct. Often covering over the sides of the rays is a layer of rectangular erect cells, sometimes with dark contents. Middle cells small, rounded, thick-walled, with contents.

**R.S.**—Fibres with occasional septa, regular.—Rays dark, with vesicular contents.

NOTE.—Mell (10) states that Lumbayao mahogany is the wood of *Tarrietia sylvatica* Merr. or of *T. javanica* Bl.

Foxworthy (6) states that Lumbayao is botanically unknown. His micro-photo as far as can be made out agrees with the above sample, but he describes the wood as ring-porous, and his sample had a sp. gr. of 0·55; but in a more recent paper (7) he refers Lumbayao to *Tarrietia javanica* Bl., illustrating it with the same microphoto.

#### 45. *Acacia koa*.

No. 212, from commercial source, labelled “Koa grown in Philippine Is.” Pl. XLIV., figs. 136, 137, 138.

Golden-brown, lustrous and roey, hard, polishes on end grain; tends to split radially and tangentially. Ill-defined zones of light and dark. Vessels scattered, not zoned. No parenchymatous laminae visible. Rays very fine. Sp. gr. = 0·76.

**C.S.**—Vessels tangentially compressed, scattered, isolated, or in radial groups of 2–4; often with black contents. M.T.D. = 0·14 mm.; 8–10 groups in 2-mm. field.—Fibres thick-walled; 2–35 between rays.—Parenchyma circumvasal irregular, 0–5 cells thick.—Rays narrow, filled.

**T.S.**—Rays irregular, not uniform; about 100 in 2-mm. field. Total width in 2 mm. = 0·26 mm. Height = 1–25 cells, 0·01–0·40 mm. Width = 0·01–0·03 mm. 1-, (2)-ply. Margin not differentiated, all cells, with contents.

**R.S.**—Wood parenchyma only circumvasal.—Fibres non-septate.—Rays of prostrate cells only.

Foxworthy (7) refers Koa wood to *Acacia koa* Gray.

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## DESCRIPTION OF PLATES.

All the figures are from microphotographs with a magnification of 31 diameters. Actual diameter of field is 2 mm. in each case.

## PLATE XXII.

Fig.

1. Cross-section of wood of *Swietenia mahagoni*, No. 48.
2. Tang. section       "       "       "       "
3. Radial section       "       "       "       "
4. Cross-section of inner wood of *S. mahagoni*. Herbarium specimen.
5. Tang. section of wood of *S. mahagoni*, No. 45.
6.       "       "       *Swietenia* sp., No. 155.

## PLATE XXIII.

7. Cross-section of wood of *Swietenia macrophylla*, No. 87.
8. Tang. section       "       "       "       "
9. Radial section       "       "       "       "
10. Cross-section       "       *Cedrela odorata*, No. 191.
11. Tang. section       "       "       "       "
12. Radial section       "       "       "       "

## PLATE XXIV.

13. Cross-section of wood of *Carapa guianensis*, No. 162.
14. Tang. section       "       "       "       "
15. Radial section       "       "       "       "
16. Cross-section       "       *Carapa* sp. No. 216.
17. Tang. section       "       "       "       "
18. Radial section       "       "       "       "

## PLATE XXV.

19. Cross-section of the wood of *Protium altissimum*, No. 164.
20. Tang. section       "       "       "       "
21. Radial section       "       "       "       "
22. Cross-section       "       *Cariniana pyriformis*, No. 146.
23. Tang. section       "       "       "       "
24. Radial section       "       "       "       "





## PLATE XXXI.

Fig.

55. Cross-section of the wood of *Khaya* sp. "Zamingila," No. 285.  
 56. Tang. section       "       "       "       "  
 57. Radial section     "       "       "       "  
 58. Cross-section     "       *Khaya* sp. "Axim," No. 76.  
 59. Tang. section     "       "       "       "  
 60. Radial section    "       "       "       "

## PLATE XXXII.

61. Cross-section of the wood of *Khaya* sp., No. 41.  
 62. Tang. section     "       "       "  
 63. Tang. section     "       "       "  
       Showing thickening of rays, owing to addition of wood parenchyma.  
 64. Cross-section of the wood of *Khaya* sp., No. 71.  
 65. Tang. section     "       "       "  
 66. Radial section    "       "       "

## PLATE XXXIII.

67. Cross-section of the wood of *Entandrophragma excelsum*, No. 152.  
 68. Tang. section     "       "       "       "  
 69. Radial           "       "       "       "  
 70. Cross-section of the wood of *Entandrophragma utile*, No. 153.  
 71. Tang. section     "       "       "       "  
 72. Radial section    "       "       "       "

## PLATE XXXIV.

73. Cross-section of the wood of *Entandrophragma candollei*? "Sapele," No. 74.  
 74. Tang. section     "       "       "       "  
 75. Radial section    "       "       "       "  
 76. Cross-section    "       *Trichilia emetica*, No. 238.  
 77. Tang. section     "       "       "       "  
 78. Radial section    "       "       "       "

## PLATE XXXV.

79. Cross-section of the wood of *Aucoumea klaineana*, No. 68.  
 80. Tang. section     "       "       "  
 81. Radial section    "       "       "  
 82. Cross-section    "       *Pterocarpus* sp., No. 215.  
 83. Tang. section     "       "       "  
 84. Radial section    "       "       "

PLATE XXXVI.

- Fig.  
 85. Cross-section of the wood of *Baillonella djava*, No. 289.  
 86. Tang. section       "                       "               "  
 87. Radial section     "                       "               "  
 88. Cross-section     "               *Chlorophora excelsa*, No. 151.  
 89. Tang. section     "                       "               "  
 90. Radial section    "                       "               "

PLATE XXXVII.

91. Cross-section of the wood of "Cape Lopez Mahogany," No. 154.  
 92. Tang. section     "                       "               "  
 93. Radial section    "                       "               "  
 94. Cross-section    "               "Moabi," No. 291.  
 95. Tang. section     "                       "               "  
 96. Radial section    "                       "               "

PLATE XXXVIII.

97. Cross-section of the wood of "African Walnut," No. 190.  
 98. Tang. section     "                       "               "  
 99. Radial section    "                       "               "  
 100. Cross-section    "               *Cedrela toona*, No. 239.  
 101. Tang. section     "                       "               "  
 102. Radial section    "                       "               "

PLATE XXXIX.

103. Cross-section of the wood of *Cedrela australis*, No. 196.  
 104. Tang. section     "                       "               "  
 105. Radial section    "                       "               "  
 106. Cross-section    "               *Cedrela serrata*, No. 240.  
 107. Tang. section     "                       "               "  
 108. Radial section    "                       "               "

PLATE XL.

109. Cross-section of the wood of *Dysoxylon lessertianum*, No. 197.  
 110. Tang. section     "                       "               "  
 111. Radial section    "                       "               "  
 112. Cross-section    "               *Pterocarpus indicus*, No. 214.  
 113. Tang. section     "                       "               "  
 114. Radial section    "                       "               "

## PLATE XLI.

|      |  |          |                         |
|------|--|----------|-------------------------|
| Fig. |  |          |                         |
| 115. | Cross-section of the wood of "East Indian mahogany," | No. 211. |                         |
| 116. | Tang. section  | "        | "                       |
| 117. | Radial section                                       | "        | "                       |
| 118. | Cross-section  | "        | "Red Serayah, No. 229." |
| 119. | Tang. section  | "        | "                       |
| 120. | Radial section                                       | "        | "                       |

## PLATE XLII.

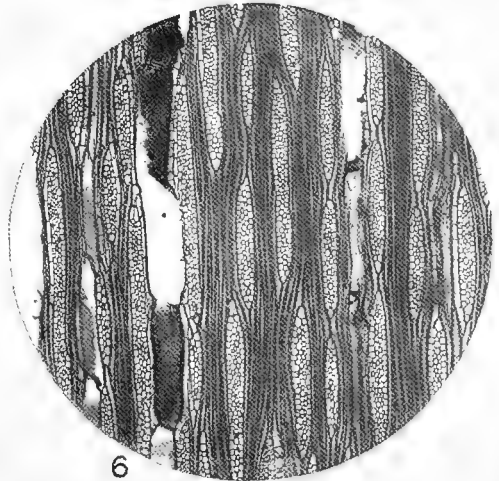
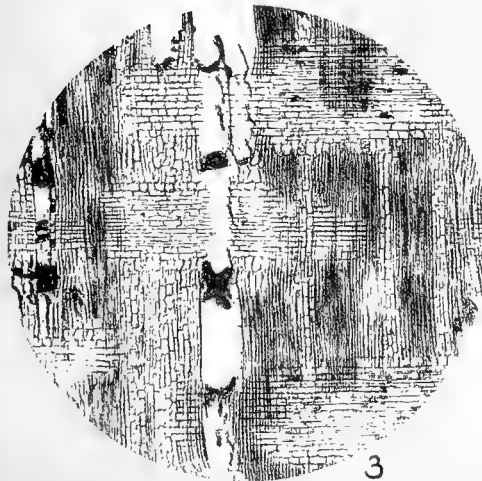
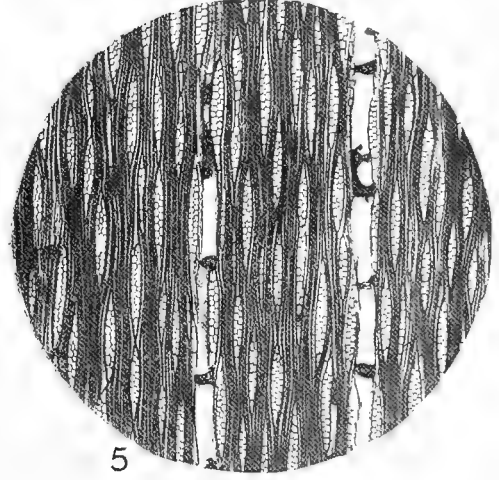
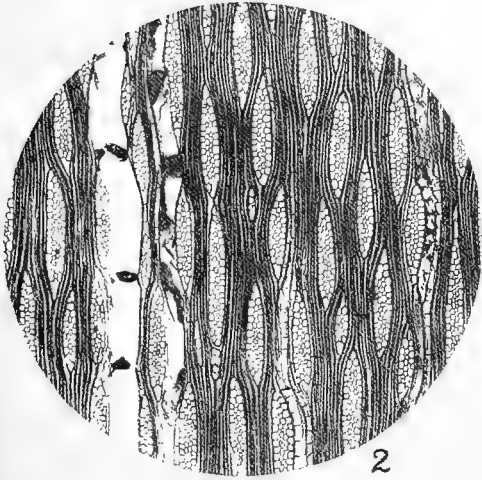
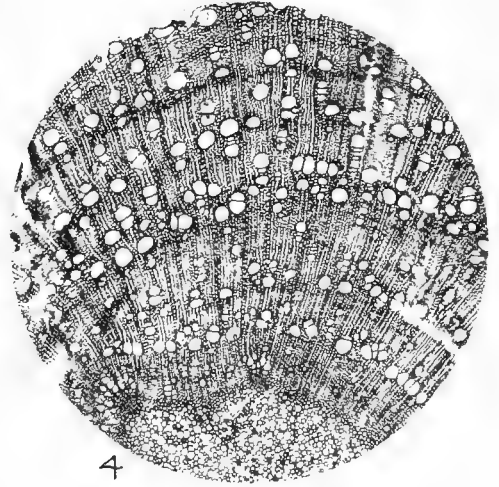
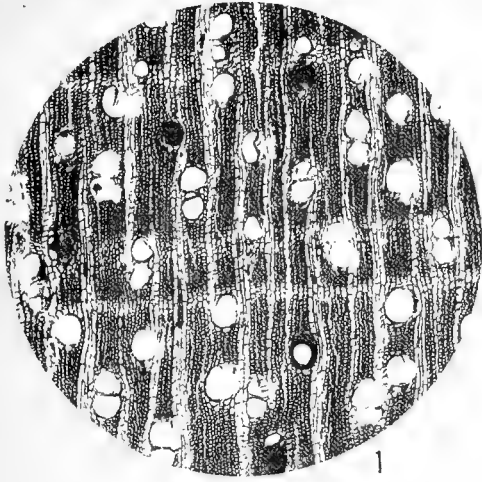
|      |  |                      |
|------|--|----------------------|
| 121. | Cross-section of the wood of <i>Shorea robusta</i> , | No. 194.             |
| 122. | Tang. section  | "                    |
| 123. | Radial section                                       | "                    |
| 124. | Cross-section  | "Eng Teak," No. 117. |
| 125. | Tang. section  | "                    |
| 126. | Radial section                                       | "                    |

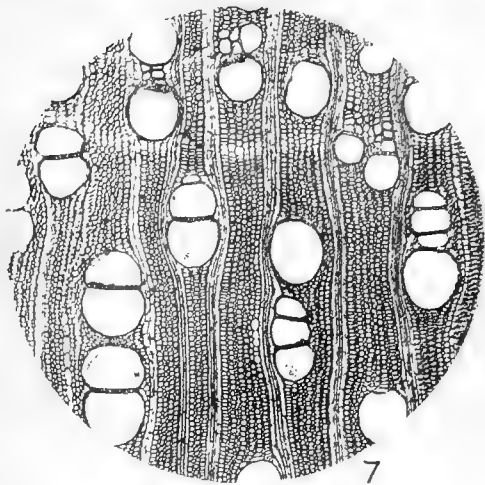
## PLATE XLIII.

|      |  |          |
|------|--|----------|
| 127. | Cross-section of wood called "Camphor Wood," | No. 237. |
| 128. | Tang. section                                | "        |
| 129. | Radial section                               | "        |
| 130. | Cross-section of wood called "Yang,"         | No. 218. |
| 131. | Tang. section                                | "        |
| 132. | Radial section                               | "        |

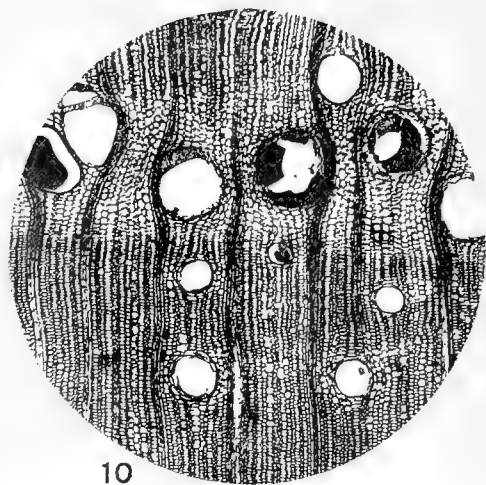
## PLATE XLIV.

|      |  |                              |
|------|--|------------------------------|
| 133. | Cross-section of wood of <i>Tarrietia javanica</i> , | No. 85.                      |
| 134. | Tang. section  | "                            |
| 135. | Radial section                                       | "                            |
| 136. | Cross-section  | <i>Acacia koa</i> , No. 212. |
| 137. | Tang. section  | "                            |
| 138. | Radial section                                       | "                            |

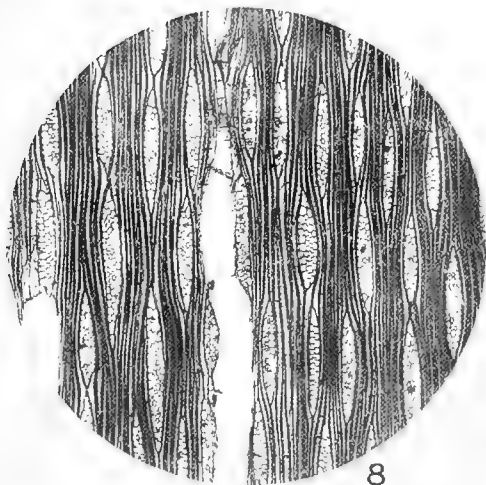




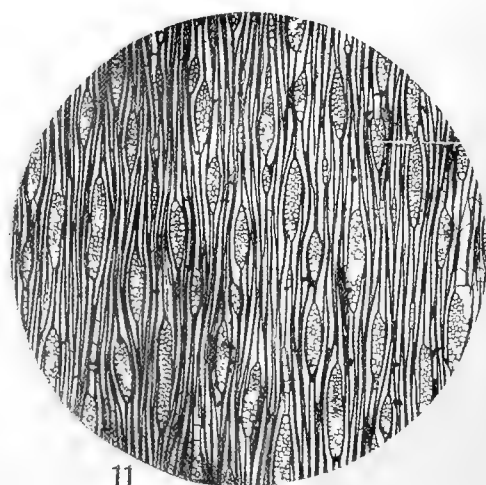
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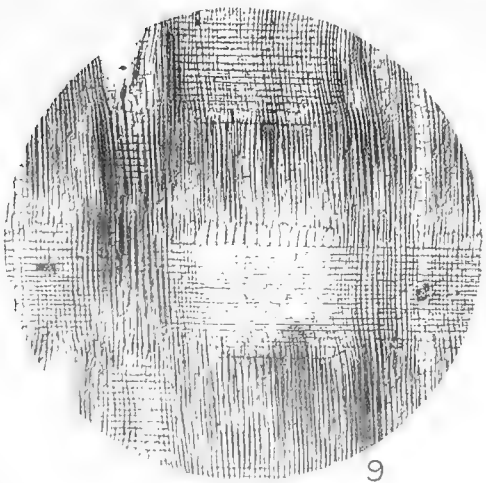
10



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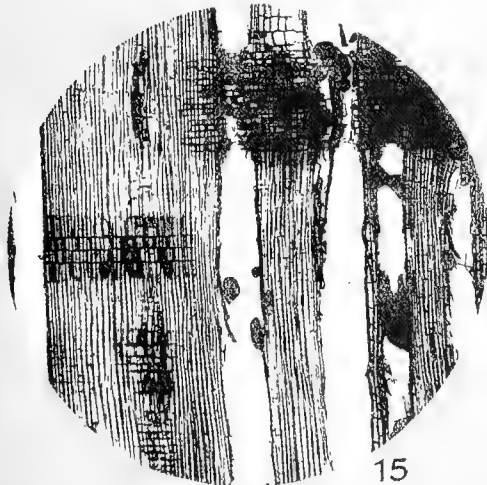
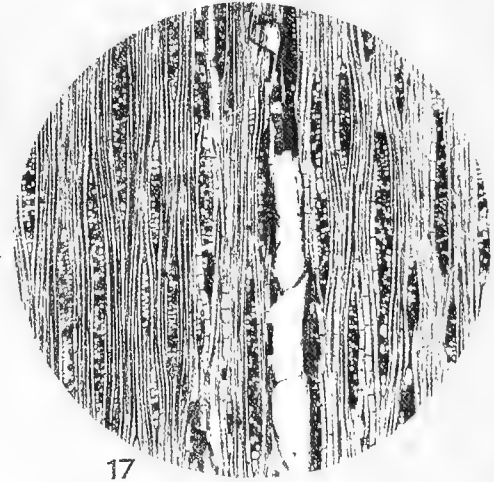
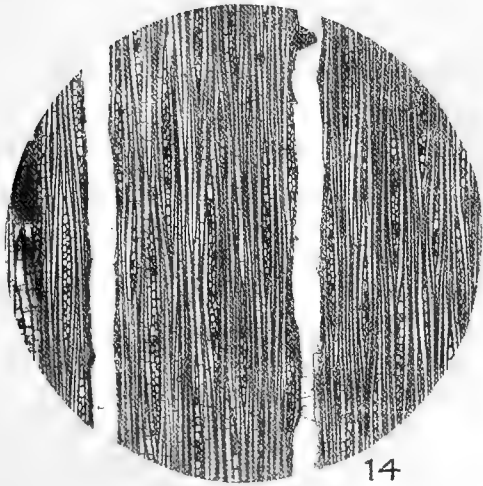
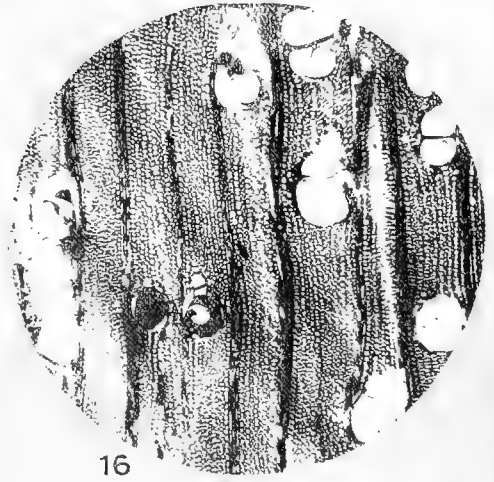
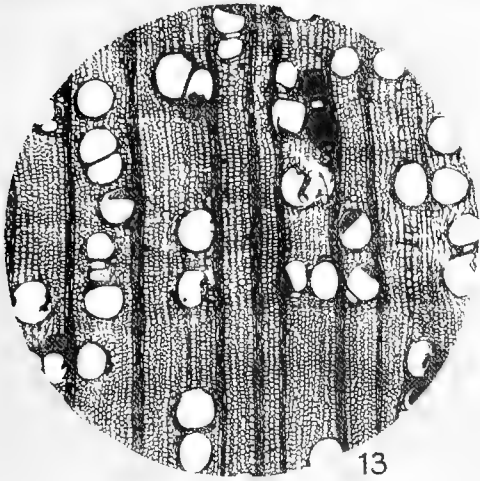
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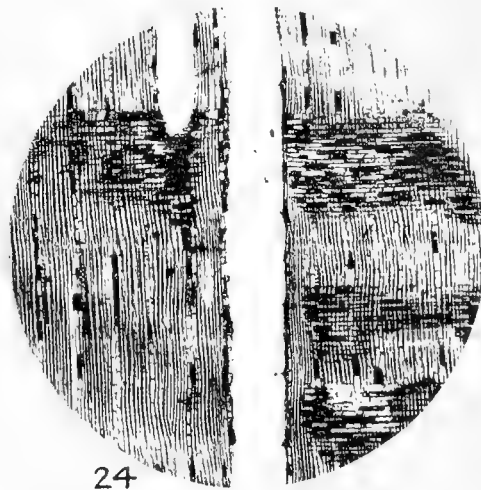
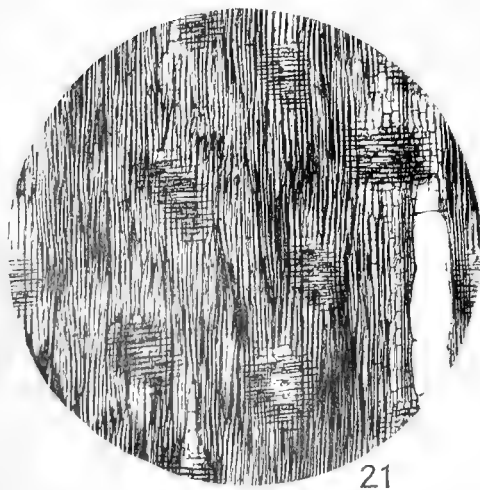
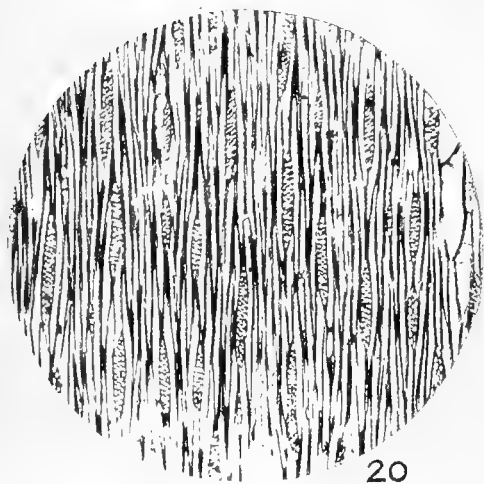
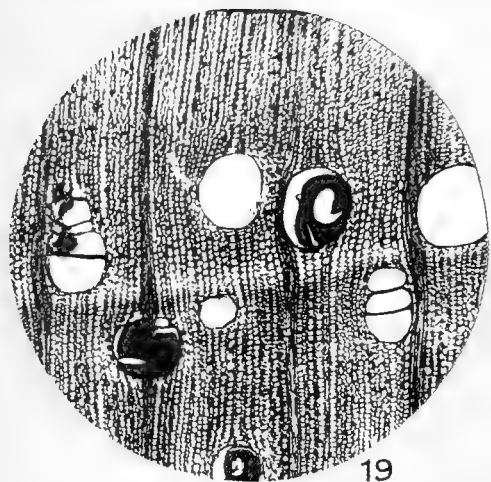


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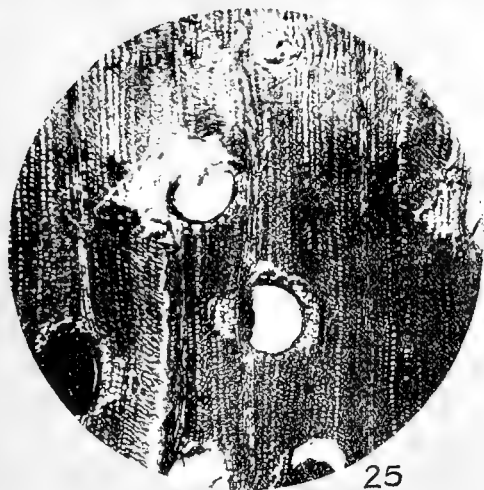


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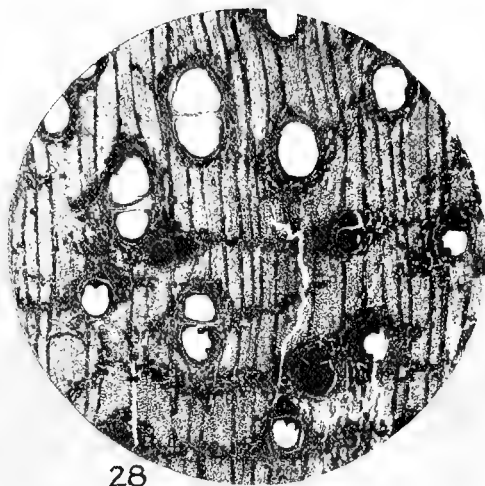




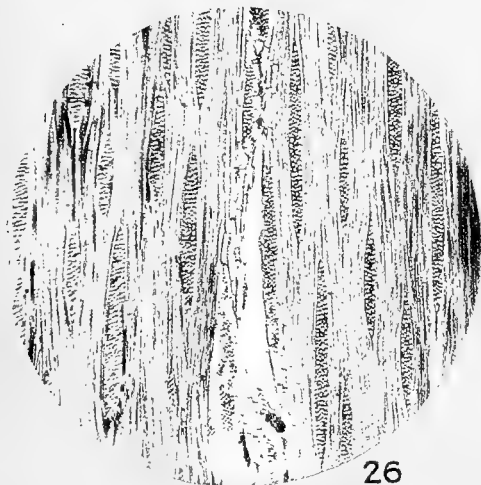




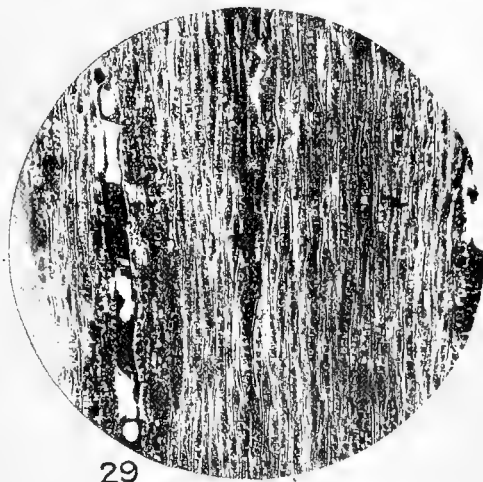
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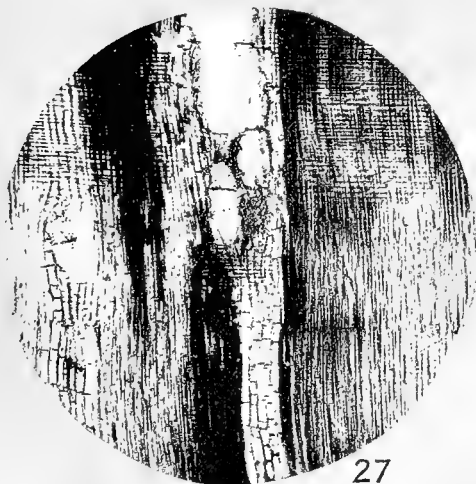
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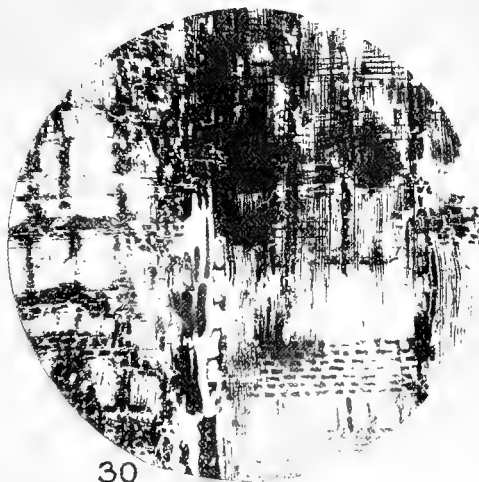
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29

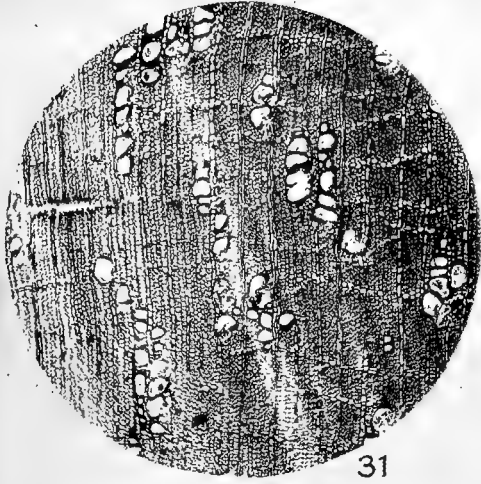


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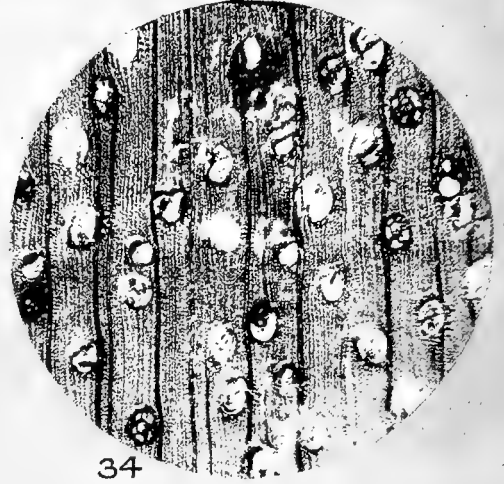


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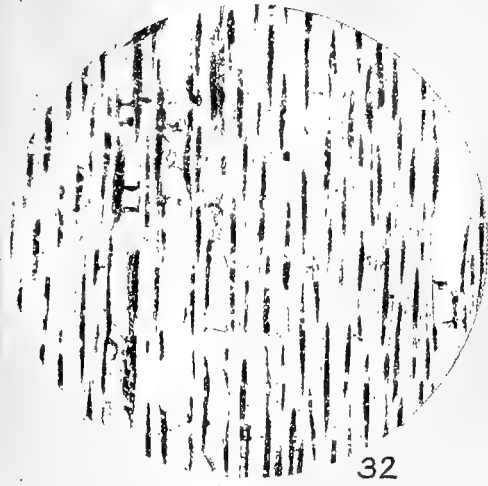




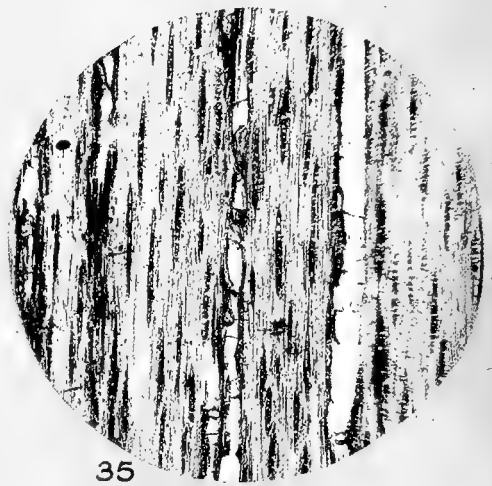
31



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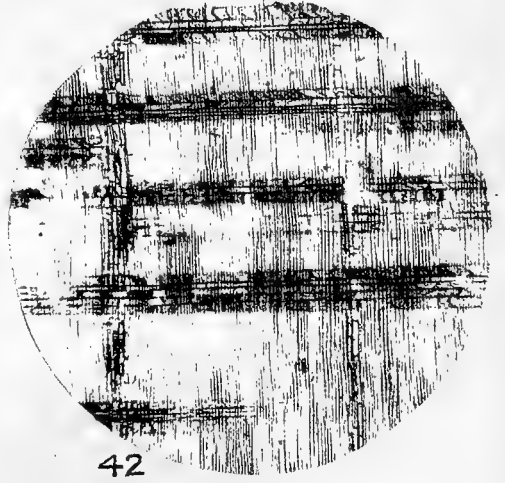
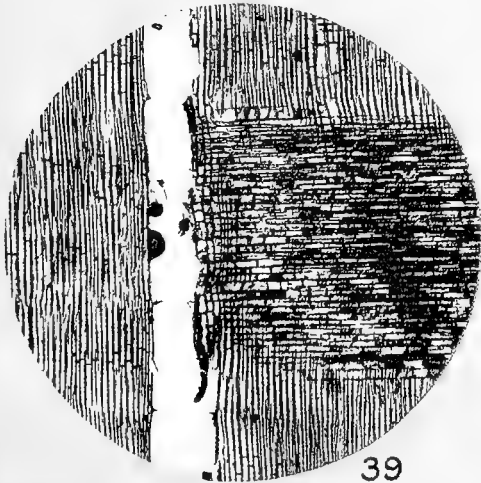
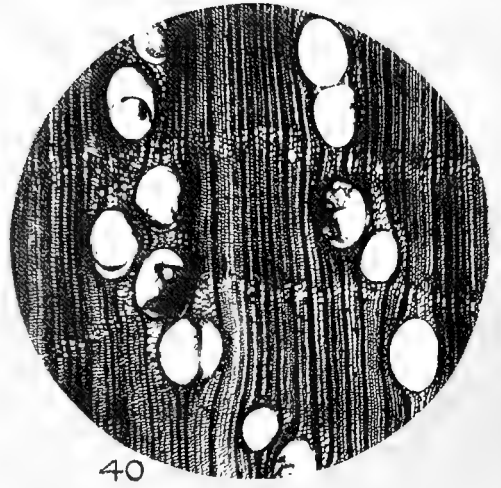
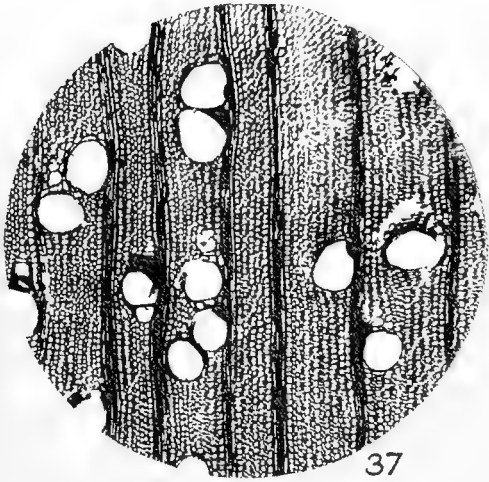
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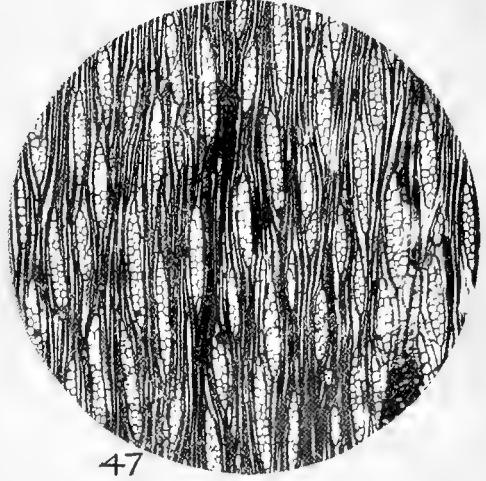
43



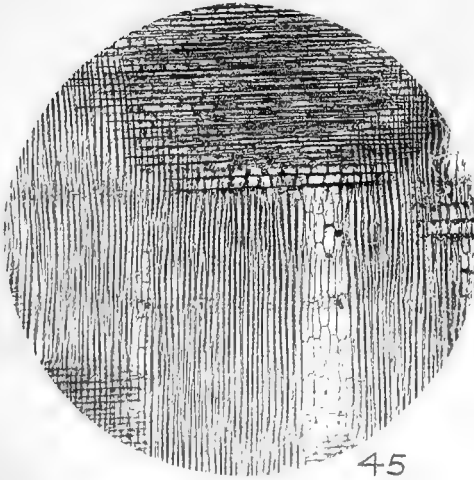
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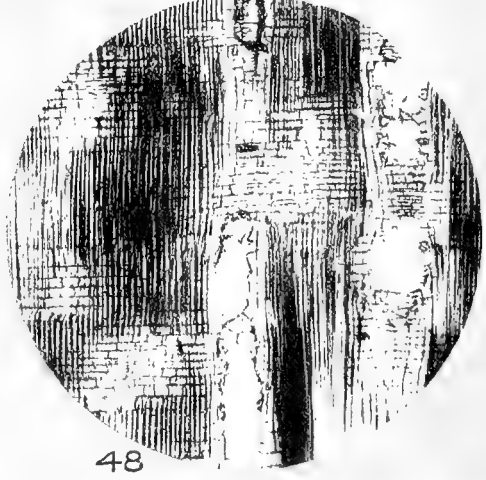
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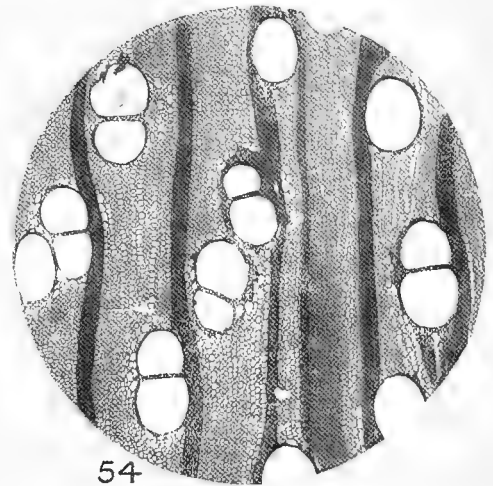
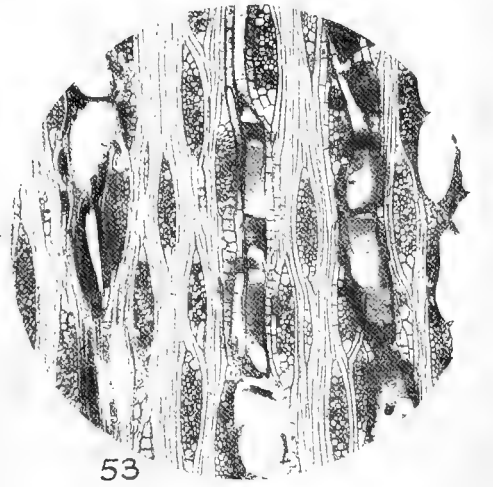
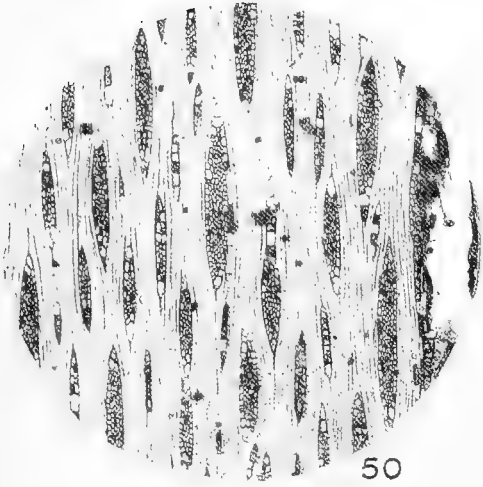
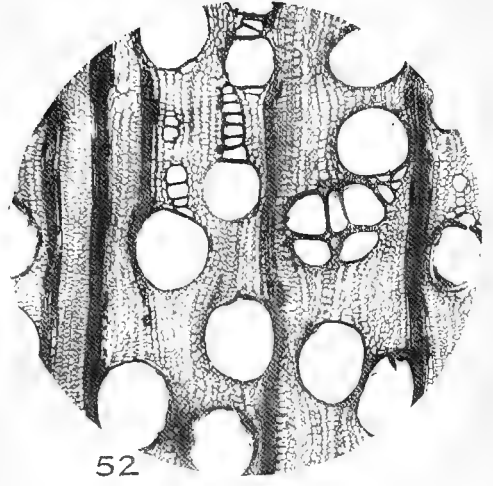
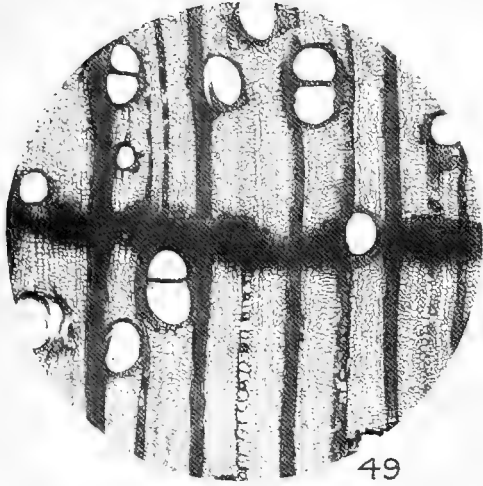
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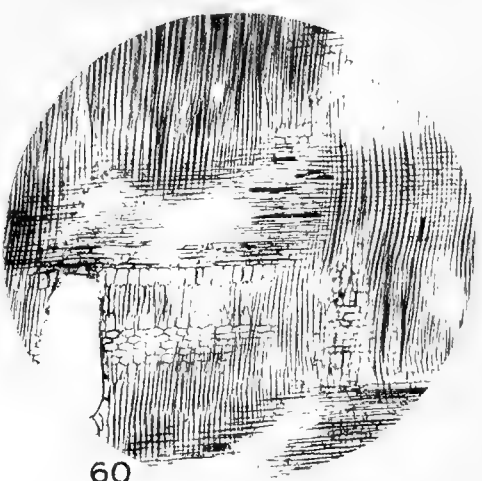
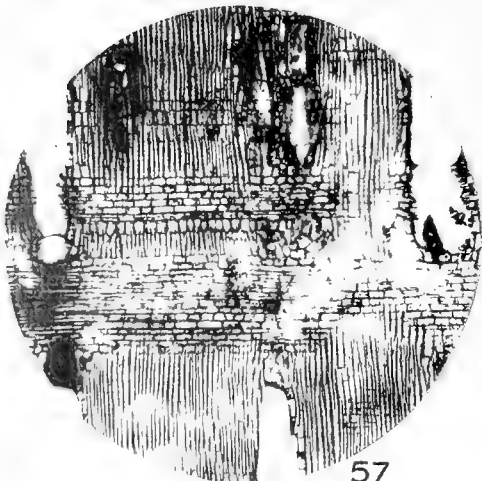
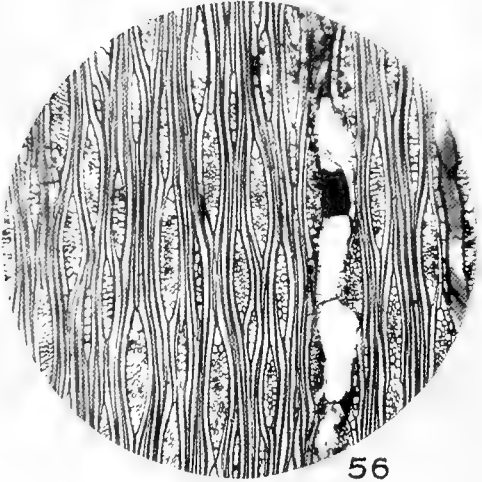
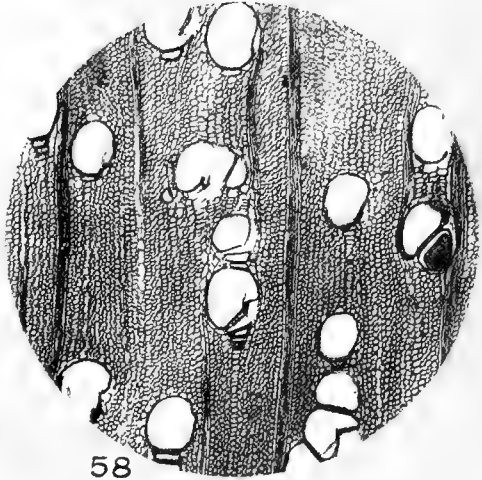
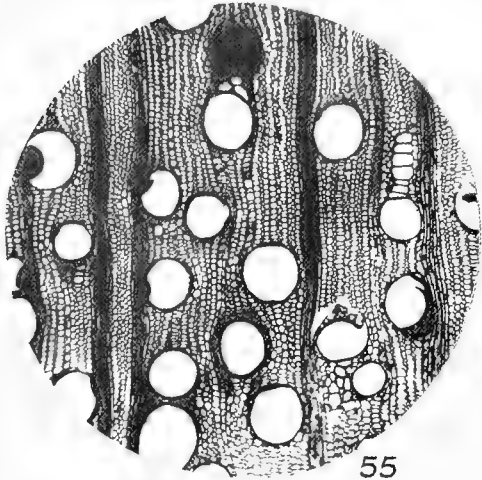


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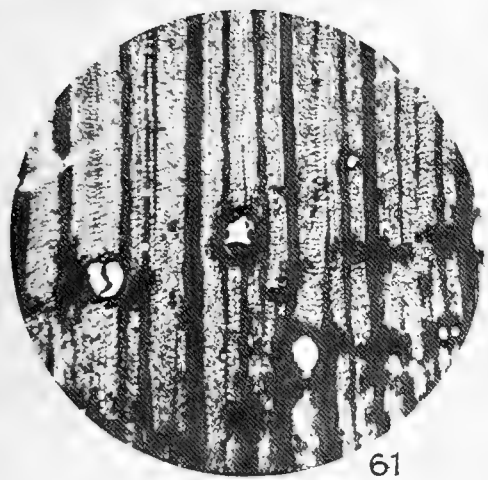


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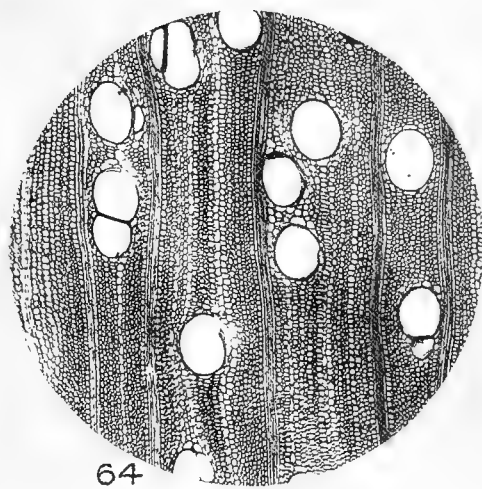








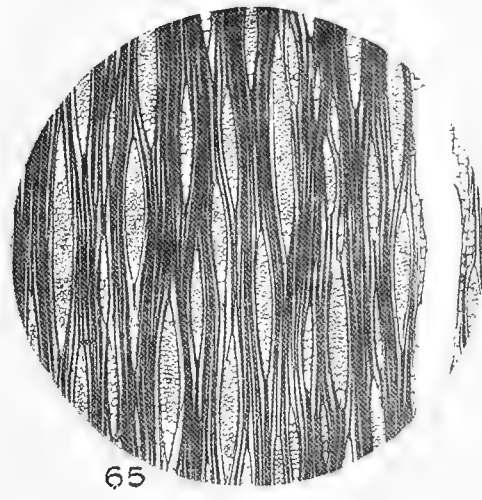
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64



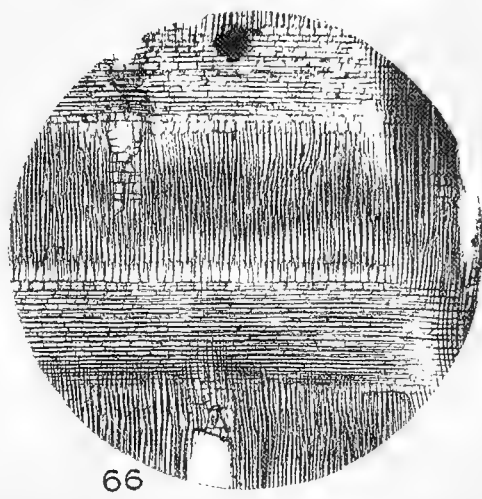
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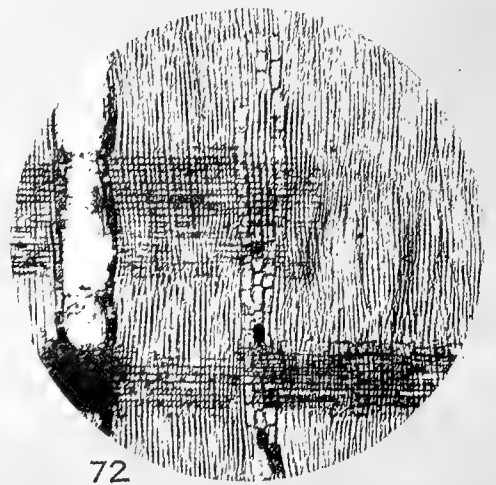
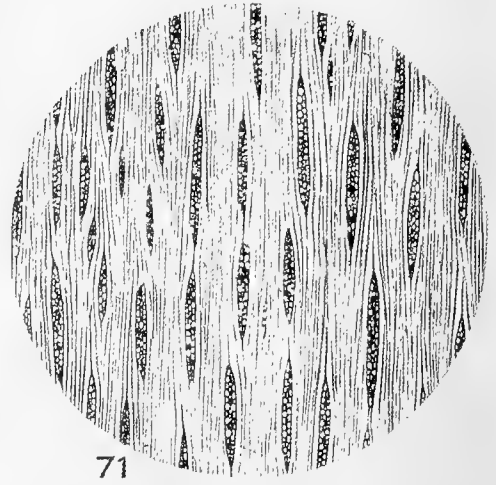
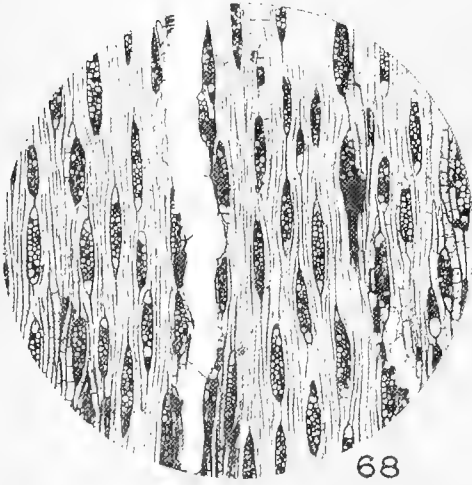
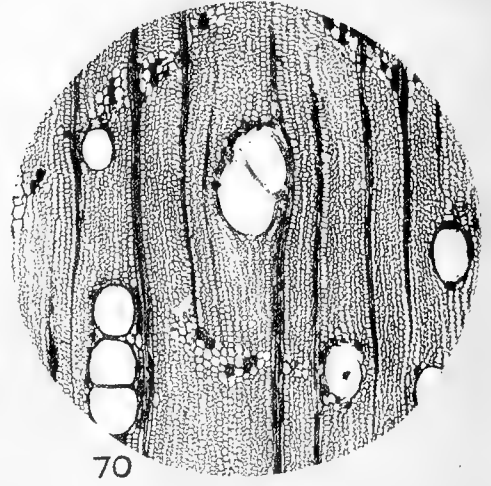
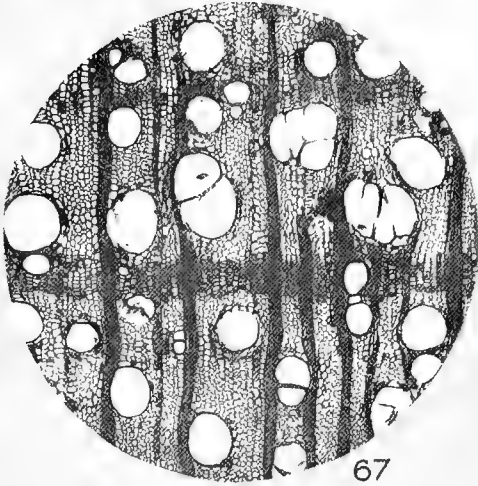
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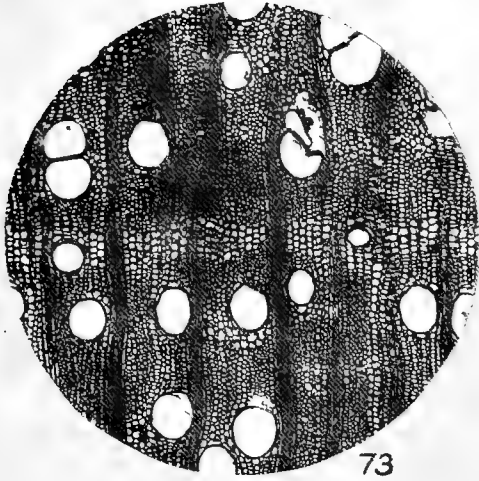


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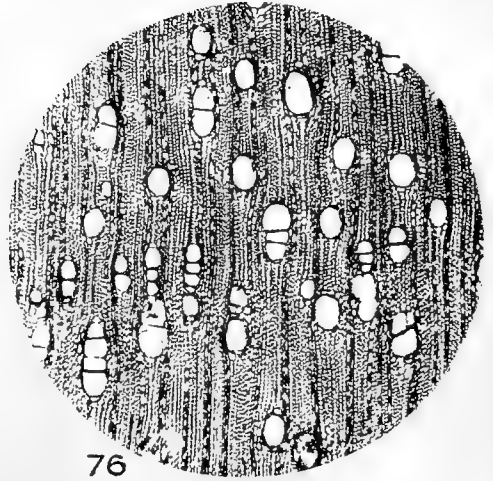


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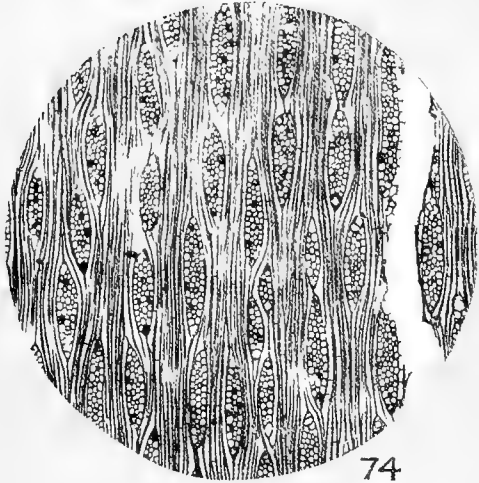




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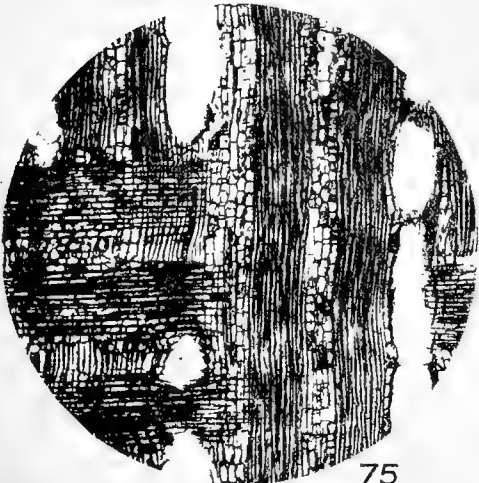
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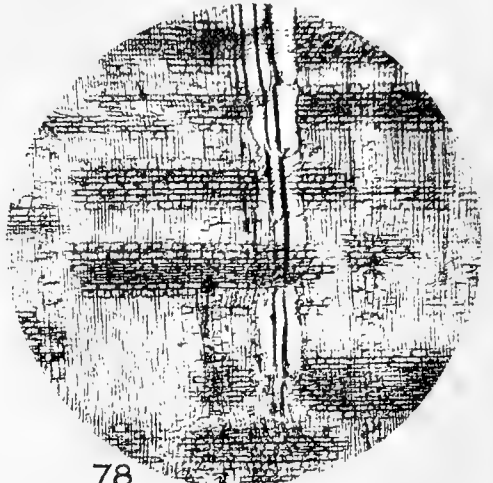
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77

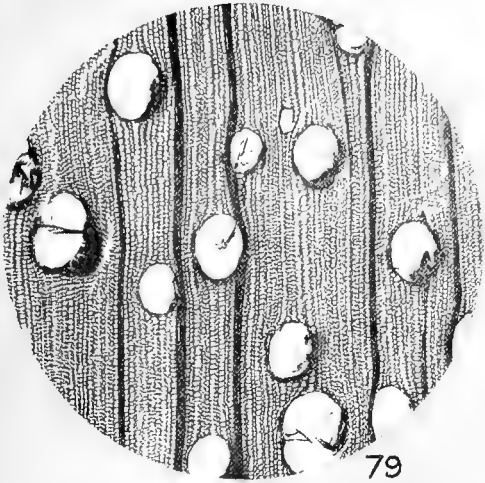


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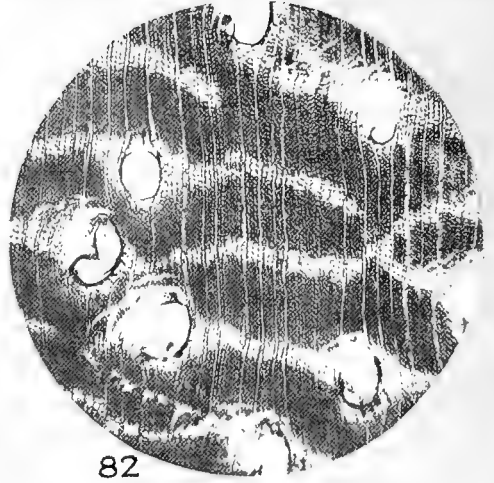


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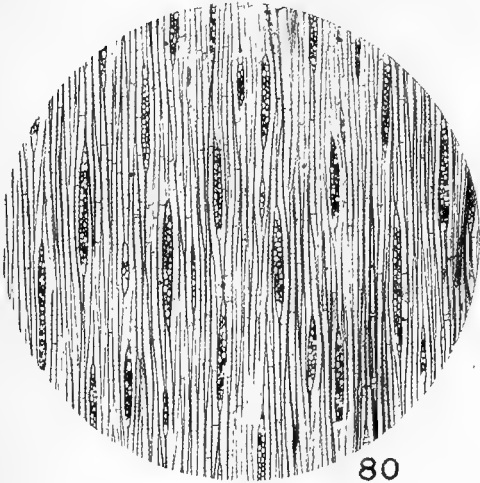




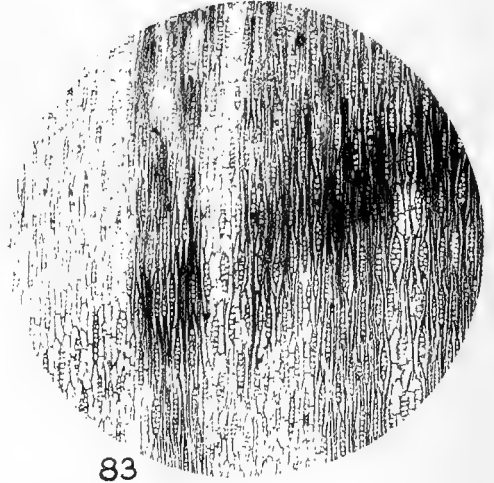
79



82



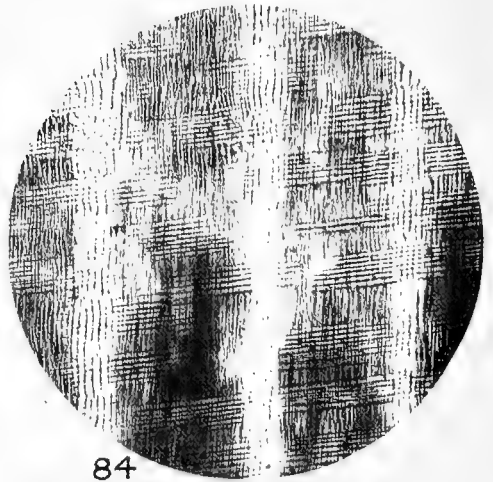
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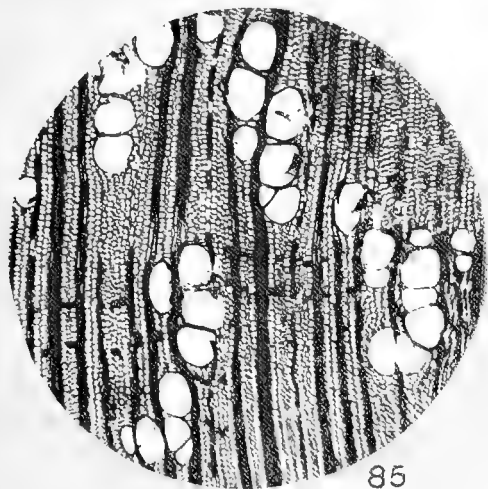
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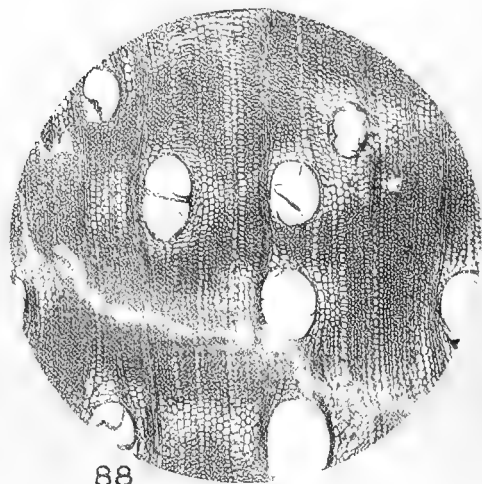
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84



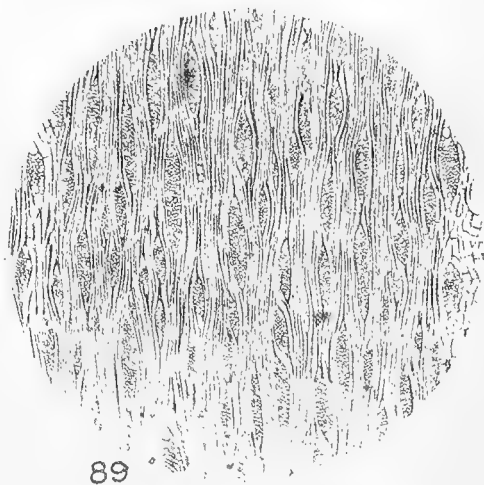
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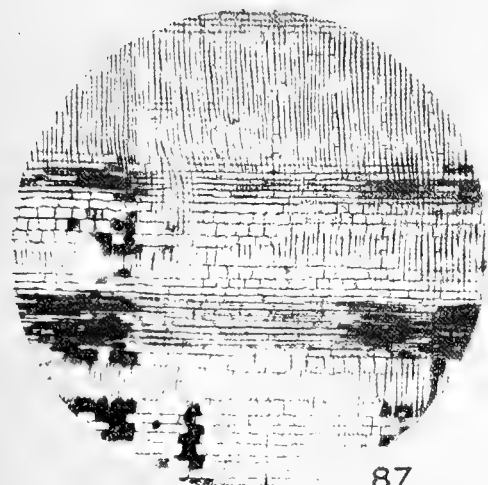
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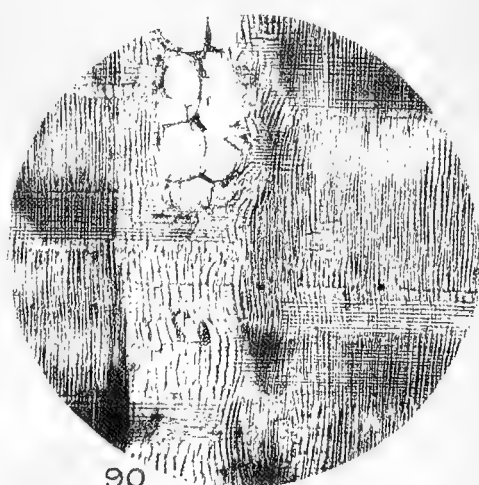
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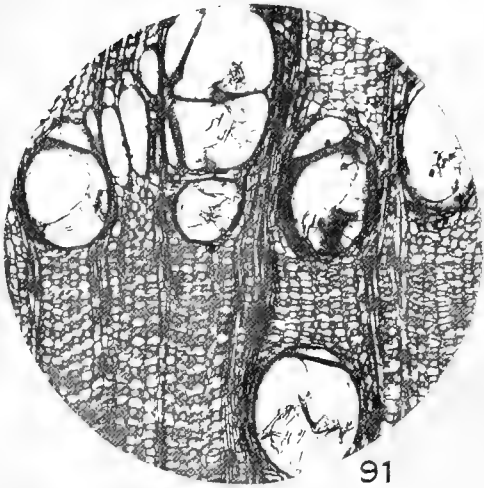
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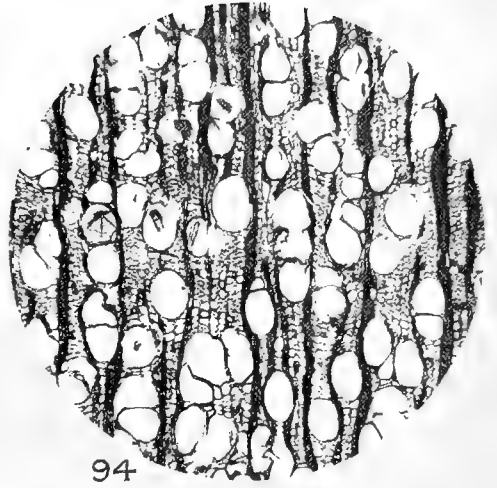
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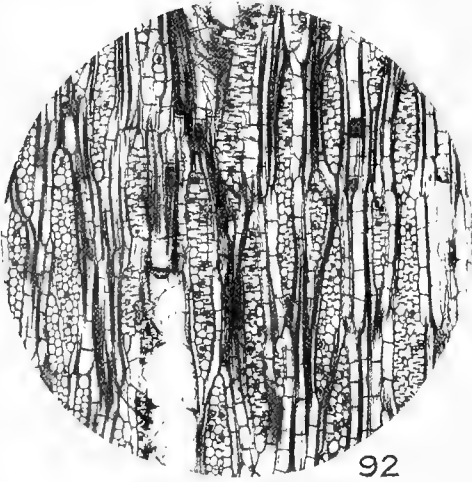
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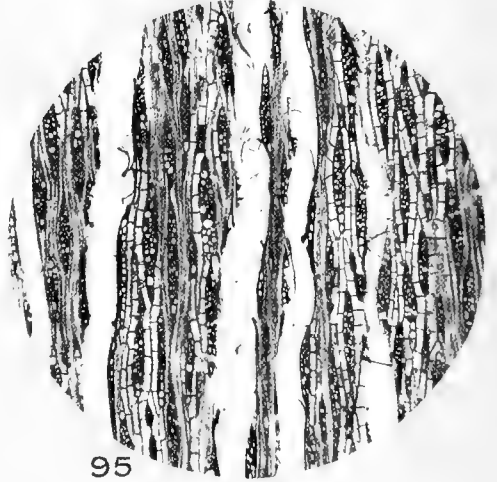
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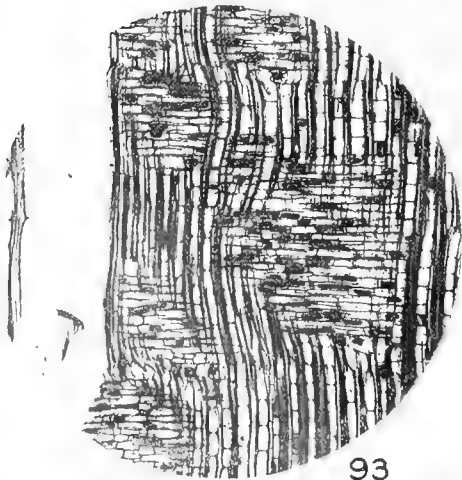
94



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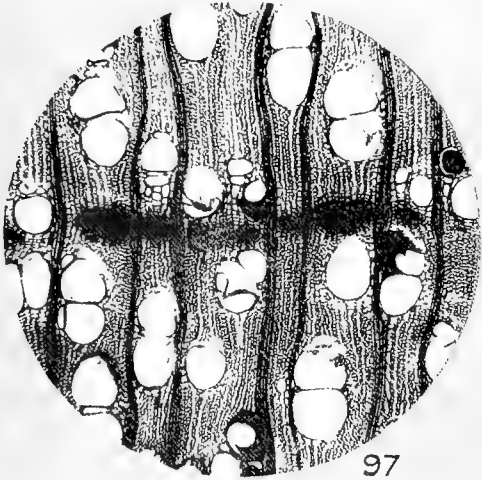
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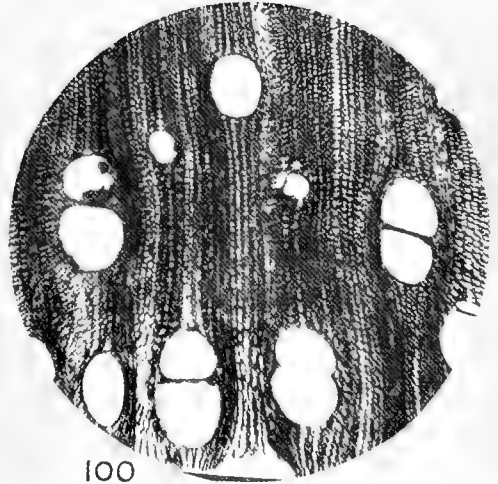
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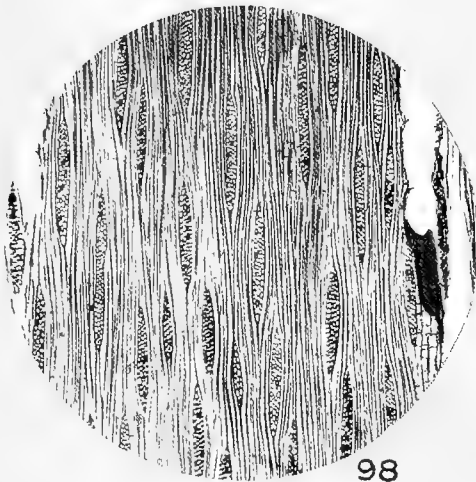
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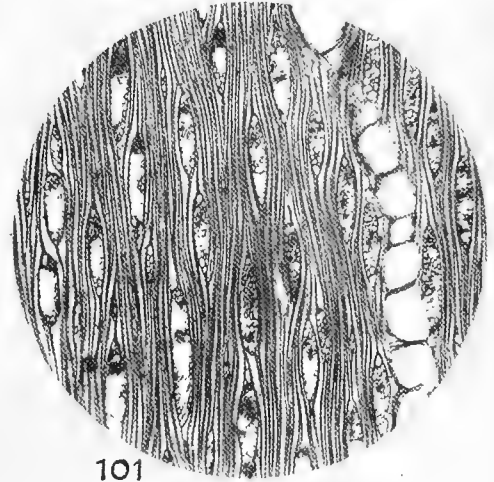
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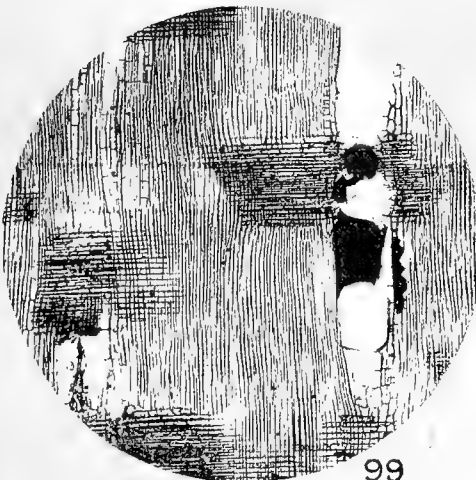
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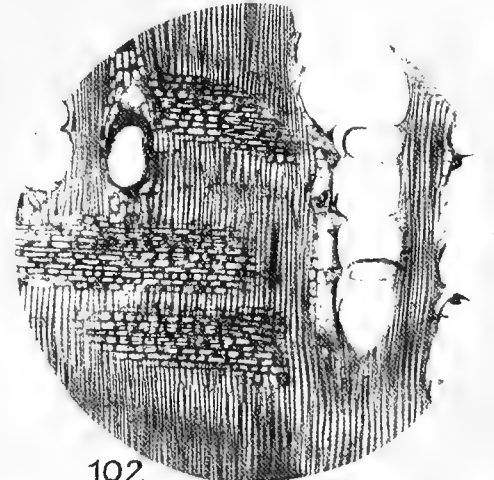
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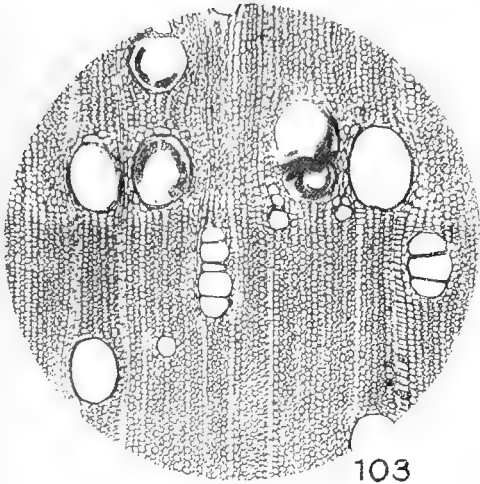
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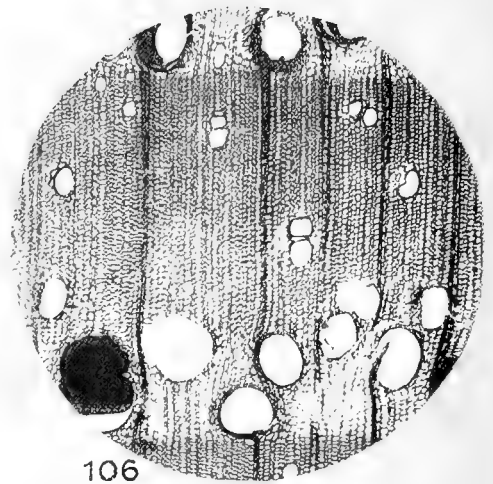
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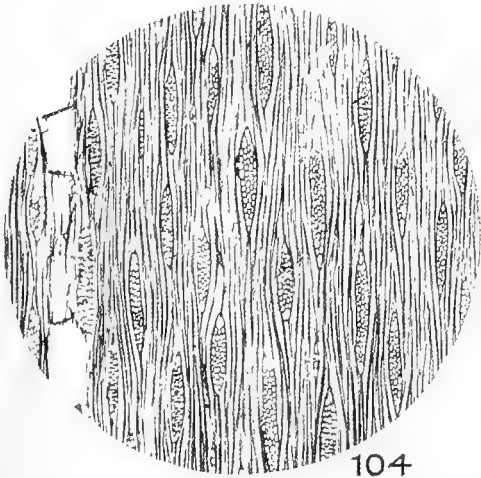
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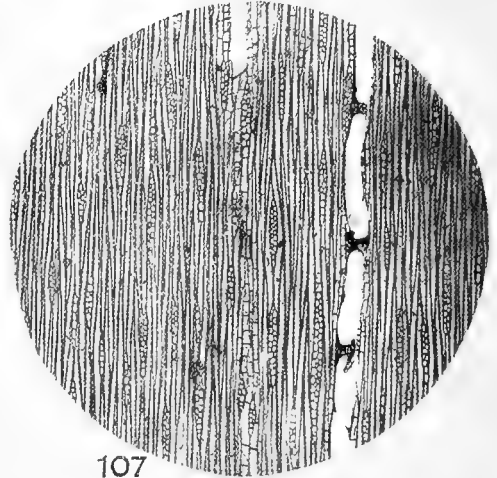
103



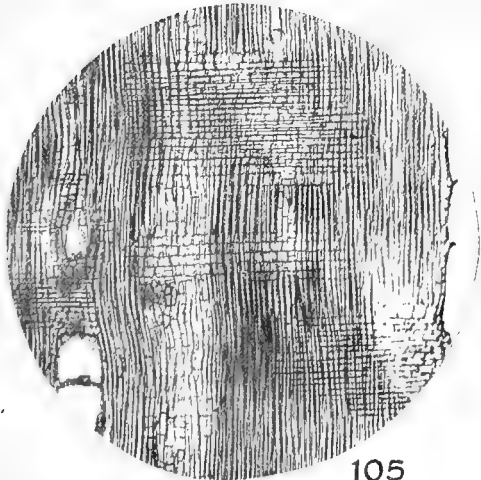
106



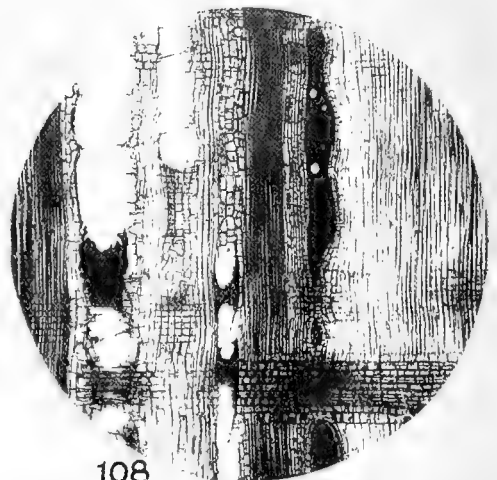
104



107

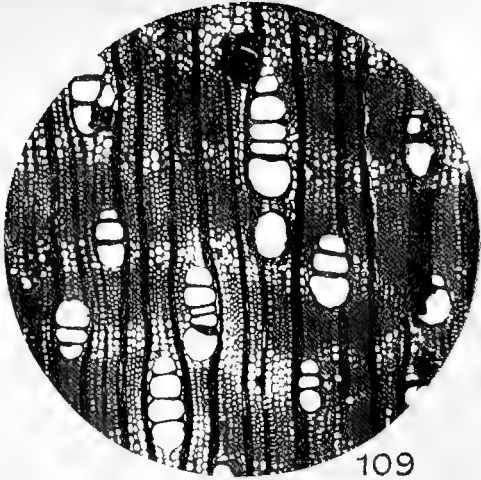


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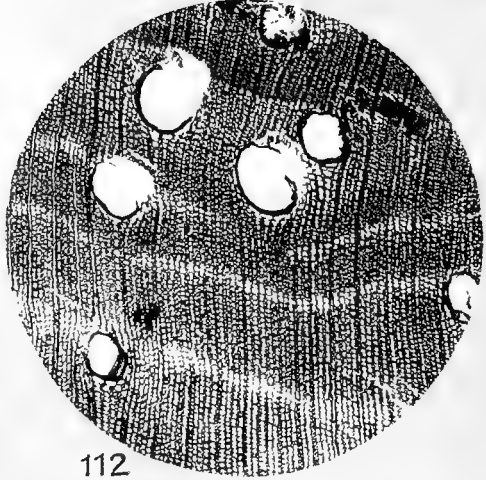


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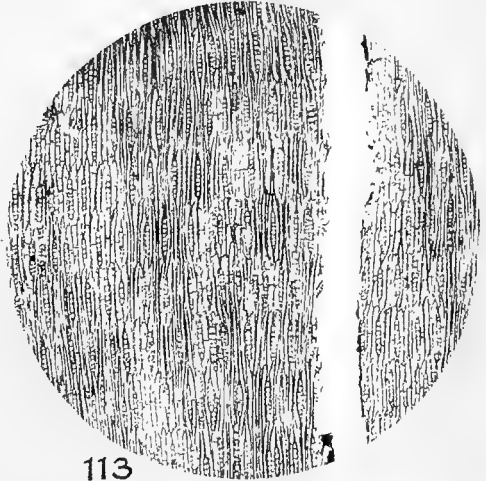
109



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110



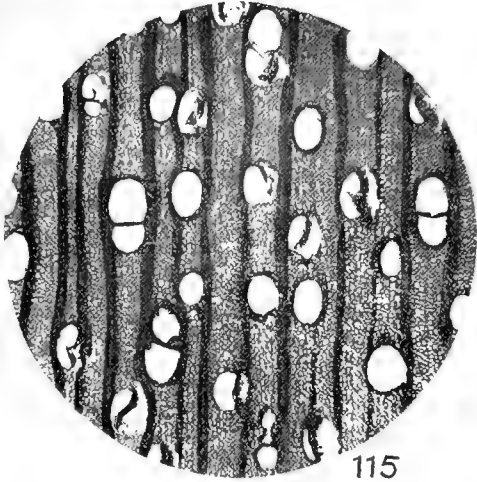
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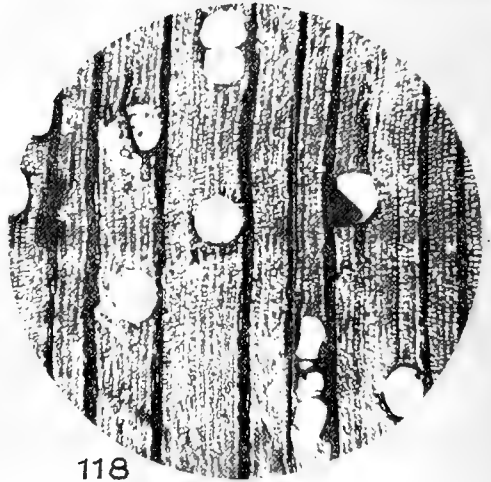
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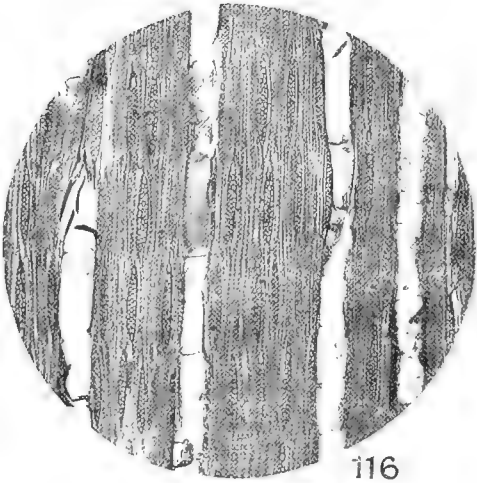
114



115



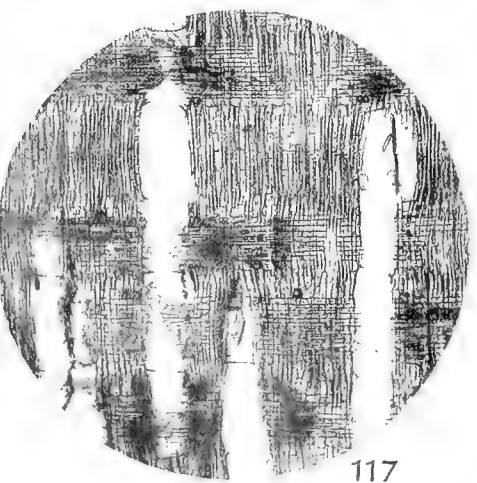
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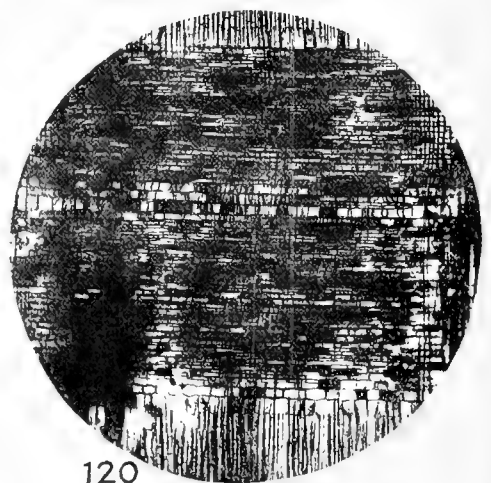
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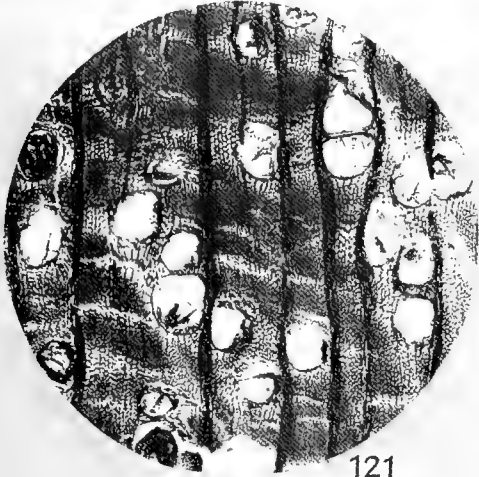
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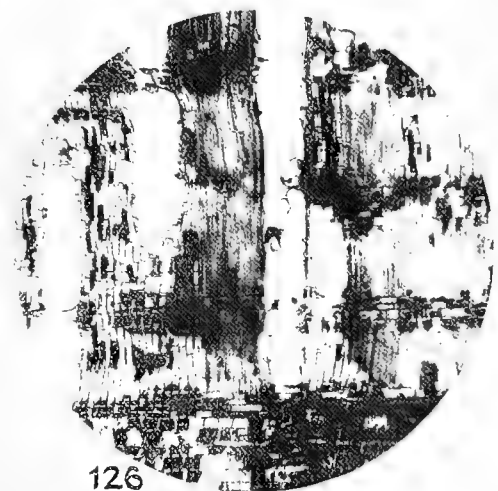
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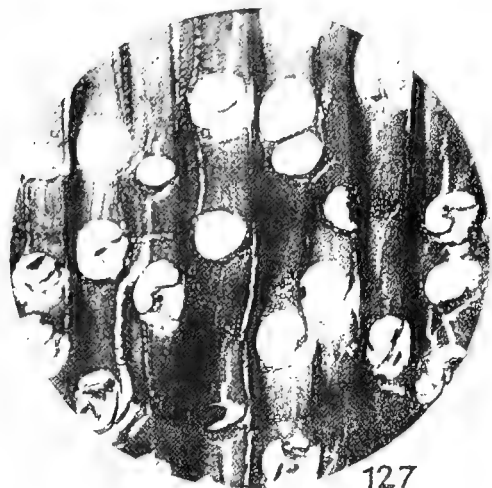


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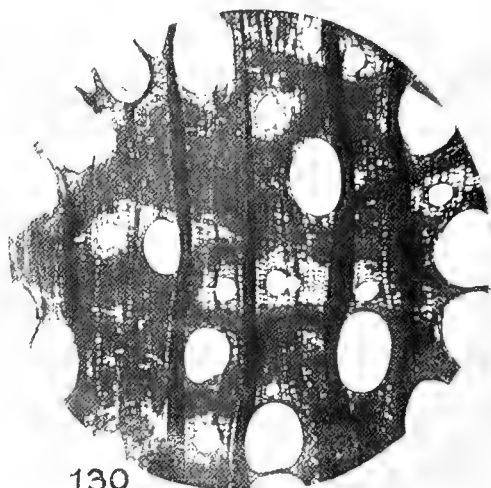


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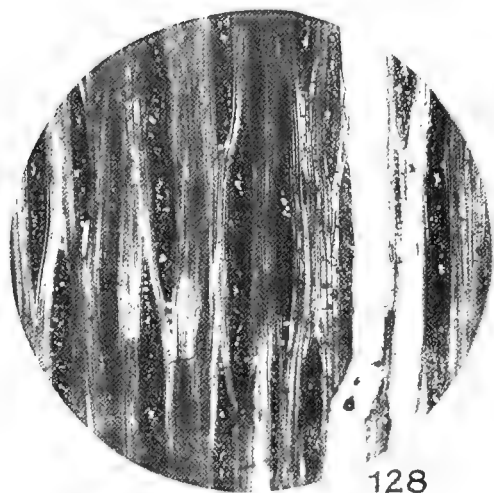




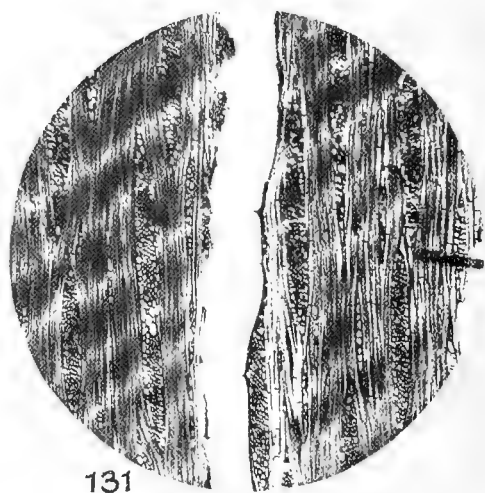
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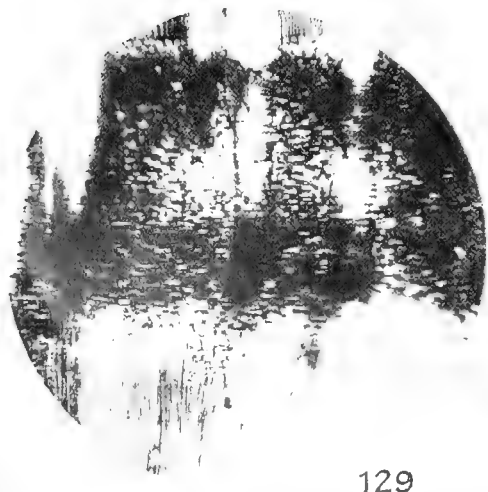
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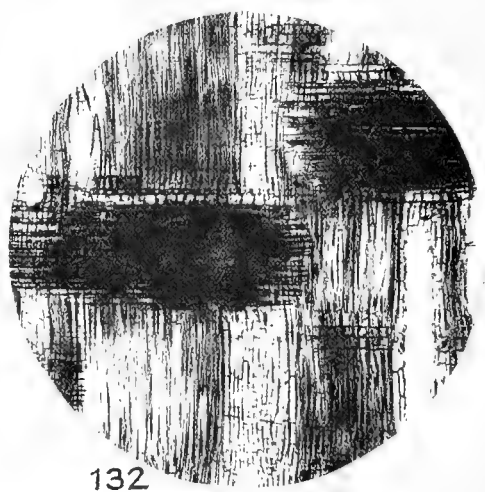
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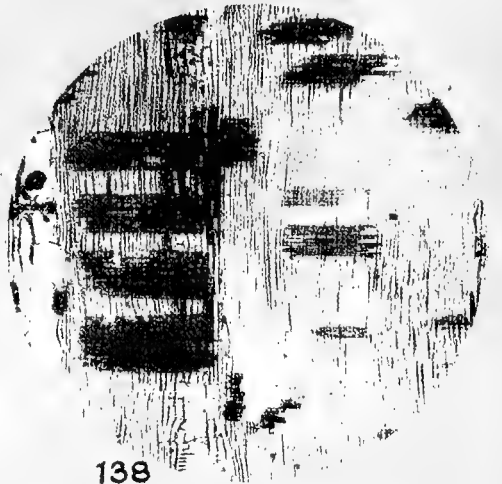
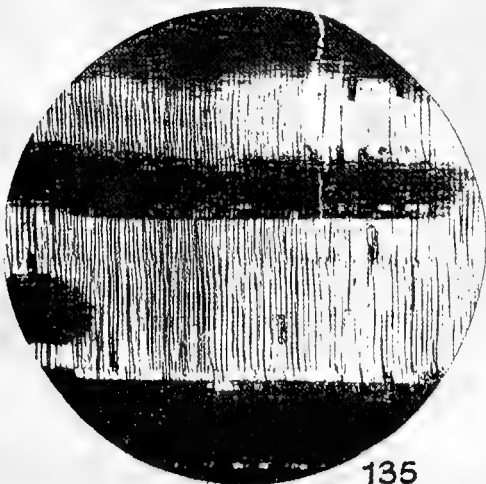
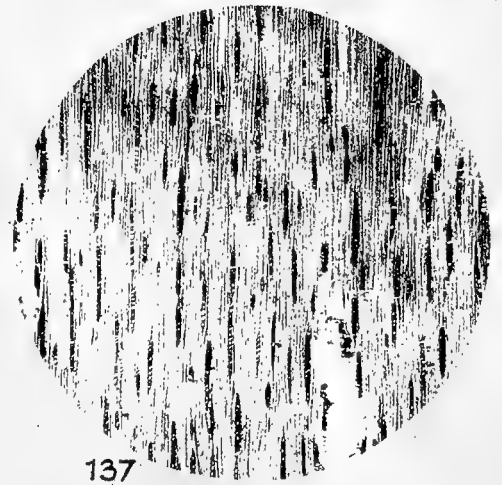
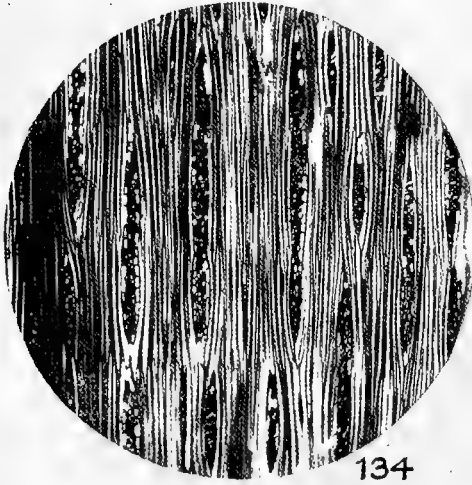
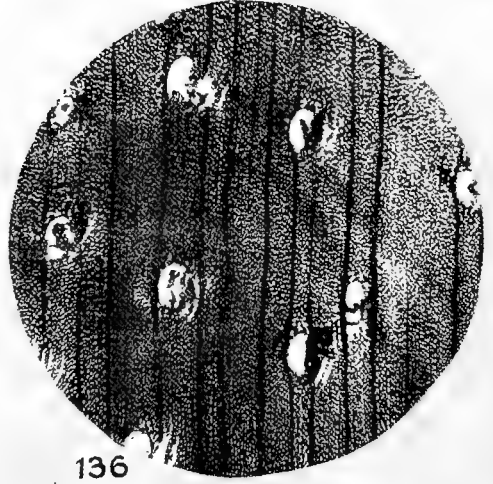
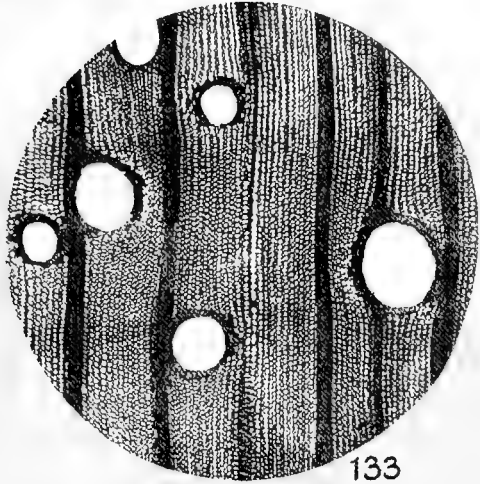
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A DISEASE OF TOMATO AND OTHER PLANTS  
CAUSED BY A NEW SPECIES OF PHYTOPH-  
THORA.

BY

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ECONOMIC BOTANIST TO THE DEPARTMENT OF AGRICULTURE AND TECHNICAL  
INSTRUCTION FOR IRELAND ;

AND

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(PLATES XLV.—XLVII.)

[*Authors alone are responsible for all opinions expressed in their Communications.*]

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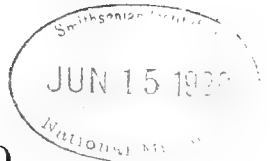
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XXXV.

A DISEASE OF TOMATO AND OTHER PLANTS CAUSED BY A  
NEW SPECIES OF PHYTOPHTHORA.

By GEORGE H. PETHYBRIDGE, B.Sc., Ph.D.,

Economic Botanist to the Department of Agriculture and Technical  
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AND

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(PLATES XLV.-XLVII.)

[Read NOVEMBER 19, 1918; published FEBRUARY 4, 1919.]

I.—INTRODUCTION.

IN the early summer of 1916 specimens of diseased young tomato plants (*Lycopersicum esculentum* Mill.) were submitted from a nursery in the suburbs of Dublin to the Seeds and Plant Disease Division of the Irish Department of Agriculture for examination and report as to the cause of the malady and the possibility of curing or preventing it.

A preliminary examination of the specimens at once showed that the trouble was not due to any of the commonly occurring diseases of the tomato. On the contrary, the disease appeared to be one of a new type; and a visit was therefore paid to the nursery in question to examine further cases of it, and to obtain information concerning its origin and degree of seriousness.

It was learned that the disease was first noticed in this nursery three years previously, only a few plants being attacked at that time. In the succeeding year it had become more serious, while at the time of our visit nearly one-half of a large stock of young tomato plants were found to be either dead or dying. In these three years, therefore, the disease had become so well established in this particular nursery as to interfere very seriously with the raising of young tomato plants.

The same disease was discovered subsequently in two other nurseries, as well as in some private gardens in the same locality, while, during the course of our study of it, young tomato plants affected with it have been received from



various places in Ireland, showing that the disease must be fairly widespread here. We now have reason to believe that the disease also occurs in England.

Subsequent to the discovery of the parasite which causes the disease, cases of attack on Asters and Petunias by the same or a very similar organism were met with; and the scope of the investigation was extended to include such cases. Some account, therefore, of this part of our work is included in the present communication.

## II.—SYMPTOMS OF THE DISEASE.

The disease is usually first fully apparent when the young affected plants are about six inches high. In certain cases, however, it can be recognized in much younger plants, while in others the attack may not become obvious until the plants are considerably older.

It is characterized by the appearance of a brownish or blackish discoloration of the external tissues of the stem at or just above ground-level. These tissues become more or less shrivelled and destroyed, and sooner or later the top-heavy stem of the young plant falls over.

At first the foliage of the young plants does not usually show any characteristic symptoms of disease. Even on plants which have already toppled over, the leaves may remain green and turgid for a time, this being due to the fact that the upward passage of sap through the woody tissue of the stem is not all too seriously curtailed at the outset. As time goes on, however, the margins of the leaflets begin to roll upwards and inwards, the leaves turn yellow and finally die.

Occasionally, but not frequently, the foliage becomes flaccid or wilted before yellowing and death occur; but, strictly speaking, the disease is not one of the "wilt" type, and it is not one of hadro- or tracheo-mycosis such as occurs in tomato and potato plants when attacked by *Verticillium albo-atrum* (7).<sup>1</sup>

If an affected plant be lifted carefully from the soil, it is found that the rotting of the tissues at the base of the stem is continued downward into its underground portion and also into the root system. This, however, is the reverse of the direction in which the rot actually proceeds; for it starts in the roots, as a rule, works its way upwards for a short distance into the stem, and then usually ceases just above soil-level.

The cessation of the rot at this point is generally a decided one, and is perhaps due to changed moisture conditions. It may be stated here that if young plants which are not too far gone be cut off above the region of decay

<sup>1</sup> The figures in brackets refer to the bibliography at the end of the paper. See p. 503.

and be treated as "cuttings," many of them throw out a fresh set of adventitious roots, and develop into healthy, useful plants.

The primary root-system of an affected plant is usually badly decayed or entirely rotten. Evidently stimulated by the loss of these roots, the plant attempts to combat the attack of the parasite by developing a system of secondary, adventitious roots from the still healthy base of the stem higher up. But these also in turn become attacked; and finally the plant dies. It is, therefore, characteristic of this disease to see the older roots dead and decayed, and to find a bunch of adventitious roots formed above them, some of which may also be in process of being killed.

Essentially, then, the disease takes the form of a more or less rapidly progressing rot of the root system in which a portion of the base of the stem also becomes involved; and if a popular name for the disease be demanded, the term "tomato foot-rot" may, perhaps, be regarded as not unsuitable for it. A typically affected young plant is illustrated in fig. 1, Pl. XIV.

The rapidity with which death supervenes appears to be closely correlated with the age of the plant when first attacked; but it is doubtless also influenced by the conditions of temperature and moisture, both of soil and atmosphere, under which the plants are being raised. If infection occurs when the seedlings are young, death rapidly ensues; but if the plants are older, their struggle for existence is more prolonged.

On cutting the base of the stem of an infected plant longitudinally it is seen that the parts most involved in the rot are the soft parenchymatous tissues surrounding and surrounded by the wood. Microscopical preparations show the presence of comparatively abundant thin-walled, branched non-septate hyphae, of relatively large diameter, traversing these tissues both intra- and inter-cellularly. Where these hyphae invade still healthy tissue, however, they travel only between the cells. In very young seedlings hyphae of a similar kind were sometimes observed running longitudinally in the wood-vessels; but in older diseased plants the elements of the wood do not become invaded with hyphae until the rotting has reached an advanced stage.

Hyphae of the kind described are always found in the diseased tissues of affected plants; and if such plants are only recently attacked, these hyphae constitute practically the whole of the mycelium present. This mycelium, as will be seen from a subsequent section of this paper, was found to belong to a hitherto undescribed species of *Phytophthora*. Of course in later stages of the disease the dead tissues become invaded with saprophytic fungi and bacteria of various kinds; and these add considerably to the difficulty of making a satisfactory diagnosis of the actual parasite in advanced cases of the disease.

In one case at least a second parasite (a species of *Pythium*) was found along with the *Phytophthora*; but although in this particular instance the former may have contributed to the death of the plant, the detailed work carried out by us on numerous cases of the disease under consideration shows clearly that the real cause is not a *Pythium* but a *Phytophthora*.

### III.—THE CAUSATIVE PARASITE.

Specific proof that the fungus, to which the mycelium described above belongs, is the actual cause of the disease will be adduced in a later section of this communication. Before proceeding to this it will be desirable to give an account of the fungus and of its development on the host plant and in pure cultures.

Scrapings made from the superficial tissues of diseased stems below ground and examined with the microscope sometimes, but by no means always, show the presence of a few sporangia of a phycomycetous fungus of the *Nozemia* or the *Phytophthora* type. If affected plants be removed from the soil and allowed to remain in a moist atmosphere for a day or two, such sporangia are developed more freely. Better still, if the plants are placed with their roots and the bases of their stems in water, mycelium bearing these sporangia (but not in great abundance) grows out into the water from the diseased parts of the plant. This mycelium sometimes bears peculiar swellings such as are illustrated in fig. 9, Pl. XLVII., and these may be looked upon possibly as abortive attempts to produce sporangia or perhaps sexual organs. Some of them at any rate are suggestive of oogonial incepts which have not met with antheridia, but which, in spite of this, have made considerable growth. Similar bodies are also sometimes developed in pure cultures.

The sporangia are borne on sporangiophores which are branched in a sympodial manner. They are inversely pear-shaped, but often much elongated and somewhat irregular in form (fig. 2, Pl. XLVII.). The apex of the ripe sporangium is always blunt, but its wall in this region is always slightly thicker and more hyaline than elsewhere. In this respect the sporangium resembles that of *Phytophthora erythroseptica*, there being no apical papilla in either case such as is present in the sporangia of *P. infestans*. (See fig. 3, Pl. XLVII.)

The sporangia are rather firmly attached to the sporangiophores, and do not break off easily. When forcibly detached each sporangium carries with it a short length of the branch of the sporangiophore on which it was borne, which forms a very short stalk. The sporangium is filled with a granular mass of protoplasm. In size the sporangia vary considerably, ranging from  $24\mu$  to  $50\mu$  in length and  $17\mu$  to  $30\mu$  in breadth at the broadest part. On

the average they measure  $40\mu$  by  $27\mu$ , and they are, therefore, somewhat larger than those of *P. erythroseptica*.

The branches of the sporangiophores do not differ markedly from the ordinary mycelial hyphae, and are as a rule long and straggling. Careful observation has shown that the first formed sporangium is terminal, and that the branch of the sporangiophore which bears the second arises near the base of the first sporangium, which thus becomes pushed aside in the manner first described by de Bary for *P. infestans*, but no local swelling of the sporangiophore occurs, as in that species. More than three sporangia attached at one time to a branched sporangiophore have never been seen. (See fig. 4, Pl. XLVII.)

The mode of germination of the sporangia has been carefully followed, and it resembles very closely that occurring in *P. erythroseptica* (5). The contents of the sporangium become more coarsely granular, contraction of the contents from the sporangium wall occurs to some extent, and aggregation into a number of zoospore units takes place (fig. 3, Pl. XLVII.). Suddenly the thicker, hyaline, apical portion of the sporangium wall becomes stretched or expanded into an almost spherical, extremely thin-walled sac, into which the whole or the major portion of the contents of the sporangium immediately passes. Practically at the same moment the wall of this sac dissolves, and the contents of the sporangium break up into a number of zoospores which swim off in all directions. Any contents which may not have escaped from the sporangium become resolved at the same time into zoospores which may swim out of the now ruptured sporangium, or may remain within it and germinate there.

The zoospores are lemon-shaped with a distinct longitudinal groove on one side, from the base of which two cilia arise, one directed forwards and the other backwards. After a short time each zoospore comes to rest, loses its cilia, assumes a more or less spherical shape, secretes a thin wall and produces a germ-tube. When at rest the zoospores measure from  $10\mu$  to  $15\mu$  in diameter, and they are, therefore, somewhat larger than those of *P. erythroseptica*.

When a sporangium has liberated its zoospores it not infrequently happens that the branch of the sporangiophore which bore it grows directly onwards and forms a second sporangium. If this branch becomes elongated the second sporangium is formed outside of and beyond the original one, now empty, as is shown in fig. 7, Pl. XLVII. But if this branch remains short, the second sporangium, being almost sessile, remains within the first formed one; and a third may be developed within the second as illustrated in fig. 8, Pl. XLVII. A similar state of things has been described by Robinson (9) for

the fungus (presumably a *Phytophthora*, and possibly identical with the one now being dealt with) which causes the "Black Neck" disease of Asters.

Less commonly than by the production of zoospores the sporangium develops by producing a single germ-tube, which usually arises at the distal end of the sporangium (figs. 5 and 6, Pl. XLVII.). One very unusual case was observed, however (fig. 10, Pl. XLVII.), in which a single sporangium developed a considerable number of germ-tubes, one of which (much shorter than any of the others) proceeded from the usual place, while the others were distributed at various points over the surface. The appearance suggested that partial segregation into zoospore-units had occurred; the sporangium did not, however, open, and the free swimming stage of the zoospores was suppressed. Nevertheless, each zoospore-unit developed its own germ-tube, which grew out in the manner illustrated.

A very considerable amount of time and trouble has been spent in searching for the sexual organs of the fungus in the dead tissues of the host plant both when naturally infected as well as when artificially inoculated. What appear to be undoubted oospores of some fungus, frequently still surrounded by the remains of the oogonial wall, have occasionally been met with, but in no case has an antheridium been observed. These spores are somewhat smaller than those which are produced by the fungus when grown in pure culture; and they lack the yellowish tinge of the latter. They have a smooth, thick wall and granular protoplasmic contents, together with a large central oil drop, and a highly refractive body, probably containing the nucleus. They closely resemble, except in size, the ripe oospores of *Phytophthora erythroseptica*.

In most of the cases in which the attempt was made, these spores were successfully germinated, and the mode of germination in its early stages exactly resembles that described for the oospores of *P. erythroseptica* (5). When, however, the germ-tubes had reached a length equal to about three times the diameter of the spore, growth either ceased at once or soon after the formation of a terminal swollen body into which the contents of the germ-tube passed. In some cases this body sent out a germ-tube of its own which reached a length of several times that of its own diameter, and then ceased to develop further. In no case was mycelium, bearing sporangia of any sort, produced from these spores; hence it is not possible to say with certainty to what fungus they belonged.

Attempts were made to raise cultures from the germinating spores, but these failed, owing either to the early death of the germ-tubes or to serious contamination of the medium with bacteria; for it was naturally impossible to obtain these spores from the diseased host plant free from contamination.

The absence of antheridia might perhaps be explained by their becoming torn away during the process of teasing out the spores from the diseased tissues, but it seems scarcely probable that all signs of them would thus be obliterated. On the other hand, there is the possibility that the fungus may produce oospores in the tissues of the host parthenogenetically. *Phytophthora infestans* develops parthenogenetic oospores in pure cultures (8), and at least one other species described as a *Phytophthora* (*P. Theobromae*) produces oospore-like bodies or chlamydospores (?) in the tissues of the host it attacks.

The disease (as will be seen in a subsequent section of this paper) is contracted from the soil, and it is reasonable to suppose that oospores, or resting spores of some kind, are developed in the dead tissues of the host. We have, however, up to the present failed to obtain convincing evidence that this is the case. That true oospores are produced in pure culture will be evident from what follows in a later section (p. 496).

#### IV.—PROOF OF PATHOGENICITY.

Owing to the comparatively sparing production of sporangia and to failure to get the fungus to grow (except to a limited extent) from what possibly were its oospores, under conditions that could be controlled, it was found impossible to obtain the fungus in pure culture by starting from a single spore. It was, however, eventually isolated in the following way:—

Portions of diseased tomato stems, about one inch long, were steeped in a weak solution of mercuric chloride (1 : 1000) for one minute. After washing in sterile water and allowing to become air-dry, small portions of the inner affected tissues were removed with sterile instruments and under as aseptic conditions as possible to set plates of sterile media such as wort-gelatine, Quaker Oat-agar, and beef extract-agar.

After a few days, fungus mycelium had grown out from the portions of tissue to the surrounding medium, and fragments of the freshly grown peripheral mycelium were transferred with aseptic precautions to slants of Quaker Oat-agar in test tubes. Some of these transfers, after further growth had occurred, were found to be impure, being usually contaminated with bacteria. In a few cases, however, careful microscopical examination and the subsequent behaviour of the cultures clearly showed that a single organism was present; and parallel isolations showed that this organism was the same in all cases.

The organism thus isolated developed sporangia in culture similar to those found on the host plant. Its pathogenicity was proved in the following way:—Into the stems of each of two healthy tomato plants, grown in pots,

a small incised wound was made with a sterile scalpel at the region of soil-level, and into each wound a small portion of a six-day-old pure culture of the fungus was inserted. The wounds and their contents were then wrapped round with a bandage of tinfoil. A third plant was treated similarly, except that no inoculating material was placed in the wound; and this plant served as a control.

After the expiration of forty-eight hours it was clear that infection of the two inoculated plants had occurred, for rotting had set in beneath the tinfoil and had extended beyond it. Both plants had a tendency to fall over at the point of infection, and one of them was staked in order to prevent this. After a further two days the unstaked plant had fallen over and its lowest leaves were beginning to turn yellow. The upper part of the plant, however, was but little affected and had responded to the stimulus of gravity by carrying out a negatively geotropic curvature. In both plants the diseased areas had become shrivelled and brown, and they closely resembled naturally infected plants as seen in the nursery. The control plant showed no symptoms of disease throughout the experiment. These plants as seen four days after inoculation are illustrated in fig. 2, Pl. XLV.

A portion of the diseased tissue of one of the plants was incubated in a moist atmosphere, and the result was the production of a fair crop of sporangia exactly similar to those already described as being found on naturally infected plants. From the remaining portion the fungus was re-isolated by the method already described, and grown in pure culture; and it was found to be similar in all respects to that used for inoculation purposes.

This experiment clearly proved the pathogenic character of the fungus; and this has been confirmed by the results of very many inoculation experiments, subsequently carried out, in which failure to produce the disease has not once occurred. In plants which are older, infection following artificial inoculation occurs more slowly, but even in such cases the fungus ultimately obtains the mastery and the plants become killed.

Successful inoculation experiments were also made with tomato fruits, both green and when ripe. The fungus causes a rather rapid rot of the ripe fruit, accompanied by a most offensive odour. The type of rot produced is quite different from that described under the name of "Buckeye" rot by Sherbakoff (13), and due to *Phytophthora terrestris*. In one case—the only one where the attempt was made—the fungus was re-isolated in pure condition from an artificially rotted ripe tomato fruit, and proved to be identical with that used for the inoculation.

Infection experiments have also been carried out with various other plants. Negative results were obtained with *Senecio vulgaris*, *Helianthus annuus*, and

*Nicotiana affinis*. The fungus, however, was found capable of attacking Asters, Petunias, Wallflowers (*Cheiranthus*), *Gilia tricolor*, and seedlings of Beech (*Fagus sylvatica*), producing in all these plants symptoms very similar to those observed in naturally affected tomato plants. In some of these, as will be seen from a later section of this paper, the same disease occurs naturally.

When inoculated into living potato-tubers, the fungus causes a rot very similar to the "pink rot" caused by *Phytophthora erythroseptica*. When portions of the rotted tissue were placed in sterile water, sporangia were developed rather sparingly, but no sexual organs were formed. Under these conditions, *P. erythroseptica* produces an abundant crop of sexual organs and sporangia.

The fungus has been found to be actively parasitic to apples and white turnips. It also slowly attacks mangels and swedes, but does not attack carrots or parsnips. In all cases inoculation was carried out through wounds.

#### V.—DEVELOPMENT OF THE FUNGUS IN PURE CULTURES.

The fungus was found to grow with more or less vegetative luxuriance on a considerable number of different agar and gelatine media, of which sixteen kinds were tried, as well as on sterilized portions of various stems, fruits, &c. It did not cause the liquefaction of gelatine media. The kind of mycelium developed is illustrated in fig. 1, Pl. XLVII.

The striking point about all these cultures was the reluctance of the fungus to produce either asexual or sexual reproductive organs. In a few cases, as, for instance, on sterile soil and on oat-extract-agar, there was a meagre development of sporangia. This also occurred when a small portion of a culture on Quaker Oat-agar was transferred to sterile tap-water or bog-soil-extract. In other cases, the addition of sterile water to tubes containing slanted cultures on various media resulted in a good development of mycelium in the water, but reproductive organs did not arise.

In the cases mentioned above in which sporangia were formed, they exactly resembled those already described both in shape and size as well as in method of zoospore production, and they need not, therefore, be described again.

At this point in our work the study of the fungus had to be suspended temporarily, owing to the pressure of urgent work more directly connected with food-production; and a period elapsed during which the only thing done was to make transfers of the cultures every few weeks in order to keep the fungus alive and in good order until the study of it could be resumed. This period lasted from January to October. At the beginning of it the stock cultures were on Quaker Oat-agar, and this medium alone was used for the subsequent transfers. The whole series of original stocks and intermediate transfers was kept for future microscopical examination.



On resuming the work in October this examination revealed the abundant presence of sexual organs in the original stock cultures, which, however, at this time were dead; and these organs were also found in a few of the intermediate transfers, the more recent of which were still living. They were also produced, but not very abundantly, in sub-cultures made subsequently; and it was found that they developed rather more readily in a hard Quaker Oat-agar medium containing  $12\frac{1}{2}$  per cent. of agar than in the one usually employed, which contains only  $1\frac{1}{2}$  per cent. of agar.

The sexual organs are of the type first described for *Phytophthora erythroseptica* (4) and *P. infestans* (8). It is, therefore, clear that the fungus is a true Phytophthora. Using Murphy's (3) terminology the antheridia are amphigynous and not paragynous, as in the genus *Nozemia*.

The antheridium may be terminal or intercalary, and often has a short hypha proceeding from it, as in *P. erythroseptica*, which, as Murphy has suggested, may play the part of a safety-valve by relieving the pressure caused by the growth of the oogonial incept when within the antheridium. Ripe antheridia are variable in form and size, and their dimensions are not of much import for diagnostic purposes.

The oogonium may also be terminal, but it is more usually a lateral outgrowth. When ripe it is pear- or balloon-shaped. The oogonial incept having penetrated the antheridium and emerged from its top swells up to form an almost spherical sac in which the oospore is developed. The lower, funnel-shaped base of the oogonium remains within the antheridium and becomes closed at its narrow end with a cellulose plug. The rather thin wall of the oogonium is at first hyaline, but becomes amber-coloured with age. The average diameter of the spherical part of the oogonium is  $30\mu$ .

Fertilization probably occurs in the manner described by Murphy (3) for *P. erythroseptica*; and the oosphere develops into a thick-walled oospore, which, when ripe, contains a large oil drop surrounded by finely granular protoplasm in which a small oval highly refractive body lies which possibly contains the nucleus. The wall of the oospore, at first hyaline, becomes straw-coloured, and averages about  $3\mu$  in thickness, while the diameter of the spore averages  $25\mu$ . The germination of the oospores developed in pure cultures has not yet been followed. The sexual organs are illustrated in figs 3, 4, and 5, Plate XLV, and fig. 11, Plate XLVII.

#### VI.—RECOGNITION OF THE FUNGUS AS A NEW SPECIES.

The peculiar morphology and mode of development of the sexual organs first discovered in *Phytophthora erythroseptica*, *P. infestans*, *P. Phaseoli*, and surmised to occur in *P. omnivora* var. *Arecae*, led to the suggestion (4), (6)

that the old genus *Phytophthora* should be divided. It was proposed that only those species with amphigynal antheridia should remain in this genus, and that the other species, with paragynal antheridia, formerly included in it, should be made to constitute a new genus, *Nozemia*. This suggestion has been followed by Murphy (3), who has recently published a detailed account of the morphology and cytology of the sexual organs of *P. erythroseptica*, but, unfortunately, not by Rosenbaum (11) in his statistical studies of species of the two genera. The latter author has, however, shown that the surmise as to the true character of the sexual organs in *P. omnivora* var. *Arecae*, above referred to, was correct (10).

Since that time five other species of *Phytophthora* have been described by the following authors:—Butler and Kulkarni (1); Dastur (2); Tanaka (Swada) (12); and Sherbakoff (13), in which the sexual organs are of the type found in *P. infestans*, the earliest described member of the group. The following is a list of all such species described up to the present:—

- |                                      |                                 |
|--------------------------------------|---------------------------------|
| (1) <i>P. erythroseptica</i> Pethyb. | (6) <i>P. Colocasiae</i> Racib. |
| (2) <i>P. infestans</i> de Bary.     | (7) <i>P. Allii</i> Saw.        |
| (3) <i>P. Phaseoli</i> Thaxt.        | (8) <i>P. Melongenae</i> Saw.   |
| (4) <i>P. Arecae</i> (Colem.).       | (9) <i>P. terrestria</i> Sherb. |
| (5) <i>P. parasitica</i> Dast.       |                                 |

It seems possible, judging from the published descriptions alone, that the last two species in this list may be identical, but this can only be decided by a careful comparison of pure cultures of the two.

The question arises as to whether the fungus which causes the disease of tomato plants described in the present paper is identical with any one of those enumerated above, or whether it must be regarded as a new species hitherto undescribed. From a careful study of the published descriptions we conclude that our fungus cannot be identical with any one of the above nine, but it is scarcely necessary to discuss the points of difference in detail here. The sporangia of the above-mentioned nine species, with the exception of *P. erythroseptica*, are all more or less distinctly papillate, while those of our fungus resemble those of the last-named species in being blunt or rounded at the apex.

Our fungus most nearly resembles *P. erythroseptica*, but differs from the latter in the size and colour of its sexual organs and also in its remarkable reluctance to produce sporangia and oospores in quantity. A long series of parallel cultures and infection experiments was carried out with these two fungi, into the details of which it is not necessary to enter here. It is

sufficient to state that the results showed conclusively that the two fungi are not identical; and we conclude that the tomato fungus is one which has hitherto not been described.<sup>1</sup>

Its diagnostic characters may be summed up briefly as follows:—

**Phytophthora cryptogea** sp. nov. Mycelio ramoso quoad partes recentiores e septato vetustiores septato; conidiis plerumque inversipyriformibus  $24-50\mu \times 17-30\mu$  apicibus obtusis non-papillatis sympodialiter genitis; zoosporis 2-ciliatis  $10-15\mu$  diam.; oogoniis hyalinis flavescentibus pyriformibus  $30\mu$  diam.; antheridiis amphigynis hyalinis; oosporis sphaericis flavescentibus crasso episporio praeditis  $25\mu$  diam.

*Hab.* in radicis caulibusque vivis *Lycopersici esculenti* et *Petuniae* sp. in Hibernia.

#### VII.—THE DISEASE IN PLANTS OTHER THAN THE TOMATO.

*Petunia.*—Some time after beginning the study of the Tomato disease we received specimens of *Petunia* seedlings suffering from a disease the symptoms of which were very similar to those observed in the Tomato plants.

Microscopic examination of the diseased tissues confirmed this similarity, for a *Phytophthora*-like fungus was present, bearing sporangia similar to those observed in the case of the Tomato.

The fungus was isolated from the *Petunia* in the same manner as was the one from the Tomato, and it was grown in pure culture. It was proved by infection experiments to be pathogenic not only to *Petunia* but also to Tomato, Aster, Wallflower, and *Gilia tricolor*.

In culture the fungus isolated from *Petunia* behaved exactly like that obtained from Tomato, and, like the latter, it produced sexual organs. These organs were similar in every respect in the two cases, and we conclude that *Phytophthora cryptogea* is the cause of the disease not only of Tomato plants but also of *Petunias*.

*Aster.*—About the same time diseased *Asters* were observed in a garden in the same locality as that from which the diseased Tomato plants were originally obtained. The root systems and the lower parts of the stems were

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<sup>1</sup> While the present paper was being prepared for press we found that Mr. G. T. Spinks (14) had described a disease under the title "Damping-off and Collar Rot of Tomatoes," which is probably identical with the one we have been dealing with. The causative parasite appeared to be a species of *Phytophthora*, but it was not grown in pure culture, and no sexual organs were obtained. It was not therefore identified or described in detail.

more or less decayed; and microscopical examination revealed in them the presence of phycomycetous mycelium bearing Phytophthora-like sporangia.

The fungus was isolated and grown in pure culture. As far as the morphological characters of its mycelium and sporangia are concerned no differences could be seen between it and the fungus isolated from Tomato plants. It was proved to be pathogenic to Aster, Tomato, Petunia, Wallflower, and *Gilia tricolor*.

The finding of this fungus in Aster recalled the disease of this plant recently described by Robinson (9) and attributed by him to a species of Phytophthora. This author did not succeed in obtaining the sexual organs of the fungus in pure culture, and hence did not identify it or name it.

Mr. Robinson was good enough to supply us with a culture of his fungus, which, unfortunately, on its arrival was found to be contaminated with bacteria. We succeeded, however, in getting it pure, and we carried out a parallel series of cultures and infection experiments with it and with the strains isolated by us from Tomato, Petunia, and Aster.

It was found that Robinson's strain was pathogenic to exactly the same plants as the others were, and produced the same type of disease. But whereas in the case of the strains isolated by us from the Tomato and Petunia sexual organs were produced in pure culture, this was not the case with the strain isolated from Aster either by us or by Robinson.

A certain amount of doubt, therefore, must exist as to whether the fungus causing the Aster disease is absolutely identical with *P. cryptogea*. Judging from their very close similarity in other respects, however, and especially seeing that the formation of sporangium within sporangium (hitherto described for no other species) is common to both, it is clear that the two fungi are very closely allied if not absolutely identical. It is possible, too, that had the cultures been carried on for a more extended period, sexual organs would have developed in the course of time. Unfortunately only *P. cryptogea* from Tomato was carried over the period of eight months, during which the work was suspended, in a living condition.<sup>1</sup>

*Cheiranthus*.—Diseased Wallflowers were observed alongside of the Asters above referred to, showing similar symptoms. A similar fungus, bearing the same kind of sporangia, was found in the affected tissues. The fungus was not in this case isolated, but inoculation of healthy Wallflower plants with

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<sup>1</sup> Mr. Brierley (Ann. App. Biology II, No. 4, Ap., 1916, p. 266) refers to tomato plants as succumbing to "Black Neck (*Phytophthora* sp. *omnivora* ?)." In correspondence he informed us that he believed that this disease in tomatoes was identical with Robinson's Black Neck of Asters, and was due to the same parasite.

a pure culture of *P. cryptogea* from Tomato produced exactly the same type of disease.

Summing up, therefore, it may be stated that *P. cryptogea* is the cause of a disease of Tomato and Petunia plants, and in all probability causes a similar disease in Asters and Wallflowers.<sup>1</sup>

#### VIII.—SOURCE OF INFECTION AND CONTROL OF THE DISEASE.

All our observations point to the conclusion that the plants become infected through their roots from the soil. This is further borne out by the experience that when Tomato seeds were sown in the soil in which a diseased plant had been growing all the seedlings became affected with the Phytophthora disease when they were about two inches high. Seeds from the same source sown in sterile soil produced healthy seedlings.

At one of the nurseries visited it was found that it was the practice to raise Tomato seedlings in a compost made up of equal parts of virgin loam and leaf-mould, without the addition of any manure. The mould usually employed was derived from decomposed beech leaves (*Fagus sylvatica*).

Only small quantities of this loam and leaf-mould which had not previously been used were still available. Equal amounts of the two were mixed and filled into two seed pans. One of these was sterilised by exposure to live steam for a period of two hours at a time on three successive days, while the other was untreated. Tomato seeds were sown in each pan, and the result was that the seedlings which developed in the untreated mixture of loam and leaf-mould became diseased, while those in the sterilised mixture remained healthy. One of the diseased seedlings was removed and placed with its roots in sterile water, when the characteristic sporangia of the fungus developed.

It was suspected that the fungus might be present in the leaf-mould and not in the loam. An experiment was carried out to settle the matter, but the result was a negative one, for, in this case, no diseased seedlings arose either in the loam or the leaf-mould. This is probably explained by the fact that only a *very small* quantity of the leaf-mould and loam was still available for the trial, and in order to get enough material to fill even a three-inch pot the leaf-mould and loam had each to be diluted with a considerable amount of previously sterilised soil.

In this connexion it is at any rate interesting to observe that the fungus was proved to be pathogenic to beech. A beech-nut was planted in soil, and

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<sup>1</sup> At the time of going to press we have received specimens of diseased cinerarias also attacked, apparently, by this fungus.

when the resulting seedling was about 4 inches high and quite healthy, it was inoculated near soil-level with a pure culture of the fungus. Within six days the seedling was dying, and microscopic examination showed the presence on it of the fungus, bearing its sporangia. *Nozemia fagi* is a well-known parasite of the beech, and it also attacks herbaceous plants such as *Clarkia*, &c. It would not be surprising therefore if *P. cryptogea* also turned out to be a parasite naturally occurring in beech-woods, and that it was carried through leaf-mould, employed in compost-making, to nurseries, there to become a serious pest to cultivated plants. This point, although at present a mere hypothesis, is well deserving of further study.

As regards the control of the "foot-rot" disease, it may in the first place be stated that this is one of those rather exceptional cases amongst plant diseases in which (as far as the Tomato is concerned at any rate) an actual cure of the individual may be effected by amputation of the attacked portion of the plant and treating the healthy portion as a cutting. The diseased portions removed should of course be destroyed by burning. Attention has already been drawn to this point; and, provided that the affected plants are old enough and are not in too advanced a stage of attack, this mode of treatment may be carried out without an undue amount of trouble and with the prospect of a reasonable degree of success. It is, perhaps, scarcely necessary to point out that the cuttings must not be planted in contaminated soil, otherwise there is serious risk of a recurrence of the trouble.

The precautionary measures which should be adopted to prevent the disease are sufficiently obvious. All diseased plants (if not treated as described above) should be destroyed by burning. All soil in which diseased plants have been growing should be discarded from the nursery. It could probably with safety be used as a top-dressing on permanent grass land. All pots, pans, boxes, &c., in which diseased seedlings have been raised should be thoroughly cleaned and disinfected or sterilised before being used again. A thorough cleansing and disinfection of glass-houses or frames in which diseased plants have been grown should also be carried out.

Seedlings should only be raised in non-contaminated soil. Experience has shown that it is not sufficient to rely on virgin loam and fresh leaf-mould for making the compost, because the fungus may already be present in one or both of these. The safest plan would be to sterilise thoroughly the compost before using it. Partial sterilisation, such as results from some of the modern methods of steaming employed in connexion with other diseases of the tomato, cucumber, &c., would probably not be sufficient.

## IX.—SUMMARY.

A disease of young Tomato plants is described in which the root system and the lower portion of the stem become involved in a rot leading ultimately to the death of the plant. The term "Tomato Foot-Rot" is suggested as appropriate for it.

A species of *Phytophthora* was isolated from the diseased tissues and was proved to be the cause of the disease.

The parasite was grown in pure cultures, and in these the development of sexual organs took place. They are the type first described in *Phytophthora erythroseptica* and *P. infestans*. The fungus is, therefore, a true *Phytophthora*, and not being identical with any one of the nine previously described members of this genus, is described as a new species under the name of *Phytophthora cryptogea*.

The same type of disease, caused by the same fungus, was found to occur naturally in *Petunia*; and it is extremely probable that the same fungus causes a similar disease in *Aster* and *Cheiranthus*.

Artificial inoculations showed that the fungus was also pathogenic to Potato (*Solanum tuberosum*), *Gilia tricolor*, and *Fagus sylvatica*, but not to *Senecio vulgaris*, *Helianthus annuus*, or *Nicotiana affinis*.

The disease was found to be contracted from the soil. Oospores of the fungus probably hibernate there; but this point has not been demonstrated conclusively.

The disease can be prevented by raising Tomato plants in soil thoroughly sterilised by heat; and individual plants can be cured in many cases by amputating the diseased portion of the plant and treating the healthy remainder as a "cutting." Methods of controlling the disease are briefly outlined.

## XI.—EXPLANATION OF PLATES.

## PLATE XLV.

- Fig. 1. A typically diseased Tomato plant at a comparatively late stage of attack. The original roots are dead and decayed. A bunch of secondary adventitious roots has been developed higher up, but these have also become attacked by the fungus. The overground stem is shrivelled up to and just beyond the point of insertion of the lowermost leaf, which is dying. The leaflets of the leaf above this one are already beginning to show the characteristic rolling upwards and inwards of their margins. The remaining leaves are still normal.
- Fig. 2. An infection experiment. The central plant (control) was wounded but not inoculated. It remained perfectly healthy. The two side plants were wounded and inoculated with a pure culture of *P. cryptogea*. Both became diseased. The one on the right has toppled over, and the shrunken base of the stem is clearly visible. The one on the left, although affected in a similar manner, was prevented from falling by being supported by a stake. The photograph was taken four days after inoculation.
- Figs. 3-5. Photographs of the sexual organs of *P. cryptogea* developed in pure culture on Quaker Oat-agar. A thick-walled oospore is present in each case within the spherical portion of the oogonium, the funnel-shaped base of which is still within the antheridium. The hyphae bearing the oogonia and antheridia are not discernible. Figs. 3 and 5.  $\times 540$ . Fig. 4 is the same as fig. 5.  $\times 850$ .

## PLATE XLVI.

Cross-inoculation experiments with *P. cryptogea* on Tomato (fig. 1), Petunia (fig. 2), Aster (fig. 3), and Cheiranthus (fig. 4). In each case the normal plant in the right-hand pot served as a control, being wounded but not inoculated. The diseased plants in the three pots on the left in each series were wounded and inoculated in each case with pure cultures of the fungus isolated from Tomato, Aster, and Petunia respectively, from left to right.



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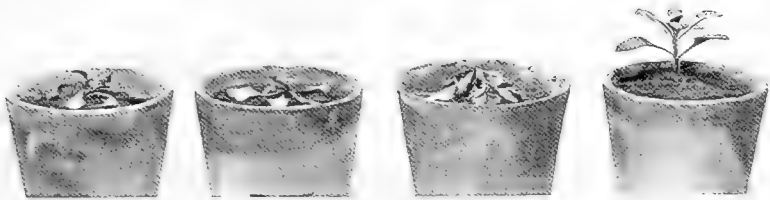


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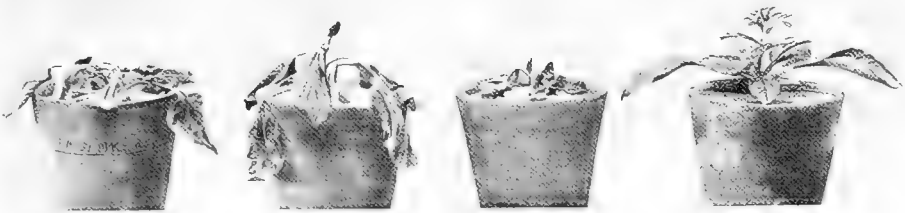




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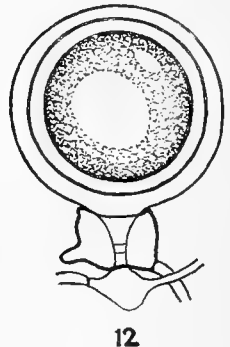
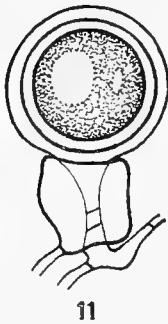
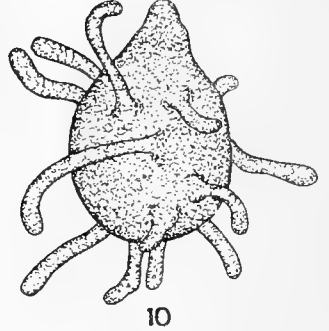
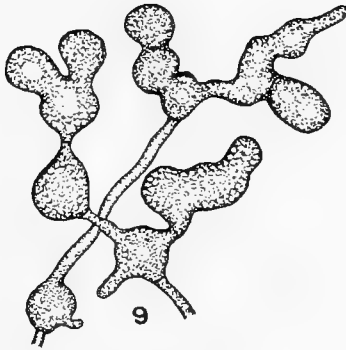
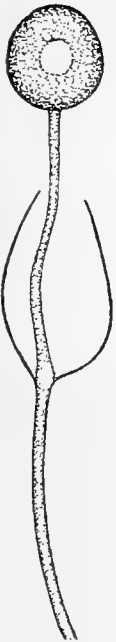
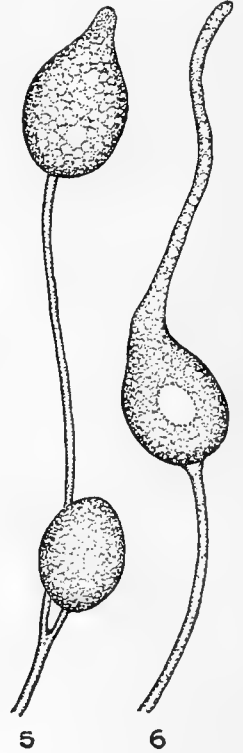
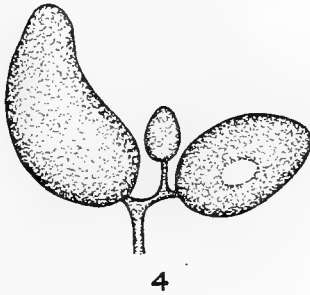
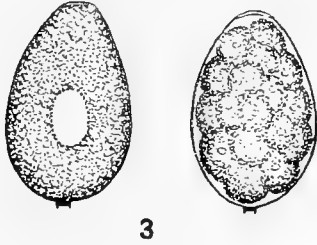
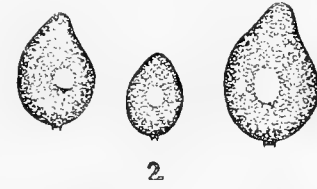
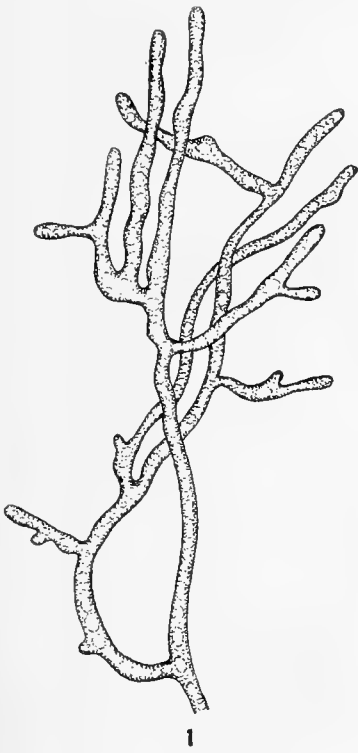


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EXUDATION OF WATER BY *COLOCASIA*  
*ANTIQUORUM*.

BY

MARGARET G. FLOOD, B.A.

[COMMUNICATED BY PROFESSOR H. H. DIXON, F.R.S.]

(PLATES XLVIII.—XLVIII A.)

[*Authors alone are responsible for all opinions expressed in their Communications.*]

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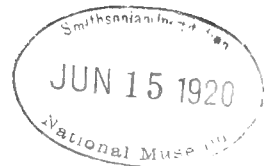
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PLATE XLVII.

- Fig. 1. Mycelium of *Phytophthora cryptogea* from a 30-day-old culture on maize meal agar. The slight constriction of the lateral branches at their points of origin is rather characteristic.  $\times 510$ .
- „ 2. Three immature sporangia from sporangiophores developed in water from mycelium in the affected portion of a young tomato plant artificially inoculated from a pure culture.  $\times 510$ .
- „ 3. More mature sporangia from the same source. The one on the left ripe, the one on the right about to liberate its zoospores.  $\times 510$ .
- „ 4. Sporangiophore and sporangia from the same source. The branching is sympodial, but the branches are unusually short.  $\times 510$ .
- Figs. 5 and 6. Sporangia produced by the fungus when growing on roots of *Cheiranthus* (after artificial inoculation). The upper sporangium in fig. 5 has commenced to develop a germ-tube. In fig. 6 the germ-tube is in a more advanced stage of growth.  $\times 510$ .
- Fig. 7. Two cases of the development of a second sporangium from within the base of the first formed one.  $\times 510$ .
- „ 8. Development of a third sporangium within two previously formed sporangia.  $\times 510$ .
- „ 9. Mycelium of *P. cryptogea* as developed occasionally from diseased portions of the host when submerged in water and also in pure culture, representing, possibly, abortive attempts at the production of sporangia or of sexual organs.  $\times 510$ .
- „ 10. Sporangium in which each zoospore-unit has developed a germ-tube without the liberation of free zoospores.  $\times 840$ .
- „ 11. Sexual organs of *P. cryptogea* from a 6-weeks-old pure culture on hard Quaker Oat-agar.  $\times 740$ .
- „ 12. Sexual organs of *P. erythroseptica* for comparison.  $\times 740$ .

## XXXVI.

EXUDATION OF WATER BY *COLOCASIA ANTIQUORUM*.

BY MARGARET G. FLOOD, B.A.

(PLATES XLVIII. AND XLVIII.A.)

[COMMUNICATED BY PROFESSOR H. H. DIXON, F.R.S.]

Read DECEMBER 17, 1918; published APRIL 3, 1919.

THE extreme purity of the water exuded from the leaf-tips of *Colocasia antiquorum* appeared strong evidence in favour of regarding the water as either raised or exuded by a special gland, or as raised osmotically and subsequently purified by glandular action. In either case we should expect to find continuous tissue interrupting the stream in which the absorption of water on one side and the exudation on the other side would take place, or in which a separation of the solutes from the solution would be effected.

At the suggestion of Professor H. H. Dixon, these experiments were carried out with the object of locating the gland or tissue responsible for effecting the exudation or the filtration of the water.

The phenomenon was first observed by Schmidt of Stettin. It was brought under the notice of Duchartre (3), and in 1859 he published a memoir recording his observations and giving an anatomical description of the plant. He considered that the exudation was related to transpiration, and stated that it is "une transpiration liquide nocturne qui remplace la transpiration gazeuse ordinaire ou diurne." In 1865 Musset (5) recorded that the drops are sometimes shot out of the pores to a considerable distance, and compared the exudation with the excretory system of animals. Haberlandt (4), in his "Text-Book of Physiological Plant Anatomy," states that the water is secreted by a hydathode, and also that the process of secretion consists in a simple filtration, the energy being provided by root-pressure or by exudation-pressure in the stems and leaves as well as in the root system.

The quantity of water produced by each leaf is considerable, the average being about 10 c.c.s. per night, so that enough can be collected for testing purposes. One of Duchartre's leaves produced 22.6 grammes in a single night, and another gave from 108 to 120 small drops per minute. When tested

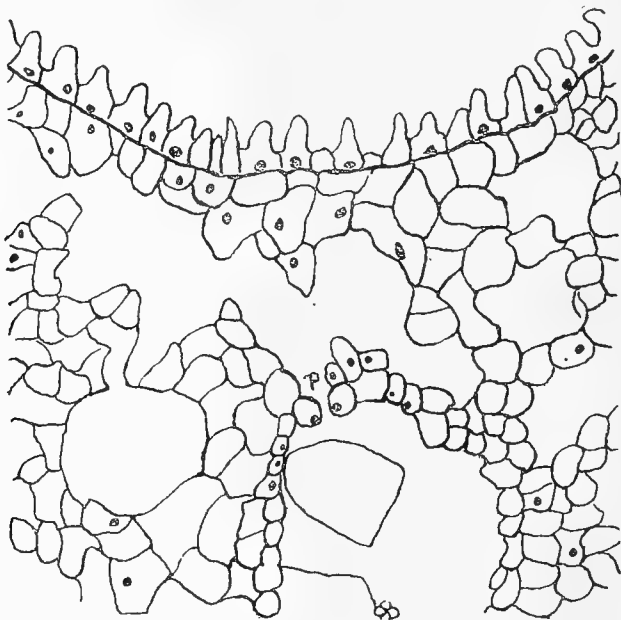
Duchartre found that it was nearly as pure as distilled water. Musset said it contained traces of broken-down cells; Haberlandt stated it contained a small amount of solids; while Dixon (2) and Atkins (1) found that its freezing point did not differ sensibly from that of distilled water, and its electrical conductivity was less than that of tap-water.

In the first place the structure of the leaf was examined. Externally (Pl. XLVIII., fig. 1) it is peltate, with a simple, heart-shaped blade, often 60 cms. wide by 90 cms. long. The two lobes are directed upwards, and the attenuated apex is directed downwards in the mature leaf. The petiole is very long and thick, and its base forms a sheath round the younger petioles. It joins the blade about three-fourths of the distance from tip to lobes, and at the junction three large veins come off. These three give origin to smaller veins, which ramify through the leaf, but both large and small eventually find their way into a vein that runs parallel to and close to the leaf edge. This vein joins the midrib just above the apex of the leaf. At the apex is a pocket-like depression, about 3 mms. wide by 5 mms. long, in the floor of which are from one to five circular pores, the larger with a diameter of about 0.1 mm. It is from these that the water exudes. Below this depression the apex is prolonged into a spur.

The following features of the minute anatomy of the leaf may be noticed. Under the epidermis of the petiole are bundles of fibrous strands, forming sub-epidermal girders, while the vascular bundles are scattered through the parenchyma, each with a large lacuna contiguous to it, and other lacunae are distributed through the parenchyma. A transverse section of the blade of the leaf shows that the epidermis is very papillate, and that the mesophyll contains large spaces. Stomata are very numerous. The vein which is parallel to the leaf edge is connected by small branches from its vascular bundle with the vascular bundle associated with the innermost of three canals that lie between it and the extreme edge (Plate XLVIII A). A transverse section of the edge of the leaf shows that these canals are lacunae formed in vascular bundles (Pl. XLVIII., fig. 2). A few tracheids can be seen towards the under surface of the leaf, and others are scattered round the margins of the lacunae. These lacunae have apparently been formed by the walls of adjacent tracheids ceasing to be in contact. Pl. XLVIII., fig. 3, is a photograph of a transverse section of a canal, and shows a split between two of the tracheids on the right, and a few vessels isolated in the middle of the lacuna. The canals lead to the apex of the leaf, and in it they become comparatively gigantic in size. A transverse section of the apex (Pl. XLVIII., fig. 4) shows that the pores in the floor of the depression lead into intercellular spaces in the mesophyll. These intercellular spaces are divided by lamellae and what might have been

a definite perforation in one of these lamellae, was noticed, connecting two of the intercellular spaces (Text fig.). No epithem was observed. All these features, the lacunae in the petiole, the canals in the leaf, the spaces and perforations in the mesophyll, point to arrangements for a rapid transfer of water up the petiole and through the blade. This does not support the hypothesis that the water is secreted by cells in the tissues of the apex, or even filtered there.

In order to find if continuous membranes responsible for filtration existed under the pores in the depression, tips of leaves were embedded in



Vertical section of leaf, showing perforation (P) in lamella dividing the spaces in the mesophyll. (From a photograph.) ( $\times 200$ .)

paraffin wax and sectioned. Although numerous attempts were made, and traces of what might have been a membrane, separating the cavity of the pore from the canals running into the leaf-tip, were found, the membrane was always discontinuous, and no case of complete continuity was demonstrated. The great objection to this method was that a discontinuity might be produced by unequal contraction and subsequent shrinkage during embedding, or by tearing during sectioning.

It thus seemed impossible to decide by histological investigation, and it was evident that some physical method would have to be adopted, and attempts were made to induce a colloid to pass through the pore into the

canals. This was done by sealing the petiole of a leaf into a bottle with plasticene, and exhausting the air from the bottle. The tip of the leaf was kept dipping into a mixture of gelatine and Indian ink, which was solid at the temperature of the laboratory, and liquid at a temperature somewhat higher. It was kept liquid during the experiment by being surrounded with hot water. The leaf was kept warm; the petiole dipping into hot water, in order to keep the conditions near to those obtaining in the hothouse from which it was brought. The result of this experiment was that no gelatine mixture was drawn in through the pore. Then the tip was cut off and the experiment repeated. This time the mixture mounted easily up the canals. This seemed to indicate the presence of a membrane; but the objection to this experiment was that the passages leading from the pore might be so small that viscosity or capillarity might prevent the mixture from getting through them. To reduce the viscosity, a mixture of water and Indian ink, without the gelatine, was used, under the same conditions, but, like the gelatine, it did not get through from the pore into the canals.

Then, owing to the fact that when the plant is in action the water does not rest in the depression, but is either shot off or runs down to the extreme tip of the leaf to form a large drop, the presence of wax or of some greasy substance was suspected. This would prevent the water and Indian ink from wetting the surface of the depression and entering the pore. To dissolve off the wax, the tip of a fresh leaf was plunged for a few minutes into ether, the ether was washed off with spirit, and the spirit in turn removed by washing with water. This was done as quickly as possible, in order to minimize the injury due to penetration by the ether and spirit. The leaf was sealed into the bottle as before, and the experiment carried out under the same conditions. It was then found that a mixture of Indian ink and water went through the pore and up the canals. The inference drawn from this experiment was that there was no continuous membrane under the depression, as a colloid pigment could pass through the pore and up the canals.

In order to verify this result further, a piece of the blade of a leaf with the tip attached was smeared with glue and rolled round a small cork in such a way that the cut edge of the blade projected at one end of the cork, and the tip hung free at the other. A hole was bored in a large cork, and the small cork with the leaf glued into it. The large cork was fitted into the neck of a receiver, so that the cut surface of the leaf-blade projected into the receiver, and the apex of the leaf hung free. When the corks were satisfactorily fitted so that the only possible outlet for water was down the canals and out by the pore, the receiver was partly filled with water and a fresh surface of the leaf cut under water. The receiver was then filled up till the water exerted a



pressure due to a head of 30 cms. The water had been boiled and allowed to cool until it was a little warmer than the temperature of the laboratory. The boiling removed the dissolved gases, and so there was less danger of bubbles blocking the canals or the supposed perforation in the membrane. The result was that drops issued from the pore in the same way as they did when the tip was attached to the leaf, and in twenty hours 6 c.cs. of water were collected.

The experiment was repeated, substituting a 0.3 per cent. solution of starch for the water. Liquid came through the pore as before, and when tested with *Liquor Iodi* turned blue, showing that starch had gone through, and proving that there could be no continuous membrane located between the water channels and the depression.

In all cases where leaves or tips had to be brought into the laboratory from Trinity College Gardens, they were kept as damp as possible, by being packed in wet *Sphagnum* moss, or put in a bottle in warm water that had been boiled and allowed to cool. This lessened the risk of flagging, consequent injury to the tissues, and the entrance of air into the canals.

From the results of these experiments it did not seem possible that the exuded water could be a secretion from a gland in the leaf-tip, as it is usually supposed. In order to test this further, the tip of a young leaf, while still attached to the plant and working vigorously, was anaesthetized. To do this, a small bottle was carefully washed free from grease, and the interior coated with glycerine and water, in order to prevent globules of dew forming on the glass and obscuring the view of what was going on inside. Some chloroform was poured in, and the tip of the leaf introduced into the bottle. The back of the leaf rested against a cushion of plasticene, so that the veins would not be injured by pressure against the glass. The neck of the bottle, after the introduction of the leaf, was closed by a plug of cotton wool. The tip was suspended in the chloroform vapour, in such a manner that the liquid anaesthetic did not touch it. Before introduction into the anaesthetizing vapour, the leaf was producing sixteen small drops per minute. The experiment was started at 8.25 a.m., and the tip of the leaf was left in the bottle till 9 a.m. Exudation continued at the same rate throughout, but by 9 a.m. both the tip and the water exuding from it were discoloured. At 9 a.m. the tip was removed from the anaesthetizing chamber and washed, and at 9.30 a.m. it was still acting at the same rate. This result supported the view that the water was not secreted by glandular action at the tip of the leaf, because if glandular action there had been its source, the exudation would have become slower or would have ceased entirely during the application of the anaesthetic.

But action continued at the same rate, so the water must be urged forward from the plant and not be produced by glands at the tips of the leaves.

That there is a liberal supply of water sent up to the leaves is shown by the following observations:—If a vigorously acting leaf be cut anywhere—across the lobes, across the middle of the blade, or round the point of insertion of the petiole—there is copious exudation from the veins at every cut, and from the canals. The cut surfaces may be plugged with mucilage after a time; but before this happens, whenever there is vigorous action going on in other leaves, exudation will recommence from these surfaces. Exudation from cut surfaces also occurs in the petioles. One evening, about 9.30, when action was going on very vigorously, water was noticed pouring from the cut end of the petiole from which the blade had been removed a few days previously. The surface was nearly horizontal, but the quantity of water was so great that it could be seen running down as a stream on the side of the petiole. A cut was made at the very base of this petiole, and water spurted out. The same thing happened when cuts were made at the bases of others.

Some roots were cleaned free from soil, with the exception of their apical regions, in the morning, and surrounded with Sphagnum moss, while still attached to the plant. That night, when action was vigorous, they were cut off from the plant, but there was no exudation of moisture from their cut surfaces. Possibly shock had checked exudation. This was repeated several times with roots that had not been previously disturbed, and in every case drops of moisture were apparent on their cut surfaces, and when wiped away more gathered. Although each root produced very little water, still, if a few hundred roots were supplying the plant from a damp soil, and if the atmosphere were saturated, both of which conditions were obtaining, the quantity of water supplied to each leaf would be appreciable.

The conclusions that may be drawn from these observations and experiments are that there is no special tissue in the leaf-tip which might be described either as a gland or epithem for the secretion. Neither is there any membrane intervening between the water-channels and the depression in the leaf for filtering the water. Arrangements have been made for the transfer of water through the plant, so it seems that cells lower down in the plant must be responsible for the secretion and filtration of the water; and there seems no evidence for the existence of special cells for this function outside the root.

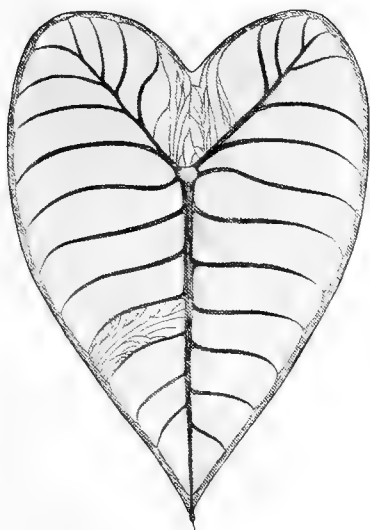
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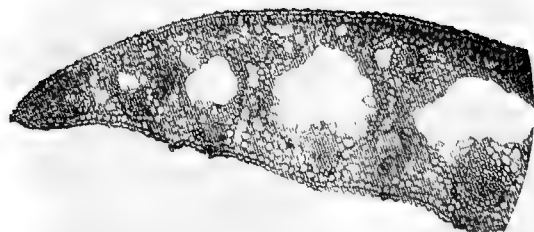
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2. DIXON, H. H., . . . Transpiration and the Ascent of Sap. 1914.
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## ERRATUM.

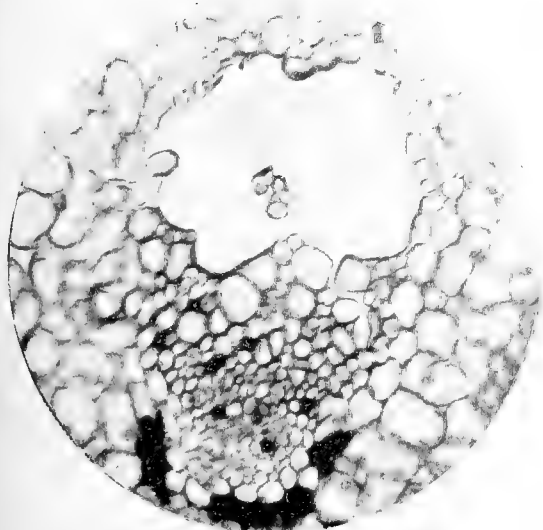
In Plate XLVIII., fig. 1, magnification  $\frac{1}{15}$ .



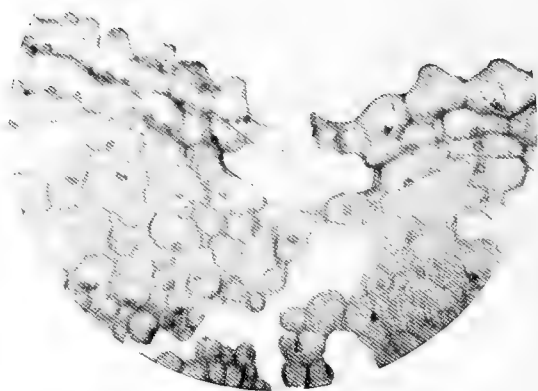
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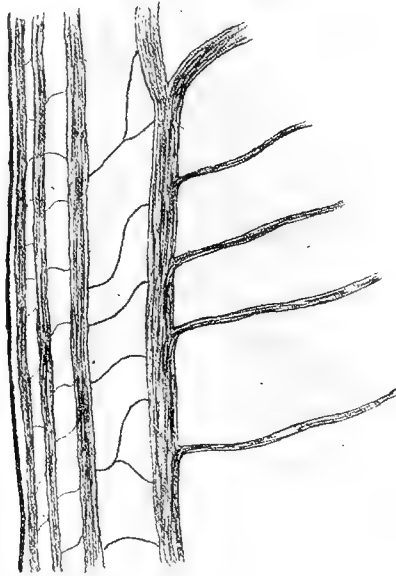


3 ( $\times 200$ ).



4 ( $\times 200$ ).





PART OF BLADE OF LEAF, SHOWING VEIN AND THREE CANALS  
PARALLEL TO THE EDGE.

THE UNIVERSITY OF CHICAGO

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FATTY ACIDS BY AN IMPROVED DIS-  
TILLATION METHOD.

BY

JOSEPH REILLY, M.A., D.Sc., F.R.C.Sc.I.,

AND

WILFRED J. HICKINBOTTOM.

[COMMUNICATED BY DR. F. E. HACKETT, M.A.]

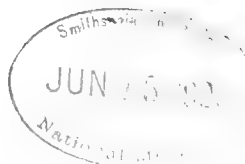
(PLATE XLIX.)

[*Authors alone are responsible for all opinions expressed in their Communications.*]

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## XXXVII.

THE DETERMINATION OF THE VOLATILE FATTY ACIDS BY  
AN IMPROVED DISTILLATION METHOD.

BY JOSEPH REILLY, M.A., D.Sc., F.R.C.Sc.I.,

AND

WILFRED J. HICKINBOTTOM.

[COMMUNICATED BY DR. F. E. HACKETT, M.A.]

(PLATE XLIX.)



Read DECEMBER 17, 1918; published APRIL 11, 1919.

DURING the course of an investigation of the volatile products obtained in certain fermentation processes, the need arose of identifying and estimating mixtures of the lower members of the fatty acid series. When experiments were carried out employing the various methods or modified methods referred to in the literature, the results obtained from comparative determinations varied considerably. It was then decided to consider the problem of the estimation of the volatile fatty acids as a separate investigation. This problem, owing to its importance in biochemical research, has attracted the attention of many workers. The methods suggested for the estimation of the acids can be classified generally into two broad groups. In the one advantage is taken of the varying solubilities of different salts or of the free acids themselves, while in the other the rate of distillation of the acids or their esters is considered. Variations in solubility between adjacent members of the fatty acid series or corresponding derivatives are, however, usually small, and sharp separations by the solubility method are difficult to obtain. In the present paper the second method only will be considered.

Separation by distillation depending on the varying rates of distillation of different acids was first suggested by Liebig.<sup>1</sup> He partially neutralised the acid mixture before distillation. This method gives, according to Holzmann,<sup>2</sup> fairly approximate results for mixtures of the higher acids, but is unsatisfactory for mixtures such as those of acetic and propionic acids.

<sup>1</sup> Annalen, 1849, **71**, 355.<sup>2</sup> Arch. Pharm., 1898, **236**, 409.

In the estimation of volatile acids by distillation the principle underlying the method is that each acid has a definite rate of volatilisation. Duclaux, relying on this principle, devised a method worked under standard conditions. He distilled 110 c.c. of a solution containing approximately 1 to 2 per cent. of acid. 100 c.c. of distillate were collected in ten fractions of 10 c.c. each. By expressing the titration of the fraction as a percentage of the total amount distilled, he was able to obtain a series of constants for each acid, which served to identify the particular acid. This method of Duclaux, or a modification of it, in which the essential features were maintained, has been used by several workers. It has, however, been subjected to much criticism.

As a result of the distillation of aqueous phenol solutions at constant volume, Naumann and Müller<sup>1</sup> came to the conclusion that under constant conditions of temperature and pressure, the amount of substance distilling was proportional to the amount of substance in the flask. They deduced values for the ratio of the amount of acid in the flask to the amount distilling in each fraction, which they denoted by the symbol  $\frac{dx'}{dx}$ , and also for the ratio of the titration of a fraction to the one preceding it, which they wrote  $\frac{d'}{d}$ . Stein<sup>2</sup> distilled aqueous solutions of certain volatile acids in a current of steam, and observed certain regularities in the distillation. By increasing the length of the carbon chain, the volatility in steam of the saturated fatty acids was increased. In order to study the effect of different groups, substitution products of acetic acid were distilled. The replacement of hydrogen by negative groups resulted in the volatility in steam being lowered, phenyl and chloro groups having less effect than hydroxy or carboxyl groups. Acids containing these latter groups were practically non-volatile. To express the rates of distillation, values were calculated from the formula  $\frac{1}{v} \log \frac{a}{a-x}$ , where  $v$  = volume distilled,  $a$  = amount of acid originally present,  $x$  = amount of acid distilled. Richmond<sup>3</sup> gives a formula  $a = 0.4013 \times 1.72^n$  where 0.4013 is a certain distillation constant for formic acid. He found that the corresponding constants ( $a$ ) for the next four members of the series could be found by giving  $n$  values from 1 to 4. For the higher acids or iso-acids the formula does not appear to hold. A method of steam distillation has also been described by Dyer.<sup>4</sup> For the analysis of mixtures Dyer is the only worker who used the method of distillation at constant volume. He aimed at keeping the volume approximately the same by introducing steam. He regulated

<sup>1</sup> *Berichte*, 1901, **34**, 224.

<sup>2</sup> *J. pr. Chem.*, 1913, **88**, 83.

<sup>3</sup> *Analyst*, 1908, **33**, 305.

<sup>4</sup> *J. Biol. Chem.*, 1917, **28**, 445.

his source of heat and his supply of steam so that the level of the liquid in the flask did not alter appreciably.

In analyses which depend on the formation of esters followed by fractional distillation, accurate results are difficult to obtain, since esterification is seldom complete and the distillation does not give a sharp fractionation. It is applicable only when relatively large amounts of solution are available and when the particular acids present in the mixture differ widely in molecular weight.

The relation between the formulae used by various workers will be shown later, after the theory of distillation of a dilute solution has been considered.

To obtain a regular rate of distillation the need for uniformity in the supply of heat to the distilling liquid has always been considered important. In addition, cooling effects which may cause irregular condensation in the stillhead have been recognized by some investigators. The influence of concentration and the effect of varying the ratio between the distillate and the volume in the flask are factors which do not appear to have received sufficient consideration. During the distillation of an aqueous solution it is obvious that, unless the solute has the same rate of volatilisation as the solvent, the concentration of the solution will alter. This effect of change of concentration has been referred to by Richmond, who finds that with formic, and to a less extent with acetic acid, the rate of distillation is influenced by the concentration of the solution. For higher acids this effect is not appreciable. These observations are important in the determination of the constitution of unknown mixtures. In the case of an ordinary distillation in which the substance in solution distils at a slower rate than the solvent, the solution will become more concentrated, with the consequent alteration of the constants. In an unknown mixture a correction cannot be applied with certainty in such cases. It is therefore important to prevent, as far as possible, any such change. Variations in concentration, with consequent alteration of constants, will be reduced to smaller limits if the distillation is carried out at a constant volume. In addition, the limits of variation can be reduced to a still narrower range if relatively larger volumes of solution are distilled compared with volumes of distillate collected.

Stein, in one experiment, found that the distillation constant of acetic acid was increased by the addition of sulphuric acid. He did not investigate this point further or offer any explanation to account for the observed results. It is possible that when a relatively large proportion of sulphuric acid is added, a hydrate or quasi-compound may be formed. In this case the "effective concentration" of the solution would be increased. However, as small quantities of sulphuric acid also have an appreciable effect, this

hypothesis is scarcely sufficient. An explanation may be suggested from Nernst's law of distribution. Since the relation between acid in the liquid and vapour phases will only remain constant provided the molecular state does not change, it might be inferred that in the solution some alteration in the state of molecular aggregation takes place on the addition of sulphuric acid. Small quantities of other non-volatile acids, such as phosphoric, have a similar effect. With a change in the state of molecular aggregation the rate of distillation will alter. It is assumed that in the case of the addition of any other volatile fatty acids the rate of distillation is not altered. On this assumption rests the basis for the determination of all mixtures of acids. As a fair agreement between the observed and calculated results has been obtained, this hypothesis is stated to have been proved. However, according to Upson, Plum, and Schott,<sup>1</sup> the Duclaux method is incapable of detecting less than four per cent. variation, consequently the statement that the rate of distillation of each acid is not affected by the presence of other volatile acids can only be stated to have been proved approximately.

During the course of a distillation following Stein's procedure, it is important that the variation in the volume should be as small as possible. This precaution is necessary as experimental results show that even a small change in the volume appreciably influences the distillation constants. Stein states that "the speed of distillation is reduced with increased amount of liquid in the distilling flask, and it appears that the rate of evaporation of the liquid in the flask is inversely proportional to the volume. To prove this, further experiments are wanting." In the present work confirmation of this hypothesis has been obtained. In the first experiment 50 c.c. of 0.08 N. solution of acetic acid were distilled at constant volume. In the second experiment 100 c.c. of 0.08 N. acetic acid was the volume used, no other conditions being altered. A series of experiments of this type were carried out, taking a different volume for each distillation. In a second series of experiments 150 c.c. of 0.08 N. acetic acid were used for each experiment. Before the distillation a definite amount of water was added to the flask. The total quantity of acid used in each experiment was therefore the same, so that with increase in volume there was a proportional decrease in concentration. From the constants obtained by the distillation of 1,000 c.c. the values of the constants when other volumes of solution have been employed were calculated, on the assumption that the rate of distillation is inversely proportional to the volume. The results are recorded in Tables 1 and 2. In figs. 1 and 2 the relation between the distillation constants and the volume of the solution is

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<sup>1</sup>J. Amer. Chem. Soc., 1917, **39**, 731.

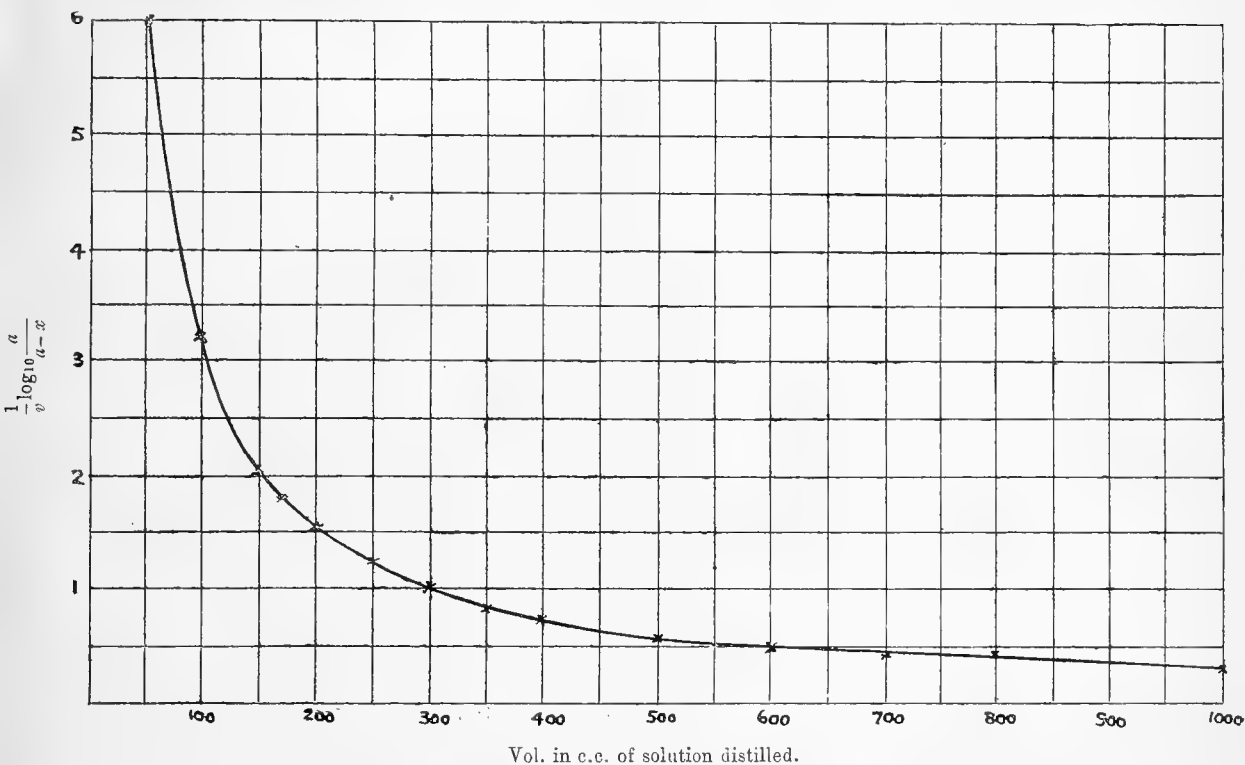


FIG. 1.

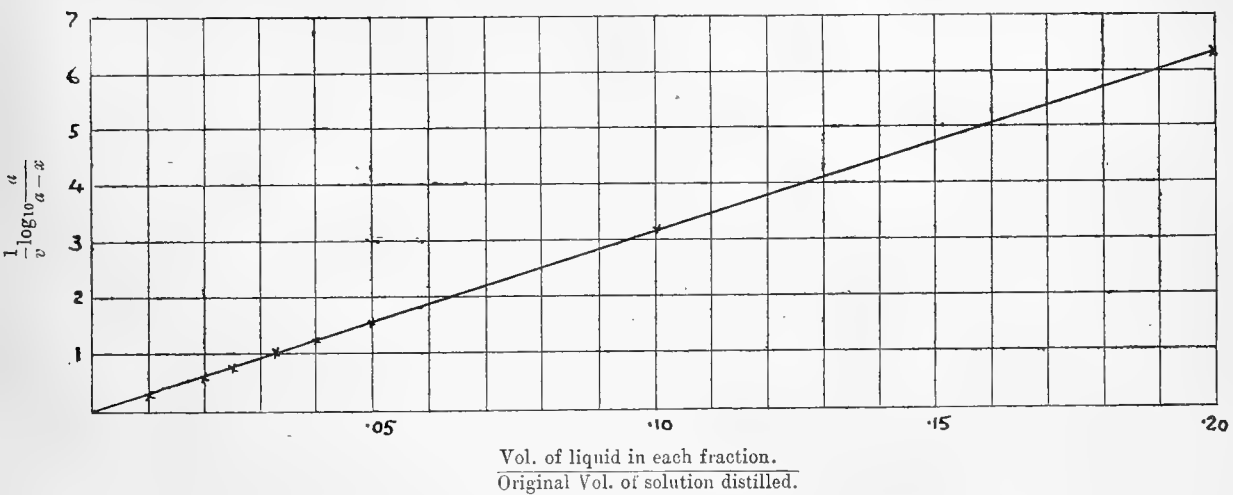


FIG. 2.



shown graphically. An examination of the tables shows that for larger volumes the distillation constant is inversely proportional to the volume, but the agreement when smaller volumes of solution are distilled is not so good, probably owing to the larger experimental error involved. It is shown later that from theoretical considerations the distillation constant is inversely proportional to the volume.

TABLE 1.—Effect of Change in Volume. Constant Concentration.

| Volume of Solution.<br>(0.80 N. Acetic Acid.) | $\frac{1}{v} \log_{10} \frac{a}{a-x}$ |        | $\frac{p_{n+1} - p_n}{100 - p_n}$ |        |
|---|---------------------------------------|--------|-----------------------------------|--------|
|   | Calculated.                           | Found. | Calculated.                       | Found. |
| 50  | 5.9                                   | 6.3    | 13.7                              | 16.0   |
| 100   | 2.95                                  | 3.22   | 6.85                              | 7.7    |
| 200   | 1.47                                  | 1.57   | 3.42                              | 3.60   |
| 300   | 0.98                                  | 1.01   | 2.28                              | 2.30   |
| 400   | 0.74                                  | 0.75   | 1.71                              | 1.70   |
| 500   | 0.59                                  | 0.60   | 1.37                              | 1.35   |
| 600   | 0.49                                  | 0.50   | 1.14                              | 1.20   |
| 700   | 0.42                                  | 0.42   | 0.98                              | 0.98   |
| 1000  | —                                     | 0.295  | —                                 | 0.685  |

TABLE 2.—Effect of change in Volume. Varying Concentration.

| Volume <sup>1</sup> of Solution. | $\frac{1}{v} \log_{10} \frac{a}{a-x}$ |        | $\frac{p_{n+1} - p_n}{100 - p_n}$ |        |
|----------------------------------|---------------------------------------|--------|-----------------------------------|--------|
|                                  | Calculated.                           | Found. | Calculated.                       | Found. |
| 150                              | 1.96                                  | 2.07   | 4.40                              | 4.6    |
| 170                              | 1.73                                  | 1.83   | 4.03                              | 4.2    |
| 200                              | 1.47                                  | 1.57   | 3.42                              | 3.5    |
| 250                              | 1.18                                  | 1.25   | 2.74                              | 2.9    |
| 300                              | 0.98                                  | 1.03   | 2.28                              | 2.3    |
| 350                              | 0.84                                  | 0.87   | 1.96                              | 2.1    |
| 400                              | 0.74                                  | 0.75   | 1.71                              | 1.7    |

<sup>1</sup> The total volume for each distillation contains 0.6048 gram of Acetic Acid.

*Theory of distillation of a dilute solution of a volatile substance in water.*

According to Nernst's law of distribution

$$\frac{\text{conc. in vapour phase}}{\text{conc. in liquid phase}} = \text{constant.}$$

The proportions of constituents in the distillate are assumed to be the same as the ratio in the vapour phase in a state of equilibrium.

This assumption is probably not strictly accurate, but approaches accuracy if distillation is carried on slowly and regularly.

Let  $x$  = amount of acid in distillate after volume has been distilled,

$a$  = initial amount of acid in flask,

$\rho$  = density of water vapour in flask,

$\sigma$  = weight of water per unit volume of distillate;

then if  $dx$  is the quantity of acid coming over in a quantity  $dv$  of distillate,

$$\frac{\rho \delta x}{\sigma \delta v} = \text{concentration in vapour phase approximately,}$$

$$\frac{a-x}{V} = \text{ " " " liquid " " }$$

where  $V$  = constant volume of liquid in a flask; then:—

$$\frac{\rho dx}{\sigma \delta v} = + k \frac{a-x}{V}$$

$$\frac{\delta x}{\delta v} = + \frac{k\sigma}{\rho V} (a-x) = + \lambda (a-x),$$

which gives

$$x = a(1 - e^{-\lambda v})$$

or

$$a-x = ae^{-\lambda v}$$

$$\frac{a}{a-x} = e^{\lambda v}$$

$$\lambda = \frac{1}{v} \log_e \frac{a}{a-x}$$

writing

$$A = \frac{1}{v} \log_{10} \frac{a}{a-x}.$$

Then  $A$  is a constant, assuming  $\frac{\sigma}{\rho}$  is constant.

This constant [ $A$ ] Stein writes as  $\frac{1}{v} \log \frac{a}{a-x}$ ,

$$A = \frac{\lambda}{2.3026}.$$

As regards the other constants the relation between them can be shown thus:—

writing  $p_1$  = percentage of total acid in the first fraction,

$p_n$  = " " " " " " " 1st  $n$  fractions.

$f$  = volume of fraction (10 c.c.);

$$\text{then } \frac{p}{100} = \frac{c}{a},$$

$$\frac{p_1}{100} = 1 - e^{-\lambda f},$$

$$\frac{p_2}{100} = 1 - e^{-2\lambda f}$$

$$\frac{p_n}{100} = 1 - e^{-n\lambda f};$$

then we have:—

$$\frac{dx'}{dx} = \frac{\text{acid distilling over in any fraction}}{\text{acid in flask before fraction distilled}} = \frac{p_{n+1} - p_n}{100 - p_n};$$

$$\frac{(1 - e^{-\lambda(n+1)f}) - (1 - e^{-n\lambda f})}{e^{-n\lambda f}} = 1 - e^{-\lambda f} = \text{const.}$$

If Naumann and Müller's constant  $\left(\frac{dx'}{dx}\right)$  is called  $B$ , then:—

$$B = 1 - e^{-\lambda f} = 1 - \frac{1}{e^{A \times 2.3026 \times 10}}$$

writing

$$y = e^{10A \times 2.3026}$$

$$\log y = 10A \times 2.3026 \log_{10} e = 10A$$

$$y = \text{antilog}(10A),$$

$$B = \frac{1}{1 - \text{antilog}(10A)},$$

$$\text{e.g. if } A = 0.00577,$$

$$B = 1 - \frac{1}{\text{antilog } 0.0577} = 0.12.$$

There is another constant ( $c$ ) which is the ratio:—

$$\frac{\text{acid left in flask after } (n+1)\text{th fraction}}{\text{acid left in flask after } n\text{th fraction}} = \frac{1 - \frac{p_{n+1}}{100}}{1 - \frac{p_n}{100}}$$

$$= \frac{e^{(n+1)\lambda f}}{e^{-n\lambda f}} = + e^{-\lambda f} = \frac{100 - p_n}{100} = \frac{100 - p_{n+1}}{100 - p_n}.$$

Naumann and Müller's constant  $\left(\frac{d'}{d}\right)$  is  $C$  and, as we note from above,  $C = 1 - B$ .

*Summary of relation between the constants.*

|                                    |   |   |  |
|------------------------------------|---|---|--|
| Theoretical form.                  | $\lambda$                               | $1 - e^{-\lambda f}$ .  | $e^{-\lambda f}$ .                                       |
| Form used in calculation.          | $\frac{1}{v} \log_{10} \frac{a}{a-x}$ . | $\frac{p_{n+1} - p_n}{100 - p_n}$ .                                 | $\frac{100 - p_{n+1}}{100 - p_n}$ .                      |
| Symbol indicating calculated form. | $A$ .                                   | $B \left(\frac{d'x}{dx}\right)$ .                                   | $C \left(\frac{d'}{d}\right)$ .                          |
| Relation,                          | $A = \frac{\lambda}{2.3026}$ .          | $B = \frac{1}{1 - \text{antilog}(10A)}$<br>$= \lambda f$ (approx.). | $C = 1 - B$ .<br>$\lambda = \frac{1}{f} \log_e C^{-1}$ . |

The distilling constant  $\lambda$  is inversely proportional to the volume of solution ( $V$ ), and as the above table shows the constants  $A$  and  $B$  should exhibit the same proportionality. This has already been demonstrated in Tables 1 and 2.

Several types of apparatus were tried in the endeavour to obtain uniform conditions during distillation. The type finally adopted is shown on Plate XLIX. In order to explain why certain modifications were introduced, it will be necessary to refer to some earlier experiments. In these experiments the solution was distilled from a round-bottomed flask, and the volume was kept constant by introducing, by means of a dropping funnel, a measured amount of cold water, through the neck of the flask. This method of keeping

the volume constant was compared with one in which the water was allowed to pass through a tube leading to the surface of the solution. In the latter case the rate of distillation was found to be higher. By replacing the cold liquid by water which had been heated, it was shown experimentally that the amount of condensation was still further reduced, and in order to bring this to a still lower figure it was decided to introduce the liquid (distilled water free from CO<sub>2</sub>) through a side tube sealed into the flask below the level of the solution. All risk of cooling the vapour by the entering liquid was completely avoided. The flask with the side tube was made of quartz, and was supplied to our design by the Silica Syndicate, Ltd., London. In a later form of the apparatus the side tube sloped at 45° to the horizontal for a short distance outside the flask before becoming vertical.

TABLE 3.

| Weight of each fraction in grams. }   | 10   | 20  | 30   | 40   | 50   | 60   | 70   | 80   | 90   | 100  |
|---|------|-----|------|------|------|------|------|------|------|------|
| Not jacketed. The entering water allowed to pass through vapour; percentage distilling. } | 4.0  | 7.0 | 11.7 | 15.4 | 18.7 | 22.9 | 26.2 | 29.2 | 32.3 | 35.2 |
| Jacketed; entering water and vapour allowed to meet; percentage distilling. }             | 4.2  | 8.5 | 12.7 | 15.1 | 19.7 | 23.4 | 26.8 | 30.0 | 33.2 | 36.2 |
| Jacketed; water and vapour prevented from coming into contact; percentage distilling. }   | 4.65 | 9.3 | 13.7 | 18.0 | 22.0 | 25.7 | 29.3 | 32.7 | 35.9 | 38.9 |

It was also found when the distillation flask was surrounded by a steam-jacket that not only was the amount of condensation in the stillhead reduced, but the rate of distillation was considerably more uniform. The steam-jacket consists of a conical-shaped copper vessel with two slots for the passing of the tubes—one at the top to carry the tube leading away the distillation products, and the other at the base, on the opposite side, for the tube leading to the bottom of the flask. The method of arranging the steam-jacket is shown on Plate XLIX. The electric hot-plate which supplied heat to the

distilling liquid was also used to boil the water in the copper jacket. When a vapour containing components of different volatility is cooled, the less volatile component tends to be removed the more quickly. For acetic acid and water, the acid being the less volatile, it is removed more quickly than the water from the vapour phase; consequently distillation constants for acetic acid will be less when cooling takes place. This is shown by results given in Table 3. For comparison the results from an experiment using the type of apparatus finally adopted are also given.

To prevent any appreciable variation in the volume of the liquid in the flask, the water (free from  $\text{CO}_2$ ) is run from a reservoir through a 10 c.c. burette, the jet of which leads through a rubber bung fitted with a small tap-funnel. By this means the flow of the water can be regulated by two taps, the level of the water in the tap-funnel being kept constant. This secures a uniform flow, accurate adjustment being left to the burette tap, after the other tap has been set.

The importance and also the difficulty of collecting an exact amount of distillate in each fraction have been emphasized several times. In all the experiments in the present work approximately 10 c.c. were collected in weighed 10 c.c. measuring cylinders, the exact amount of distillate being obtained by weighing the full cylinder. As the concentration of the acid is small, a density of 1 may be taken for the solution. Each cylinder, as filled, was weighed, and the contents then poured into a small, numbered flask. The cylinder was washed twice with small quantities of water (free from  $\text{CO}_2$ ), and the washings added to the same flask. The stoppered numbered vessels (1 to 10) containing the various fractions were left aside and the titrations carried out after distillation was completed. Immediately before collecting a new fraction the level of the water in the burette was restored to zero, and the rate of flow so regulated that the volume run in from the burette corresponded with the volume distilled, as measured by the amount of liquid in the measuring cylinder. It was found that equal quantities of distillate were collected in approximately equal intervals of time.

The acids used in the determinations of distillation constants were carefully purified by repeated fractionation, using a five-section "Young evaporator stillhead," when the quantities available permitted. Usually a fraction boiling over a range of  $0.2^\circ$ – $0.4^\circ$  C. was used.

*Formic Acid* obtained from Paulène Frères, Paris, described as pure, and containing 98 per cent. anhydrous formic acid was fractionated once, the fraction boiling at  $100.2$ – $100.5^\circ$  C. (uncorr.) being taken. The distillation constants are given in Table 4.

## FORMIC ACID.

TABLE 4.—(Concentration. 150 c.c. of solution requires 101.16 c.c. O. 1 N. Ba(OH)<sub>2</sub> to neutralize.)

| Weight <sup>1</sup><br>of<br>Fraction<br>in grams. | Titration<br>in c.c. | Percentage<br>distilled. | Per cent.<br>of first<br>100 c.c.<br>distilled<br>over. | Distillation Constants. <sup>2</sup> |                                   |                                   |
|--|----------------------|--------------------------|---|--------------------------------------|-----------------------------------|-----------------------------------|
|  |                      |                          |   | $\frac{1}{v} \log \frac{a}{a-x}$     | $\frac{p_{n+1} - p_n}{100 - p_n}$ | $\frac{100 - p_{n+1}}{100 - p_n}$ |
| 10   | 2.96                 | 2.9                      | 11.8  | 1.29                                 | 2.9                               | 0.971                             |
| 20   | 2.90                 | 5.8                      | 23.3  | 1.30                                 | 3.0                               | 0.971                             |
| 30   | 2.72                 | 8.5                      | 34.1  | 1.28                                 | 2.9                               | 0.971                             |
| 40   | 2.60                 | 11.1                     | 44.4  | 1.27                                 | 2.8                               | 0.971                             |
| 50   | 2.55                 | 13.6                     | 54.5  | 1.27                                 | 2.8                               | 0.971                             |
| 60   | 2.50                 | 16.0                     | 64.4  | 1.26                                 | 2.9                               | 0.971                             |
| 70   | 2.36                 | 18.4                     | 73.8  | 1.26                                 | 2.8                               | 0.971                             |
| 80   | 2.29                 | 20.6                     | 82.9  | 1.25                                 | 2.8                               | 0.972                             |
| 90   | 2.20                 | 22.8                     | 91.6  | 1.25                                 | 2.7                               | 0.972                             |
| 100  | 2.11                 | 24.9                     | 100.0   | 1.24                                 | 2.7                               | 0.972                             |
| 110  | 2.09                 | 27.0                     | —   | 1.24                                 | 2.8                               | 0.972                             |
| 120  | 1.95                 | 28.9                     | —   | 1.23                                 | 2.6                               | 0.972                             |
| 130  | 1.93                 | 30.8                     | —   | 1.23                                 | 2.7                               | 0.972                             |
| 140  | 1.88                 | 32.7                     | —   | 1.23                                 | 2.7                               | 0.972                             |
| 150  | 1.79                 | 34.4                     | —   | 1.22                                 | 2.6                               | 0.972                             |
| 160  | 1.77                 | 36.2                     | —   | 1.22                                 | 2.7                               | 0.972                             |
| 170  | 1.70                 | 37.9                     | —   | 1.22                                 | 2.6                               | 0.972                             |
| 180  | 1.68                 | 39.5                     | —   | 1.21                                 | 2.7                               | 0.973                             |
| 190  | 1.66                 | 41.2                     | —   | 1.21                                 | 2.7                               | 0.973                             |
| 200  | 1.56                 | 42.7                     | —   | 1.21                                 | 2.6                               | 0.973                             |

<sup>1</sup> The nearest whole number, to the actual weight recorded, is given, and the titration figure in column 2 altered accordingly.

<sup>2</sup> For convenience in tabulating the comparative constants, the values in the first column represent

$$\left[ \frac{1}{v} \log \frac{a}{a-x} \right] \times 10^3.$$

The figures in the second column represent

$$\left[ \frac{p_{n+1} - p_n}{100 - p_n} \right] \times 10^2.$$

This system of recording results is adopted in all tables.

*Acetic Acid.* Commercially pure glacial acetic acid was purified by freezing out several times, and distillation over potassium permanganate, as described by Bousefield and Lowry.<sup>1</sup> The distillate boiling at 116–117° C. was fractionally distilled, a fraction boiling over a range of 0.2° C. being reserved. Specimens from two different sources, (a) “glacial acetic acid pure for analysis,” and (b) “glacial acetic acid 50° F.,” were also used. The constants agreed within limits of experimental error. Table 5 gives acetic acid distillation constants.

## ACETIC ACID.

TABLE 5.—(Concentration. 150 c.c. of solution requires 164.0 c.c. 0.1 N. Ba(OH)<sub>2</sub> to neutralize.)

| Weight of Fraction in grams. | Titration in c.c. | Percentage distilled. | Per cent. of first 100 c.c. distilled over. | $\frac{1}{v} \log \frac{a}{a-x}$ | $\frac{p_{n+1} - p_n}{100 - p_n}$ | $\frac{100 - p_{n+1}}{100 - p_n}$ |
|------------------------------|-------------------|-----------------------|---|----------------------------------|-----------------------------------|-----------------------------------|
| 10                           | 7.65              | 4.7                   | 12.0  | 2.07                             | 4.7                               | 0.953                             |
| 20                           | 7.56              | 9.3                   | 23.8  | 2.11                             | 4.8                               | 0.952                             |
| 30                           | 7.26              | 13.7                  | 35.2  | 2.13                             | 4.9                               | 0.952                             |
| 40                           | 6.94              | 17.9                  | 46.1  | 2.15                             | 4.9                               | 0.952                             |
| 50                           | 6.52              | 21.9                  | 56.3  | 2.15                             | 4.9                               | 0.952                             |
| 60                           | 6.15              | 25.7                  | 65.9  | 2.15                             | 4.8                               | 0.952                             |
| 70                           | 5.98              | 29.3                  | 75.3  | 2.15                             | 4.9                               | 0.952                             |
| 80                           | 5.56              | 32.7                  | 84.0  | 2.15                             | 4.8                               | 0.952                             |
| 90                           | 5.25              | 35.9                  | 92.2  | 2.15                             | 4.8                               | 0.952                             |
| 100                          | 4.96              | 38.9                  | 100.0                                       | 2.14                             | 4.7                               | 0.952                             |

*Propionic Acid.* Samples of propionic acid from three different sources, namely, “Kahlbaum’s propionic acid,” “propionic acid, extra pure,” from British Drug Houses, and a sample of pure propionic acid of unknown origin, were fractionally distilled two or three times. The distillate collected between 140.2–140.5° C. (uncorr.) was used. The three samples gave results agreeing closely among themselves. Table 6 gives the constants obtained.

*n-Butyric Acid.* Kahlbaum’s “brown label” “purest butyric acid” was fractionated. For determination of the distillation constants, as given in table, the acid collected over a range of 0.4° C. was used [boiling-point 163–163.4° C.]. The constants are tabulated in Table 7.

<sup>1</sup>J. Chem. Soc., 1911, 99, 1432.



## PROPIONIC ACID.

TABLE 6.—(Concentration. 150 c.c. of solution requires 93.0 c.c., 0.1 N.  
Ba(OH)<sub>2</sub> to neutralize.)

| Weight of Fraction in grams. | Titration in c.c. | Percentage distilled. | Per cent. of first 100 c.c. distilled over. | $\frac{1}{v} \log \frac{a}{a-x}$ | $\frac{p_{n+1} - p_n}{100 - p_n}$ | $\frac{100 - p_{n+1}}{100 - p_n}$ |
|------------------------------|-------------------|-----------------------|---|----------------------------------|-----------------------------------|-----------------------------------|
| 10                           | 7.23              | 7.8                   | 13.8  | 3.51                             | 7.8                               | 0.922                             |
| 20                           | 6.91              | 15.2                  | 27.0  | 3.58                             | 8.1                               | 0.921                             |
| 30                           | 6.35              | 22.0                  | 39.2  | 3.60                             | 8.1                               | 0.920                             |
| 40                           | 5.88              | 28.4                  | 50.4  | 3.62                             | 8.1                               | 0.920                             |
| 50                           | 5.64              | 34.4                  | 61.2  | 3.66                             | 8.5                               | 0.919                             |
| 60                           | 4.79              | 39.6                  | 70.3  | 3.65                             | 7.9                               | 0.919                             |
| 70                           | 4.44              | 44.3                  | 78.9  | 3.64                             | 7.9                               | 0.920                             |
| 80                           | 4.27              | 48.9                  | 87.0  | 3.65                             | 8.3                               | 0.919                             |
| 90                           | 3.57              | 52.8                  | 93.8  | 3.62                             | 7.5                               | 0.920                             |
| 100                          | 3.24              | 56.3                  | 100.0                                       | 3.59                             | 7.4                               | 0.921                             |

## N-BUTYRIC ACID.

TABLE 7.—(Concentration 150 c.c. of solution requires 119.1 c.c. 0.1 N.  
Ba(OH)<sub>2</sub> to neutralize.)

| Weight of Fraction in grams. | Titration in c.c. | Percentage distilled. | Per cent. of first 100 c.c. distilled over. | $\frac{1}{v} \log \frac{a}{a-x}$ | $\frac{p_{n+1} - p_n}{100 - p_n}$ | $\frac{100 - p_{n+1}}{100 - p_n}$ |
|------------------------------|-------------------|-----------------------|---|----------------------------------|-----------------------------------|-----------------------------------|
| 10                           | 14.35             | 12.0                  | 17.0  | 5.58                             | 12.0                              | 0.880                             |
| 20                           | 12.71             | 22.7                  | 32.1  | 5.60                             | 12.1                              | 0.879                             |
| 30                           | 10.16             | 31.3                  | 44.1  | 5.42                             | 11.0                              | 0.883                             |
| 40                           | 9.82              | 39.5                  | 55.8  | 5.45                             | 12.0                              | 0.882                             |
| 50                           | 8.54              | 46.7                  | 65.9  | 5.46                             | 11.9                              | 0.882                             |
| 60                           | 7.40              | 52.9                  | 74.7  | 5.44                             | 11.6                              | 0.882                             |
| 70                           | 6.42              | 58.3                  | 82.3  | 5.42                             | 11.4                              | 0.883                             |
| 80                           | 5.61              | 63.0                  | 88.9  | 5.39                             | 11.3                              | 0.883                             |
| 90                           | 4.90              | 67.1                  | 94.7  | 5.36                             | 11.1                              | 0.884                             |
| 100                          | 4.45              | 70.8                  | 100.0                                       | 5.35                             | 11.4                              | 0.884                             |

*iso-Butyric Acid.* Sodium isobutyrate, from Kahlbaum, was purified by two crystallisations from absolute alcohol and the free acid obtained by distillation with glacial phosphoric acid. The distillate after partly drying with a small amount of phosphorous pentoxide was fractionated twice, the acid being collected over a range of 0.2° C., boiling-point, 155.3–155.5° (uncorr.).

*n-Valeric Acid*, from Kahlbaum, was fractionally distilled twice, using a rod and disc column, the fraction collected between 183.2–183.5° (uncorr.) being reserved for a determination of the constants.

*iso-Caproic Acid* (isobutylacetic acid). A specimen of Kahlbaum's isocaproic acid was distilled twice through a rod and disc column, the fraction collected between 199.7–200° C. (uncorr.) being used.

For the acids higher than butyric similar tables to these given for the lower fatty acids have been worked out. These data are not given in full here, but Table 8 gives a summary of results obtained.

TABLE 8.

| Acid.                          | Percentage distilled in first 100 c.c. | $\frac{1}{v} \log \frac{a}{a-x}$ | $\frac{p_{n+1} - p_n}{100 - p_n}$ | $\frac{100 - p_{n+1}}{100 - p_n}$ |
|--------------------------------|--|----------------------------------|-----------------------------------|-----------------------------------|
| iso-Butyric, . . .             | 80.2                                   | 7.3                              | 15.2                              | 0.847                             |
| n-Valeric, . . .               | 80.4                                   | 7.1                              | 14.9                              | 0.848                             |
| n-Caproic, . . .               | 87.8                                   | 9.5                              | 19.3                              | 0.806                             |
| iso-Caproic (iso-butylacetic), | 89.1                                   | 10.6                             | 22.5                              | 0.776                             |

Examining Tables 4-7 it will be seen that although there is only a small change in the constants for the lower members of the series, there is a more decided fall with some of the higher members. It is probable that this cannot be due to change of constant with concentration, as the constants of fatty acids other than acetic and formic acids are not altered to any appreciable extent by change of concentration.<sup>1</sup> It is possible, therefore, that the fall in the constants may be brought about by traces of impurities which are very difficult to remove completely from the higher members. Also it should be noted that with the higher fatty acids the difficulty of accurately determining the constants increases with the fall in solubility of the acids.

<sup>1</sup> Compare Richmond, *loc. cit.*

Fig. 3 shows the relation between the volume of solution distilled and the value  $\log \frac{a}{a-x}$  for the single acids.

In Table 9 is given the distillation constant  $\frac{p_{n+1} - p_n}{100 - p_n}$  for normal acids from formic to caprylic and also for isobutyric, isovaleric and isocaproic acids. For isovaleric, heptolic, and caprylic acids Dyer's data have been employed to calculate the constants.

TABLE 9.

| Acids.                 | $\frac{p_{n+1} - p_n}{100 - p_n}$ |
|------------------------|-----------------------------------|
| Formic, . . . . .      | 2.8                               |
| Acetic, . . . . .      | 4.8                               |
| Propionic, . . . . .   | 7.9                               |
| n-Butyric, . . . . .   | 11.6                              |
| n-Valeric, . . . . .   | 14.9                              |
| n-Caproic, . . . . .   | 19.3 ± 1                          |
| n-Heptolic, . . . . .  | 24.5 ± 1.5                        |
| n-Caprylic. . . . .    | 30.0 ± 3                          |
| iso-Butyric, . . . . . | 15.2                              |
| iso-Valeric, . . . . . | 18.8                              |
| iso-Caproic, . . . . . | 22.5 ± 1                          |

From Table 9 it will be noticed that for each addition of a  $\text{CH}_2$  group to the series of normal fatty acids there is an approximately regular increase in the distillation constant, while if these constants are plotted against the number of  $\text{CH}_2$  groups present, the curve obtained (fig. 4) approximates to a straight line. There is evidently a definite relation existing between the rate of steam distillation and the chemical constitution of the fatty acids. Experimental results have been obtained which indicate that the above connexion between the rate of steam distillation and the chemical constitution holds in other types of organic compounds, such as phenols, amines, etc., and this line of investigation is being followed up. The distillation constants are proportional to  $\frac{\sigma}{\rho V}$ . Since the density of the water vapour in the flask is practically constant, the distillation constants become proportional to  $\frac{\sigma}{V}$ , that is, proportional to the value for the distribution of acid in the aqueous and

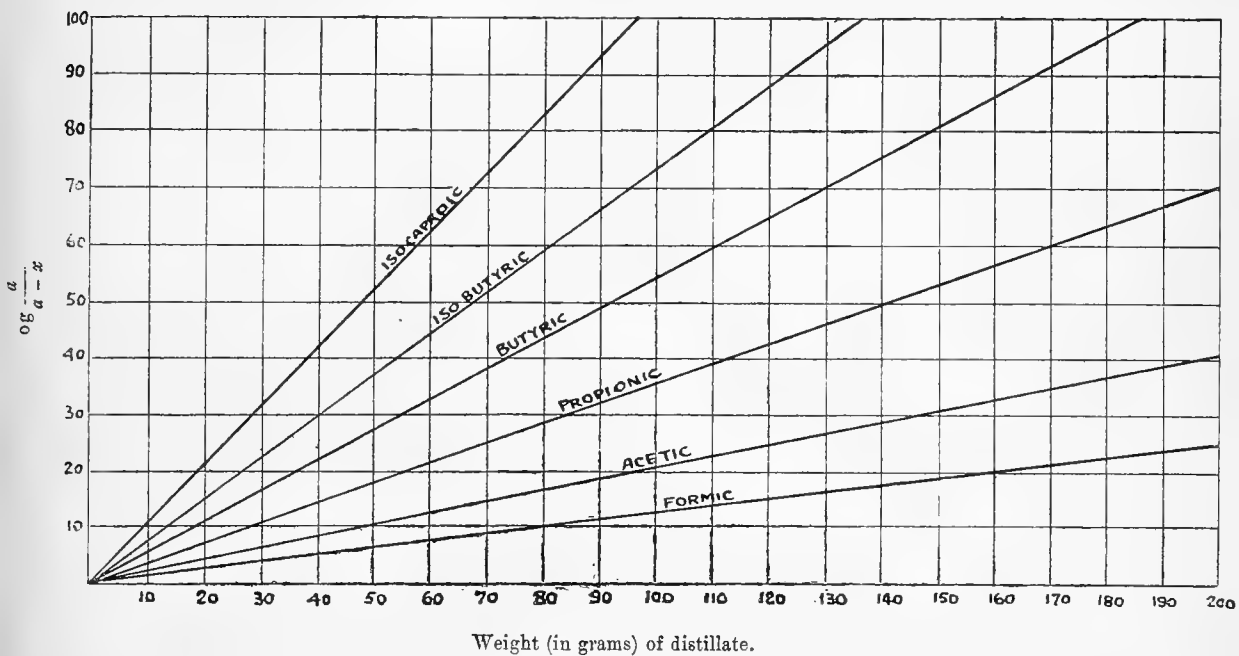


FIG. 3.

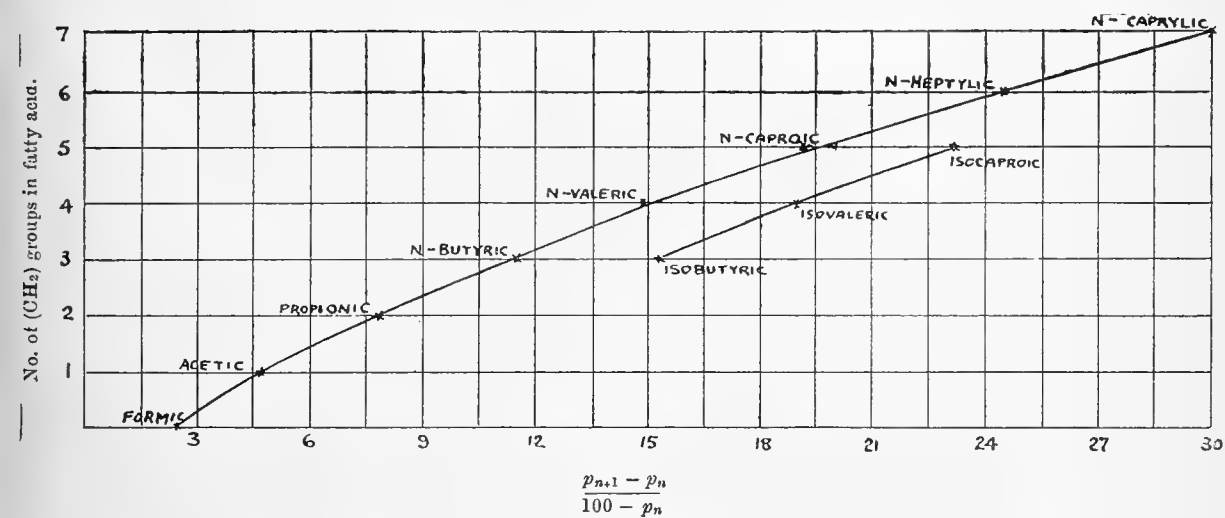


FIG. 4.

vapour phases. It therefore becomes a connexion between Nernst's law of distribution and molecular complexity. It is probable, however, in this case that the molecular state of the substance in solution may also play a part. The further investigation of this point is also being continued.

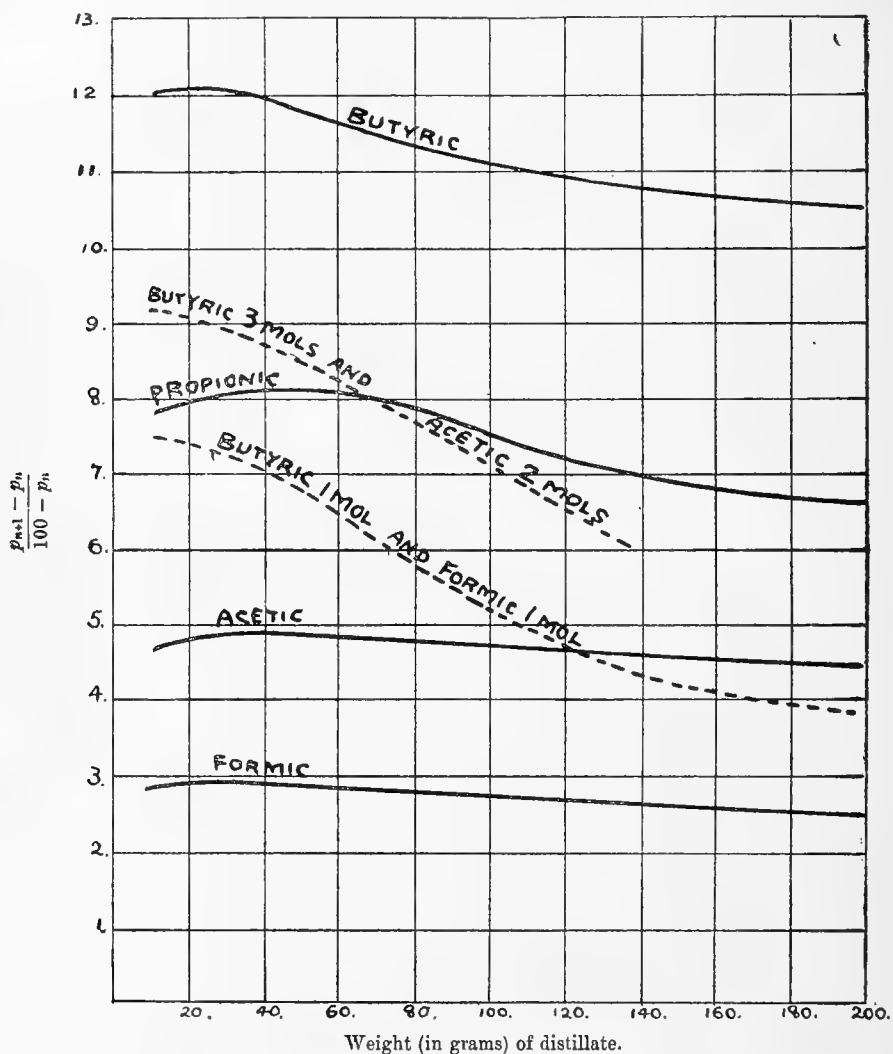


FIG. 5.

By distilling an aqueous solution of a mixture of two acids having different rates of volatilisation, it becomes evident that as the distillation proceeds, the solution in the flask will become relatively richer in the less volatile acid, so that the solution gradually changes in composition with a corresponding change in the vapour. (Figs. 5 and 6 show the relation

between weight of distillate and different constants both for single acids and mixtures.) It is obvious therefore that although a consideration of the logarithmic and other constants will give an accurate idea of the composition of the vapour at any given time, it cannot be employed with certainty to decide the composition of the solution distilled. The method suggested by

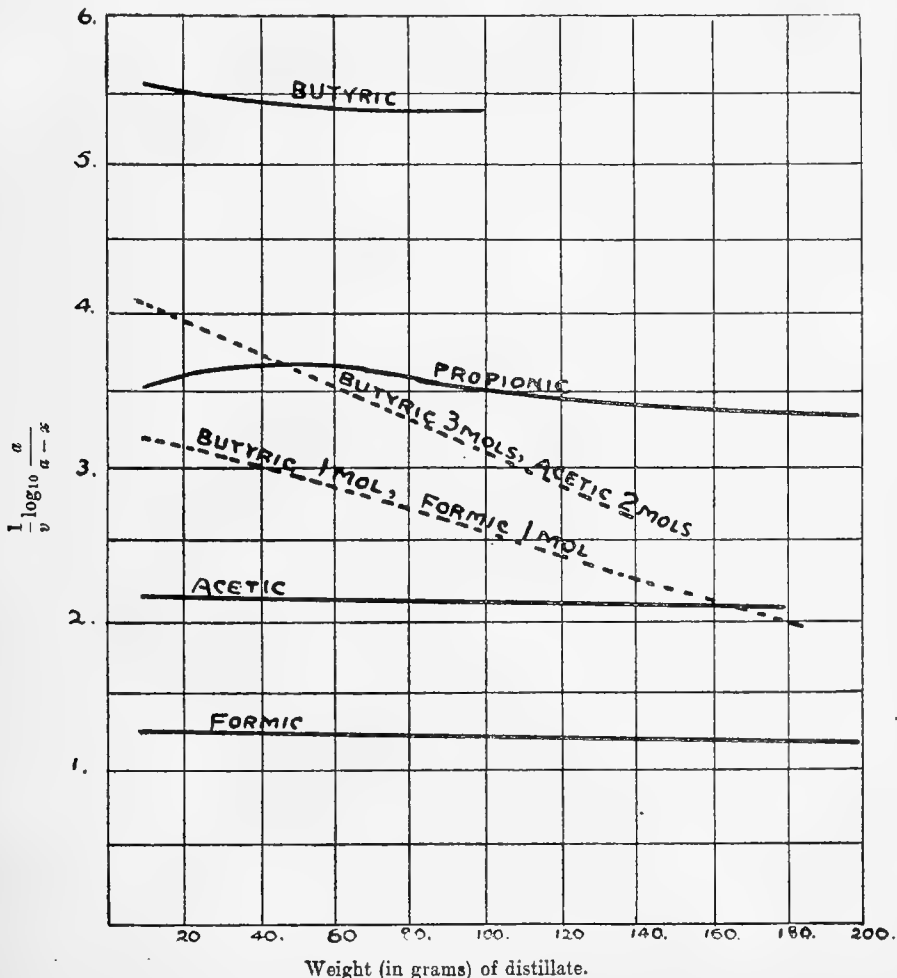


FIG. 6.

Dyer of taking the point at which the logarithmic curve of the mixture becomes parallel to that of the less volatile component is therefore open to a very wide error, and can only be approximate. The theory of mixtures may be considered thus:—Let  $a$  and  $b$  be the amounts of acid present in flask initially, and  $x_n, y_n$  the amounts distilled over in  $n$  fractions.

We get

$$\begin{aligned} a - x_n &= ae^{-\lambda_1 n f} \text{ for first acid,} \\ b - y_n &= be^{-\lambda_2 n f} \text{ for second acid;} \end{aligned}$$

or,

$$a + b - (x_n + y_n) = ae^{-\lambda_1 n f} + be^{-\lambda_2 n f}$$

The fraction of original left:—

$$1 - \frac{x_n + y_n}{a + b} = \frac{a}{a + b} e^{-\lambda_1 n f} + \frac{b}{a + b} e^{-\lambda_2 n f},$$

write

$$\frac{a}{a + b} = m, \quad \frac{b}{a + b} = n.$$

$m$  and  $n$  represent the ratio in which acids were present initially, and we have  $m + n = 1$ ,

$$\frac{x_n + y_n}{a + b} = \frac{\text{percentage of acid distilled over}}{100} = \frac{P_n}{100}.$$

We have then

$$1 - \frac{P_n}{100} = me^{-\lambda_1 n f} + ne^{-\lambda_2 n f}.$$

writing

$$e^{-\lambda_1 f} = c_1 \quad \text{and} \quad e^{-\lambda_2 f} = c_2$$

$$1 - \frac{P_n}{100} = mc_1^n + nc_2^n,$$

if we write  $p'_n$  = per cent. of 1st acid coming over in  $n$ -fractions.

„ „  $p''_n$  = „ „ 2nd „ „ „ „ „ „

$$1 - \frac{p'_n}{100} = c_1^n \quad 1 - \frac{p''_n}{100} = c_2^n.$$

$$1 - \frac{P_n}{100} = m \left( 1 - \frac{p'_n}{100} \right) + n \left( 1 - \frac{p''_n}{100} \right),$$

or

$$P_n = mp'_n + np''_n.$$

Pure formic and acetic acids were mixed in known proportions in aqueous solution, and from the percentage of the total acid distilling in each fraction the composition of the mixture was determined with the aid of the above expression. Various mixtures, each containing two fatty acids, were similarly treated. The compositions of the mixtures, as determined from the distillation results, agreed closely with the actual proportions in which the acids were present. This agreement holds both when the results are calculated from the formula or obtained graphically, using Fig. 7.

Tables 10-13 give the results for the distillation of mixtures, and show the order of accuracy of the method from the comparison of the estimated

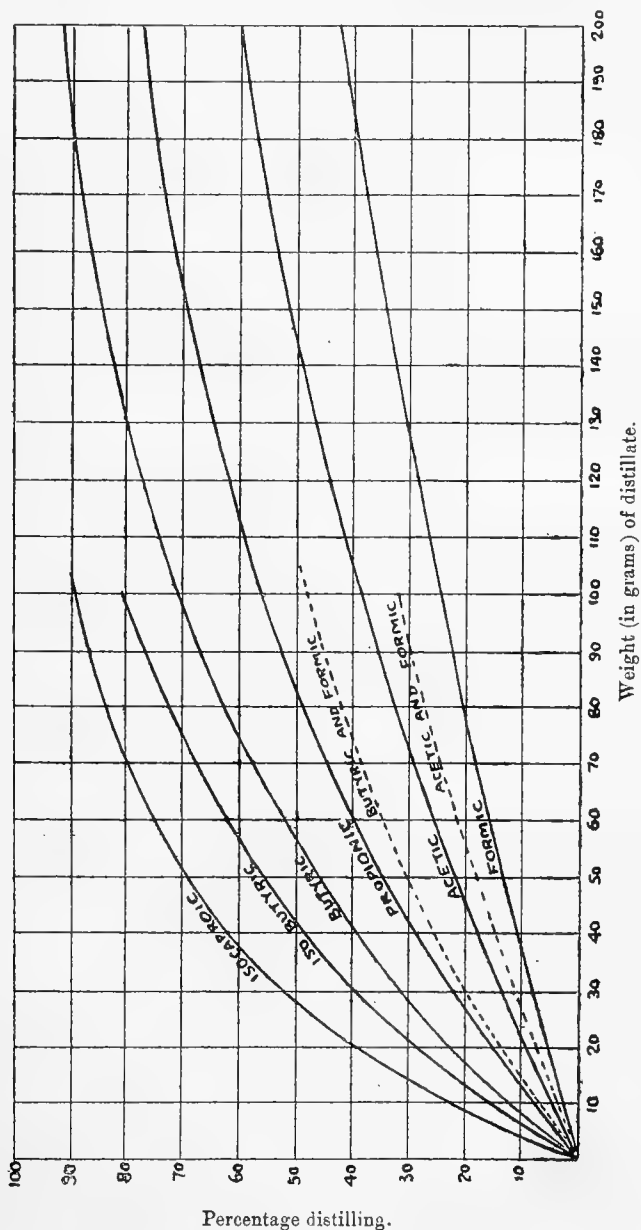


FIG. 7.

results with the actual theoretical composition of the mixture. In Table 14 an analysis of a mixture of three acids is given with similar comparisons.



Table 15 gives a summary of the experimental results obtained from the analyses of various mixtures.

TABLE 10.—Mixture of Formic Acid 0·483 mols.: Acetic Acid 0·517 mols.  
(Concentration 150 c.c. of solution requires 133·50 c.c. 0·1 N. Ba(OH)<sub>2</sub>  
to neutralize.)

| Weight of distillate,    | 10            | 20    | 30    | 40    | 50    | 60    | 70    | 80    | 90    | 100   |       |
|--------------------------|---------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Titration, . . .         | 5·01          | 4·92  | 4·91  | 4·62  | 4·68  | 4·37  | 4·05  | 3·95  | 3·59  | 3·44  |       |
| Percentage distilled,    | 3·8           | 7·4   | 11·1  | 14·6  | 18·1  | 21·4  | 24·4  | 27·4  | 30·0  | 32·6  |       |
| Percentage calculated, } | 3·8           | 7·6   | 11·2  | 14·6  | 17·9  | 21·0  | 24·0  | 26·9  | 29·6  | 32·1  |       |
| Found {                  | Formic, . . . | 0·531 | 0·529 | 0·496 | 0·488 | 0·462 | 0·448 | 0·450 | 0·444 | 0·449 | 0·450 |
|                          | Acetic, . . . | 0·469 | 0·471 | 0·504 | 0·512 | 0·538 | 0·552 | 0·550 | 0·556 | 0·551 | 0·550 |

TABLE 11.—Mixture of n-Butyric Acid 0·495 mol.: Formic Acid  
0·505 mol.

(Concentration. 150 c.c. of solution requires 98·40 c.c. 0·1 N. Ba(OH)<sub>2</sub>  
to neutralize.)

| Weight of distillate }<br>in grams, | 10             | 20    | 30    | 40    | 50    | 60    | 70    | 80    | 90    | 100   |       |
|-------------------------------------|----------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Titration in c.c., .                | 7·40           | 6·65  | 5·92  | 5·21  | 4·72  | 4·23  | 3·86  | 3·48  | 3·09  | 2·82  |       |
| Percentage distilled, .             | 7·5            | 14·3  | 20·3  | 25·6  | 30·4  | 34·7  | 38·6  | 42·1  | 45·3  | 48·2  |       |
| Percentage calculated,              | 7·4            | 14·2  | 19·8  | 25·1  | 30·0  | 34·3  | 38·1  | 41·6  | 44·7  | 47·6  |       |
| Found {                             | Formic, . . .  | 0·497 | 0·499 | 0·481 | 0·489 | 0·492 | 0·494 | 0·493 | 0·492 | 0·493 | 0·494 |
|                                     | Butyric, . . . | 0·503 | 0·501 | 0·519 | 0·511 | 0·508 | 0·506 | 0·507 | 0·508 | 0·507 | 0·506 |

TABLE 12.—Mixture of Acetic Acid 0.10 mol.: Butyric Acid 0.90 mol.  
 (Concentration. 150 c.c. of solution requires 103.8 c.c. 0.1 N. Ba(OH)<sub>2</sub>  
 to neutralize.)

| Weight of distillate }<br>in grams, | 10         | 20    | 30    | 40    | 50    | 60    | 70    | 80    | 90    | 100   |       |
|-------------------------------------|------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Titration in c.c., .                | 11.47      | 10.17 | 9.43  | 8.20  | 6.80  | 5.93  | 5.29  | 5.03  | 4.06  | 3.48  |       |
| Percentage distilled, .             | 11.1       | 20.8  | 29.9  | 37.8  | 44.4  | 50.1  | 55.2  | 60.0  | 64.0  | 67.3  |       |
| Percentage calculated,              | 11.3       | 21.4  | 29.5  | 37.3  | 44.2  | 50.2  | 55.4  | 60.0  | 64.0  | 67.6  |       |
| Found {                             | Acetic, .  | 0.134 | 0.140 | 0.075 | 0.078 | 0.093 | 0.102 | 0.106 | 0.097 | 0.101 | 0.111 |
|                                     | Butyric, . | 0.866 | 0.860 | 0.925 | 0.922 | 0.907 | 0.898 | 0.894 | 0.903 | 0.899 | 0.889 |

TABLE 13.—Mixture of Acetic Acid 0.526 mol.: n-Butyric Acid 0.474 mol.  
 (Concentration. 150 c.c. of solution requires 139.2 c.c. 0.1 N. Ba(OH)<sub>2</sub>  
 to neutralize.)

| Weight of distillate }<br>in grams, | 10         | 20    | 30    | 40    | 50    | 60    | 70    | 80    | 90    | 100   |       |
|-------------------------------------|------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Titration in c.c., .                | 11.65      | 10.73 | 9.49  | 8.54  | 7.60  | 6.83  | 6.21  | 5.54  | 4.97  | 4.54  |       |
| Percentage distilled, .             | 8.4        | 16.1  | 22.9  | 29.0  | 34.5  | 39.4  | 43.9  | 47.8  | 51.4  | 54.7  |       |
| Percentage calculated,              | 8.2        | 15.7  | 22.0  | 28.2  | 33.7  | 38.6  | 43.0  | 47.1  | 50.7  | 54.0  |       |
| Found {                             | Acetic, .  | 0.499 | 0.494 | 0.477 | 0.486 | 0.492 | 0.496 | 0.498 | 0.500 | 0.503 | 0.507 |
|                                     | Butyric, . | 0.501 | 0.506 | 0.523 | 0.514 | 0.508 | 0.504 | 0.502 | 0.500 | 0.497 | 0.493 |

TABLE 14.—Mixture of Formic Acid 0·360 mol. : Acetic Acid 0·386 mol. :  
n-Butyric Acid 0·254 mol.(Concentration. 150 c.c. of solution requires 117·9 c.c. 0·1 N. Ba(OH)<sub>2</sub>  
to neutralize.)

This mixture was prepared by the addition of a known amount of pure n-Butyric Acid to a known amount of mixture used in Table 10, and the calculations worked on the assumption that two acids only were present.

| Weight of distillate<br>in grams, } | 10         | 20    | 30    | 40    | 50    | 60    | 70    | 80    | 90    | 100   |       |
|-------------------------------------|------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Titration in c.c., .                | 7·14       | 6·57  | 5·93  | 5·66  | 5·00  | 4·77  | 4·21  | 4·17  | 4·02  | 3·42  |       |
| Percentage distilled, .             | 6·1        | 11·6  | 16·7  | 21·5  | 25·7  | 29·8  | 33·3  | 36·9  | 40·3  | 43·2  |       |
| Percentage calculated,              | 5·9        | 11·4  | 16·3  | 20·9  | 25·2  | 29·1  | 32·7  | 36·1  | 39·1  | 42·0  |       |
| Found {                             | Formic, .  | 0·383 | 0·384 | 0·360 | 0·353 | 0·339 | 0·329 | 0·331 | 0·325 | 0·325 | 0·326 |
|                                     | Acetic, .  | 0·339 | 0·342 | 0·365 | 0·371 | 0·394 | 0·405 | 0·405 | 0·408 | 0·399 | 0·398 |
|                                     | Butyric, . | 0·278 | 0·274 | 0·275 | 0·276 | 0·267 | 0·266 | 0·264 | 0·267 | 0·276 | 0·276 |

TABLE 15.

|   | Acid Mixtures. |         |         |            |         |          |         |            |         |         |            |
|---|----------------|---------|---------|------------|---------|----------|---------|------------|---------|---------|------------|
|   | Formic.        | Acetic. | Formic. | n-Butyric. | Acetic. | n-Butyri | Acetic. | n-Butyric. | Formic. | Acetic. | n-Butyric. |
| Quantities<br>of acid<br>(gram)<br>present in<br>150 c.c. of<br>solution. } | 0·297          | 0·414   | 0·229   | 0·429      | 0·062   | 0·823    | 0·439   | 0·581      | 0·195   | 0·273   | 0·264      |
| Proportions<br>found by<br>distillation<br>method. }                        | 0·292          | 0·421   | 0·223   | 0·440      | 0·065   | 0·819    | 0·414   | 0·619      | 0·187   | 0·271   | 0·282      |

It will be noticed in Tables 10 to 14 that in practically all cases there is an approximately constant difference between the theoretical and the recorded figure. Whether this is due to unavoidable experimental errors or to the acids present affecting each other is not certain. Richmond recorded a similar observation. The deviation, however, is not much larger than the experimental error, and does not affect the analysis of mixtures to any appreciable extent. Provided that the modifications previously indicated are adopted, the identity and purity of a solution of a single volatile fatty acid can be readily established in most cases. Also, in the case of mixtures it is possible to quickly determine with a fair degree of accuracy the proportions in which the acids are present. The conversion of the acids, in a known volume of solution, into the corresponding barium salts, and estimating the barium in the dried separated compounds, is often a useful confirmatory test.

When the method of calculation used in the case of "two-acid" mixtures is extended so as to include the analysis of mixtures of three acids, the agreement between the calculated and the actual results is generally not so close. This may be accounted for by the larger experimental error involved. Furthermore, if in the case of two acids there is a disturbing influence, it will be greater in the case of three acids. When dealing with more than two acids a partial fractionation first is sometimes advisable. The separated fractions are analysed, and from the data obtained the composition of the original mixture is calculated.

In addition to employing the distillation method for the estimation of mixtures, in which the components are present in relatively large proportions, it may also be employed to determine the purity of commercial products. It has been found that with commercially pure substances the fall in the distilling constants is small, but when appreciable amounts of impurities are present the fall is very marked.

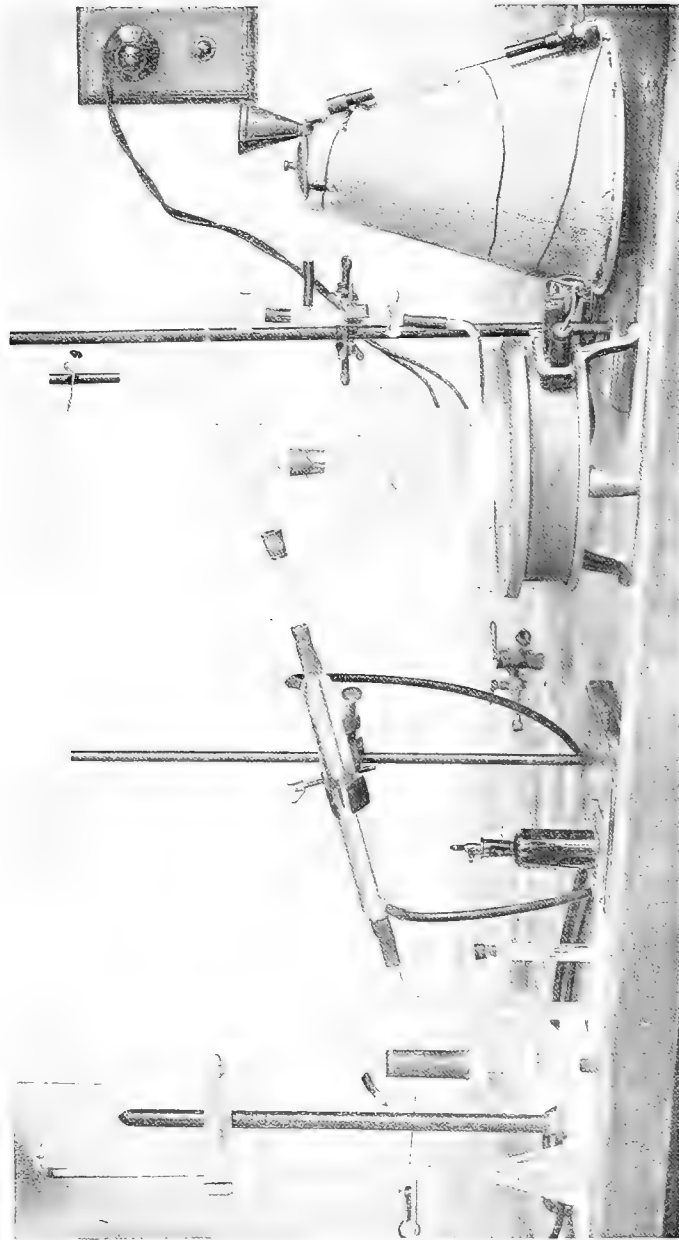
When dealing with fermentation or other liquids containing non-volatile or slightly volatile acids, we have found it advisable to distil off the volatile acids under reduced pressure, and then to estimate them in the condensed liquids by the ordinary distillation method.

A knowledge of the behaviour of the higher volatile fatty acids on distillation is desirable on account of their occurrence in many commercial oils and fats. By suitably adapting the apparatus described in this paper the distillation constants for the volatile acids contained in butter and coco-butter can be determined. Utilizing these constants the presence of adulteration may be detected. It is observed that these distillation constants change when a variation is made in the relative proportion in which

the acids are present, consequently the method may have further practical applications in physiological or biochemical investigations.

In conclusion, the authors take this opportunity of expressing their thanks to Capt. Desborough, R.A., Superintendent, and Mr. W. T. Thomson, Manager, of the Royal Naval Cordite Factory, Dorset, both for the interest they have taken in this investigation, and for securing permission to publish the results obtained. In addition we are indebted to Dr. Hackett, of the Royal College of Science for Ireland, for his kind assistance in the above mathematical treatment, and for his criticism of the work generally.

MAIN LABORATORY,  
ROYAL NAVAL CORDITE FACTORY,  
DORSET.





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THE  
SCIENTIFIC PROCEEDINGS  
OF THE  
ROYAL DUBLIN SOCIETY.

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Vol. XV. (N.S.), No. 38.

APRIL, 1919.

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SOLAR HALOS SEEN AT GREYSTONES, CO.  
WICKLOW, ON SEPTEMBER 22<sup>ND</sup>, 1879; AND  
IN TEXAS AND OHIO, U.S.A., ON OCTOBER  
3<sup>RD</sup>, 1917.

BY

SIR JOHN MOORE, M.A., M.D., D.Sc., F.R. MET. Soc.

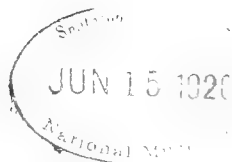
(PLATE L.)

[*Authors alone are responsible for all opinions expressed in their Communications.*]

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## XXXVIII.

SOLAR HALOS SEEN AT GREYSTONES, CO. WICKLOW, ON  
SEPTEMBER 22ND, 1879; AND IN TEXAS AND OHIO, U.S.A.;  
ON OCTOBER 3RD, 1917.

BY SIR JOHN MOORE, M.A., M.D., D.Sc., F.R. Met. Soc.

(PLATE L.)

[Read APRIL 23, 1918. Published APRIL 16, 1919.]

THROUGH the courtesy of Mr. Charles F. Marvin, Chief of the Weather Bureau of the United States Department of Agriculture, I am favoured with a copy of the *Monthly Weather Review*, published by that great organization, prepared and printed entirely within the Meteorological Office at Washington, D.C. Each number of the Review contains a number of contributions on climatology. Since August, 1915, the material for its pages has been prepared and classified in accordance with the following sections:—Aerology, General Meteorology, Forecasts, and General Conditions of the Atmosphere, Rivers and Floods, Seismology, Bibliography, and Weather of the Month.

In the number of the Review for October, 1917 (vol. xlv, No. 10, p. 486), I came across the following account of a remarkable complex series of solar halos, which were seen at Houston, Texas, on the forenoon of October 3rd, 1917. Some hours later a modified form of the same phenomena appeared at Gallia, Ohio, about 1,000 miles, as the crow flies, to the north-east of Houston. At the time that these halos were developed a system of relatively low atmospheric pressure was crossing the United States from the Rocky Mountain region, at first in a south-easterly direction, afterwards directly eastwards, and finally north-eastwards. This was exactly the condition which would predispose to the formation of halos in a thin veil of cirriform cloud suspended at an unusual height in the "free air," and consisting of prismatic ice-crystals:—

"HOUSTON, TEXAS.—The following notes and sketch [Pl. L., fig. 1] of a solar halo observed at Houston, Tex., on October 3rd, 1917, are furnished by

Mr. B. Bunnemeyer, Meteorologist. Of special interest are the oblique arcs of the anthelion marked 'g,' which are shown to meet in the upper part of the 22° halo.

"A perfect solar halo was observed at Houston, Tex., at 11.30 a.m., October 3rd, 1917, consisting of—(a) a halo of 22° radius; (b) an elliptical circumscribed halo; (c) arcs of a halo of 45°; (d) supralateral arc tangent to halo of 45°; (e) infralateral arcs tangent to halo of 45°; (f) parhelic circle of approximately 35° radius with zenith as centre; and (g) oblique arcs of the anthelion touching the halo of 22°. The halo was at its best when first observed. The accompanying sketch [Pl. L., fig. 1] of the phenomenon was prepared by Mr. I. R. Tannehill, assistant observer. [Additional inquiry of the Houston office force confirms the correctness of this point in the sketch here published as fig. 1.—C. A. jun.]

"There were no parhelia. The parhelic circle (f) and the oblique arcs of the anthelion (g) were white; all other circles or arcs of circles exhibited the colours of the rainbow, with the red colour towards the sun. The display was indescribably beautiful, and caused general comment and numerous inquiries as to its significance. The day was perfect, with an average cloudiness of only 3/10. Cirrus and cirro-stratus clouds surrounded the sun, intermingled with a very few cirro-cumulus. Here and there a few small cumulus clouds drifted across the sky. A faint cirrus haze was also observed. The parhelic circle and oblique arcs of the anthelion seemed to be projected for a large part upon a clear sky. The northern portion of the circumference of the halo of 22° and of the elliptical circumscribed halo were superimposed for a distance of about 40°, and the southern for a distance of perhaps 12°.

"The phenomenon began to dissolve slowly toward noon, and by 2.30 p.m. the last traces had faded away. For twelve days preceding its appearance, and for four days following it, the weather was perfect, with mostly clear sky.

"The time used was that of the 90th meridian."

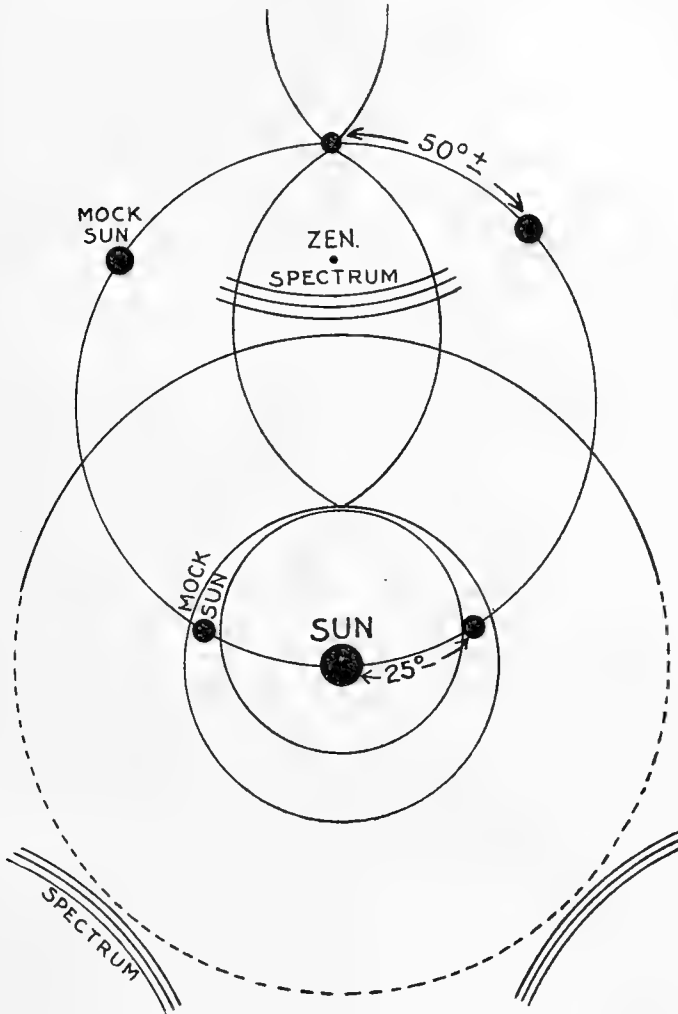
"GALLIA, OHIO.—Solar halo-phenomena were also observed on this date by Mr. J. S. Houser, Associate Entomologist of the Ohio Agricultural Experiment Station. His description and sketch (Pl. L., fig. 2) follow:—

"I am enclosing a sketch of parhelia re-drawn from a field-sketch made at Gallia, Ohio, October 3rd, 1917, at 2.30 in the afternoon.

"Perhaps such phenomena are quite common to you, but they were decidedly unusual to me. The semicircular bands of light A and B, while indistinct, were continuous; and the intensified patches of light C, D, E, F, G, H, I, and J, appeared with varying degrees of distinctness. Patch C was

the most distinct of all, but was scarcely more distinct than the X-shaped area J. The figure as shown represents the phenomenon in its most glorious stage. It was, of course, constantly changing.

“My observations and the field-sketch were checked and verified by Dr. Tipton, of Gallia.”



From a drawing on a tennis-ball (inscribed, "9.45 A.M. Greystones, 22nd Sept. '79. R. S. B."), as interpreted by Mr. Thomas Mason, Dame Street, Dublin.

My attention was at once arrested by the illustrations of these unusual halos, for I remembered that a certain historic and classical tennis-ball had been in my possession and treasured for as many as thirty-eight years. On it, in the autumn of 1879, my friend, the late Sir Robert Stawell Ball, had

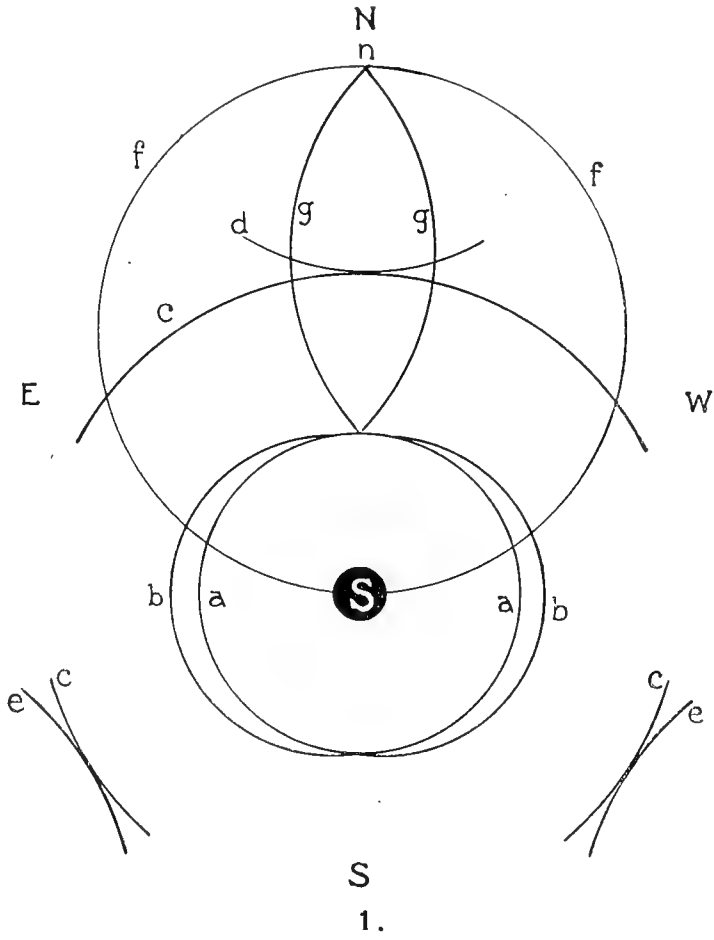
drawn a picture of an almost identical display of solar halos which he had witnessed on the forenoon of September 22nd in that year at Greystones, Co. Wicklow.

I have much pleasure in showing the tennis-ball in question, and also a picture, drawn from it by Mr. Thomas Mason, photographer, Dame Street, Dublin. In the picture the sun should be in the centre of the circle of  $22^\circ$  radius.

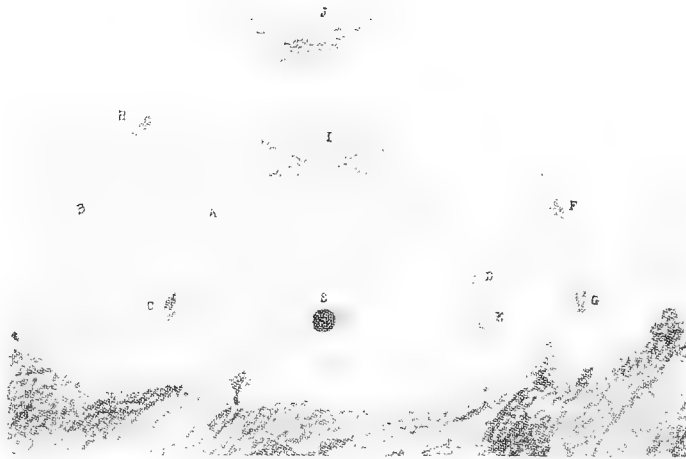
While touching on the subject of halos, I may allude to a beautiful double corona which encircled the moon on the evening of Friday, March 22nd, 1918.

Following on a summer's day of warmth and sunshine, that evening was signalized by the appearance of a "glory" round the gibbous moon of unusual beauty. In the afternoon a thin film of cirrus cloud spread over the sky at a great height from the westward. Although the thermometer at the surface of the ground in Dublin rose to  $63^\circ$  deg. in the shade under the combined influence of bright sunshine and a brisk south-westerly wind, that cloud was evidently composed of prismatic ice-crystals of singular tenuity, for at 8 p.m. and again at 9.30 p.m. a double-coloured corona developed round the moon. It consisted of two concentric circles outside an ordinary "glory." Both circles showed prismatic colours as in a rainbow. The inner circle, with a radius of 6 degrees from the moon's centre, displayed the colours red, orange, yellow, green, blue, and violet from within outwards. The outer circle showed these tints in a fainter degree and in the reverse order.

The phenomenon was a corona, or "glory"—not a halo, which is a great circle, with a radius of 22 degrees 30 minutes of arc, or less commonly of 45 degrees, round the sun or moon. In a halo all the colours of the rainbow may be seen, and the phenomena attending it can be explained only by the refraction of light through ice-crystals composing the feathery cirrus clouds which float at a vast height in the atmosphere. The beautiful coloured corona observed on the evening of March 22nd was of a like origin.



S  
1.



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APRIL, 1919.

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TWO NEW SPECIES OF COLLEMBOLA FROM  
NYASSALAND.

BY

GEORGE H. CARPENTER, D.Sc., M.R.IA.,

PROFESSOR OF ZOOLOGY IN THE ROYAL COLLEGE OF SCIENCE, DUBLIN.

(PLATE LI.)



*[Authors alone are responsible for all opinions expressed in their Communications.]*

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XXXIX.

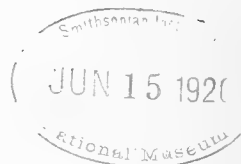
TWO NEW SPECIES OF COLLEMBOLA FROM NYASSALAND.

By GEORGE H. CARPENTER, D.Sc., M.R.I.A.,

Professor of Zoology in the Royal College of Science, Dublin.

(PLATE LI.)

[Read JANUARY 28; published APRIL 16, 1919.]



SOME years ago Dr. G. A. K. Marshall, Director of the Imperial Bureau of Entomology in London, was so good as to send me a number of small collections of Collembola and Thysanura from various tropical regions of the British dominions. Among these was a mass of small springtails, collected at Port Herald, Nyassaland, on the 28th April, 1913, by Dr. J. E. S. Old. The vast majority of the hundreds of specimens in this gathering belong to a species of *Isotomina*, but there are a few examples of an *Achorutes*, allied to the common European *A. viaticus*. Both these insects appear to belong to undescribed species.

**COLLEMBOLA.**

**PODURIDAE.**

Genus *Achorutes* Templeton.

*Hypogastrura* Börner.

*Achorutes caduceator* sp. nov. (Pl. LI, figs. 1-10).

Length 2mm. Eight ocelli on each side of head, post-antennal organ with four acute prominences (figs. 2, 4), a distinct ovoid accessory post-antennal area in front of ocellar patch (fig. 2). Foot with two tenent hairs, claw with small inner tooth, empodial appendage with sinuate lamella and tapering acute tip (fig. 7). Spring with dens as long as manubrium, two and a-half times as long as mucro, which has an evenly curved ventral edge, and a narrow dorsal lamella (figs. 9, 10). Bristles on trunk segments straight (figs. 1, 8). Anal spines short, slightly procurved (fig. 8). Colour deep blue-black.

Locality: Port Herald, Nyassaland.

Types in British Museum.

This species is closely related to the European—indeed cosmopolitan—*A. viaticus* (Linn.), wherewith it agrees in the straight, stiff bristles of the trunk-segments, in the small anal spines, in the general build of the feet and spring, the mucro in particular resembling that of *A. viaticus* almost exactly. The foot, however, of *A. caduceator* has two (not three) tenent hairs, and an empodial lamella more sinuate than that of *A. viaticus*. The most definite structural character appears to be found in the acute post-antennal prominences, which are borne on a cylindrical axis (fig. 4). There is a typical retractile vesicle surrounded by four or five sensory hairs at the tip of the fourth antennal segment, and three short sensory spines on the distal edge of the third antennal segment (fig. 5).

#### ENTOMOBRYIDAE.

Genus *Isotomina* Börner.

*Isotomina xii-oculata*, sp. nov. (Pl. LI, figs. 11–16).

Length, 1.25 mm. Six ocelli on each side of head. Post-antennal organ narrowly ovate, as long as diameter of inner anterior ocellus (fig. 12). Feeler as long as head, second and third segments sub-equal, the fourth longer (fig. 11). Foot-claw, and empodial lamella with distinct internal teeth; forefoot with one tenent hair (fig. 13); middle and hind foot with two (fig. 14). Fourth abdominal segment as long as third. Dentess as long as manubrium (fig. 15); mucro with three upturned acute teeth (figs. 15, 16).

Colour of head, feelers, and body deep violet-blue; only the prothorax, legs, and spring pale.

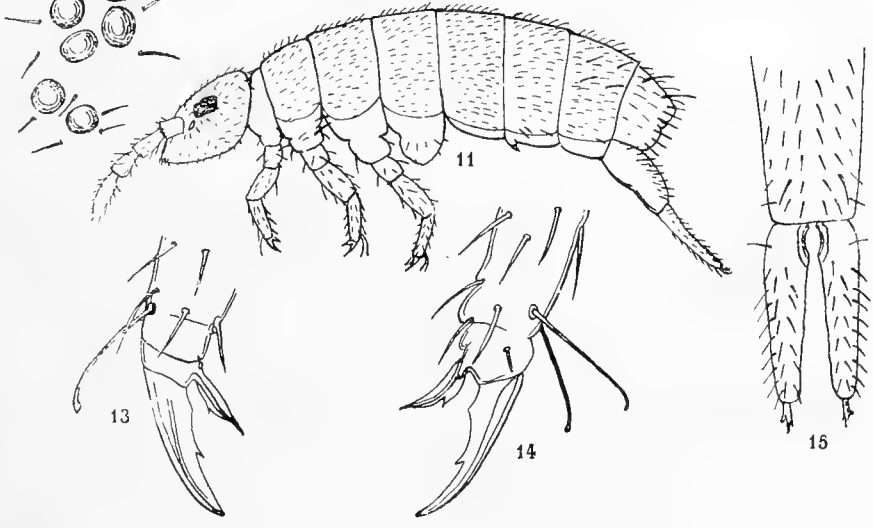
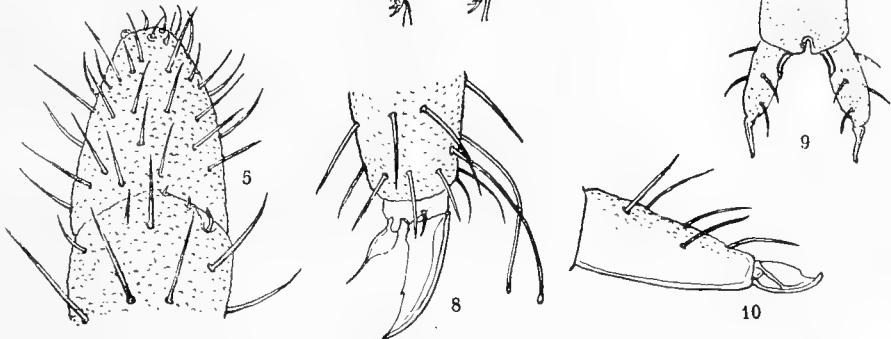
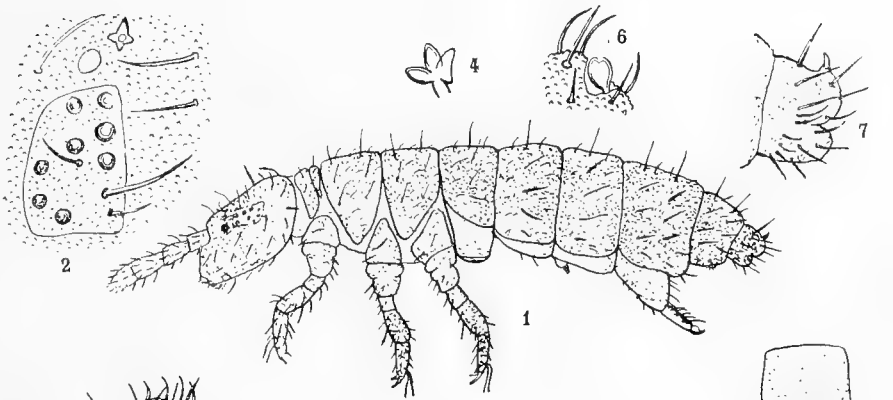
Locality: Port Herald, Nyassaland.

Types in British Museum.

This species is distinguished from other members of the genus (or subgenus) *Isotomina* by the reduction in the number of ocelli to six (instead of the usual eight) on each side, the third ocellus of both inner and outer series being absent. It is not distantly related to *I. fasciata* Carpenter,<sup>1</sup> from Benin, Southern Nigeria, but the latter has sixteen ocelli, its foot-claws and empodial lamella are without teeth, and its post-antennal organ is shorter and relatively broader than that of the species from Nyassaland now described. The number of specimens collected by Dr. Old is enormous; all students of springtails know that under favourable conditions these tiny insects present vast assemblages of individuals of the same kind.

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<sup>1</sup> *Bull. Entom. Research*, vol. iii, 1912, pp. 79–80.







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MAY, 1919.

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AN ECONOMIC METHOD OF DETERMINING  
THE AVERAGE PERCENTAGE OF FAT  
IN A COW'S MILK FOR A LACTATION  
PERIOD.

BY

E. J. SHEEHY, F.R.C.Sc.I.,

DEMONSTRATOR IN ZOOLOGY IN THE ROYAL COLLEGE OF SCIENCE, DUBLIN.

[COMMUNICATED BY PROFESSOR JAMES WILSON, M.A., B.SC.]

(PLATES LII.—LIII.)

[*Authors alone are responsible for all opinions expressed in their Communications.*]

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1919.

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EXPLANATION OF PLATE LI.

FIGS. 1-10.—*Achorutes caduicator.*

Fig.

1. Side view.  $\times 36$ .
2. Ocelli and post-antennal organ of left side.  $\times 280$ .
4. Post-antennal organ in profile.  $\times 560$ .
5. Terminal part of right feeler, dorsal view.  $\times 280$ .
6. Antennal organ on top of fourth segment of right feeler, ventral view.  
 $\times 560$ .
7. Third foot, side view.  $\times 300$ .
8. Sixth abdominal segment, with anal spine, side view.  $\times 110$ .
9. Spring, dorsal view.  $\times 110$ .
10. Dens and mucro of spring, side view.  $\times 300$ .

FIGS. 11-16.—*Isotomina xii.-oculata.*

Fig.

11. Side view.  $\times 48$ .
12. Ocelli and post-antennal organ of left side.  $\times 560$ .
13. Fore foot, side view.  $\times 560$ .
14. Hind foot, side view.  $\times 560$ .
15. Spring, dorsal view.  $\times 240$ .
16. Tip of mucro and dens, side view.  $\times 560$ .

## XL.

## AN ECONOMIC METHOD OF DETERMINING THE AVERAGE PERCENTAGE OF FAT IN A COW'S MILK FOR A LACTATION PERIOD.

BY E. J. SHEEHY, F.R.C.Sc.I.,

Demonstrator in Zoology, Royal College of Science, Dublin.

[COMMUNICATED BY PROFESSOR JAMES WILSON, M.A., B.Sc.]

(PLATES LII., LIII.)

Read NOVEMBER 19, 1918. Published MAY 13, 1919.

THE irregularity of the returns for fat percentage in cows' milk often obtained by the usual method of testing a number of samples taken at intervals during a lactation period has occasioned comment. Similarly, in experiments on the comparison of the fat-producing value of foods, observers have sometimes doubted the accuracy of the actual results because of some unaccountable diversion from the expected. This occurs when the average milk fat percentage is determined from samples taken at intervals during the period of investigation. Experiments of this nature are often conducted without a full appreciation of the difficulty of ascertaining accurately what might be called the mean fat percentage. The difficulty in this connexion arises from the fact that all cows exhibit some, and many cows exhibit very great, variation in the daily returns. To investigate this phenomenon an experiment was conducted in 1915 at the Albert Agricultural College on eleven cows during the period June 23rd to August 1st (inclusive), i.e., during a period when the cows were under continuous normal conditions in the field.

The following table contains relevant information regarding these cows:—

| Name or Number. | Approximate age. | Time calved. | In calf again on. | Estimated annual normal yield. | Average daily yield during July. |
|-----------------|------------------|--------------|-------------------|--------------------------------|----------------------------------|
| 122             | 6 years.         | 8 months.    | 2 July.           | 700 gallons.                   | 15 lb.                           |
| 128             | 5 "              | 5 "          | —                 | 600 "                          | 13 "                             |
| 130             | 6 "              | 5 "          | 18 March.         | 500 "                          | 14 "                             |
| 131             | 5 "              | 4 "          | 10 June.          | 900 "                          | 25 "                             |
| 132             | 6 "              | 3½ "         | —                 | 800 "                          | 27 "                             |
| 133             | 5 "              | 3½ "         | —                 | 800 "                          | 28 "                             |
| 134             | 6 "              | 3½ "         | 2 July.           | 700 "                          | 20 "                             |
| 135             | 7 "              | 2½ "         | —                 | 900 "                          | 30 "                             |
| 136             | 6 "              | 2½ "         | 22 June.          | 850 "                          | 27 "                             |
| 137             | 6 "              | 2½ "         | 2 July.           | 850 "                          | 24 "                             |
| 97              | 4 "              | 3 "          | —                 | 900 "                          | 26 "                             |

The cows were milked twice a day, at 5 a.m. and 2 p.m. The milk was weighed, duplicate samples drawn at each milking and tested by the Gerber method. The cows were milked throughout by the same milkers. In no case were the duplicate samples found to differ from each other, in fat content, by more than 1 per cent., which is the limit in the Gerber method.

Table 1 gives the morning and evening yields and fat percentages for each cow throughout the investigation.

From the table the following general results may be noted:—

(1) The milk yields are generally much higher in the morning than in the evening.

(2) The fat percentage is generally much lower in the morning than in the evening; the morning milk of each cow frequently contains less than 3 per cent. of butter-fat.

(3) The percentage fat for successive evenings or successive mornings fluctuates considerably; the milk yield fluctuates to a less extent.

The fat percentages for two cows (128 and 97) are represented graphically in diagram 1. 97 is the most variable of the experimental cows, while 128 represents an average type, that is, neither the greatest nor the least variable. It is obvious that general conclusions regarding a method of estimating the butter-fat value of a cow can be arrived at only after considering the most variable of the experimental groups, because of the possibility of any untested cow showing similar variation.



Results 1 and 2 above are obviously influenced by the unequal intervals between the milkings—fifteen hours between the evening and morning and nine hours between the morning and evening. Professor Crowther<sup>1</sup> has shown that the yield of milk and percentage fat are factors of the intervals

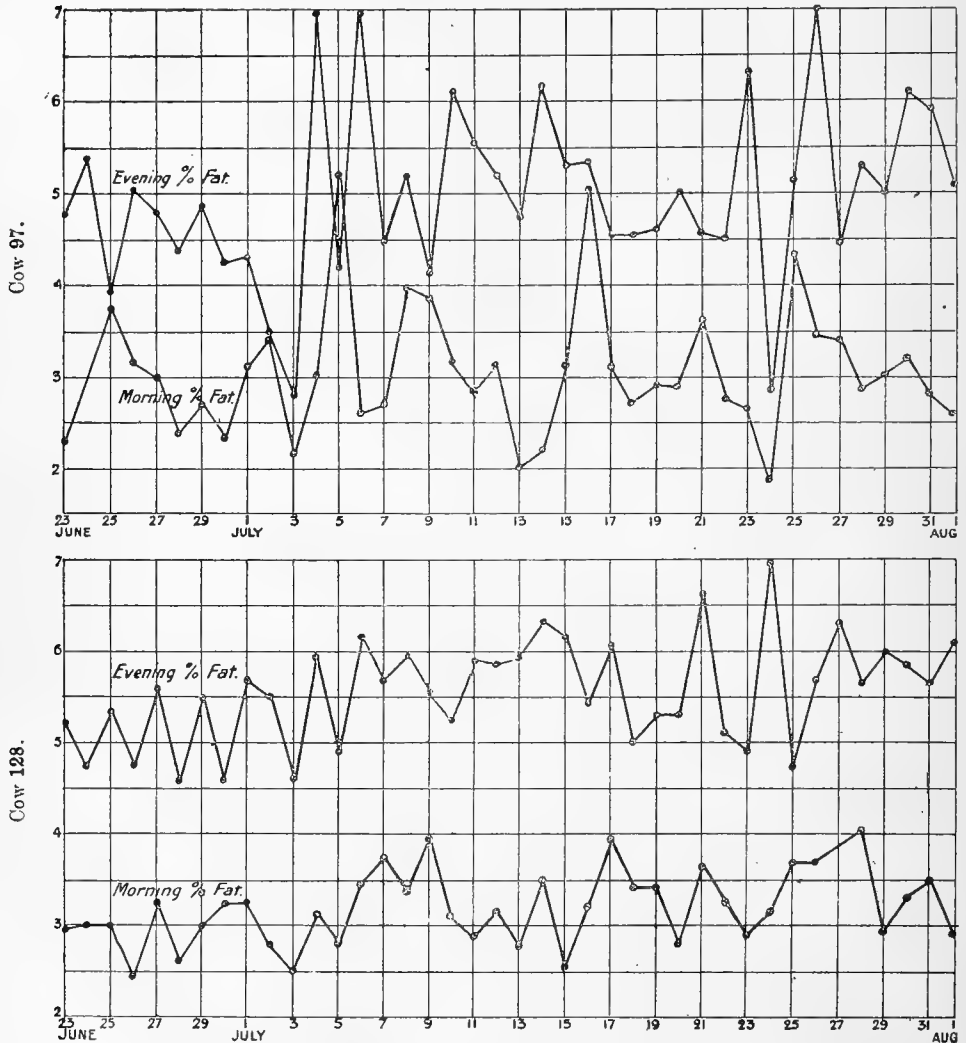


Diagram I.—Representing percentage of fat in morning and evening milk.

after which the cows are milked, and that the total daily yields are not altered by the inequality of the intervals, provided they are not unreasonably unequal. From Table 1 the total daily milk, daily percentage fat, and total daily fat for each cow are calculated, and the returns for three of them are

<sup>1</sup> Charles Crowther, "Variation in the Composition of Cows' Milk," *Journal of Agricultural Science*, 1905-6, vol. i, p. 152.

presented in Table 2. The figures obtained from cows 128 and 97 are displayed in graphic form in diagrams II and III.

lbs of milk.

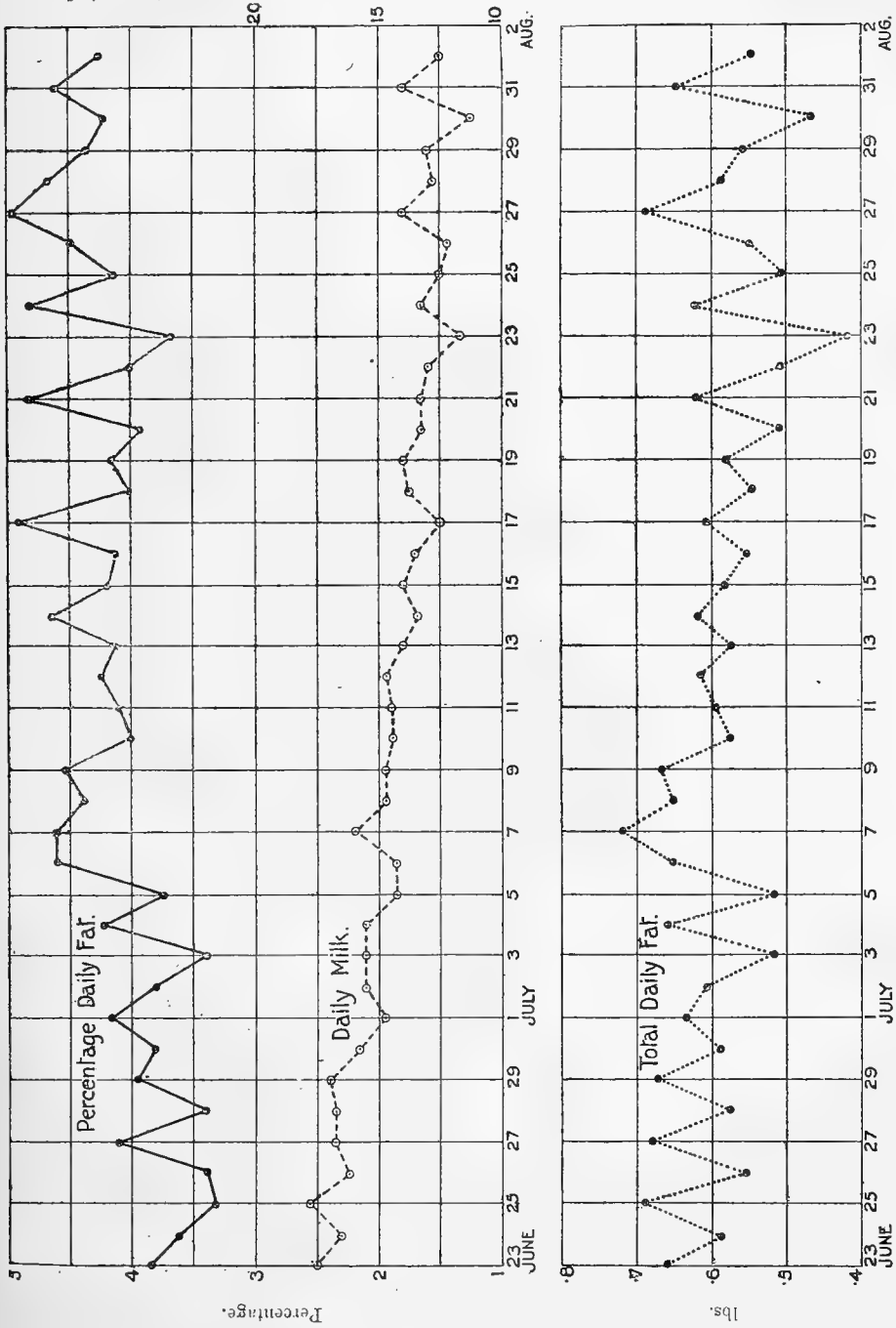


Diagram II.—Representing yields from Cow 128.

The tables and diagrams show—

(1) that the daily milk yield declines gradually as the lactation period proceeds, but the decline fluctuates from day to day ;

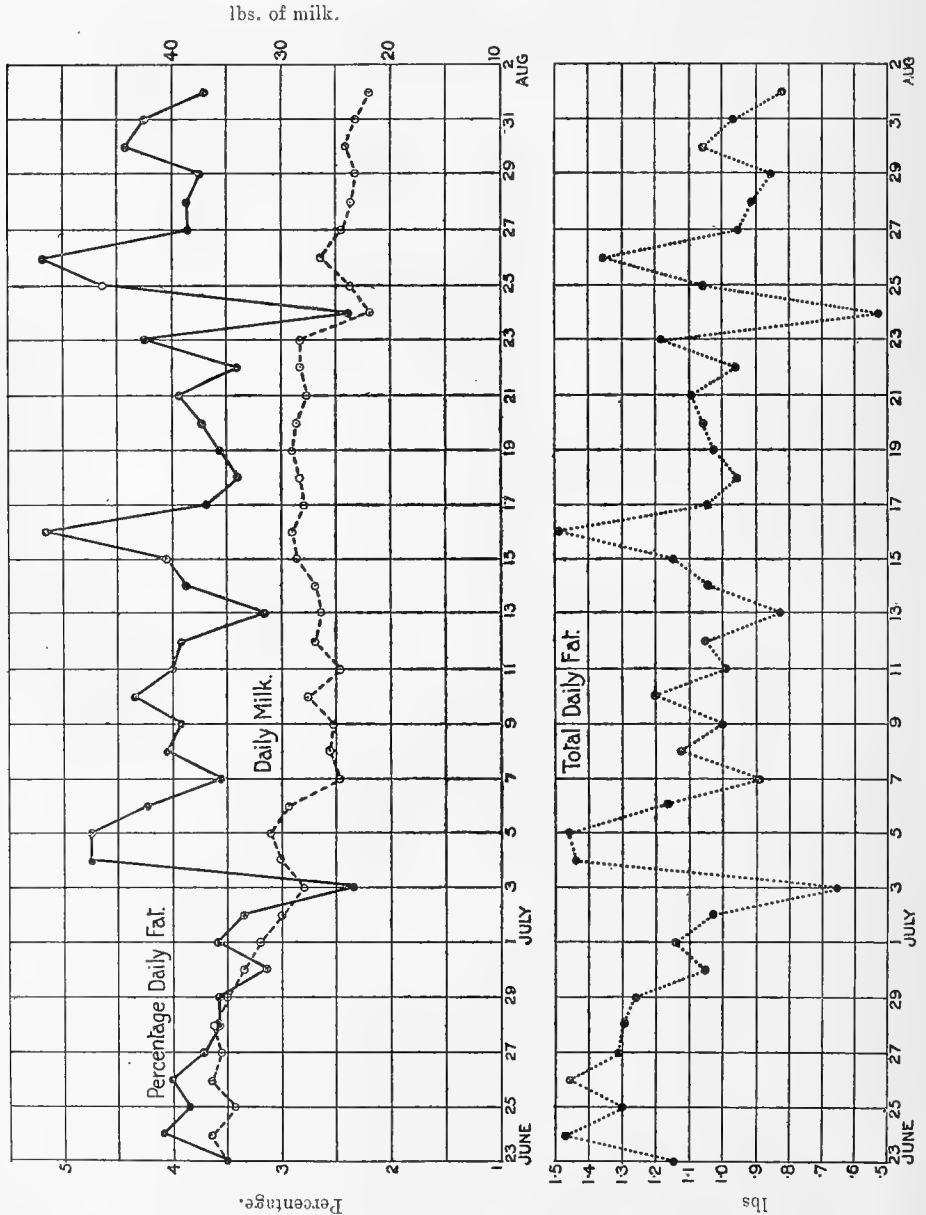


Diagram III. — R. representing yields from Cow 97.

(2) that the daily fat percentage increases gradually, but with considerable daily fluctuations. It is evident from the graphs that the variations in fat percentage are much greater than the corresponding variations in the milk yield.

The graphs clearly demonstrate that an estimate of fat percentage made from a few samples taken at random can seldom be correct. Thus in the case of cow 97 readings from the crests of the graph of fat percentage would give over 5 per cent. fat, while readings from the troughs would give less than  $2\frac{1}{2}$  per cent. fat. The case of cow 128 is similar, but the difference between the extremes is less marked. The mean fat percentage for each cow during the investigation period may be represented by a smooth line drawn across the irregular curves which join the actual daily fat percentages. The frequent diversion of the irregular curve outside this average line is very considerable in the case of most of the experimental cows. The following table gives the recorded maximum diversions outside the mean for a period of twenty days extending equally on either side of the date on which the diversion occurs: the noticeable disturbance of the first week of July being excluded:—

| Number of cow. | Maximum variation outside the average. | Calculated percentage error. | Occurred on  |
|----------------|--|------------------------------|--------------|
| 122            | .8                                     | —                            | July 16      |
| 128            | .65                                    | 17                           | July 23      |
| 130            | .42                                    | —                            | July 22 & 23 |
| 131            | .42                                    | —                            | July 24      |
| 132            | .78                                    | —                            | July 12      |
| 133            | .88                                    | —                            | July 22      |
| 134            | .82                                    | —                            | July 16      |
| 135            | .42                                    | —                            | July 1       |
| 136            | .63                                    | —                            | July 22      |
| 137            | .72                                    | —                            | July 3       |
| 97             | 1.50                                   | 38                           | July 24      |

Since the results obtained from the fat percentage in a number of random samples are not satisfactory, it was thought that a better result would be obtained by determining the total fat in a number of random samples. A glance at diagrams II and III immediately disproves the truth of this supposition, because the total fat shows variations at least as great as, if not greater than, the percentage fat. In these diagrams the perpendicular scale is such that in the three curves similar ascents and descents, that is, similar lengths of line on the graphs, approximately represent similar variations. This observation regarding total fat might have been inferred from the figures of

daily milk yields and fat percentages, because if the total fat varied directly as the total milk, then the graph of the fat percentage would be a straight line. No better result is obtained, therefore, from the total fat in a number of random samples.

It now remains to suggest some other method of determining the average fat percentage in a cow's milk throughout a lactation period. The true fat percentage for the period could be got with accuracy by sampling and testing the milk every day; but this is far too laborious. The problem is, therefore, how is the milk to be sampled and tested in order, with the least labour, to arrive at the average fat percentage with such approximate accuracy as the case demands? How shall sampling and testing be carried out so that the approximate average shall differ from the true calculated average by, say, not more than 10 per cent., i.e., that the approximate average for a cow with a true calculated average of, say, 4 per cent. shall neither be above 4.4 per cent. nor under 3.6 per cent.? The average percentage of fat in the milk of cow No. 97 over the whole period of observation is 3.86. It is obvious from a glance at either the figures or the diagram that single samples taken at random during the period might have given very erroneous results. A sample taken on July 3rd would give 2.37 per cent. of fat; another on July 4th, 4.75 per cent.; another on July 16th, 5.16 per cent.; another on July 26th, 5.19 per cent. A number of random samples combined or a similar number of samples at equal intervals would probably give a more satisfactory result.

The averages of four samples taken at intervals of ten days are as follows:—

|                                |                                |
|--------------------------------|--------------------------------|
| June 24 to July 24, . . . 3.77 | June 29 to July 29, . . . 3.70 |
| „ 25 „ 25, . . . 4.32          | „ 30 „ 30, . . . 3.89          |
| „ 26 „ 26, . . . 4.64*         | July 1 „ 31, . . . 3.93        |
| „ 27 „ 27, . . . 3.70          | „ 2 to Aug. 1, . . . 3.61      |
| „ 28 „ 28, . . . 3.72          |                                |

The averages of four samples taken at intervals of seven days are as follows:—

|                                |                                |
|--------------------------------|--------------------------------|
| June 24 to July 15, . . . 3.93 | July 3 to July 24, . . . 3.19* |
| „ 25 „ 16, . . . 4.09          | „ 4 „ 25, . . . 4.20           |
| „ 26 „ 17, . . . 3.59          | „ 5 „ 26, . . . 4.36*          |
| „ 27 „ 18, . . . 3.97          | „ 6 „ 27, . . . 3.73           |
| „ 28 „ 19, . . . 3.95          | „ 7 „ 28, . . . 3.81           |
| „ 29 „ 20, . . . 3.56          | „ 8 „ 29, . . . 3.80           |
| „ 30 „ 21, . . . 3.63          | „ 9 „ 30, . . . 4.44**         |
| July 1 „ 22, . . . 3.76        | „ 10 „ 31, . . . 3.66          |
| „ 2 „ 23, . . . 4.19           | „ 11 to Aug. 1, . . . 3.93     |

The averages of six samples taken at seven-day intervals are as follows:—

|                                |                                |
|--------------------------------|--------------------------------|
| June 24 to July 29, . . . 3·81 | June 26 to July 31, . . . 3·51 |
| ,, 25 ,, 30, . . . 4·16        | ,, 27 to Aug. 1, . . . 4·03    |

Assuming that a figure departing by not more than 10 per cent. from the calculated average would be satisfactory—that is that the result in this case should be not less than 3·47 per cent., and not greater than 4·25—any of the above would, in the majority of cases, give a fair approximation. Sometimes, however, the result is outside the limits of error (averages outside limits of error are marked thus \*); and, therefore, samples taken in this way are not always to be relied on. Four samples are not sufficient, but as the number of samples is increased the result becomes more reliable.

Can an equally or more satisfactory result be got by any less laborious method? A glance at an imaginary smoothed-out curve of fat percentage rising gradually during the period in diagrams II and III shows that the curve approximates to the true average for the whole period near its centre, say from July 7th to July 21st. It will be noticed also that a large fluctuation above or below the smoothed curve is usually compensated by a fluctuation in the opposite direction immediately afterwards. It is, therefore, suggested that a good approximation might be got from samples taken on two or preferably four consecutive days near the middle of the period. For cow 97 the following are the averages of some four-successive-day tests:—

|                                |                                |
|--------------------------------|--------------------------------|
| June 23 to June 26, . . . 3·79 | July 12 to July 15, . . . 3·76 |
| ,, 24 ,, 27, . . . 3·89        | ,, 13 ,, 16, . . . 4·06        |
| ,, 25 ,, 28, . . . 3·76        | ,, 14 ,, 17, . . . 4·20        |
| ,, 26 ,, 29, . . . 3·70        | ,, 15 ,, 18, . . . 4·08        |
| ,, 27 ,, 30, . . . 3·50        | ,, 16 ,, 19, . . . 3·95        |
| ,, 28 to July 1, . . . 3·46    | ,, 17 ,, 20, . . . 3·59        |
| ,, 29 ,, 2, . . . 3·43         | ,, 18 ,, 21, . . . 3·65        |
| ,, 30 ,, 3, . . . 3·12*        | ,, 19 ,, 22, . . . 3·64        |
| July 1 ,, 4, . . . 3·52        | ,, 20 ,, 23, . . . 3·82        |
| ,, 2 ,, 5, . . . 3·83          | ,, 21 ,, 24, . . . 3·49        |
| ,, 3 ,, 6, . . . 40·3          | ,, 22 ,, 25, . . . 3·66        |
| ,, 4 ,, 7, . . . 4·32*         | ,, 23 ,, 26, . . . 4·11        |
| ,, 5 ,, 8, . . . 4·15          | ,, 24 ,, 27, . . . 4·01        |
| ,, 6 ,, 9, . . . 3·94          | ,, 25 ,, 28, . . . 4·38*       |
| ,, 7 ,, 10, . . . 3·97         | ,, 26 ,, 29, . . . 4·16        |
| ,, 8 ,, 11, . . . 4·08         | ,, 27 ,, 30, . . . 3·96        |
| ,, 9 ,, 12, . . . 4·05         | ,, 28 ,, 31, . . . 4·06        |
| ,, 10 ,, 13, . . . 3·85        | ,, 29 to Aug. 1, . . . 4·01    |
| ,, 11 ,, 14, . . . 3·74        |                                |

In three cases out of thirty-seven four-day tests the average is outside the error limit (\* on table). On applying the same test to cow 128 it is found that in no case does the result diverge seriously from the average of a period extending equally on both sides of the period of the test. The same thing holds for all the other cows under observation. Even in the case of the hyper-sensitive cow 97, the three exceptional results above (\* on table) are easily explained. It is known that cows are affected differently as regards milk and butter-fat yields by the return of the oestrus period; in some cases the fat rises, in others falls, and in others still remains unchanged. Cow 97 belongs to the group which is seriously affected. The oestrus recurred on the night of June 15th; and the result is a rapid rise in fat (see diagram III): the increase is not sufficient, however, to upset the accuracy of the four-day test. On July 2nd and July 3rd, and again on July 25th, it was noticed that other cows in the same field were in oestrus; and it is a fair inference that the excitation of cow 97, due to the disturbing effect of those others, influenced her fat yield in a fashion similar to that shown after July 15th. Because of these disturbances the four-day test for June 30th-July 3rd, for July 4th-7th, and again for July 25th-28th are outside the usual limits. But even the appearance of these exceptions in the case of a hyper-sensitive cow does not invalidate the four-day test, because the careful sampler always makes observations regarding oestrus, violent weather changes, and so on; and if one of these disturbing elements should intrude into the period of sampling, the number of samples may be extended to six; and a six-consecutive-day test is in all cases, without exception, reliable. While it is necessary to make provision for serious disturbing factors by an extension of the test to six days, a four-consecutive-day period is in normal circumstances sufficiently long to give a result which comes within the 10 per cent. limit of error, and in the majority of cases within a 5 per cent. limit, frequently approximating even to the correct average for the period concerned.

The average of a two-day test would be unreliable, thus—

|              | Per cent. |              | Per cent. |              | Per cent. |
|--------------|-----------|--------------|-----------|--------------|-----------|
| July 15, . . | 4.06      | July 16, . . | 5.16      | July 18, . . | 3.42      |
| „ 16, . .    | 5.16      | „ 17, . .    | 3.69      | „ 19, . .    | 3.54      |
|              | <hr/>     |              | <hr/>     |              | <hr/>     |
| Total, . .   | 9.22      |              | 8.85      |              | 6.96      |
| Average, . . | 4.61      |              | 4.42      |              | 3.48      |

The average calculated in this way is, in one instance, 20 per cent. outside the true average for the period.

A successive three-day test frequently gives a better result than a two-

day one, but occasionally it gives a less accurate one, and for that reason it is not to be recommended. For instance, in diagram II (cow 128) the average of the readings for June 25th, 26th, and 27th is further from the flattened curve than that of June 26th and 27th; that of July 7th, 8th, and 9th further than that of July 7th and 8th. In diagram III (cow 97) the average of July 3rd, 4th, and 5th is less correct than that of July 3rd and 4th; that of July 22nd, 23rd, and 24th is less correct than that of July 22nd and 23rd.

The four-consecutive-day test having been suggested by the observations made in 1915, the investigation was resumed in 1916. The work was begun earlier, however, and continued till later in the year, so that periods of extreme variation, if there were any, connected with the changes from house-feeding to pasture in spring, and from pasture to house-feeding in autumn, should be included. The investigation re-started on February 2nd and ended on December 8th. An additional purpose in 1916 was to discover the relative variability of the different milk constituents; to discover, for example, whether the butter fat is relatively more variable than the water.<sup>1</sup> Twelve normal cows giving a good average yield were selected, and the following are relevant particulars:—

| No. | Time calved when experiment started. | Put in calf again on. | Calved during experiment.                |
|-----|--------------------------------------|-----------------------|--|
| 128 | 1½ months                            | —                     | —  |
| 141 | 6 „                                  | —                     | —  |
| 149 | 4½ „                                 | —                     | —  |
| 150 | 4½ „                                 | —                     | —  |
| 151 | 4½ „                                 | —                     | —  |
| 152 | 4 „                                  | —                     | —  |
| 154 | 3½ „                                 | —                     | —  |
| 155 | 2½ „                                 | August                | —  |
| 158 | 2 „                                  | —                     | —  |
| 159 | 3 weeks                              | February 20           | September 20. (Foetus only 7 months old) |
| 160 | 3 „                                  | —                     | —  |
| 161 | 3 „                                  | June                  | —  |

The samples were taken and tested as before. In addition, a sample of

<sup>1</sup> Result of this part of experiment in another paper.



about one pint in volume was drawn daily from March 28th to June 17th, inclusive, and from it the specific gravity of the milk was ascertained by means of a lactometer.<sup>1</sup>

The cows were fed as follows:—

In house from February to May 11th:

6lb. of concentrates.

6 stone of roots.

oat straw or hay ad lib.

From April 28th roots were replaced by  $\frac{1}{2}$  cwt. rye.

„ May 3rd rye was „ „ vetches and rye.

„ May 7th vetches and rye „ „ rape and hardy greens.

To grass on May 11th—pasture:

From October 19th, cabbage on pasture.

„ „ 25th, hay on pasture.

Into house on October 28th:

6lb. concentrates.

cabbage and hay.

Table 3 gives the measured and calculated results for cow 155. Similar data were accumulated for each of the twelve cows. Diagrams were drawn to represent the total daily milk, total daily fat and per cent. fat for each cow. Two of these are appended, one—Plate LII—for cow 155, which did not calve nor become in calf during the period, and another—Plate LIII—for cow 159, which was served on February 20th, and calved on September 20th. This group of cows exhibits variations in the daily returns similar to those observed in the 1915 lot. When the four-consecutive-day method of sampling for fat percentage is put to the test, it is found that in every case it gives the approximate average for a period of about one month extending equally on both sides of the date of sampling. From the tables and graphs the following observations also can be made.

(1) There is a pronounced variation in the daily fat percentage both when the cows are in the house and on pasture.

(2) The milk and total fat decline gradually before the cows go on to the grass, but because the milk declines more quickly than the fat, the percentage of fat rises slightly.

(3) Green feeding in the house does not materially alter the yield either of milk or fat.

<sup>1</sup> Required for the second part of the experiment. From specific gravity and per cent. fat the total solids have been calculated.

(4) There is a great increase in milk and total fat yields when the cows go on the grass. The fat percentage is not affected till a few weeks later, when it drops considerably, and shows much greater daily variations than before.

(5) After the disappearance of this disturbance, the milk and total fat gradually decrease and the percentage fat gradually increases.

(6) A day or two after the removal from the field to the house, there is another increased variation in fat percentage.

(7) The curve for cow 159 shows that there is a very high fat percentage, with an increased variation, during the six weeks at the end of the lactation period and during the first three or four weeks of a new lactation period. This is known to be general among cows.

Assuming that the twelve cows whose milk was investigated behaved in a fashion normal to cows generally, it may be concluded that there are four periods in a lactation when the percentage of butter fat in the milk may diverge so seriously from the average for the whole lactation that they should be avoided by a sampler if a fair average for a whole lactation is to be based upon a few samples. These periods are :—

(1) The first three or four weeks of a lactation.

(2) The last five or six weeks of a normal lactation.

(3) A period of about six weeks after the cows go on to the grass from the house, in the case of cows entirely house-fed during the winter and spring.

(4) The first three weeks after the cows go into the house in autumn. In this connexion it is interesting to compare the above with the diagram IV taken from Professor Berry's Report.<sup>1</sup> The cows represented were put on to the pasture in May and housed again in October.

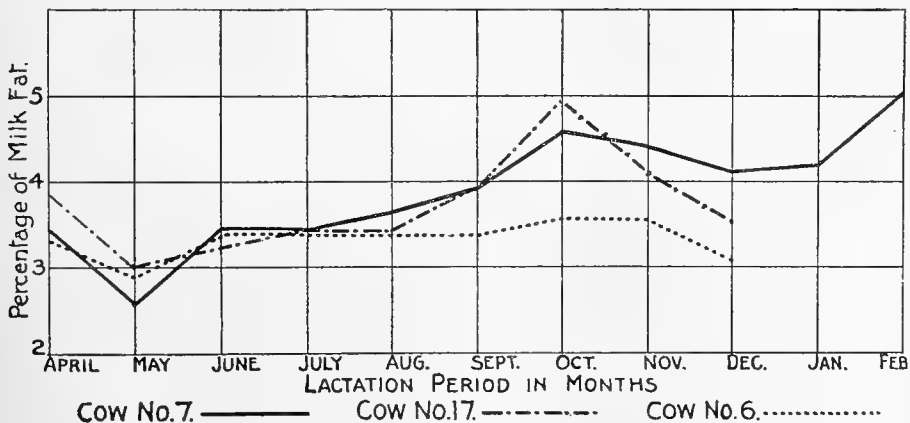


Diagram IV.

<sup>1</sup> The Yield and Composition of Cows' Milk during Lactation, Bulletin No. 76, The West of Scotland Agricultural College.

Having found a reliable method of determining the average fat percentage for a short period, it remains to consider its application to the entire lactation period—the abnormal periods, as found during the 1916 investigation, being avoided. For some weeks after calving, and for several weeks at the end of a lactation, the quality of a cow's milk is above the average for the whole lactation, as in diagram V. At the beginning of the interval between these two periods it is below and at the end above the average. There must, therefore, be a short period within this interval when the quality of the milk is close to the average for the whole lactation. Evidently this period occurs about midway between the extremes, but it is necessary in this connexion to investigate data from other sources.

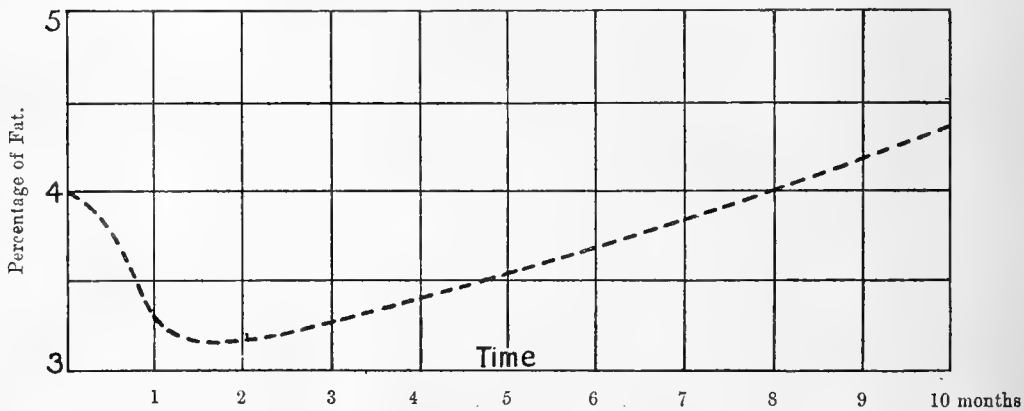


Diagram V.—Percentage of fat in milk during a lactation period.

From figures compiled by the Department of Agriculture, from the returns of the Irish creameries, it is found that the milk required to make a pound of butter in the month of August is approximately the quantity required on the average throughout the year. The following are the figures:—

GALLONS OF MILK REQUIRED TO MAKE A POUND OF BUTTER.

|                             | 1910 | 1911 | 1912  | 1913 | 1914  |
|-----------------------------|------|------|-------|------|-------|
| Average for the year, . . . | 2.39 | 2.39 | 2.382 | 2.38 | 2.39  |
| Average for August, . . .   | 2.39 | 2.40 | 2.37  | 2.41 | 2.383 |

Since the great majority of the cows supplying the Irish creameries calve in March and April, it is a fair inference that the quality of their milk is about the average during the month of August: that is, when they are about five months calved.

Professor Eckles and Mr. Roscoe H. Shaw made a similar investigation in the United States, with twelve cows belonging to four different breeds,<sup>1</sup> and give the percentage of fat in each cow's milk during successive four-week periods and the averages for the complete lactation. On examining these figures, which are for individual cows, one finds that in only one case does the four-week average depart from the lactation average seriously, i.e., by more than ten per cent., if the first eight weeks and those after the thirty-second be excluded.

In investigations carried out in Sweden by K. A. Högström with Ayrshire cows, and by Nils Hansson with Dutch cows, it was found that the quality of milk is at the average when the cows are calved just over five months. The results of both investigations are expressed in diagram VI, which is copied from Professor Nils Hansson's "Utfodringlära."

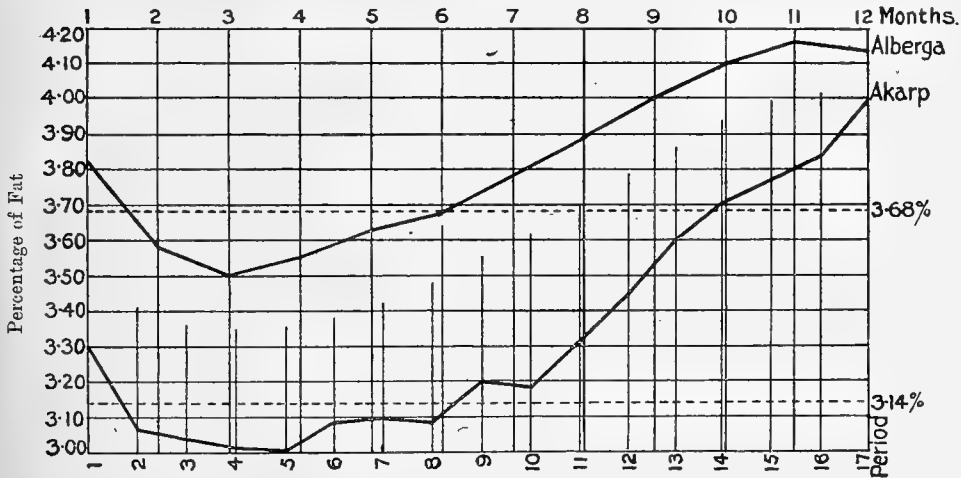


Diagram VI.

The upper curve refers to the Ayrshire cows; the lower to the Dutch. It will be noticed that from the beginning of the third to the end of the seventh

<sup>1</sup>The Influence of Breed and Individuality on the Composition and Properties of Milk, U. S. Department of Agriculture, Bureau of Animal Industry, Bulletin 156.

month, both included, neither curve diverges more than six per cent. from the average. The actual divergencies for the Ayrshire cows are:—

|  | Per cent. |
|--|-----------|
| At the beginning of the 3rd month, . . . . .     | 5         |
| "    "    "    "    "    4th    "    .    .    . | 3·5       |
| "    "    "    "    "    5th    "    .    .    . | 1·3       |
| "    "    "    "    "    6th    "    .    .    . | —         |
| "    "    "    "    "    7th    "    .    .    . | 2·9       |
| "    "    "    "    "    8th    "    .    .    . | 5·4       |

Now, the four-day test is usually not more than 5 per cent., and never more than 10 per cent., outside the average for the short period it represents. There is, however, the possibility of the divergence being in the same direction as that recorded above; and in that case the error is accumulated. That is to say, when the four-day test is applied during a period extending from the beginning of the third to the beginning of the eighth month, there is the possibility of a 10 per cent. error in the majority of cases, and of a maximum of 15 per cent. error in some cases. The possible error can be reduced by limiting the time of sampling to a shorter period, and by confining it to the fifth and sixth months of the lactation we ensure a result generally not more than 5 per cent., and never more than 10 per cent., outside the average for the entire period of milking.

The returns of weekly tests from twenty cows during normal lactation periods have been tabulated from data kindly supplied by Sir Gilbert Greenall from his dairy herd at Kilmallock, where the quality of each cow's milk is tested one day a week. Single-day tests are always liable to occasional severe fluctuations such as were found in the milk of the cows at Glasnevin, which also appear in the Kilmallock returns. When these are allowed for, the Kilmallock data show that, when the lactation period is of normal length—that is, when the next calf is expected within eleven to thirteen months after its predecessor—tests may be relied on from samples taken at any time from the third to the eighth month (inclusive) after calving, the error limit appearing less than in the returns from Högström and Hansson. In a prolonged lactation the period of sampling may be extended; but in any general scheme it is well to adhere to the general rule. Postponing the date of sampling might in cases be overdone.

It is, therefore, suggested that, to ascertain the percentage of fat in a cow's milk over a normal lactation at the smallest cost and with approximate

accuracy, samples be drawn during four successive days at any time between the third and eighth months (inclusive) after the cow has calved. Should disturbing factors supervene, samples should be drawn and tested for six consecutive days. No samples should, however, be taken for six weeks after the cows go on to the pasture from the house, nor during the first three weeks after the cows have come into the house from the pasture. The result is more reliable if the period of sampling be limited; and when this is confined to the fifth and sixth months of the lactation period, the possibility of error is reduced to a minimum.

[TABLES.]

TABLE 1.—MORNING AND EVENING

The HEAVY TYPE FIGURES under M. and E. represent the percentage fat in the morning's and evening's milk.  
The numbers on top represent the

|         | 122  |      | 128  |      | 130  |      | 131  |      | 132  |      | 133  |      | 134  |      | 135  |      | 136  |      | 137  |      | 97   |      |
|---------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
|         | M.   | E.   | M.   | E.   | M.   | E.   | M.   | E.   | M.   | E.   | M.   | E.   | M.   | E.   | M.   | E.   | M.   | E.   | M.   | E.   | M.   | E.   |
| June 23 | 2.95 | 3.30 | 2.95 | 5.20 | 2.70 | 3.82 | 2.50 | 3.25 | 2.35 | 4.12 | 3.10 | 3.70 | 3.10 | 3.95 | 2.20 | 4.40 | 3.45 | 4.90 | 3.09 | 3.85 | 2.30 | 4.77 |
| " 24    | 3.17 | 3.90 | 2.85 | 4.75 | 3.87 | 3.87 | 2.70 | 3.92 | 2.72 | 4.25 | 2.72 | 3.87 | 3.70 | 4.20 | 1.80 | 5.22 | 3.17 | 4.30 | 3.00 | 3.60 | 3.00 | 5.40 |
| " 25    | 2.60 | 3.27 | 2.82 | 5.35 | 3.20 | 3.20 | 2.75 | 2.80 | 3.50 | 3.50 | 2.75 | 3.80 | 3.65 | 2.92 | 2.25 | 4.90 | 3.00 | 4.00 | 2.70 | 3.80 | 3.75 | 3.95 |
| " 26    | 2.92 | 4.12 | 2.77 | 4.75 | 3.90 | 3.90 | 2.70 | 3.75 | 3.85 | 3.85 | 2.70 | 4.20 | 3.67 | 4.20 | 2.02 | 4.42 | 2.90 | 3.90 | 2.60 | 3.80 | 3.17 | 5.05 |
| " 27    | 2.97 | 3.57 | 2.52 | 5.60 | 4.17 | 4.17 | 2.60 | 3.55 | 4.92 | 4.92 | 2.80 | 3.87 | 3.42 | 3.67 | 2.45 | 4.50 | 2.95 | 4.80 | 2.70 | 4.00 | 3.00 | 4.80 |
| " 28    | 2.77 | 4.47 | 3.02 | 4.57 | 3.65 | 3.65 | 2.35 | 3.45 | 2.30 | 4.50 | 2.80 | 4.25 | 3.40 | 3.90 | 2.35 | 4.80 | 2.85 | 3.87 | 3.45 | 2.37 | 2.37 | 4.37 |
| " 29    | 2.50 | 3.30 | 3.10 | 5.50 | 3.10 | 3.17 | 2.50 | 3.47 | 4.80 | 4.80 | 2.82 | 4.42 | 3.12 | 3.20 | 2.52 | 5.27 | 2.90 | 4.17 | 3.30 | 4.47 | 2.70 | 4.87 |
| " 30    | 2.27 | 2.60 | 2.97 | 4.60 | 2.97 | 2.97 | 3.00 | 3.25 | 3.52 | 3.52 | 2.80 | 3.97 | 3.15 | 3.50 | 2.45 | 3.90 | 3.00 | 4.25 | 1.85 | 2.20 | 2.32 | 4.25 |
| July 1  | 3.62 | 4.67 | 3.05 | 5.97 | 3.62 | 3.62 | 3.15 | 3.95 | 4.90 | 4.90 | 3.40 | 4.75 | 3.72 | 4.92 | 3.00 | 5.20 | 3.10 | 4.30 | 3.60 | 4.17 | 3.10 | 4.32 |
| " 2     | 3.65 | 5.12 | 2.60 | 5.50 | 3.11 | 3.11 | 2.80 | 4.00 | 4.77 | 4.77 | 3.20 | 4.20 | 3.52 | 3.50 | 2.20 | 4.90 | 3.17 | 4.35 | 3.37 | 4.10 | 3.40 | 3.50 |
| " 3     | 3.60 | 4.70 | 2.85 | 4.60 | 4.20 | 4.20 | 2.52 | 3.50 | 4.00 | 4.00 | 3.50 | 3.85 | 4.15 | 4.12 | 2.35 | 4.60 | 3.02 | 4.30 | 3.62 | 5.15 | 2.15 | 2.80 |
| " 4     | 3.10 | 3.50 | 3.10 | 5.90 | 3.10 | 3.20 | 2.60 | 3.55 | 6.12 | 6.12 | 2.50 | 3.55 | 3.10 | 4.00 | 2.40 | 4.90 | 3.17 | 4.55 | 3.12 | 4.35 | 3.02 | 6.97 |
| " 5     | 2.65 | 4.05 | 2.97 | 4.90 | 3.80 | 3.80 | 2.77 | 3.60 | 4.00 | 4.00 | 2.80 | 3.70 | 2.90 | 4.10 | 2.32 | 5.20 | 3.00 | 4.10 | 3.05 | 3.65 | 5.20 | 4.20 |
| " 6     | 2.80 | 4.00 | 3.65 | 6.15 | 3.65 | 3.95 | 2.70 | 3.50 | 4.80 | 4.80 | 3.50 | 4.10 | 3.15 | 4.12 | 2.80 | 5.45 | 3.50 | 4.70 | 3.10 | 4.30 | 2.60 | 6.97 |
| " 7     | 3.17 | 3.87 | 2.50 | 5.67 | 4.72 | 4.72 | 2.70 | 3.57 | 4.90 | 4.90 | 3.60 | 4.05 | 2.90 | 3.80 | 2.30 | 5.02 | 3.05 | 4.30 | 3.35 | 3.85 | 2.75 | 4.47 |
| " 8     | 2.80 | 3.50 | 3.10 | 5.95 | 3.10 | 4.15 | 2.62 | 2.75 | 4.25 | 4.25 | 3.20 | 4.60 | 3.35 | 3.55 | 2.65 | 5.02 | 3.25 | 4.40 | 3.30 | 4.22 | 3.97 | 5.20 |
| " 9     | 3.00 | 3.30 | 2.90 | 5.55 | 3.77 | 3.77 | 2.87 | 3.65 | 4.60 | 4.60 | 3.75 | 3.90 | 4.20 | 2.80 | 2.50 | 5.07 | 3.20 | 4.70 | 3.30 | 4.35 | 3.85 | 4.12 |
| " 10    | 2.30 | 3.70 | 3.42 | 5.25 | 4.20 | 4.20 | 2.62 | 3.55 | 4.35 | 4.35 | 2.70 | 2.90 | 3.37 | 3.50 | 2.40 | 5.10 | 3.22 | 4.20 | 2.65 | 4.27 | 3.17 | 6.10 |
| " 11    | 3.40 | 3.90 | 3.05 | 5.90 | 3.92 | 3.92 | 2.70 | 3.70 | 5.07 | 5.07 | 3.35 | 5.50 | 3.92 | 4.30 | 2.17 | 5.32 | 3.60 | 4.30 | 3.27 | 3.75 | 2.82 | 5.55 |

YIELDS AND FAT PERCENTAGES.

The LIGHTER TYPE FIGURES under M. and E. represent the weights of milk (in lbs.) produced in the morning and evening.  
byre numbers of the cows.

|      |    |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
|------|----|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| "    | 12 | 2-80 | 3-50 | 3-15 | 5-87 | 2-60 | 3-67 | 2-30 | 3-37 | 3-75 | 4-25 | 2-90 | 3-80 | 2-40 | 5-00 | 3-10 | 4-65 | 3-20 | 4-20 | 3-12 | 5-20 |
| "    | 13 | 3-47 | 3-85 | 2-77 | 5-92 | 2-55 | 4-67 | 3-20 | 5-30 | 3-30 | 4-20 | 3-70 | 3-80 | 2-50 | 4-65 | 3-10 | 4-37 | 3-20 | 4-20 | 2-00 | 4-75 |
| "    | 14 | 2-97 | 3-85 | 3-50 | 6-32 | 3-80 | 3-52 | 2-70 | 5-62 | 2-85 | 4-05 | 2-90 | 4-70 | 2-20 | 5-00 | 3-12 | 4-22 | 3-15 | 4-35 | 2-20 | 6-15 |
| "    | 15 | 3-30 | 4-27 | 2-52 | 6-15 | 2-77 | 4-15 | 2-40 | 4-15 | 3-22 | 4-10 | 3-67 | 3-17 | 1-97 | 4-45 | 5-20 | 4-60 | 2-72 | 4-50 | 3-12 | 5-80 |
| "    | 16 | 2-20 | 2-90 | 3-20 | 5-42 | 3-40 | 3-30 | 1-80 | 4-50 | 3-75 | 3-67 | 2-60 | 2-90 | 2-20 | 5-42 | 3-05 | 4-30 | 2-35 | 3-37 | 5-02 | 5-35 |
| "    | 17 | 3-90 | 4-30 | 3-95 | 6-10 | 3-27 | 4-32 | 2-00 | 3-52 | 2-70 | 3-85 | 3-32 | 4-25 | 2-15 | 4-45 | 3-02 | 4-75 | 2-80 | 4-20 | 3-10 | 4-55 |
| "    | 18 | 2-90 | 3-40 | 3-40 | 5-00 | 3-17 | 4-80 | 2-80 | 5-80 | 2-72 | 4-20 | 3-52 | 4-60 | 2-70 | 5-20 | 3-10 | 4-67 | 3-45 | 5-35 | 2-70 | 4-55 |
| "    | 19 | 3-30 | 4-02 | 3-40 | 5-30 | 3-05 | 3-67 | 2-57 | 5-00 | 4-00 | 3-87 | 2-60 | 5-05 | 2-20 | 5-05 | 3-12 | 4-80 | 3-00 | 4-25 | 2-90 | 4-60 |
| "    | 20 | 2-30 | 4-40 | 2-80 | 5-30 | 3-17 | 4-25 | 2-25 | 5-40 | 2-60 | 4-12 | 2-65 | 4-10 | 2-47 | 4-80 | 3-25 | 4-20 | 2-60 | 4-00 | 2-90 | 5-02 |
| "    | 21 | 2-92 | 3-60 | 3-62 | 6-60 | 3-20 | 3-60 | 2-37 | 4-10 | 3-57 | 3-50 | 3-60 | 4-90 | 2-17 | 4-47 | 3-37 | 4-60 | 3-60 | 4-87 | 3-60 | 4-55 |
| "    | 22 | 2-10 | 4-60 | 3-25 | 5-10 | 3-00 | 2-50 | 2-90 | 5-12 | 4-15 | 4-85 | 3-00 | 2-40 | 2-77 | 5-10 | 3-47 | 5-50 | 3-60 | 4-22 | 2-77 | 4-50 |
| "    | 23 | 2-70 | 2-75 | 2-90 | 4-90 | 2-50 | 3-60 | 2-90 | 4-27 | 3-10 | 3-55 | 3-85 | 4-35 | 2-40 | 4-10 | 3-10 | 4-42 | 3-30 | 4-10 | 2-65 | 6-32 |
| "    | 24 | 3-05 | 3-30 | 3-15 | 6-95 | 2-82 | 4-30 | 2-30 | 4-80 | 3-10 | 4-20 | 2-90 | 3-65 | 2-82 | 5-60 | 3-10 | 4-47 | 2-90 | 3-87 | 1-87 | 2-85 |
| "    | 25 | 3-00 | 3-02 | 3-60 | 4-75 | 3-42 | 3-90 | 3-67 | 4-90 | 3-57 | 3-85 | 3-62 | 4-10 | 2-90 | 5-10 | 3-55 | 4-50 | 3-32 | 4-55 | 4-35 | 5-15 |
| "    | 26 | 2-37 | 3-80 | 3-70 | 5-70 | 2-95 | 2-95 | 2-20 | 5-35 | 3-05 | 4-20 | 3-10 | 3-50 | 2-80 | 5-10 | 3-47 | 4-30 | 3-27 | 4-25 | 3-45 | 7-00 |
| "    | 27 | 3-30 | 3-20 | 3-90 | 6-30 | 3-35 | 4-47 | 3-20 | 4-60 | 3-60 | 4-30 | 3-55 | 4-30 | 2-32 | 5-45 | 3-20 | 4-42 | 3-05 | 4-42 | 3-42 | 4-47 |
| "    | 28 | 3-30 | 4-32 | 4-05 | 5-65 | 3-40 | 3-80 | 2-80 | 3-82 | 3-60 | 4-80 | 3-15 | 4-05 | 2-55 | 5-80 | 3-20 | 4-90 | 3-30 | 4-40 | 2-85 | 5-30 |
| "    | 29 | 2-90 | 3-80 | 2-92 | 6-00 | 3-40 | 4-20 | 2-40 | 5-67 | 3-00 | 4-20 | 3-30 | 4-05 | 2-60 | 5-50 | 3-45 | 4-45 | 3-25 | 4-40 | 3-00 | 5-00 |
| "    | 30 | 2-85 | 3-95 | 3-30 | 5-85 | 2-50 | 3-30 | 3-60 | 4-40 | 3-17 | 2-95 | 2-95 | 3-60 | 2-90 | 4-60 | 3-30 | 4-40 | 3-05 | 4-15 | 3-20 | 6-10 |
| "    | 31 | 2-35 | 3-30 | 3-50 | 5-65 | 3-60 | 3-85 | 2-55 | 4-70 | 3-40 | 3-60 | 3-15 | 3-70 | 2-50 | 5-05 | 3-15 | 4-50 | 2-90 | 5-10 | 2-80 | 5-90 |
| Aug. | 1  | 2-90 | 3-80 | 2-90 | 6-10 | 2-80 | 3-20 | 3-10 | 5-05 | 3-50 | 4-60 | 3-00 | 4-00 | 2-00 | 5-40 | 3-60 | 4-60 | 2-85 | 4-60 | 2-60 | 5-10 |



TABLE 2.

TOTAL DAILY MILK; PERCENTAGE DAILY FAT; TOTAL DAILY FAT.

|         | 122                   |                |                      | 128                   |                |                      | 97                    |                |                      |
|---------|-----------------------|----------------|----------------------|-----------------------|----------------|----------------------|-----------------------|----------------|----------------------|
|         | DAILY.                |                |                      | DAILY.                |                |                      | DAILY.                |                |                      |
|         | Total Milk.<br>(lbs.) | Per cent. Fat. | Total Fat.<br>(lbs.) | Total Milk.<br>(lbs.) | Per cent. Fat. | Total Fat.<br>(lbs.) | Total Milk.<br>(lbs.) | Per cent. Fat. | Total Fat.<br>(lbs.) |
| June 23 | 18½                   | 3.06           | .567                 | 17½                   | 3.85           | .674                 | 35                    | 3.32           | 1.164                |
| 24      | 19¾                   | 3.40           | .671                 | 16½                   | 3.60           | .594                 | 36¼                   | 4.06           | 1.471                |
| 25      | 18                    | 2.98           | .537                 | 17¾                   | 3.33           | .691                 | 34                    | 3.82           | 1.298                |
| 26      | 19¾                   | 3.33           | .659                 | 16¼                   | 3.39           | .551                 | 36½                   | 3.97           | 1.449                |
| 27      | 17¾                   | 3.18           | .564                 | 16¾                   | 4.09           | .685                 | 35½                   | 3.70           | 1.312                |
| 28      | 20                    | 3.37           | .674                 | 16¾                   | 3.42           | .574                 | 36¼                   | 3.56           | 1.291                |
| 29      | 18½                   | 2.87           | .520                 | 17                    | 3.95           | .673                 | 35½                   | 3.58           | 1.262                |
| 30      | 17¼                   | 2.38           | .410                 | 15¾                   | 3.78           | .596                 | 33½                   | 3.13           | 1.049                |
| July 1  | 20½                   | 3.95           | .811                 | 14¾                   | 4.28           | .631                 | 32                    | 3.56           | 1.139                |
| 2       | 13½                   | 3.87           | .523                 | 15½                   | 3.81           | .609                 | 30                    | 3.43           | 1.030                |
| 3       | 20¾                   | 3.94           | .818                 | 15½                   | 3.41           | .529                 | 28                    | 2.37           | .664                 |
| 4       | 17¼                   | 3.26           | .562                 | 15½                   | 4.25           | .659                 | 30¼                   | 4.75           | 1.437                |
| 5       | 19¼                   | 3.17           | .612                 | 14¼                   | 3.72           | .530                 | 31                    | 4.76           | 1.477                |
| 6       | 18¼                   | 3.19           | .592                 | 14¼                   | 4.59           | .654                 | 29½                   | 4.23           | 1.248                |
| 7       | 18½                   | 3.44           | .633                 | 16                    | 4.59           | .735                 | 24¾                   | 3.56           | .881                 |
| 8       | 18½                   | 3.07           | .569                 | 14¾                   | 4.41           | .650                 | 25¾                   | 4.04           | 1.139                |
| 9       | 17½                   | 3.09           | .542                 | 14¾                   | 4.54           | .669                 | 25¼                   | 3.94           | .996                 |
| 10      | 18¼                   | 2.81           | .513                 | 14½                   | 4.03           | .584                 | 27¾                   | 4.33           | 1.203                |
| 11      | 17                    | 3.55           | .603                 | 14½                   | 4.12           | .598                 | 24¾                   | 4.00           | .991                 |
| 12      | 16¾                   | 3.02           | .506                 | 14¾                   | 4.26           | .628                 | 27                    | 3.94           | 1.066                |
| 13      | 16                    | 3.59           | .574                 | 14                    | 4.12           | .577                 | 26¼                   | 3.15           | .827                 |
| 14      | 16¼                   | 3.24           | .527                 | 13½                   | 4.65           | .628                 | 27                    | 3.89           | 1.048                |
| 15      | 16¾                   | 3.64           | .608                 | 14                    | 4.20           | .589                 | 28½                   | 4.06           | 1.156                |
| 16      | 15¼                   | 2.45           | .374                 | 13½                   | 4.13           | .557                 | 29                    | 5.16           | 1.496                |
| 17      | 16¼                   | 4.02           | .653                 | 12½                   | 4.90           | .612                 | 28                    | 3.69           | 1.035                |
| 18      | 15                    | 3.07           | .460                 | 13¾                   | 4.01           | .552                 | 28¼                   | 3.42           | .966                 |
| 19      | 17½                   | 3.53           | .617                 | 14                    | 4.15           | .581                 | 29                    | 3.54           | 1.028                |
| 20      | 16                    | 3.22           | .515                 | 13¼                   | 3.93           | .521                 | 28¾                   | 3.71           | 1.067                |
| 21      | 15¼                   | 3.17           | .484                 | 13¼                   | 4.80           | .636                 | 27¾                   | 3.94           | 1.093                |
| 22      | 16                    | 3.27           | .523                 | 13                    | 4.00           | .520                 | 28¼                   | 3.38           | .956                 |
| 23      | 14                    | 2.71           | .380                 | 11¾                   | 3.67           | .431                 | 28¼                   | 4.24           | 1.189                |
| 24      | 15                    | 3.11           | .466                 | 13¼                   | 4.79           | .636                 | 21¾                   | 2.39           | .522                 |
| 25      | 16                    | 3.20           | .511                 | 12½                   | 4.12           | .515                 | 23¼                   | 4.63           | 1.077                |
| 26      | 15¼                   | 2.90           | .451                 | 12¼                   | 4.47           | .548                 | 26½                   | 5.19           | 1.376                |
| 27      | 14¾                   | 3.26           | .481                 | 14                    | 4.93           | .690                 | 24½                   | 3.85           | .943                 |
| 28      | 15¾                   | 3.76           | .589                 | 12½                   | 4.67           | .596                 | 23½                   | 3.86           | .908                 |
| 29      | 13½                   | 3.25           | .439                 | 13                    | 4.34           | .564                 | 23                    | 3.74           | .860                 |
| 30      | 13½                   | 3.28           | .442                 | 11¼                   | 4.21           | .473                 | 24                    | 4.41           | 1.058                |
| 31      | 12½                   | 2.75           | .338                 | 13                    | 4.57           | .641                 | 23                    | 4.22           | .969                 |
| Aug. 1  | 12¾                   | 3.18           | .406                 | 12½                   | 4.44           | .544                 | 21¾                   | 3.69           | .803                 |

TABLE 3.

COW 155—FEBRUARY 27TH TO NOVEMBER 16TH.

|         | M.       |                |            | E.      |                |            | DAILY.     |             |                |
|---------|----------|----------------|------------|---------|----------------|------------|------------|-------------|----------------|
|         | Milk.    | Per cent. Fat. | Total Fat. | Milk.   | Per cent. Fat. | Total Fat. | Total Fat. | Total Milk. | Per cent. Fat. |
| Feb. 27 | lbs. 20½ | 3·5            | lbs. ·717  | lbs. 12 | 3·9            | lbs. ·468  | lbs. 1·19  | lbs. 32½    | 3·7            |
| 28      | 21       | 2·5            | ·525       | 10½     | 3·35           | ·341       | ·87        | 31½         | 2·7            |
| 29      | 19½      | 2·65           | ·517       | 11¼     | 3·7            | ·416       | ·93        | 30¾         | 3·2            |
| Mar. 1  | 21       | 2·7            | ·567       | 11¾     | 3·3            | ·387       | ·95        | 32¾         | 2·9            |
| 2       | 7        | 3·25           | ·227       | 11      | 4·0            | ·440       | ·67        | 18          | 3·7            |
| 3       | 21       | 2·65           | ·556       | 12      | 4·6            | ·552       | 1·11       | 33          | 3·3            |
| 4       | 21½      | 2·25           | ·484       | 11      | 3·6            | ·396       | ·88        | 32½         | 2·7            |
| 5       | 19       | 2·0            | ·380       | 11      | 4·5            | ·495       | ·88        | 30          | 2·9            |
| 6       | 21       | 2·65           | ·556       | 9¼      | 4·0            | ·370       | ·92        | 30¼         | 3·0            |
| 7       | 20¾      | 2·9            | ·602       | 12      | 5·9            | ·708       | 1·31       | 32¾         | 4·0            |
| 8       | 19½      | 2·1            | ·409       | 12½     | 4·4            | ·550       | ·96        | 32          | 3·0            |
| 9       | 24½      | 3·3            | ·808       | 10½     | 4·0            | ·420       | 1·23       | 35          | 3·5            |
| 10      | 19       | 2·75           | ·522       | 8½      | 4·2            | ·357       | ·88        | 27½         | 3·2            |
| 11      | 19       | 3·4            | ·646       | 10      | 3·9            | ·390       | 1·04       | 29          | 3·6            |
| 12      | 16       | 3·1            | ·496       | 10¾     | 4·4            | ·462       | ·96        | 26¾         | 3·6            |
| 13      | 17       | 2·6            | ·442       | 8½      | 4·2            | ·357       | ·80        | 25½         | 3·1            |
| 14      | 18       | 2·5            | ·450       | 9       | 4·0            | ·360       | ·81        | 27          | 3·0            |
| 15      | 18       | 2·9            | ·520       | 9       | 3·5            | ·315       | ·83        | 27          | 3·1            |
| 16      | 12½      | 1·8            | ·225       | —       | 3·7            | —          | —          | —           | —              |
| 17      | —        | 2·9            | —          | 11½     | 3·3            | ·380       | —          | —           | —              |
| 18      | 16       | 2·45           | ·392       | 9       | 4·1            | ·369       | ·76        | 25          | 3·04           |
| 19      | 15       | 2·2            | ·330       | 11      | 4·0            | ·44        | ·77        | 26          | 3·0            |
| 20      | 17       | 3·8            | ·646       | 7½      | 4·2            | ·315       | ·96        | 24½         | 3·9            |
| 21      | 15       | 2·4            | ·360       | 10      | 5·4            | ·540       | ·90        | 25          | 3·6            |
| 22      | 14½      | 3·4            | ·493       | 10      | 5·1            | ·510       | 1·00       | 24½         | 4·0            |
| 23      | 16¼      | 3·15           | ·512       | 8½      | 4·5            | ·383       | ·90        | 24¾         | 3·6            |
| 24      | 14       | 2·8            | ·392       | 10      | 4·8            | ·480       | ·87        | 24          | 3·6            |
| 25      | 15       | 3·65           | ·547       | 9¼      | 4·8            | ·444       | ·99        | 24¼         | 4·0            |
| 26      | 16½      | 3·8            | ·627       | 9¼      | 5·4            | ·500       | 1·13       | 25¾         | 4·4            |
| 27      | 16¼      | 3·8            | ·617       | 8¾      | 5·0            | ·438       | 1·06       | 25          | 4·24           |

TABLE 3—continued.

|         | M.    |                |            | E.    |                |            | DAILY.     |             |                |
|---------|-------|----------------|------------|-------|----------------|------------|------------|-------------|----------------|
|         | Milk. | Per cent. Fat. | Total Fat. | Milk. | Per cent. Fat. | Total Fat. | Total Fat. | Total Milk. | Per cent. Fat. |
| Mar. 28 | 13½   | 3·1            | ·418       | 10    | 4·7            | ·470       | ·89        | 23½         | 3·8            |
| 29      | 15    | 3·4            | ·51        | 8½    | 4·7            | ·388       | ·90        | 23½         | 3·8            |
| 30      | 16    | 3·4            | ·544       | 5¼    | 4·1            | ·388       | ·93        | 24¼         | 3·8            |
| 31      | 16½   | 3·7            | ·611       | 8     | 4·5            | ·360       | ·97        | 24½         | 4·0            |
| April 1 | 19    | 3·1            | ·589       | 9     | 4·2            | ·378       | ·97        | 28          | 3·5            |
| 2       | 17¼   | 3·0            | ·518       | 10    | 4·2            | ·420       | ·94        | 27¼         | 3·4            |
| 3       | 17    | 3·2            | ·544       | 8¼    | 4·0            | ·330       | ·87        | 25¼         | 3·5            |
| 4       | 16¾   | 3·3            | ·553       | 9¾    | 4·2            | ·410       | ·96        | 26½         | 3·6            |
| 5       | 17¼   | 3·1            | ·535       | 9     | 4·3            | ·387       | ·92        | 26¼         | 3·1            |
| 6       | 16¼   | 2·7            | ·439       | 7½    | 4·1            | ·308       | ·75        | 23¾         | 3·1            |
| 7       | 17¼   | 3·2            | ·552       | 10    | 4·6            | ·460       | 1·01       | 27¼         | 3·7            |
| 8       | 16¼   | 3·1            | ·504       | 9     | 4·5            | ·405       | ·91        | 25¼         | 3·6            |
| 9       | 16¼   | 3·6            | ·585       | 9     | 4·4            | ·396       | ·98        | 25¼         | 3·9            |
| 10      | 16    | 3·5            | ·560       | 9¼    | 4·5            | ·416       | ·98        | 25¼         | 3·9            |
| 11      | 16    | 3·8            | ·608       | 8¾    | 5·2            | ·455       | 1·06       | 24¾         | 4·3            |
| 12      | 14¾   | 2·6            | ·462       | 9½    | 4·7            | ·448       | ·91        | 24¼         | 3·8            |
| 13      | 15¼   | 3·4            | ·519       | 9     | 4·5            | ·405       | ·92        | 24¼         | 3·8            |
| 14      | 15½   | 3·2            | ·496       | 9¼    | 5·0            | ·463       | ·96        | 24¾         | 3·9            |
| 15      | 15½   | 4·3            | ·667       | 8¾    | 4·5            | ·394       | 1·06       | 24¼         | 4·4            |
| 16      | 13    | 3·7            | ·481       | 9     | 4·6            | ·414       | ·90        | 22          | 4·1            |
| 17      | 14    | 3·3            | ·462       | 8½    | 4·0            | ·340       | ·80        | 22½         | 3·5            |
| 18      | 15    | 3·8            | ·570       | 8     | 4·2            | ·336       | ·91        | 23          | 4·0            |
| 19      | 14½   | 4·0            | ·580       | 6¾    | 4·2            | ·284       | ·86        | 21¼         | 4·0            |
| 20      | 15    | 3·3            | ·495       | 7¼    | 3·8            | ·276       | ·77        | 22¼         | 3·5            |
| 21      | 11½   | 5·6            | ·644       | 8¼    | 3·6            | ·297       | ·94        | 19¾         | 4·8            |
| 22      | 15½   | 3·3            | ·512       | 7¼    | 3·5            | ·25        | ·77        | 22¾         | 3·4            |
| 23      | 14    | 2·1            | ·294       | 7½    | 3·1            | ·233       | ·53        | 21½         | 2·5            |
| 24      | 13½   | 3·5            | ·473       | 7¼    | 4·2            | ·305       | ·78        | 20¾         | 3·8            |
| 25      | 13½   | 3·0            | ·405       | 7½    | 3·5            | ·263       | ·67        | 21          | 3·2            |
| 26      | 7¼    | 3·6            | ·261       | 8¼    | 4·3            | ·355       | ·62        | 15½         | 4·0            |
| 27      | 10    | 3·4            | ·340       | 7¾    | 4·0            | ·310       | ·650       | 17¾         | 3·7            |
| 28      | 14¼   | 3·8            | ·546       | 8½    | 3·7            | ·314       | ·86        | 22¾         | 3·8            |

TABLE 3—continued.

|          | M.               |                |            | E.                  |                |            | DAILY.     |                  |                |
|----------|------------------|----------------|------------|---------------------|----------------|------------|------------|------------------|----------------|
|          | Milk.            | Per cent. Fat. | Total Fat. | Milk.               | Per cent. Fat. | Total Fat. | Total Fat. | Total Milk.      | Per cent. Fat. |
| April 29 | lbs. 15          | 3·1            | ·465       | lbs. $7\frac{1}{4}$ | 4·3            | ·312       | ·78        | 22 $\frac{3}{4}$ | 3·5            |
| 30       | 14 $\frac{1}{4}$ | 2·85           | ·410       | 7 $\frac{3}{4}$     | 3·7            | ·286       | ·70        | 22               | 3·2            |
| May 1    | 12 $\frac{1}{2}$ | 3·7            | ·453       | 7 $\frac{1}{2}$     | 4·6            | ·345       | ·80        | 19 $\frac{3}{4}$ | 4·0            |
| 2        | 11 $\frac{3}{4}$ | 2·4            | ·272       | 8 $\frac{1}{4}$     | 4·8            | ·396       | ·67        | 20               | 3·35           |
| 3        | 11               | 3·2            | ·382       | 8                   | 4·4            | ·362       | ·74        | 19               | 4·3            |
| 4        | 14               | 3·3            | ·462       | 8 $\frac{1}{4}$     | 4·0            | ·330       | ·79        | 22 $\frac{1}{4}$ | 3·6            |
| 5        | 14               | 3·6            | ·504       | 7 $\frac{1}{4}$     | 4·2            | ·304       | ·81        | 21 $\frac{1}{4}$ | 3·86           |
| 6        | 14               | 3·4            | ·476       | 7                   | 4·6            | ·322       | ·80        | 21               | 3·38           |
| 7        | 13 $\frac{3}{4}$ | 3·2            | ·440       | 9                   | 3·25           | ·292       | ·73        | 22 $\frac{1}{2}$ | 3·2            |
| 8        | 12               | 3·3            | ·396       | 9 $\frac{1}{4}$     | 4·2            | ·389       | ·78        | 21 $\frac{1}{4}$ | 3·7            |
| 9        | 13 $\frac{1}{2}$ | 3·3            | ·472       | 7 $\frac{1}{2}$     | 3·9            | ·292       | ·76        | 21               | 3·6            |
| 10       | 14 $\frac{1}{4}$ | 3·3            | ·470       | 7                   | 4·0            | ·280       | ·75        | 21 $\frac{1}{4}$ | 3·5            |
| 11       | 14               | 3·25           | ·455       | 7                   | 4·3            | ·301       | ·76        | 21               | 3·6            |
| 12       | 13               | 3·3            | ·429       | 10                  | 4·2            | ·420       | ·85        | 23               | 3·7            |
| 13       | 18               | 3·5            | ·63        | 9 $\frac{3}{4}$     | 4·0            | ·39        | 1·02       | 27 $\frac{3}{4}$ | 3·7            |
| 14       | 20               | 3·5            | ·70        | 9 $\frac{3}{4}$     | 3·2            | ·312       | 1·01       | 29 $\frac{3}{4}$ | 3·4            |
| 15       | 22 $\frac{1}{2}$ | 3·0            | ·675       | 11                  | 2·6            | ·286       | ·96        | 33 $\frac{1}{2}$ | 2·9            |
| 16       | 22 $\frac{1}{4}$ | 4·2            | ·934       | 10 $\frac{1}{2}$    | 4·2            | ·441       | 1·37       | 32 $\frac{3}{4}$ | 4·2            |
| 17       | 18 $\frac{3}{4}$ | 3·7            | ·693       | 12                  | 4·0            | ·480       | 1·17       | 30 $\frac{3}{4}$ | 3·8            |
| 18       | 20 $\frac{1}{4}$ | 3·6            | ·729       | 12                  | 4·05           | ·486       | 1·21       | 32 $\frac{1}{4}$ | 3·8            |
| 19       | 20 $\frac{1}{2}$ | 3·8            | ·769       | 11                  | 4·5            | ·495       | 1·26       | 31 $\frac{1}{4}$ | 4·0            |
| 20       | 19 $\frac{1}{2}$ | 3·3            | ·643       | 11 $\frac{1}{2}$    | 4·4            | ·506       | 1·15       | 31               | 3·7            |
| 21       | 17 $\frac{1}{2}$ | 3·2            | ·560       | 7 $\frac{1}{4}$     | 4·3            | ·312       | ·87        | 24 $\frac{3}{4}$ | 3·5            |
| 22       | 19 $\frac{1}{4}$ | 3·5            | ·673       | 7                   | 6·6            | ·462       | 1·13       | 26 $\frac{1}{4}$ | 4·3            |
| 23       | 19 $\frac{3}{4}$ | 3·7            | ·731       | 9 $\frac{1}{2}$     | 5·0            | ·475       | 1·21       | 29 $\frac{1}{4}$ | 4·2            |
| 24       | 18 $\frac{1}{4}$ | 3·0            | ·547       | 12 $\frac{3}{4}$    | 4·7            | ·599       | 1·15       | 31               | 3·7            |
| 25       | 16               | 2·9            | ·464       | 12 $\frac{1}{2}$    | 2·5            | ·312       | ·78        | 28 $\frac{1}{2}$ | 2·7            |
| 26       | 21 $\frac{3}{4}$ | 2·5            | ·564       | 11 $\frac{1}{4}$    | 5·9            | ·664       | 1·23       | 33               | 3·7            |
| 27       | 21               | 3·5            | ·735       | 10                  | 4·7            | ·470       | 1·21       | 31               | 3·9            |
| 28       | 19               | 2·85           | ·541       | 8 $\frac{1}{4}$     | 5·6            | ·462       | 1·00       | 27 $\frac{1}{4}$ | 3·7            |
| 29       | 16               | 2·7            | ·432       | 10 $\frac{3}{4}$    | 3·75           | ·403       | ·84        | 26 $\frac{3}{4}$ | 3·1            |
| 30       | —                | —              | —          | 10                  | —              | —          | —          | —                | —              |

TABLE 3—continued.

|        | M.       |                |            | E.      |                |            | DAILY.     |            |                |
|--------|----------|----------------|------------|---------|----------------|------------|------------|------------|----------------|
|        | Milk.    | Per cent. Fat. | Total Fat. | Milk.   | Per cent. Fat. | Total Fat. | Total Fat. | Total Milk | Per cent. Fat. |
| May 31 | lbs. 10½ | 2·95           | lbs. ·309  | lbs. 11 | 1·8            | lbs. ·198  | lbs. ·51   | lbs. 21½   | 2·4            |
| June 1 | 20¼      | ·80            | ·162       | 12¼     | 1·5            | ·184       | ·35        | 32½        | 1·1            |
| 2      | 16       | 6·35           | 1·016      | 11      | 4·2            | ·462       | 1·48       | 27         | 5·7            |
| 3      | 18¼      | 1·2            | ·219       | 12½     | 2·6            | ·325       | ·54        | 30¾        | 1·8            |
| 4      | 21½      | 1·0            | ·215       | 11      | 3·6            | ·396       | ·61        | 32½        | 1·9            |
| 5      | 21       | 2·9            | ·609       | 11      | 4·8            | ·528       | 1·14       | 32         | 3·5            |
| 6      | 20¾      | 1·1            | ·228       | 11½     | 1·9            | ·218       | ·45        | 32¼        | 1·4            |
| 7      | 21       | 3·0            | ·630       | 11½     | 3·6            | ·414       | 1·04       | 32½        | 3·2            |
| 8      | 21¾      | 3·8            | ·826       | 10¼     | 1·2            | ·123       | ·95        | 32         | 3·0            |
| 9      | 19¼      | 1·8            | ·346       | 11½     | 3·05           | ·351       | ·70        | 30¾        | 2·3            |
| 10     | 18       | 1·3            | ·231       | 11¼     | 3·0            | ·337       | ·57        | 29¼        | 2·0            |
| 11     | 18½      | 2·3            | ·425       | 11      | 3·6            | ·396       | ·82        | 29½        | 2·8            |
| 12     | 23¾      | 2·2            | ·522       | 10½     | 4·3            | ·451       | ·97        | 34¼        | 2·8            |
| 13     | 22       | 2·9            | ·638       | 13      | 3·4            | ·442       | 1·08       | 35         | 3·1            |
| 14     | 19       | 1·5            | ·285       | 11½     | 4·9            | ·563       | ·85        | 30½        | 2·8            |
| 15     | 20       | 1·25           | ·250       | 12      | 3·8            | ·456       | ·71        | 32         | 2·2            |
| 16     | 6¼       | ·6             | ·037       | 21      | 3·05           | ·641       | ·68        | 27¼        | 2·5            |
| 17     | 14½      | 4·2            | ·609       | 12¼     | 4·3            | ·527       | 1·13       | 26¾        | 4·2            |
| 18     | 12¼      | 1·4            | ·181       | 13      | 5·0            | ·65        | ·83        | 25¼        | 3·3            |
| 19     | 19¼      | ·9             | ·173       | 11¼     | 1·3            | ·146       | ·32        | 30½        | 1·1            |
| 20     | 21       | 2·8            | ·588       | 10½     | 3·5            | ·409       | 1·00       | 31½        | 3·2            |
| 21     | 19       | 3·0            | ·57        | 11½     | 2·5            | ·287       | ·86        | 30½        | 2·8            |
| 22     | 21       | 3·0            | ·63        | 11      | 2·0            | ·220       | ·85        | 32         | 2·7            |
| 23     | 19½      | 3·4            | ·663       | 11½     | 4·3            | ·494       | 1·16       | 31         | 3·8            |
| 24     | 27       | 3·3            | ·561       | 10      | 3·6            | ·360       | ·92        | 27         | 3·4            |
| 25     | 18½      | 3·1            | ·573       | 10      | 4·0            | ·401       | ·97        | 23½        | 3·4            |
| 26     | 18       | 2·9            | ·522       | 11      | 4·2            | ·462       | ·98        | 29         | 3·4            |
| 27     | 17½      | 3·0            | ·525       | 16½     | 4·4            | ·726       | 1·25       | 34         | 3·7            |
| 28     | 18       | 3·1            | ·558       | 10¼     | 3·9            | ·400       | ·96        | 28¼        | 3·4            |
| 29     | 15½      | 2·9            | ·450       | 11      | 4·3            | ·400       | ·92        | 26½        | 3·5            |
| 30     | 17       | 2·7            | ·459       | 9       | 4·2            | ·378       | ·83        | 26         | 3·2            |
| July 1 | 17¼      | 3·9            | ·673       | 11      | 3·3            | ·393       | 1·07       | 28¼        | 3·8            |

TABLE 3—continued.

|        | M.               |                |            | E.                      |                |            | DAILY.       |                          |                |
|--------|------------------|----------------|------------|-------------------------|----------------|------------|--------------|--------------------------|----------------|
|        | Milk.            | Per cent. Fat. | Total Fat. | Milk.                   | Per cent. Fat. | Total Fat. | Total Fat.   | Total Milk.              | Per cent. Fat. |
| July 2 | lbs.<br>17       | 3.9            | .663       | lbs.<br>8 $\frac{1}{4}$ | 4.3            | .355       | lbs.<br>1.02 | lbs.<br>25 $\frac{1}{4}$ | 4.0            |
| 3      | 14               | 2.5            | .350       | 11 $\frac{1}{2}$        | 3.8            | .437       | .88          | 25 $\frac{1}{2}$         | 3.6            |
| 4      | 16 $\frac{1}{4}$ | 3.2            | .520       | 10                      | 4.7            | .470       | .99          | 26 $\frac{1}{4}$         | 3.8            |
| 5      | 17 $\frac{1}{2}$ | 3.3            | .578       | 1                       | 2.2            | .022       | .60          | 18 $\frac{1}{2}$         | 3.2            |
| 6      | 18               | 4.1            | .738       | 7                       | 5.4            | .378       | 1.10         | 25                       | 4.4            |
| 7      | 15 $\frac{3}{4}$ | 3.9            | .614       | 9 $\frac{1}{2}$         | 4.9            | .466       | 1.08         | 25 $\frac{1}{4}$         | 4.3            |
| 8      | 18 $\frac{1}{4}$ | 3.0            | .548       | 9 $\frac{1}{2}$         | 4.2            | .399       | .94          | 27 $\frac{3}{4}$         | 3.4            |
| 9      | 18 $\frac{1}{4}$ | 3.3            | .602       | 10 $\frac{1}{4}$        | 4.3            | .441       | 1.04         | 28 $\frac{1}{2}$         | 3.7            |
| 10     | 15               | 2.8            | .420       | 10 $\frac{1}{4}$        | 4.1            | .420       | .84          | 25 $\frac{1}{4}$         | 3.3            |
| 11     | 19               | 3.2            | .608       | 10 $\frac{3}{4}$        | 4.9            | .527       | 1.14         | 29 $\frac{3}{4}$         | 3.8            |
| 12     | 16 $\frac{1}{2}$ | 3.3            | .545       | 10                      | 4.0            | .400       | .96          | 26 $\frac{1}{2}$         | 3.6            |
| 13     | 17 $\frac{1}{4}$ | 2.6            | .448       | 10 $\frac{1}{2}$        | 5.2            | .576       | 1.02         | 27 $\frac{3}{4}$         | 3.7            |
| 14     | 16 $\frac{1}{2}$ | 3.8            | .627       | 7 $\frac{1}{4}$         | 4.2            | .395       | 1.02         | 23 $\frac{3}{4}$         | 4.3            |
| 15     | 11 $\frac{1}{2}$ | 3.5            | .403       | 10 $\frac{1}{4}$        | 4.6            | .472       | .88          | 21 $\frac{3}{4}$         | 4.0            |
| 16     | 17 $\frac{1}{2}$ | 3.4            | .595       | 7 $\frac{3}{4}$         | 5.1            | .395       | .99          | 25 $\frac{1}{4}$         | 3.8            |
| 17     | 15 $\frac{1}{2}$ | 3.2            | .496       | 8 $\frac{1}{2}$         | 4.1            | .349       | .81          | 24                       | 3.4            |
| 18     | 16 $\frac{1}{4}$ | 3.7            | .600       | 8 $\frac{3}{4}$         | 3.7            | .324       | .92          | 25                       | 3.9            |
| 19     | 15 $\frac{1}{4}$ | 3.6            | .549       | 8 $\frac{1}{4}$         | 2.9            | .239       | .79          | 23 $\frac{1}{2}$         | 3.4            |
| 20     | 11               | 3.0            | .330       | 8 $\frac{1}{2}$         | 4.4            | .363       | .69          | 19 $\frac{1}{4}$         | 3.6            |
| 21     | 15 $\frac{1}{2}$ | 3.5            | .543       | 8 $\frac{1}{4}$         | 4.0            | .330       | .87          | 23 $\frac{3}{4}$         | 3.6            |
| 22     | 16               | 3.5            | .560       | 9                       | 5.5            | .495       | 1.06         | 25                       | 4.2            |
| 23     | 15 $\frac{1}{4}$ | 3.0            | .458       | 9                       | 4.1            | .369       | .83          | 24 $\frac{1}{4}$         | 3.4            |
| 24     | 14 $\frac{1}{4}$ | 3.8            | .542       | 9 $\frac{1}{2}$         | 4.2            | .399       | .94          | 23 $\frac{3}{4}$         | 3.9            |
| 25     | 14 $\frac{3}{4}$ | 3.0            | .443       | 10 $\frac{1}{4}$        | 4.9            | .502       | .95          | 25                       | 3.8            |
| 26     | 12               | 3.8            | .456       | 8                       | 5.7            | .456       | .91          | 20                       | 4.5            |
| 27     | 7 $\frac{3}{4}$  | 3.4            | .264       | 9 $\frac{3}{4}$         | 4.0            | .390       | .65          | 17 $\frac{1}{2}$         | 3.7            |
| 28     | 16 $\frac{1}{4}$ | 4.0            | .650       | 9                       | 4.3            | .390       | 1.04         | 25 $\frac{1}{4}$         | 4.0            |
| 29     | 16 $\frac{1}{2}$ | 3.3            | .540       | 8 $\frac{1}{2}$         | 3.9            | .320       | .86          | 24 $\frac{3}{4}$         | 3.5            |
| 30     | 16               | 3.5            | .560       | 8                       | 4.3            | .340       | .90          | 24                       | 3.8            |
| 31     | 16 $\frac{1}{4}$ | 3.4            | .550       | —                       | —              | —          | —            | —                        | —              |
| Aug. 1 | 15 $\frac{1}{2}$ | 3.2            | .500       | 9                       | 4.3            | .490       | .99          | 24 $\frac{1}{2}$         | 4.0            |
| 2      | 16 $\frac{1}{4}$ | 3.0            | .490       | 9 $\frac{1}{4}$         | 4.4            | .420       | .91          | 25 $\frac{1}{2}$         | 3.6            |

TABLE 3—continued.

|         | M.      |                |            | E.      |                |            | DAILY.     |             |                |
|---------|---------|----------------|------------|---------|----------------|------------|------------|-------------|----------------|
|         | Milk.   | Per cent. Fat. | Total Fat. | Milk    | Per cent. Fat. | Total Fat. | Total Fat. | Total Milk. | Per cent. Fat. |
| Aug. 3  | lbs. 16 | 3.3            | lbs. .533  | lbs. 8½ | 4.5            | lbs. .380  | lbs. .91   | lbs. 24½    | 3.7            |
| 4       | 14¼     | 3.2            | .460       | 8½      | 4.7            | .400       | .86        | 22¾         | 3.8            |
| 5       | 15      | 3.3            | .500       | 7¾      | 5.2            | .400       | .90        | 22¾         | 4.0            |
| 6       | 14      | 3.2            | .450       | 7¼      | 3.5            | .250       | .70        | 21¼         | 3.1            |
| 7       | 13      | 3.3            | .430       | 8       | 5.3            | .420       | .85        | 21          | 4.0            |
| 8       | 12½     | 3.5            | .440       | 8¼      | 3.6            | .300       | .74        | 20¾         | 3.5            |
| 9       | 9½      | 3.4            | .320       | 9       | 5.4            | .490       | .81        | 18½         | 4.4            |
| 10      | 14¾     | 3.7            | .550       | 7½      | 4.8            | .360       | .91        | 22¼         | 4.1            |
| 11      | 13      | 4.8            | .620       | 8       | 4.8            | .380       | 1.00       | 21          | 4.8            |
| 12      | 9¼      | 4.5            | .416       | 6¼      | 3.7            | .230       | .64        | 15½         | 4.1            |
| 13      | 9¼      | 3.3            | .300       | 7¾      | 4.9            | .380       | .68        | 17          | 4.0            |
| 14      | 13      | 3.5            | .460       | 7½      | 4.7            | .350       | .81        | 20½         | 4.0            |
| 15      | 9¾      | 4.2            | .410       | 7¼      | 4.5            | .330       | .74        | 17          | 4.4            |
| 16      | 12½     | 4.0            | .500       | 7¼      | 5.5            | .400       | .90        | 19¾         | 4.6            |
| 17      | 12      | 3.5            | .420       | 7       | 4.6            | .320       | .74        | 19          | 3.9            |
| 18      | 12½     | 3.7            | .460       | 6½      | 5.0            | .330       | .79        | 19          | 4.2            |
| 19      | 12½     | 3.1            | .390       | 8       | 5.1            | .410       | .80        | 20½         | 3.9            |
| 20      | 13¾     | 3.6            | .500       | 7¾      | 5.2            | .400       | .90        | 21½         | 4.2            |
| 21      | 13      | 3.6            | .470       | 7½      | 5.0            | .370       | .84        | 20½         | 4.1            |
| 22      | 14¼     | 3.6            | .510       | 7¾      | 4.5            | .350       | .86        | 22          | 3.9            |
| 23      | 12¾     | 3.6            | .460       | 7½      | 5.1            | .380       | .84        | 20¼         | 4.1            |
| 24      | 11½     | 3.5            | .403       | 8       | 5.2            | .420       | .82        | 19½         | 4.2            |
| 25      | 11¼     | 3.0            | .340       | 7¾      | 5.6            | .430       | .77        | 19          | 4.0            |
| 26      | 9½      | 3.8            | .360       | 6¼      | 4.7            | .290       | .65        | 15¼         | 4.1            |
| 27      | 12      | 4.2            | .500       | 6½      | 4.3            | .280       | .78        | 18½         | 4.2            |
| 28      | 12¼     | 3.5            | .43        | 6½      | 4.8            | .31        | .74        | 18¾         | 4.0            |
| 29      | 11½     | 4.1            | .47        | 7½      | 4.2            | .32        | .79        | 19          | 4.2            |
| 30      | 12¾     | 4.1            | .52        | 6       | 5.0            | .30        | .82        | 18¾         | 4.4            |
| 31      | 12½     | 3.8            | .48        | 5       | 4.5            | .23        | .71        | 17½         | 4.1            |
| Sept. 1 | 11      | 4.1            | .45        | 5¾      | 4.5            | .26        | .71        | 16¾         | 4.2            |
| 2       | 10½     | 3.7            | .39        | 7¼      | 4.6            | .33        | .72        | 17¾         | 4.1            |
| 3       | 12      | 3.6            | .43        | 6       | 4.3            | .26        | .69        | 18          | 3.8            |

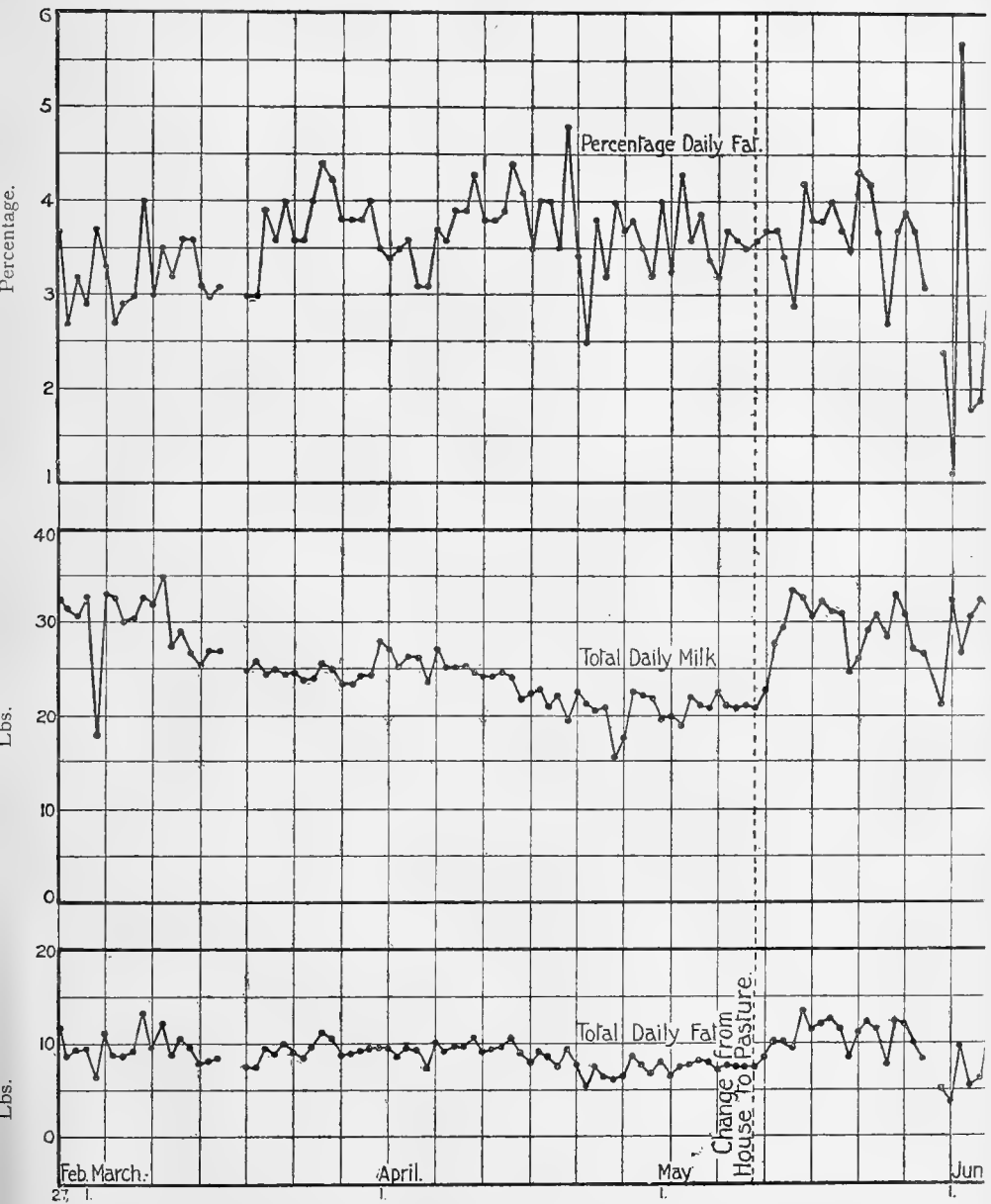
TABLE 3—continued.

|         | M.               |                |            | E.              |                |            | DAILY.     |                  |                |
|---------|------------------|----------------|------------|-----------------|----------------|------------|------------|------------------|----------------|
|         | Milk.            | Per cent. Fat. | Total Fat. | Milk.           | Per cent. Fat. | Total Fat. | Total Fat. | Total Milk.      | Per cent. Fat. |
| Sept. 4 | 9 $\frac{1}{4}$  | 3·8            | ·37        | 6               | 4·6            | ·28        | ·65        | 15 $\frac{3}{4}$ | 4·1            |
| 5       | 7 $\frac{3}{4}$  | 2·7            | ·21        | 5 $\frac{3}{4}$ | 4·5            | ·26        | ·47        | 13 $\frac{1}{2}$ | 3·5            |
| 6       | 12 $\frac{1}{4}$ | 3·6            | ·44        | 6 $\frac{1}{4}$ | 3·5            | ·22        | ·66        | 18 $\frac{1}{2}$ | 3·6            |
| 7       | 10 $\frac{1}{2}$ | —              | —          | 6 $\frac{1}{2}$ | —              | —          | —          | 17               | —              |
| 8       | 10 $\frac{1}{4}$ | 3·1            | ·31        | 7 $\frac{1}{2}$ | 3·5            | ·26        | ·57        | 17 $\frac{3}{4}$ | 3·2            |
| 9       | 12               | 3·4            | ·41        | 6 $\frac{1}{2}$ | 3·5            | ·23        | ·61        | 18 $\frac{1}{2}$ | 3·5            |
| 10      | 10 $\frac{1}{4}$ | 4·0            | ·41        | 6               | 5·3            | ·32        | ·73        | 16 $\frac{1}{4}$ | 4·5            |
| 11      | 8                | 3·5            | ·28        | 6               | 5·3            | ·32        | ·60        | 14               | 4·3            |
| 12      | 10 $\frac{1}{2}$ | 4·0            | ·42        | 6 $\frac{1}{2}$ | 4·3            | ·28        | ·70        | 17               | 4·1            |
| 13      | 11               | 4·4            | ·48        | 5               | 5·1            | ·26        | ·74        | 16               | 4·6            |
| 14      | 9                | 3·5            | ·32        | 5 $\frac{3}{4}$ | 5·2            | ·30        | ·62        | 14 $\frac{3}{4}$ | 3·5            |
| 15      | 8                | 3·9            | ·32        | 6               | 4·2            | ·25        | ·57        | 14               | 4·1            |
| 16      | 9                | 3·9            | ·35        | 6 $\frac{1}{2}$ | 4·0            | ·26        | ·61        | 15 $\frac{1}{2}$ | 4·0            |
| 17      | 9                | 4·0            | ·36        | 6               | 5·3            | ·32        | ·68        | 15               | 4·5            |
| 18      | 10               | 4·2            | ·42        | 1 $\frac{3}{4}$ | 4·2            | ·67        | ·49        | 11 $\frac{3}{4}$ | 4·2            |
| 19      | 10 $\frac{1}{2}$ | 4·2            | ·14        | 6               | 4·2            | ·25        | ·69        | 16 $\frac{1}{2}$ | 4·2            |
| 20      | 8                | 4·0            | ·32        | 5               | 5·0            | ·25        | ·57        | 13               | 4·4            |
| 21      | 8 $\frac{1}{2}$  | 4·3            | ·37        | 6 $\frac{1}{4}$ | 4·5            | ·28        | ·65        | 14 $\frac{3}{4}$ | 4·4            |
| 22      | 8 $\frac{3}{4}$  | 4·4            | ·39        | 6               | 6·2            | ·37        | ·76        | 14 $\frac{3}{4}$ | 5·2            |
| 23      | 9                | 4·9            | ·44        | 5 $\frac{1}{4}$ | 4·7            | ·25        | ·69        | 14 $\frac{1}{4}$ | 4·9            |
| 24      | 7 $\frac{1}{2}$  | 4·0            | ·30        | 5               | 5·5            | ·28        | ·58        | 12 $\frac{1}{2}$ | 4·6            |
| 25      | 6 $\frac{1}{4}$  | 3·8            | ·24        | 6 $\frac{1}{2}$ | 4·6            | ·30        | ·54        | 12 $\frac{3}{4}$ | 4·2            |
| 26      | 9                | 3·7            | ·33        | 3               | 4·5            | ·14        | ·47        | 12               | 3·9            |
| 27      | 8 $\frac{3}{4}$  | 4·3            | ·38        | 3 $\frac{1}{2}$ | 5·4            | ·19        | ·57        | 12 $\frac{1}{4}$ | 4·7            |
| 28      | 8 $\frac{3}{4}$  | 3·6            | ·52        | 4 $\frac{3}{4}$ | 5·0            | ·24        | ·56        | 13 $\frac{1}{2}$ | 4·1            |
| 29      | 8                | 5·3            | ·42        | 5               | 4·5            | ·23        | ·65        | 13               | 5·0            |
| 30      | 5 $\frac{1}{4}$  | 4·6            | ·24        | 6 $\frac{1}{2}$ | 4·9            | ·31        | ·55        | 11 $\frac{1}{2}$ | 4·8            |
| Oct. 1  | 6 $\frac{1}{4}$  | 4·4            | ·28        | 5 $\frac{1}{4}$ | 3·7            | ·19        | ·47        | 11 $\frac{1}{2}$ | 4·1            |
| 2       | 6 $\frac{3}{4}$  | 3·8            | ·26        | 2 $\frac{1}{4}$ | 5·0            | ·11        | ·37        | 9                | 4·1            |
| 3       | 7                | 4·2            | ·29        | 4 $\frac{3}{4}$ | 5·2            | ·25        | ·54        | 11 $\frac{3}{4}$ | 4·6            |
| 4       | 6                | 3·0            | ·18        | 5               | 5·2            | ·26        | ·44        | 11               | 4·0            |
| 5       | 7 $\frac{1}{2}$  | 4·3            | ·31        | 6               | 4·7            | ·28        | ·59        | 13 $\frac{1}{4}$ | 4·5            |

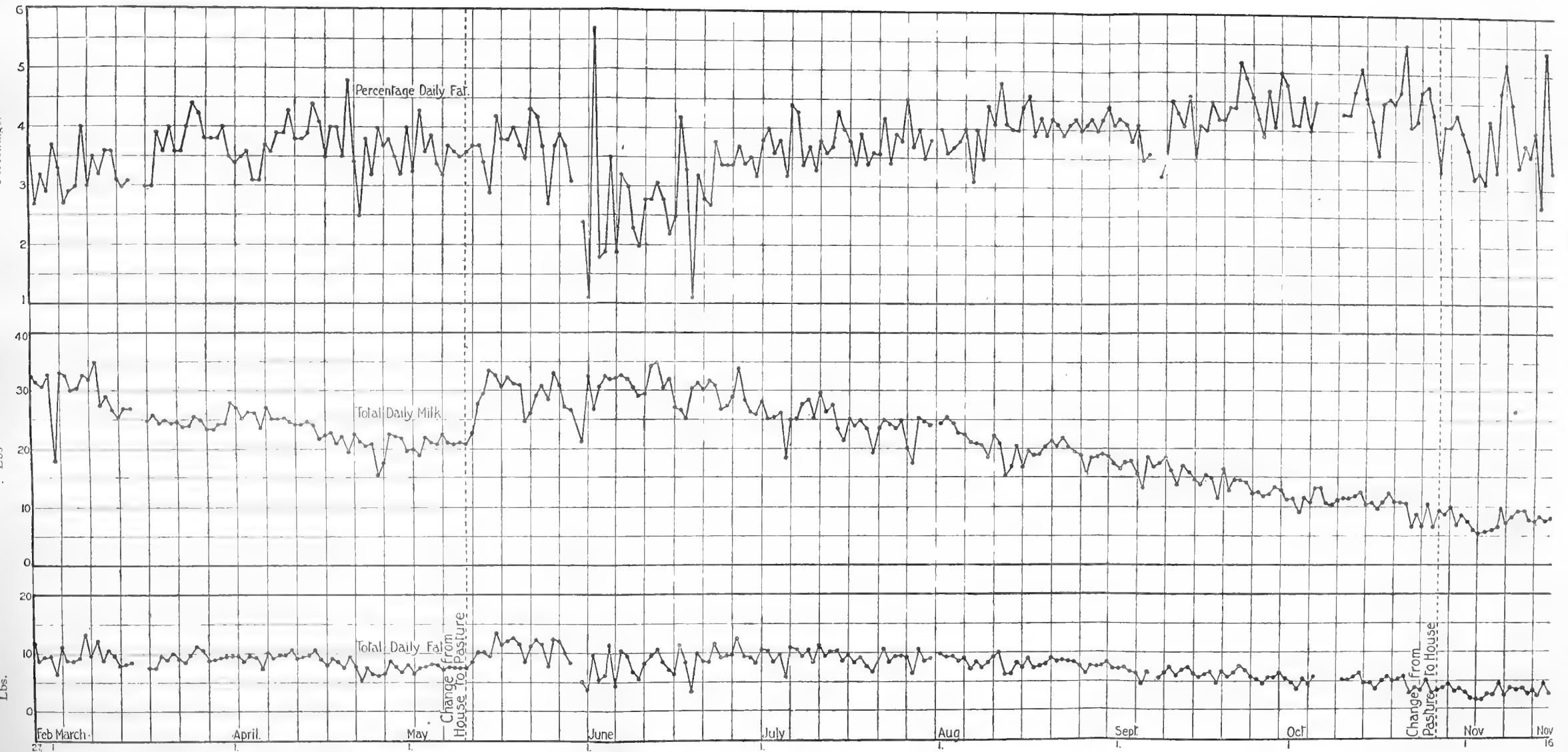


TABLE 3—continued.

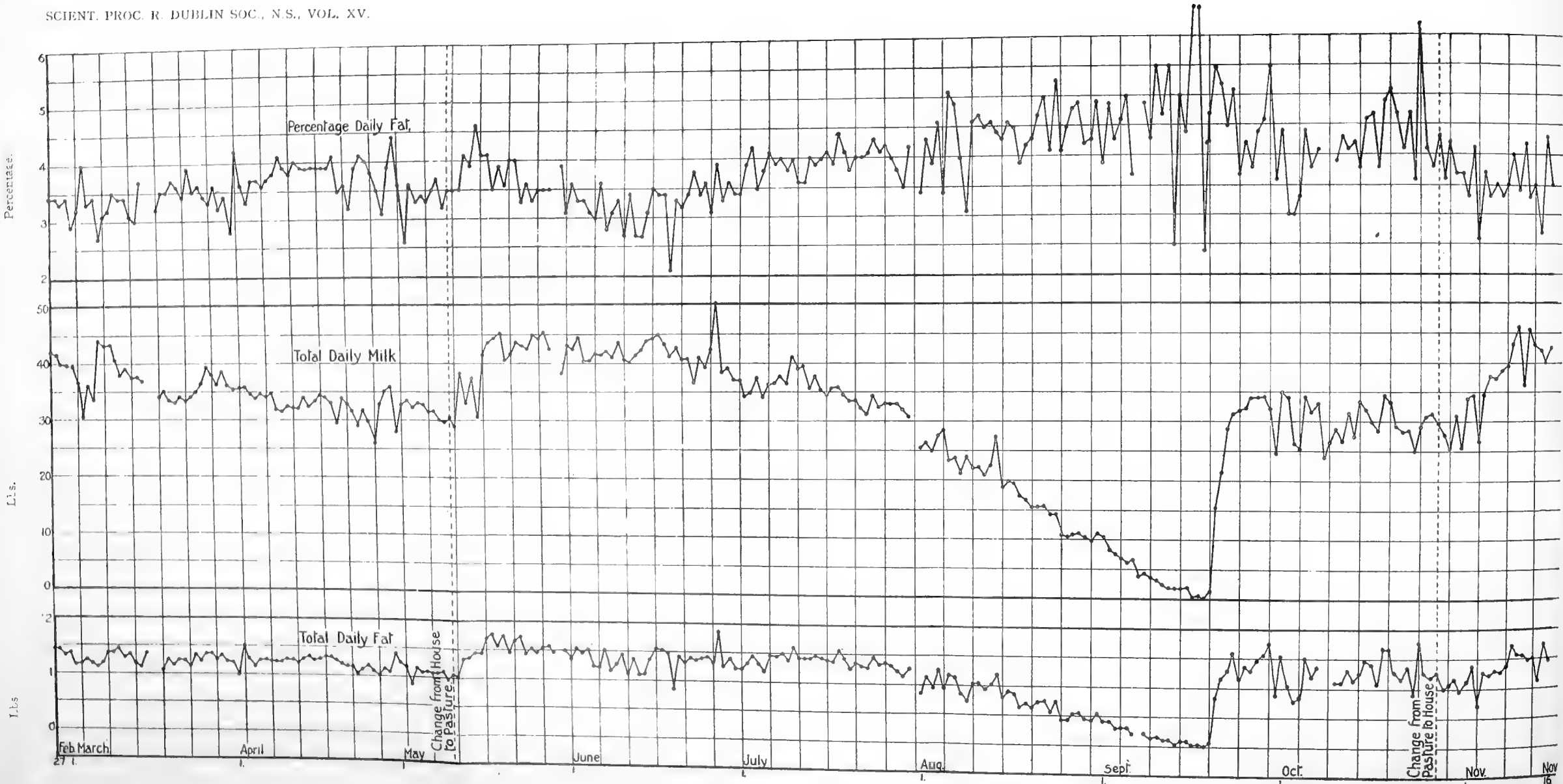
|        | M.                  |                |            | E.             |                |            | DAILY.     |                      |                |
|--------|---------------------|----------------|------------|----------------|----------------|------------|------------|----------------------|----------------|
|        | Milk.               | Per cent. Fat. | Total Fat. | Milk.          | Per cent. Fat. | Total Fat. | Total Fat. | Total Milk.          | Per cent. Fat. |
| Oct. 6 | lbs. $7\frac{1}{4}$ | —              | lbs. —     | lbs. 6         | —              | lbs. —     | lbs. —     | lbs. $13\frac{1}{4}$ | —              |
| 7      | $7\frac{1}{2}$      | —              | —          | $3\frac{1}{2}$ | —              | —          | —          | 11                   | —              |
| 8      | $7\frac{1}{2}$      | —              | —          | 3              | —              | —          | —          | $10\frac{1}{2}$      | —              |
| 9      | $7\frac{3}{4}$      | —              | —          | $3\frac{1}{2}$ | —              | —          | —          | $11\frac{1}{4}$      | —              |
| 10     | $7\frac{1}{4}$      | 4·2            | ·30        | $4\frac{1}{2}$ | 4·7            | ·21        | ·51        | $11\frac{3}{4}$      | 4·3            |
| 11     | $7\frac{1}{4}$      | 4·2            | ·30        | $4\frac{1}{2}$ | 4·6            | ·21        | ·51        | $11\frac{3}{4}$      | 4·3            |
| 12     | $7\frac{1}{4}$      | 3·8            | ·28        | $4\frac{3}{4}$ | 5·8            | ·28        | ·56        | 12                   | 4·7            |
| 13     | $8\frac{1}{4}$      | 4·4            | ·36        | $4\frac{1}{2}$ | 6·5            | ·29        | ·65        | $12\frac{3}{4}$      | 5·1            |
| 14     | $6\frac{1}{2}$      | 4·5            | ·29        | 4              | 4·7            | ·19        | ·48        | $10\frac{1}{2}$      | 4·6            |
| 15     | $6\frac{1}{4}$      | 3·7            | ·23        | $4\frac{1}{2}$ | 5·7            | ·26        | ·49        | $10\frac{3}{4}$      | 4·2            |
| 16     | 6                   | 4·0            | ·24        | $3\frac{3}{4}$ | 2·8            | ·11        | ·35        | $9\frac{3}{4}$       | 3·6            |
| 17     | 7                   | 4·0            | ·28        | 4              | 5·6            | ·22        | ·50        | 11                   | 4·5            |
| 18     | $7\frac{1}{2}$      | 4·3            | ·32        | 5              | 5·3            | ·26        | ·58        | $12\frac{1}{2}$      | 4·6            |
| 19     | $7\frac{1}{4}$      | 4·0            | ·29        | $3\frac{3}{4}$ | 5·5            | ·21        | ·50        | 11                   | 4·5            |
| 20     | $7\frac{1}{4}$      | 4·6            | ·33        | $3\frac{3}{4}$ | 5·0            | ·19        | ·52        | 11                   | 4·7            |
| 21     | $6\frac{3}{4}$      | 5·2            | ·35        | 4              | 5·9            | ·24        | ·59        | $10\frac{3}{4}$      | 5·5            |
| 22     | $6\frac{1}{2}$      | 4·1            | ·26        | $\frac{1}{2}$  | 4·3            | ·02        | ·28        | $6\frac{3}{4}$       | 4·1            |
| 23     | $6\frac{1}{2}$      | 3·5            | ·23        | $2\frac{1}{4}$ | 6·3            | ·14        | ·37        | $8\frac{3}{4}$       | 4·2            |
| 24     | $4\frac{3}{4}$      | 5·5            | ·26        | 2              | 2·8            | ·06        | ·32        | $6\frac{3}{4}$       | 4·7            |
| 25     | $6\frac{1}{2}$      | 5·0            | ·33        | 4              | 4·3            | ·17        | ·50        | $10\frac{1}{2}$      | 4·8            |
| 26     | 5                   | 3·9            | ·20        | $1\frac{1}{2}$ | 5·1            | ·08        | ·28        | $6\frac{1}{2}$       | 4·3            |
| 27     | $4\frac{3}{4}$      | 3·0            | ·14        | $4\frac{1}{2}$ | 3·7            | ·17        | ·31        | $9\frac{1}{4}$       | 3·3            |
| 28     | $4\frac{1}{2}$      | 3·6            | ·16        | $4\frac{1}{4}$ | 4·8            | ·20        | ·36        | $8\frac{3}{4}$       | 4·1            |
| 29     | 5                   | 3·0            | ·15        | 5              | 5·1            | ·26        | ·41        | 10                   | 4·1            |
| 30     | 5                   | 3·0            | ·15        | 2              | 7·3            | ·15        | ·30        | 7                    | 4·3            |
| 31     | $5\frac{1}{4}$      | 4·2            | ·22        | $3\frac{1}{4}$ | 3·8            | ·12        | ·34        | $8\frac{1}{2}$       | 4·0            |
| Nov. 1 | $5\frac{1}{2}$      | 2·8            | ·15        | 2              | 6·4            | ·13        | ·28        | $7\frac{1}{2}$       | 3·7            |
| 2      | $3\frac{1}{4}$      | 3·5            | ·11        | $2\frac{1}{4}$ | 3·7            | ·08        | ·19        | 6                    | 3·2            |
| 3      | $3\frac{1}{2}$      | 2·7            | ·09        | 2              | 4·5            | ·09        | ·18        | $5\frac{1}{2}$       | 3·3            |
| 4      | $3\frac{1}{2}$      | 3·2            | ·11        | $2\frac{1}{4}$ | 3·3            | ·07        | ·18        | $5\frac{3}{4}$       | 3·1            |
| 5      | $3\frac{1}{4}$      | 3·0            | ·10        | $2\frac{3}{4}$ | 5·4            | ·15        | ·25        | 6                    | 4·2            |
| 6      | $3\frac{3}{4}$      | 1·2            | ·05        | $3\frac{3}{4}$ | 5·3            | ·20        | ·25        | $7\frac{1}{2}$       | 3·3            |





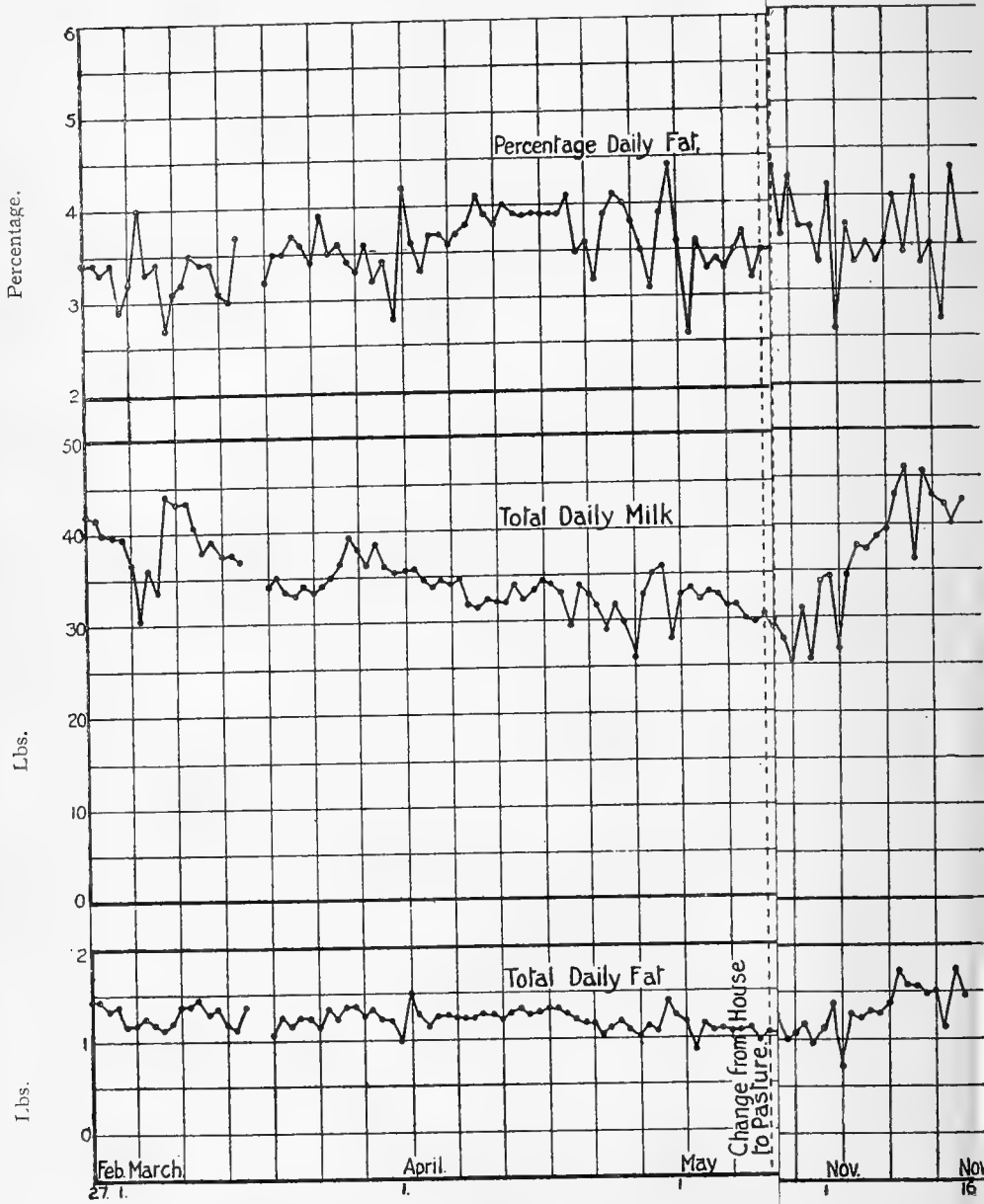


YIELDS OF COW, 155.



YIELDS OF COW, 159.





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## VOLUME XV.

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THE  
SCIENTIFIC PROCEEDINGS

OF THE  
ROYAL DUBLIN SOCIETY.

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Vol. XV. (N.S.), No. 41.

MAY, 1919.

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THE COMPARATIVE VARIATION OF THE  
CONSTITUENT SUBSTANCES OF COWS' MILK.

BY

E. J. SHEEHY, F.R.C.Sc.I.,

DEMONSTRATOR IN ZOOLOGY IN THE ROYAL COLLEGE OF SCIENCE, DUBLIN.

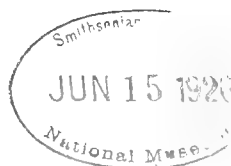
[COMMUNICATED BY PROFESSOR JAMES WILSON, M.A., B.Sc.]

[*Authors alone are responsible for all opinions expressed in their Communications.*]

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TABLE 3—continued.

|        | M.                  |                |            | E.             |                |            | DAILY.     |                     |                |
|--------|---------------------|----------------|------------|----------------|----------------|------------|------------|---------------------|----------------|
|        | Milk.               | Per cent. Fat. | Total Fat. | Milk.          | Per cent. Fat. | Total Fat. | Total Fat. | Total Milk.         | Per cent. Fat. |
| Nov. 7 | lbs. $4\frac{3}{4}$ | 4.7            | lbs. .22   | lbs. 5         | 4.7            | lbs. .24   | lbs. .46   | lbs. $9\frac{3}{4}$ | 4.7            |
| 8      | $4\frac{3}{4}$      | 3.0            | .14        | $2\frac{1}{2}$ | 3.5            | .09        | .23        | $7\frac{1}{4}$      | 5.2            |
| 9      | $5\frac{1}{4}$      | 4.3            | .23        | 3              | 4.8            | .14        | .37        | $8\frac{1}{4}$      | 4.5            |
| 10     | $6\frac{1}{4}$      | 3.0            | .19        | 3              | 4.0            | .12        | .31        | $9\frac{1}{4}$      | 3.4            |
| 11     | 6                   | 4.0            | .24        | $3\frac{1}{4}$ | 3.4            | .11        | .35        | $9\frac{1}{4}$      | 3.8            |
| 12     | $4\frac{1}{2}$      | 2.4            | .11        | $3\frac{1}{4}$ | 5.2            | .17        | .28        | $7\frac{3}{4}$      | 3.6            |
| 13     | $4\frac{1}{4}$      | 3.2            | .14        | $3\frac{1}{4}$ | 4.9            | .16        | .30        | $7\frac{1}{2}$      | 4.0            |
| 14     | 5                   | 2.9            | .15        | $3\frac{1}{4}$ | 2.2            | .07        | .22        | $8\frac{1}{4}$      | 2.7            |
| 15     | $4\frac{3}{4}$      | 5.6            | .27        | 3              | 5.1            | .15        | .42        | $7\frac{3}{4}$      | 5.4            |
| 16     | $5\frac{1}{4}$      | 2.9            | .15        | $2\frac{3}{4}$ | 4.0            | .11        | .26        | 8                   | 3.3            |

## XLI.

THE COMPARATIVE VARIATION OF THE CONSTITUENT  
SUBSTANCES OF COWS' MILK.

By E. J. SHEEHY, F.R.C.Sc.I.;

Demonstrator in Zoology, Royal College of Science, Dublin.

(COMMUNICATED BY PROFESSOR J. WILSON, M.A., B.Sc.)

----- [Read NOVEMBER 19, 1918; published MAY 26, 1919.]

THE milk yield of cows varies in both quantity and quality. The variation in quality, however, as judged by any single test, is not similar to that in quantity; that is to say, the relative proportions of total milk, sugar, fat, protein, and ash are not absolutely constant. They differ in the different breeds of cattle, in the individuals within a breed, and also in the successive days' yields from an individual cow. It is generally recognized that the percentage of solids other than fat in milk is more or less constant, varying only with the period of lactation, and Richmond has shown that a definite relationship exists between the percentage of total solids and a combination of fat percentage and specific gravity. To what relative degree do these different constituents vary, and how much is contributed by each towards the variation shown in the total milk yield? The answering of this question constituted one of the objects of an experiment conducted at the Albert Agricultural College in 1916.

The milk from twelve cows was weighed and sampled twice daily for a period extending from March 28 to June 17 (inclusive). From the sample, which consisted of about half a pint, the percentage of fat was determined by the Gerber method, and the percentage of total solids by Richmond's formula ( $T = 1.2F + .25D + .14$ ), the specific gravity being obtained by means of a lactometer. The cows were milked at 5 a.m. and 2 p.m., and the following table gives relevant information concerning the individuals:—

| No. | Time calved when experiment started. | Put in calf again on | Calved during Experiment.                    |
|-----|--------------------------------------|----------------------|--|
| 128 | 1½ months                            | —                    | —  |
| 141 | 6 „                                  | —                    | —  |
| 149 | 4½ „                                 | —                    | —  |
| 150 | 4½ „                                 | —                    | —  |
| 151 | 4½ „                                 | —                    | —  |
| 152 | 4 „                                  | —                    | —  |
| 154 | 3½ „                                 | —                    | —  |
| 155 | 2½ „                                 | August               | —  |
| 158 | 2 „                                  | —                    | —  |
| 159 | 3 weeks                              | February 20          | September 20<br>(Fœtus only<br>7 months old) |
| 160 | 3 „                                  | —                    | —  |
| 161 | 3 „                                  | June                 | —  |

From the figures obtained, the morning, evening, and total daily solids and daily fat were calculated: the solids-not-fat were obtained by subtracting the total fat from the total solids, and the water by taking the total solids from the total milk. Table I (pp. 582-584) gives the accumulated data from one of the cows—155—and diagram I (p. 576) is a graphical representation of the total milk, total water, total solids other than fat, and total fat in the milk of the same cow during successive days for the entire period. The table represents one-twelfth of the data, and the graphs one-twelfth of the figures from which the conclusions below are drawn. The ordinates of the diagrams are so scaled that in each constituent part, as well as in the total milk, the percentage fluctuation is represented by a line equal in length to that representing a similar percentage fluctuation in the others. Thus, a 50 per cent. increase in 30 pounds of milk, containing approximately 1.05 pound of fat, 2.7 pounds of solids-not-fat, and 26.25 pounds of water, would give the following figures:—milk, 45 pounds; fat, 1.57 pounds; solids-not-fat, 4.05 pounds; and water, 39.37 pounds. On diagram I, which represents figures approximating to the above, the 50 per cent. increase in each case is represented by similar lengths of ordinate. The comparative lengths of line joining any two successive days on the different curves in the same sheet give empirically the exact comparative variations in the various parts.

From the diagrams, the following observations can be made:—

(i) The daily variation in water is approximately equal and practically similar to that in the total milk.

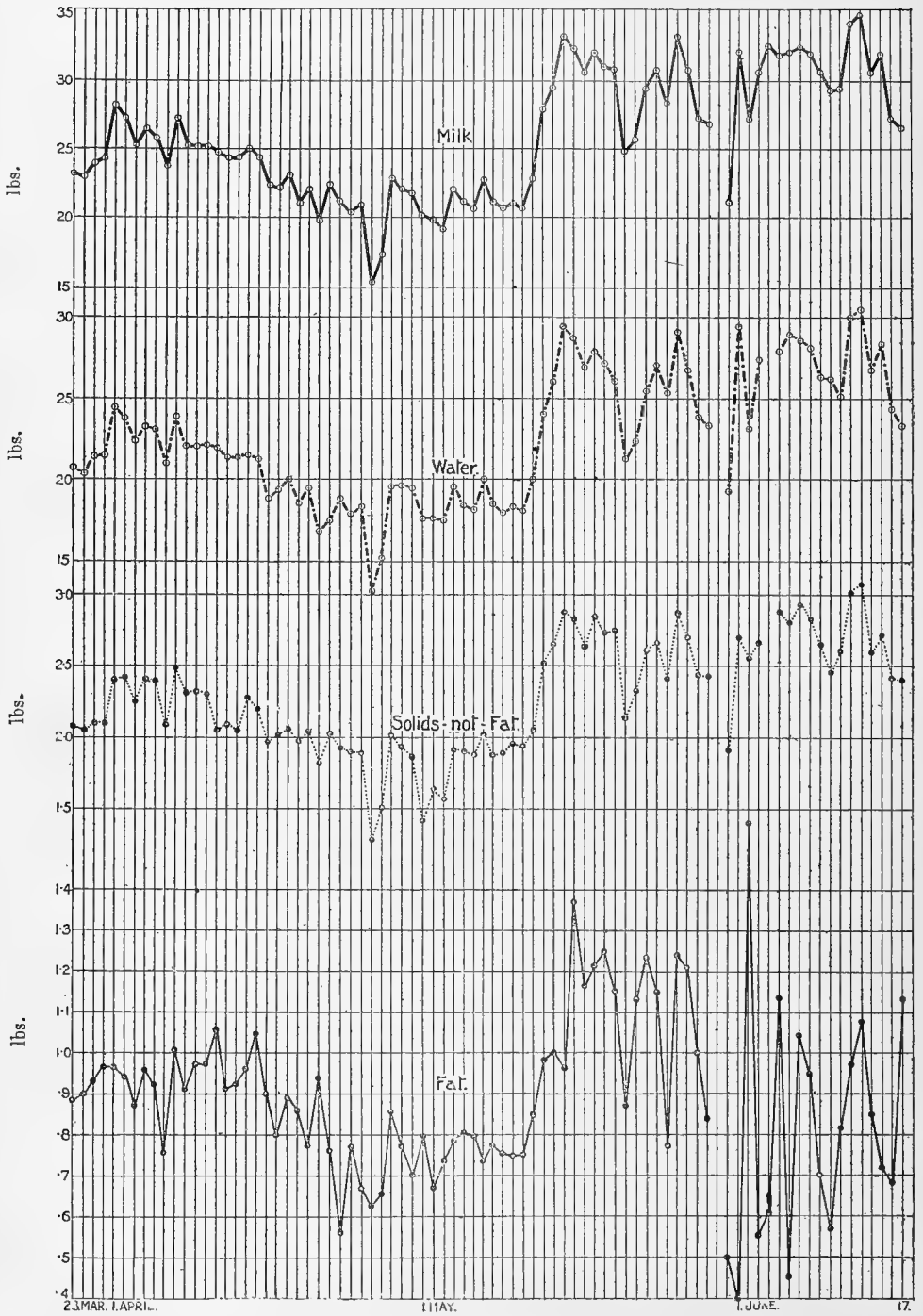


Diagram 1. Representing  $\left\{ \begin{array}{l} \text{Total Daily Milk.} \\ \text{Total Water in Daily Milk.} \\ \text{Total Solids-not-fat in Daily Milk.} \\ \text{Total Fat in Daily Milk.} \end{array} \right\}$  Cow 155.

(ii) The daily variation in solids-not-fat is approximately equal and practically similar to that in the total milk.

(iii) The daily variation in fat is not equal to that in the total milk.

Fat is therefore the great variable among the constituent parts of milk. While alterations in quantity of total milk are accompanied by practically similar alterations in the quantities of water and of solids-not-fat, the same does not hold for the total fat. Generally, however, a marked increase or decrease in milk results in an increase or decrease in fat, but the magnitude of the fluctuation of the latter is seldom equal to that of the former; and frequently an increase in milk is accompanied by a decrease in fat or *vice versa*.

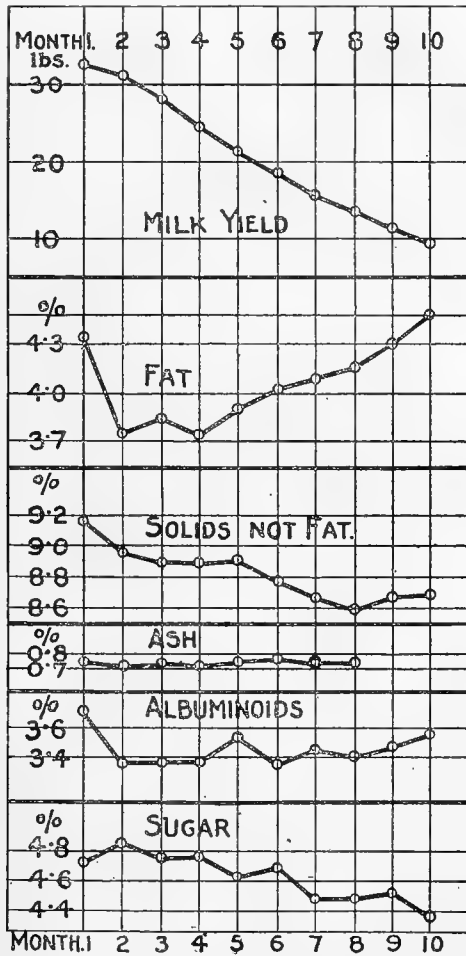


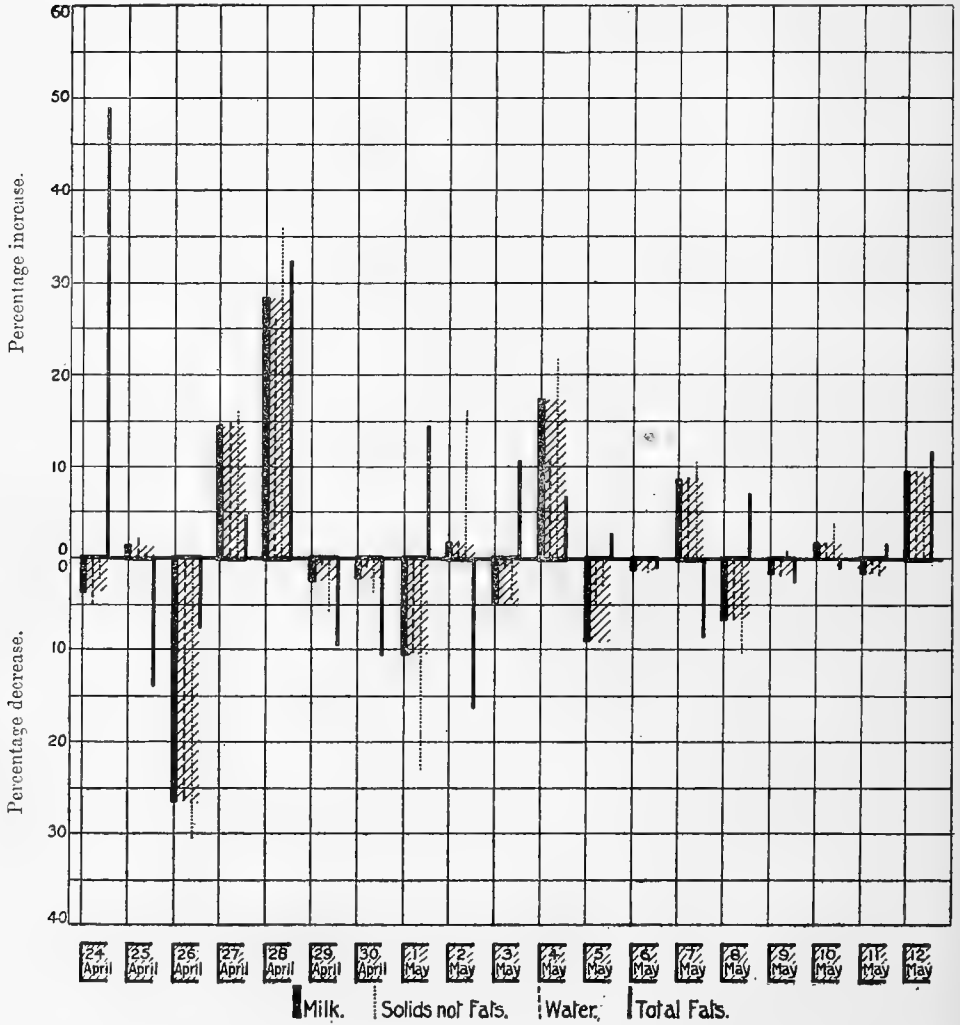
Diagram II.

When the figures representing the percentages of the various constituents for a lactation period are examined, it is seen, as in diagram II,<sup>1</sup> that,

<sup>1</sup> Crowther and Ruston, Transactions of the Highland and Agricultural Society of Scotland, vol. xxiii, 1911, p. 97.

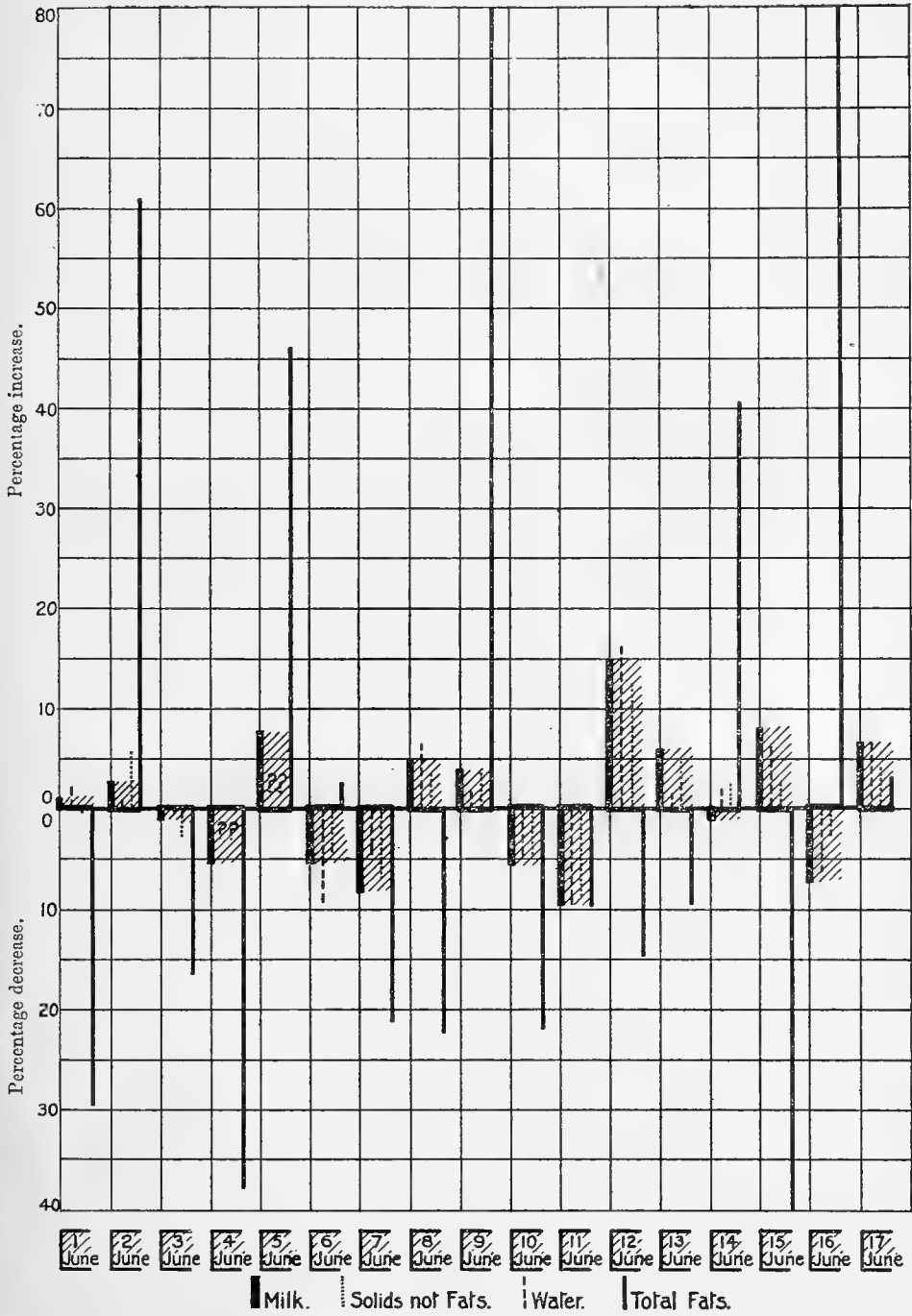


while the percentage of butter fat rises rapidly after the first four or five weeks of the lactation period, the percentage of solids-not-fat falls slightly. This gradual but dissimilar change in the proportion of these constituents is evidently due to the fact that, as the lactation period proceeds, the total daily fat yielded declines much less rapidly than the total milk, while the daily solids-not-fat in the milk decline more rapidly than the milk. The accelerated decline in solids-not-fat is principally due to the decrease in the quantity



Cow 155.

Diagram III.—Variation,  $\left\{ \begin{array}{c} \text{Increase} \\ \text{or} \\ \text{Decrease} \end{array} \right\}$  of  $\left\{ \begin{array}{c} \text{Milk} \\ \text{Total Water} \\ \text{Total Solids-not-Fat} \\ \text{Total Fat} \end{array} \right\}$  On previous day.



Cow 128.

Diagram III (continued).—Variation, &c., see p. 578.

of sugar. In an investigation extending over a short period, these changes are not obvious, particularly in the case of solids-not-fat where the percentage remains a practically constant quantity. But the proportions of solids-not-fat and of water are subject to slight daily variations. This can be observed on diagram I, and is better illustrated in diagram III.

Here the percentage variation in the milk of each day above or below that of the previous day is represented by a series of vertical lines above or below a horizontal one marked off in days. Beside the line representing the variation in milk there are three others for each day, one for the water, one for the solids-not-fat, and one for the total fat, each representing, as in the line for milk, the percentage variation on the previous day's yield of that constituent, whether an increase or decrease. In this way the variation of the four quantities can be compared by observing the comparative lengths of the four lines for each day. The returns from cow 155 for the period April 24th to May 12th are represented on the left side of the diagram (p. 578), and those from cow 128 for the period June 1st to June 17th on the right (p. 579). The first group (left side) is taken from a portion of diagram I where the line representing fat approximates most closely to the other three (milk, solids-not-fat, and water), whereas the second group (right side) represents a much more representative section of the curves. From diagram III it is obvious that the percentage increase or decrease of water and solids-not-fat on the previous day is not always exactly equal to the increase or decrease in milk, the variations being at least sufficiently great to prevent the utilization of formulae involving these factors in the determination of a result which can claim to a greater accuracy than the nearest whole number. For instance, the addition of water to milk cannot be determined accurately to a decimal when the variation in solids-not-fat is more than this quantity. When, however, the variations in solids-not-fat, water, and fat are compared with the variation of the total milk, we realize that while the first two constituents vary approximately as the milk the total fat varies in a fashion peculiar to itself.

That is to say, fat is the great variable constituent of milk. In the mixed milk of a herd much smaller daily variations appear, the solids-not-fat probably remaining, for a short period, nearly constant. This is due to the fact that diverging fluctuations in different cows balance each other in the composite sample. A lactating cow produces water, and solids-not-fat, in proportions which are practically constant, and produces fat in proportions which bear no constant ratio to the total milk, thus indicating that fat-production is influenced by factors<sup>1</sup> which are not identical with those influencing the production of the other constituents of the milk.

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<sup>1</sup> To be dealt with in a later paper.

In this and also in another investigation,<sup>1</sup> the report of which is going to press simultaneously, I have received much help from Mr. Carey, Albert Agricultural College, Glasnevin; Mr. Torrens, Royal College of Science, Dublin; and Mr. R. D. Cole, Department of Agriculture, whose kind assistance rendered it possible to continue the work over the long period of 1916 (March to November). Throughout the investigation I have got much support from Professor Wilson, Royal College of Science, who contributed many valuable suggestions, and helped to make the calculations and to elaborate the reports.

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<sup>1</sup> "An Economical Method of Determining the Average Percentage of Fat in a Cow's Milk during a Lactation Period."—*Scient. Proc. Roy. Dub. Soc.*

[TABLE.

TABLE I.—COW 155, MARCH 28TH TO JUNE 17TH.

|       | MEASURED RESULTS. |                |                              |                 |                |                              | M.         |                  |              | E.         |                  |              | DAILY TOTAL. |       |                  |                 |        |
|-------|-------------------|----------------|------------------------------|-----------------|----------------|------------------------------|------------|------------------|--------------|------------|------------------|--------------|--------------|-------|------------------|-----------------|--------|
|       | M.                |                |                              | E.              |                |                              | Total Fat. | Per cent. Solid. | Total Solid. | Total Fat. | Per cent. Solid. | Total Solid. | Fat          | Solid | Milk.            | Solids-not-Fat. | Water. |
|       | Milk.             | Per cent. Fat. | Sp. Grav. (lactom. readings) | Milk.           | Per cent. Fat. | Sp. Grav. (lactom. readings) |            |                  |              |            |                  |              |              |       |                  |                 |        |
| March | lbs.              |                |                              | lbs.            |                |                              | lbs.       | lbs.             | lbs.         | lbs.       | lbs.             | lbs.         | lbs.         | lbs.  | lbs.             | lbs.            | lbs.   |
| 28    | 13 $\frac{1}{2}$  | 3.1            | 328                          | 10              | 4.7            | 308                          | .418       | 12.07            | 1.63         | .470       | 13.49            | 1.35         | .89          | 2.98  | 23 $\frac{1}{2}$ | 2.09            | 20.52  |
| 29    | 15                | 3.4            | 323                          | 8 $\frac{1}{4}$ | 4.7            | 313                          | .510       | 12.30            | 1.85         | .388       | 13.60            | 1.12         | .90          | 2.97  | 23 $\frac{1}{4}$ | 2.07            | 20.28  |
| 30    | 16                | 3.4            | 326                          | 8 $\frac{1}{4}$ | 4.1            | 318                          | .544       | 12.38            | 1.98         | .388       | 13.00            | 1.07         | .93          | 3.05  | 24 $\frac{1}{4}$ | 2.12            | 21.20  |
| 31    | 16 $\frac{1}{2}$  | 3.7            | 322                          | 8               | 4.5            | 318                          | .611       | 12.63            | 2.08         | .360       | 13.50            | 1.08         | .97          | 3.16  | 24 $\frac{1}{2}$ | 2.19            | 21.34  |
| April |                   |                |                              |                 |                |                              |            |                  |              |            |                  |              |              |       |                  |                 |        |
| 1     | 19                | 3.1            | 309                          | 9               | 4.2            | 323                          | .589       | 11.59            | 2.20         | .378       | 13.27            | 1.19         | .97          | 3.39  | 28               | 2.42            | 24.61  |
| 2     | 17 $\frac{1}{4}$  | 3.0            | 331                          | 10              | 4.2            | 320                          | .518       | 12.01            | 2.07         | .420       | 13.19            | 1.32         | .94          | 3.39  | 27 $\frac{1}{4}$ | 2.45            | 23.86  |
| 3     | 17                | 3.2            | 327                          | 8 $\frac{1}{4}$ | 4.0            | 317                          | .544       | 12.17            | 2.07         | .330       | 12.87            | 1.06         | .87          | 3.13  | 25 $\frac{1}{4}$ | 2.26            | 22.12  |
| 4     | 16 $\frac{3}{4}$  | 3.3            | 331                          | 9 $\frac{3}{4}$ | 4.2            | 320                          | .553       | 12.39            | 2.08         | .410       | 13.19            | 1.29         | .96          | 3.37  | 26 $\frac{1}{2}$ | 2.41            | 23.13  |
| 5     | 17 $\frac{1}{4}$  | 3.1            | 334                          | 9               | 4.3            | 319                          | .535       | 12.21            | 2.11         | .387       | 13.29            | 1.20         | .92          | 3.31  | 26 $\frac{1}{4}$ | 2.39            | 22.94  |
| 6     | 16 $\frac{1}{4}$  | 2.7            | 334                          | 7 $\frac{1}{2}$ | 4.1            | 317                          | .439       | 11.72            | 1.90         | .308       | 12.99            | .97          | .75          | 2.87  | 23 $\frac{3}{4}$ | 2.12            | 20.88  |
| 7     | 17 $\frac{1}{4}$  | 3.2            | 338                          | 10              | 4.6            | 320                          | .552       | 12.43            | 2.14         | .460       | 13.65            | 1.37         | 1.01         | 3.51  | 27 $\frac{1}{4}$ | 2.50            | 23.74  |
| 8     | 16 $\frac{1}{4}$  | 3.1            | 338                          | 9               | 4.5            | 325                          | .504       | 12.31            | 2.00         | .405       | 13.68            | 1.23         | .91          | 3.23  | 25 $\frac{1}{4}$ | 2.32            | 22.02  |
| 9     | 16 $\frac{1}{4}$  | 3.6            | 340                          | 9               | 4.4            | 325                          | .585       | 12.97            | 2.11         | .396       | 13.54            | 1.22         | .98          | 3.30  | 25 $\frac{1}{4}$ | 2.35            | 21.92  |
| 10    | 16                | 3.5            | 334                          | 9 $\frac{1}{4}$ | 4.5            | 322                          | .560       | 12.70            | 2.03         | .416       | 13.60            | 1.26         | .98          | 3.29  | 25 $\frac{1}{2}$ | 2.31            | 21.96  |
| 11    | 16                | 3.8            | 327                          | 8 $\frac{3}{4}$ | 5.2            | 315                          | .608       | 12.89            | 2.06         | .455       | 14.27            | 1.25         | 1.06         | 3.11  | 24 $\frac{3}{4}$ | 2.05            | 21.64  |
| 12    | 14 $\frac{3}{4}$  | 2.6            | 338                          | 9 $\frac{1}{2}$ | 4.7            | 311                          | .462       | 11.70            | 1.72         | .448       | 13.55            | 1.29         | .91          | 3.01  | 24 $\frac{1}{4}$ | 2.10            | 21.24  |
| 13    | 15 $\frac{1}{4}$  | 3.4            | 301                          | 9               | 4.5            | 317                          | .519       | 11.74            | 1.79         | .405       | 13.58            | 1.22         | .92          | 3.01  | 24 $\frac{1}{4}$ | 2.09            | 21.24  |
| 14    | 15 $\frac{1}{2}$  | 3.2            | 338                          | 9 $\frac{1}{4}$ | 5.0            | 324                          | .496       | 12.43            | 1.93         | .463       | 14.23            | 1.32         | .96          | 3.25  | 24 $\frac{3}{4}$ | 2.29            | 21.50  |
| 15    | 15 $\frac{1}{2}$  | 4.3            | 331                          | 8 $\frac{3}{4}$ | 4.5            | 315                          | .667       | 13.59            | 2.11         | .394       | 13.42            | 1.17         | 1.06         | 3.28  | 24 $\frac{1}{4}$ | 2.22            | 20.97  |
| 16    | 13                | 3.7            | 330                          | 9               | 4.6            | 309                          | .481       | 12.83            | 1.67         | .414       | 13.39            | 1.21         | .90          | 2.88  | 22               | 1.98            | 19.12  |
| 17    | 14                | 3.3            | 331                          | 8 $\frac{1}{2}$ | 4.0            | 317                          | .462       | 12.39            | 1.73         | .340       | 12.87            | 1.09         | .80          | 2.82  | 22 $\frac{1}{2}$ | 2.02            | 19.68  |
| 18    | 15                | 3.8            | 328                          | 8               | 4.2            | 323                          | .570       | 12.90            | 1.94         | .336       | 13.26            | 1.06         | .91          | 3.00  | 23               | 2.09            | 20.00  |
| 19    | 14 $\frac{1}{2}$  | 4.0            | 332                          | 6 $\frac{3}{4}$ | 4.2            | 337                          | .580       | 13.24            | 1.92         | .284       | 13.60            | .92          | .86          | 2.84  | 21 $\frac{1}{4}$ | 1.98            | 18.41  |
| 20    | 15                | 3.3            | 340                          | 7 $\frac{1}{4}$ | 3.8            | 344                          | .495       | 12.60            | 1.89         | .276       | 13.30            | .96          | .77          | 2.85  | 22 $\frac{1}{4}$ | 2.08            | 19.40  |
| 21    | 11 $\frac{1}{2}$  | 5.6            | 316                          | 8 $\frac{1}{4}$ | 3.6            | 328                          | .644       | 14.77            | 1.70         | .297       | 12.78            | 1.05         | .94          | 2.75  | 19 $\frac{3}{4}$ | 1.81            | 17.00  |
| 22    | 15 $\frac{1}{2}$  | 3.3            | 341                          | 7 $\frac{1}{4}$ | 3.5            | 309                          | .512       | 12.61            | 1.95         | .254       | 12.06            | .87          | .77          | 2.82  | 22 $\frac{3}{4}$ | 2.05            | 19.93  |
| 23    | 14                | 2.1            | 341                          | 7 $\frac{1}{2}$ | 3.1            | 317                          | .294       | 11.19            | 1.57         | .233       | 11.80            | .89          | .53          | 2.46  | 21 $\frac{1}{2}$ | 1.93            | 19.04  |
| 24    | 13 $\frac{1}{2}$  | 3.5            | 332                          | 7 $\frac{1}{4}$ | 4.2            | 325                          | .473       | 12.64            | 1.71         | .305       | 13.30            | .96          | .78          | 2.67  | 20 $\frac{3}{4}$ | 1.59            | 18.08  |
| 25    | 13 $\frac{1}{2}$  | 3.0            | 333                          | 7 $\frac{1}{2}$ | 3.5            | 324                          | .405       | 12.08            | 1.63         | .263       | 12.45            | .93          | .67          | 2.56  | 21               | 1.89            | 18.44  |
| 26    | 7 $\frac{1}{4}$   | 3.6            | 304                          | 8 $\frac{1}{4}$ | 4.3            | 304                          | .261       | 12.05            | .87          | .355       | 12.90            | 1.06         | .62          | 1.93  | 15 $\frac{1}{2}$ | 1.31            | 13.57  |
| 27    | 10                | 3.4            | 298                          | 7 $\frac{3}{4}$ | 4.0            | 316                          | .340       | 11.67            | 1.17         | .310       | 12.85            | 1.0          | .65          | 2.17  | 17 $\frac{3}{4}$ | 1.52            | 15.58  |
| 28    | 14 $\frac{1}{4}$  | 3.8            | 328                          | 8 $\frac{1}{2}$ | 3.7            | 324                          | .546       | 12.90            | 1.84         | .314       | 12.68            | 1.08         | .86          | 2.92  | 22 $\frac{1}{4}$ | 2.06            | 19.63  |



TABLE I.—COW 155—continued.

|        | MEASURED RESULTS. |                |                             |       |                |                             |            |                  |              | M.         |                  |              | E.   |        |       | DAILY TOTAL.    |        |  |  |  |
|--------|-------------------|----------------|-----------------------------|-------|----------------|-----------------------------|------------|------------------|--------------|------------|------------------|--------------|------|--------|-------|-----------------|--------|--|--|--|
|        | M.                |                |                             | E.    |                |                             |            |                  |              |            |                  |              |      |        |       |                 |        |  |  |  |
|        | Milk.             | Per cent. Fat. | Sp. Grav. (lactom. reading) | Milk. | Per cent. Fat. | Sp. Grav. (lactom. reading) | Total Fat. | Per cent. Solid. | Total Solid. | Total Fat. | Per cent. Solid. | Total Solid. | Fat. | Solid. | Milk. | Solids-not-Fat. | Water. |  |  |  |
| May 31 | 10½               | 2.95           | 330                         | 11    | 1.8            | 327                         | .309       | 11.93            | 1.25         | .198       | 10.49            | 1.15         | .51  | 2.40   | 21½   | 1.89            | 19.10  |  |  |  |
| June 1 | 20¼               | .8             | 328                         | 12¼   | 1.5            | 312                         | .162       | 9.30             | 1.88         | .184       | 9.72             | 1.19         | .35  | 3.07   | 32½   | 2.72            | 29.43  |  |  |  |
| 2      | 16                | 6.35           | 328                         | 11    | 4.2            | 320                         | 1.016      | 16.00            | 2.56         | .462       | 13.19            | 1.45         | 1.48 | 4.01   | 27    | 2.53            | 22.99  |  |  |  |
| 3      | 18½               | 1.1            | 338                         | 12½   | 2.6            | 317                         | .219       | 10.00            | 1.82         | .325       | 11.20            | 1.40         | .54  | 5.22   | 30¾   | 2.68            | 27.53  |  |  |  |
| 4      | 21½               | 1.0            | —                           | 11    | 3.6            | —                           | .215       | —                | —            | .296       | —                | —            | .61  | —      | 32½   | —               | —      |  |  |  |
| 5      | 21                | 2.9            | 328                         | 11    | 4.8            | 323                         | .609       | 11.81            | 2.48         | .528       | 13.99            | 1.54         | 1.14 | 4.02   | 32    | 2.88            | 27.98  |  |  |  |
| 6      | 20¾               | 1.1            | 333                         | 11½   | 1.9            | 320                         | .228       | 9.79             | 2.02         | .218       | 10.41            | 1.20         | .45  | 3.23   | 32½   | 2.78            | 29.02  |  |  |  |
| 7      | 21                | 3.0            | 326                         | 11½   | 3.6            | 320                         | .630       | 11.90            | 2.50         | .414       | 12.48            | 1.44         | 1.04 | 3.94   | 32½   | 2.90            | 28.56  |  |  |  |
| 8      | 21¾               | 3.8            | 319                         | 10¼   | 1.2            | 320                         | .826       | 12.79            | 2.78         | .123       | 9.58             | .98          | .95  | 3.76   | 32    | 2.81            | 28.24  |  |  |  |
| 9      | 19¼               | 1.8            | 326                         | 11½   | 3.05           | 320                         | .346       | 10.45            | 2.01         | .351       | 11.80            | 1.36         | .70  | 3.37   | 30¾   | 2.67            | 26.38  |  |  |  |
| 10     | 18                | 1.3            | 318                         | 11½   | 3.0            | 310                         | .231       | 9.64             | 1.74         | .337       | 11.50            | 1.29         | .57  | 3.03   | 29¼   | 2.46            | 26.22  |  |  |  |
| 11     | 18½               | 2.3            | 331                         | 11    | 3.6            | 320                         | .425       | 11.19            | 2.07         | .396       | 12.47            | 1.37         | .82  | 3.45   | 29½   | 2.62            | 25.06  |  |  |  |
| 12     | 23¾               | 2.2            | 330                         | 10½   | 4.3            | 325                         | .522       | 11.03            | 2.62         | .451       | 13.43            | 1.41         | .97  | 4.03   | 34¼   | 3.06            | 30.22  |  |  |  |
| 13     | 22                | 2.9            | 333                         | 13    | 3.4            | 305                         | .638       | 11.95            | 2.63         | .442       | 11.85            | 1.54         | 1.08 | 4.17   | 35    | 3.09            | 30.83  |  |  |  |
| 14     | 19                | 1.5            | 312                         | 11½   | 4.9            | 316                         | .285       | 9.72             | 1.85         | .563       | 13.91            | 1.60         | .85  | 3.45   | 30½   | 2.60            | 27.05  |  |  |  |
| 15     | 20                | 1.25           | 321                         | 12    | 3.8            | 318                         | .250       | 9.65             | 1.93         | .456       | 12.65            | 1.52         | .71  | 3.45   | 32    | 2.74            | 28.55  |  |  |  |
| 16     | 6¼                | .6             | 354                         | 21    | 3.05           | 318                         | .037       | 9.70             | .61          | .641       | 11.75            | 2.47         | .68  | 3.08   | 27¼   | 2.40            | 24.17  |  |  |  |
| 17     | 14½               | 4.2            | 333                         | 12¼   | 4.3            | 300                         | .609       | 13.49            | 1.96         | .527       | 12.80            | 1.57         | 1.13 | 3.53   | 26¾   | 2.40            | 23.22  |  |  |  |

## SCIENTIFIC PROCEEDINGS.

### VOLUME XV.

1. The Subsidence of Torsional Oscillations and the Fatigue of Iron Wires when subjected to the Influence of Alternating Magnetic Fields of Frequencies up to 250 per second. By WILLIAM BROWN, B.SC. (January, 1916.) 6*d*.
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POSSIBLE CAUSES OF VARIATION IN THE  
QUANTITY AND QUALITY OF COWS' MILK.

BY

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[COMMUNICATED BY PROFESSOR JAMES WILSON, M.A., B.SC.]

[*Authors alone are responsible for all opinions expressed in their Communications.*]

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## XLII.

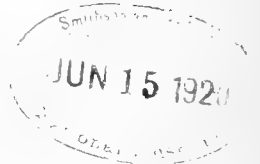
POSSIBLE CAUSES OF VARIATION IN THE QUANTITY AND  
QUALITY OF COWS' MILK.

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[COMMUNICATED BY PROFESSOR J. WILSON, M.A., B.SC.]

[Read DECEMBER 17, 1918; published MAY 26, 1919.]



THE cow normally produces milk which is inconstant in quantity and quality. When milking is performed at equal intervals, twice daily, the percentage of fat is very slightly higher after the day interval than after the night one.<sup>1</sup> When the intervals are unequal the quantities of milk are, more or less, in the direct ratio, and the percentages of fat in the indirect ratio of the times after which milking takes place. The total fat yield after the short interval is, however, practically equal to that given after the long one.<sup>2</sup> In successive-day yields the quantities of milk and of butter-fat vary considerably. The variation in total milk is accompanied by more or less similar variation in solids-not-fat and water, but the total fat seems to vary in a fashion peculiar to itself.<sup>3</sup>

Some of these peculiarities may be explained as the effect of external influences.<sup>4</sup> Thus the conditions obtaining during the day seem to have a slightly different effect on a cow's milk-yielding capacity from those which prevail at night; violent weather changes seriously affect the condition of some cows, and the manner of treatment undoubtedly so influences the nervous condition that there is a probable effect on the milk yield. None of these things explains all the phenomena of variation outlined above. It is necessary to refer to the "individuality" of the cow, and to explore the complex mechanism and co-ordinated activities of the milk-producing organs for the basis of an explanation.

<sup>1</sup> "Variation in the Composition of Cows' Milk," Crowther, *Journal of Agricultural Science*, vol. i, p. 153.

<sup>2</sup> *Ibid.*

<sup>3</sup> Sheehy: *Scientific Proceedings of the Royal Dublin Society*, vol. xv, No. xl.

<sup>4</sup> "Variation in the Composition of Cows' Milk," Crowther, *Journal of Agricultural Science*, vol. i, p. 152.

It has been shown that the secretion of milk in cows is increased by the absorption of the extract of certain other organs of the body,<sup>1</sup> for instance, the pituitary gland and the corpus luteum. These substances temporarily increase the quantity both of milk and butter-fat, and what can be shown to take place experimentally no doubt happens in the normal working of the body. Admitting the action of these hormones on the mammary gland, and recognizing that the daily variation in total fat-yield is not similar to that of the other milk constituents, it appears that those hormones which influence the production of fat are not identical with those which affect the production of the other constituents of the milk. Professor Wilson<sup>2</sup> has shown that the factors for the quantity and quality (fat) are separately inherited. It is possible that extract of pituitary gland or corpus luteum contains different hormones which have various effects, and it is probable that there are other organs in the body which contribute to the blood a substance or substances which, when conveyed to the mammary gland, influence its production of some or all of the constituent substances of milk. The quantity of the hormones liberated depends on the activity of the secreting glands, and since this is regulated by the general tone of the body—a variable factor—the quantity and, perhaps, the quality of the product vary. The liberation of these substances in varying quantities according to the cow's condition would account for the daily variation of milk and butter-fat.

The question then arises as to the relative activity, during successive periods, of the mammary gland, because of the apparently anomalous production of practically as much butter-fat after nine hours as after fifteen hours. This fact seems to suggest that the gland is more active during the shorter period. If that were so it would be advisable to draw the milk from cows several times during the twenty-four hours, and always after short intervals; but in practice it is found that frequent milkings do not materially increase the yield. More milk can, however, be obtained from animals which are milked several times a day than from those which are milked only once;<sup>3</sup> but this can be accounted for by the injurious effects on the cow of the pressure from a large store of milk in the udder for such a long time. An explanation of the apparent varying activity of the gland during successive periods of the day must, therefore, be sought elsewhere.

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<sup>1</sup> Chapter on "Lactation" in "The Physiology of Reproduction," F. H. Marshall, 1910. Proc. Soc. Exp. Biol. and Med., vol. viii, No. 2, 1910. Proc. Royal Society, B, vol. lxxxiv, 1911. Gavin: Quarterly Journal Experimental Physiology, vol. vi, 1913. *Ibid.*, vol. vi, 1913, Schäfer. *Ibid.*, vol. vi, 1913, Hammond.

<sup>2</sup> "The Separate Inheritance of Quantity and Quality in Cows' Milk," Wilson: Scientific Proc. Royal Dublin Society, July 29th, 1910.

<sup>3</sup> Kellner: "The Scientific Feeding of Animals." London, 1909.

To explain some of the results of the 1915 and 1916 experiments,<sup>1</sup> conducted by the writer at the Albert Agricultural College, supplemental experiments were started in 1918. The milk from each teat of an individual cow was sampled at three stages of the milking, namely, when the operation started, when about half the milk was drawn from the udder, and, finally, when nothing was left in the udder except the amount of the sample. Thus twelve samples of about half a pint each were taken at each milking, and from these the percentage of fat and the specific gravity were determined. The percentages of solids and of solids-not-fat were then calculated. Table I contains the accumulated data from cow 23 and cow 15. At the beginning of the milking the half pint sample of the first—"fore" in table—milk was drawn from each teat separately in the order from left to right on the table. All the teats were then milked in the normal fashion till the cow had given about half the expected quantity, when the teats were again milked in the same order into the sample bottles. This sample is labelled "middle" on the table. Milking was again proceeded with till only approximately half a pint was left in each quarter of the udder; then the teats were again emptied in the same order into the third set of sample bottles—last on table. The percentages of fat and of solids-not-fat in the fore, middle, and last samples from each of three milkings of cow 23 are represented in diagram I. From the table and diagram it is evident that, as the operation of milking proceeds, the milk yielded gives a percentage of fat which increases from the "fore" milk up to the "strippings," and a percentage of solids-not-fat, which decreases: that is, the percentage of fat is much higher, and that of solids-not-fat lower in the strippings than in the first milk.

The alveolar cells of the mammary gland pour out their secretion into the ducts or canals which lead to the little milk reservoirs where the material is stored. It has been calculated that the udders of cows could not contain all the milk which is sometimes drawn at one milking, so that secretion must be proceeding at the same time.<sup>2</sup> Lehman<sup>3</sup> injected sulphindigotate of soda solution into a vein of a milch goat; and, on milking the animal immediately afterwards, found a blue tinge in the strippings. A considerable quantity of the fluid drawn at a milking is, therefore, secreted during the process of milking. That secretion proceeds during milking in a lactating cat is shown conclusively by the experiments of Jackson and Rothera,<sup>4</sup> where 29-47 per cent. of the milk was produced in the short period during which the kittens were sucking the mother.

<sup>1</sup>Sheehy: *Scient. Proc. Royal Dublin Society*, vol. xv, 1919, pp. 546 and 574.

<sup>2</sup>Schäfer: "*Text Book of Physiology.*" vol. i, p. 663.

<sup>3</sup>*Ibid.*

<sup>4</sup>*Biochemical Journal*, viii, 1914.

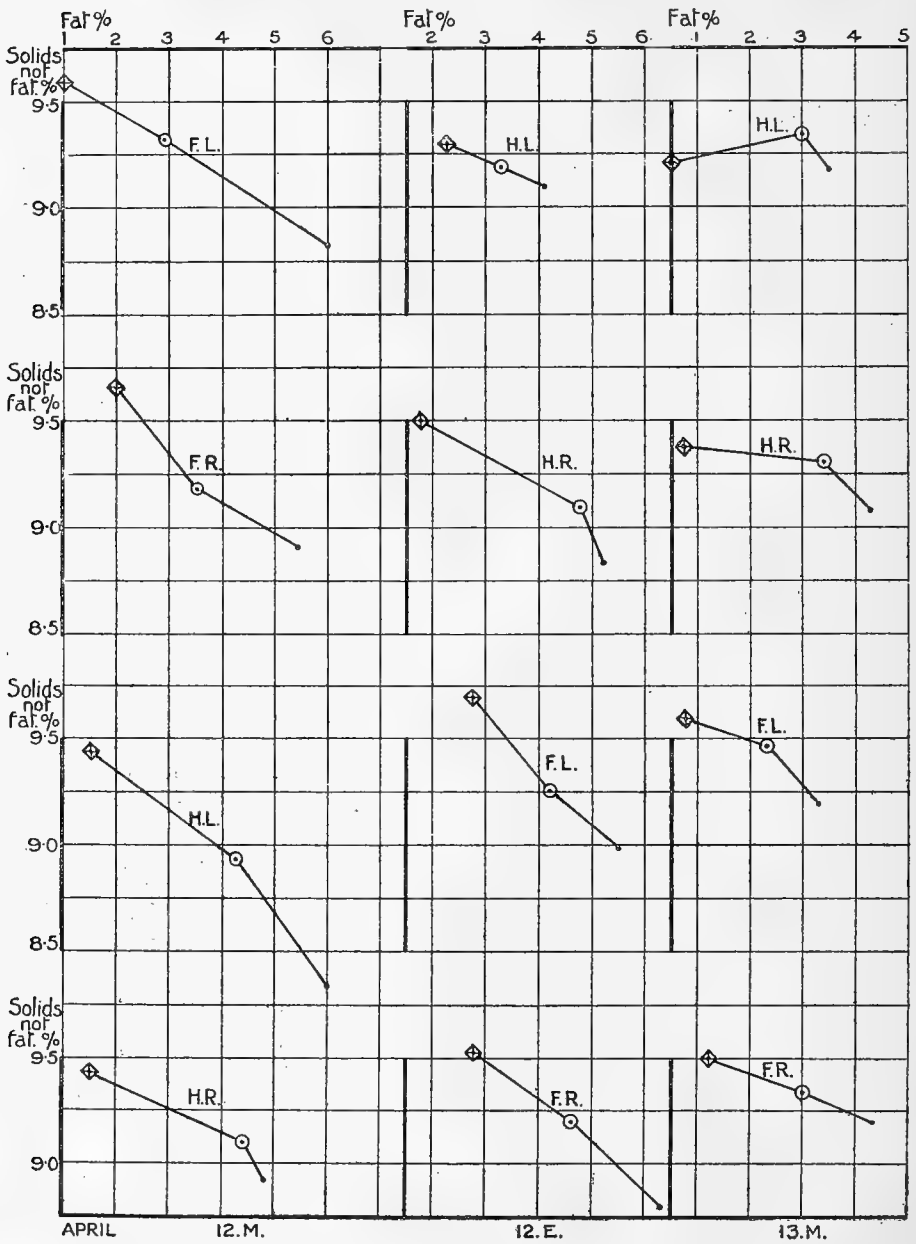


Diagram I.—Represents the yields of the individual teats during a milking.

F.L., fore left teat; F.R., fore right teat; H.L., hind left teat; H.R., hind right teat.  
 Square and cross represents fore milk. Circle and dot represents middle milk. Dot represents strippings.  
 M., Morning. E., Evening.

The figures for the proportion of solids-not-fat indicate that the concentration of some or all of the components increases while the milk is resting in the udder. That is to say, diffusion must take place through the walls of the gland tubules. The proteids of milk are not diffusible: consequently the possibility of diffusion is confined to the sugars, salts, and water. That sugars can be and are re-absorbed is suggested by the fact that lactose<sup>1</sup> is found in the blood of mammals immediately after parturition. If the "strippings" be taken to contain the percentage of solids-not-fat in milk as it is poured out by the alveolar cells, and the fore milk, which contains a higher percentage of solids-not-fat, be considered as that which has been lying in the reservoir of the udder for several hours, re-absorption of water must take place. A similar theory of concentration of salts in the urine has been formulated by Carl Ludwig,<sup>2</sup> in which he states that the salts poured through Bowman's capsule in the Malpighian bodies of the kidney are concentrated along the uriniferous tubules. Fat, in the globular form, as it exists in milk, is not diffusible. This, combined with the fact that the percentage of fat is much higher in the strippings than in the first milk, suggests that the percentage of fat in the strippings is not similar to that in the milk liberated from the alveolar cells at other times.

In the above experiment the order in which the teats were milked was successively changed as the investigation proceeded. No definite effect was produced by this procedure: the four quarters, which are anatomically distinct from one another, give milk which differs in the proportion of both fat and solids-not-fat. A peculiar feature is the inconsistency of the yield of any part, both in solids-not-fat and butter-fat; there is some variation in the successive yields of any individual quarter, showing that the glands therein are not constant in action. Histological examination also shows that while the gland is actively at work there may be some alveoli inactive for the time being; and chemical examination suggests different composition<sup>3</sup> for different parts of the mammary gland. A pail of milk drawn from a cow is, therefore, a compound product; it is the sum of the products of four separate and different quarters,<sup>4</sup> in each of which the activities of the neighbouring alveoli probably differ.

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<sup>1</sup> "Compt. rend. Acad. Sci.," vol. cxxviii, 1904. "Arch. f. wiss. u. prakt. Tierheilk," vol. xxxv, 1904. Marsh: "Physiology of Reproduction," 1910.

<sup>2</sup> Halliburton's "Physiology," 1913, p. 577.

<sup>3</sup> "The Chemistry of the Mammary Gland," J. A. Campbell: Quarterly Journal of Experimental Physiology, vol. vii, p. 53.

<sup>4</sup> "Variation in the Composition of Cows' Milk," Crowther: Journal of Agri. Science, vol. i, p. 171.



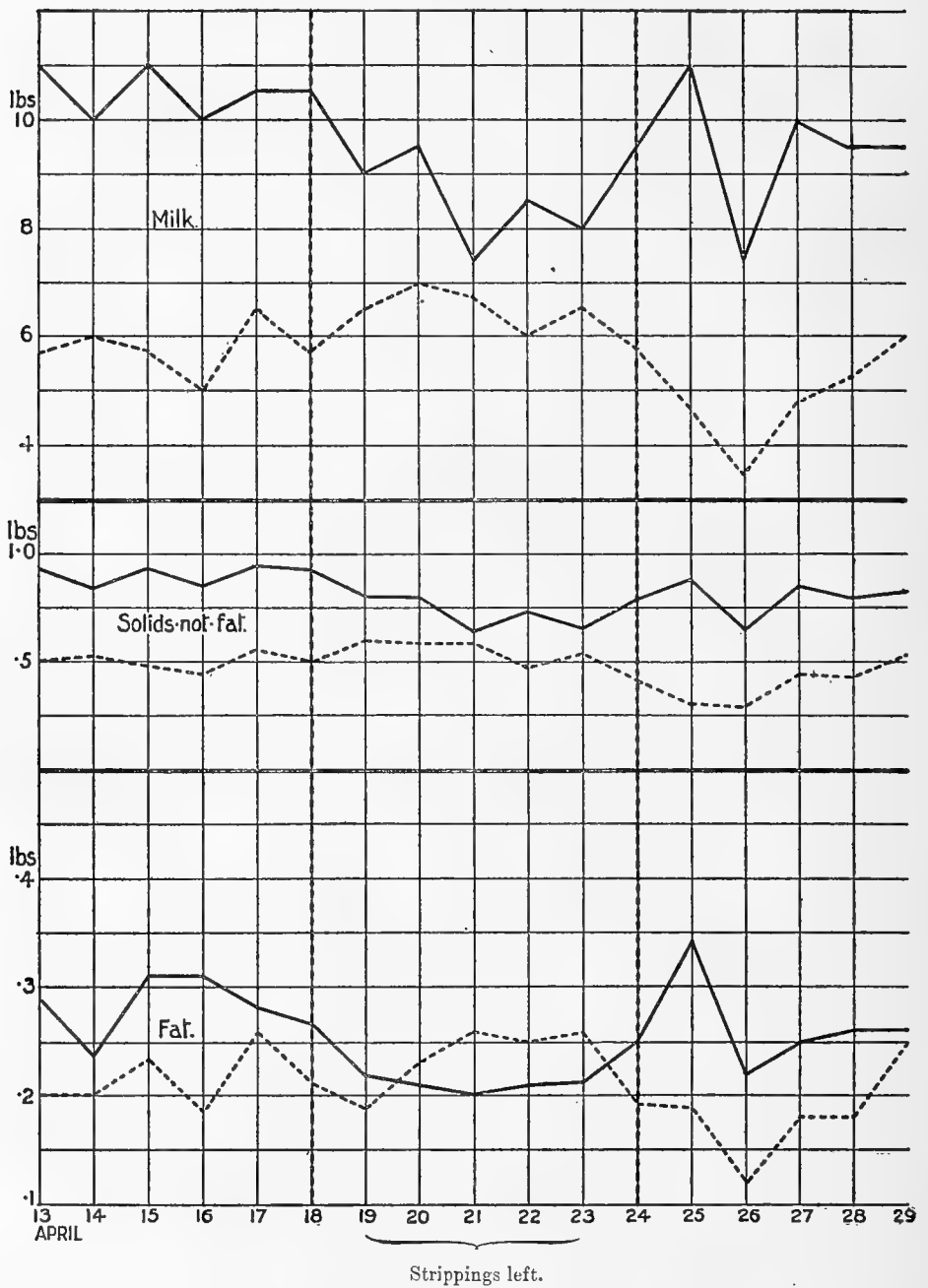


Diagram II.—Showing the Morning and Evening Yields of Milk, Solids-not-fat (total), and Fat (total) Cow 7.

Morning ——— Evening .....

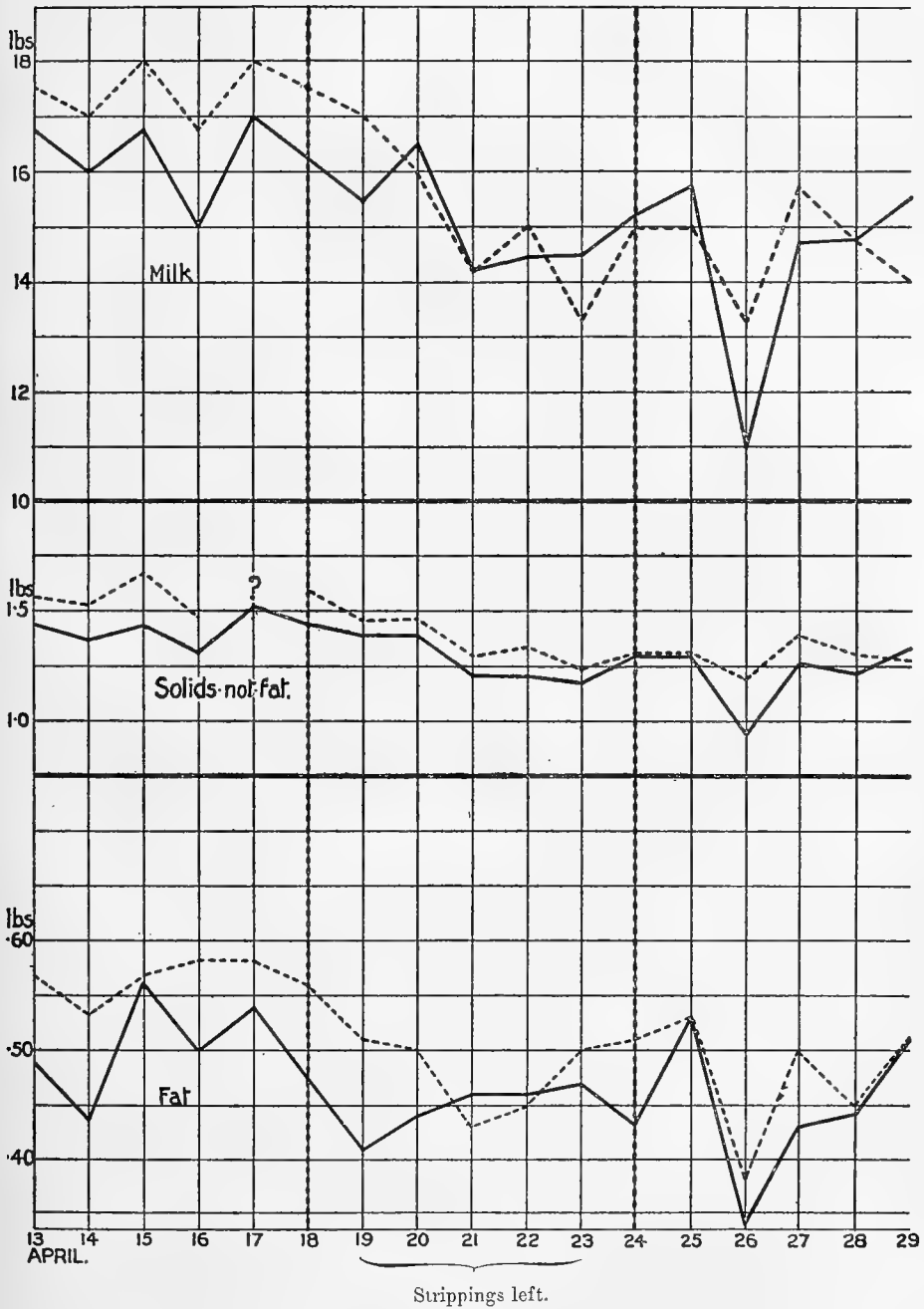


Diagram III.—Showing the Daily Yields of Milk, Solids-not-fat (total), and Fat (total).

Cow 19 ————— Cow 7 .....

The experiments of 1915 and 1916 suggested various explanations for the peculiarities in the proportion of butter-fat in the morning and evening milk; and a supplementary experiment was performed in 1918. Two cows were milked perfectly dry at each milking for six days; for the succeeding five days the strippings were left with them at each milking; and for another six days after the cows were again milked dry. Samples were taken, and the percentages of fat and solids determined in the usual way throughout the period. Diagram II represents the morning and evening yields for cow 7, diagram III the daily yield for cows 7 and 19 for the same time. From diagram III it is evident that leaving the strippings tends in two or three days to reduce the quantities of milk and of solids-not-fat; but the reduction is not so evident in the case of total fat. The effect on the morning and evening yields (diagram II) is to decrease the morning milk, solids-not-fat, and fat, and either to increase or leave unchanged the evening milk, solids-not-fat, and fat. This influence is more evident in the case of total fat than in the other constituents.

The strippings include the residue from the upper part of the gland ducts, and the immediate secretion of the alveolar cells. The experiment suggests that more fat remains in the same quantity of strippings after the morning than after the evening milking. When a cow is milked dry there remain in the alveolar cells substances which are either identical with the constituents of milk, or are milk-precursors, and, probably, the quantity of these materials is considerable. "The effect of an injection of pituitary extract is to cause the immediate secretion of the milk (stored in the gland) which would otherwise have been drawn off at the next milking. Thus by injecting after the morning milking, a large portion of the evening milk can be obtained at once. The conclusion from this is that the milk constituents are stored in the gland cells in the form of precursors; for it is difficult to imagine that these substances could be formed from the blood in the time, and in such definite quantities."<sup>1</sup> Assuming that the gland works more or less uniformly throughout the day, one concludes that these substances are being poured into the ducts continuously, the fats in suspension in the form of globules, and the solids-not-fat in solution. When the ducts are filled, back pressure on the alveolar cells is produced, and this acts in opposition to their secreting action. Because of the globular condition of the fat, it is more difficult for it to pass from the alveolar cells into the ducts against pressure than it is for the solids-not-fat and water; and, consequently, at the beginning of a milking there is a surplus store of fat globules not extruded

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<sup>1</sup> Hammond: Quarterly Journal of Experimental Physiology, vol. vi, p. 315.

from the alveolar cells. The longer the interval before milking the greater the store of fat in the cells; and, therefore, more fat remains in the udder after a milking succeeding a long interval than after a short one. In the case of the 1915 and 1916 experiments more fat remained in the udder after the morning milking (fifteen hours' interval) than after the evening (nine hours' interval). Assuming, as before, that the gland activity is more or less constant, the total fat produced in the evening is equal to the nine hours' secretion of fat plus the reserve left after the previous morning milking; and that produced in the morning is equal to the fifteen hours' secretion added to the reserve from the previous evening; but as the morning reserve is greater than the evening one, the evening total fat is approximately equal to the morning total fat, notwithstanding the shorter interval. The storage of fat in the alveolar cells also explains the increasing richness in fat of the milk during the process of milking. As the already manufactured milk with its low percentage of fat is drawn away, the back pressure on the gland cells is decreased and the fat is liberated rapidly, thereby increasing the percentage of fat in the milk right up to the "strippings," in which it is greatest.

Injecting pituitrin into the blood of a milch cow produces a large increase in the milk, and a proportionately greater increase in the total fat yielded at the next milking. Hammond has shown that by injecting pituitrin into a goat and milking again very shortly after a milking has taken place, it is possible to get away a considerable quantity of the milk and butter-fat which would come normally at the next milking. When injection and subsequent milking are performed after the afternoon milking, the deficiency at the next milking is less than when the operation is performed in the morning. Furthermore, the milk yielded as a result of injection does not increase in fat percentage from the fore milk to the "strippings." From these facts Hammond concluded that milk-precursors are stored in the alveolar cells. It is possible to go further and state that the proportion of fat stored is greater than that of the other constituents of the milk.

During the process of milking the manipulation of the teats produces a reflex action the result of which is an increased secretion from the gland cells similar to that produced by the action of pituitrin. The extent of the reflex no doubt depends on the milker, and this agrees with the well-known fact that a quick, thorough milker can obtain more milk from a cow than a slow and careless one.

[TABLE.

TABLE 1.—COW 23.

RETURNS FROM THE INDIVIDUAL QUARTERS (TEATS) OF THE UDDER.

*Order of Milking from Left to Right.*

| Date.        | Milk Sample. | Per cent. Fat. | Per cent. Solids. | Per cent. Solids-not-Fat. | Per cent. Fat. | Per cent. Solids. | Per cent. Solids-not-Fat. | Per cent. Fat. | Per cent. Solids. | Per cent. Solids-not-Fat. | Per cent. Fat. | Per cent. Solids. | Per cent. Solids-not-Fat. |
|--------------|--------------|----------------|-------------------|---------------------------|----------------|-------------------|---------------------------|----------------|-------------------|---------------------------|----------------|-------------------|---------------------------|
| 11 April, E. | —            | Fore Right.    |                   |                           | Fore Left.     |                   |                           | Hind Right.    |                   |                           | Hind Left.     |                   |                           |
|              | Fore,        | 2·8            | 11·65             | 8·85                      | 3·3            | 12·12             | 8·82                      | 3·5            | 12·6              | 8·80                      | 3·3            | 12·12             | 8·82                      |
|              | Middle,      | 3·9            | 12·6              | 8·71                      | 4·2            | —                 | —                         | 5·0            | 13·9              | 8·90                      | 4·3            | —                 | —                         |
|              | Last,        | 5·7            | 14·39             | 8·69                      | 6·3            | 14·6              | 8·30                      | 4·9            | 13·55             | 8·65                      | 5·5            | 14·01             | 8·51                      |
| 12 April, M. | —            | Fore Left.     |                   |                           | Fore Right.    |                   |                           | Hind Left.     |                   |                           | Hind Right.    |                   |                           |
|              | Fore,        | 1·0            | 10·6              | 9·60                      | 2·0            | 11·67             | 9·67                      | 1·5            | 10·94             | 9·44                      | 1·5            | 10·94             | 9·44                      |
|              | Middle,      | 2·9            | 12·22             | 9·32                      | 3·5            | 12·68             | 9·18                      | 4·2            | 13·13             | 8·93                      | 4·4            | 13·5              | 9·10                      |
|              | Last,        | 6·0            | 14·68             | 8·68                      | 5·4            | 14·32             | 8·92                      | 5·0            | 13·34             | 8·34                      | 4·8            | 13·72             | 8·92                      |
| 12 April, E. | —            | Hind Left.     |                   |                           | Hind Right.    |                   |                           | Fore Left.     |                   |                           | Fore Right.    |                   |                           |
|              | Fore,        | 2·3            | 11·6              | 9·30                      | 1·8            | 11·3              | 9·50                      | 2·8            | 12·5              | 9·70                      | 2·8            | 12·32             | 9·50                      |
|              | Middle,      | 3·3            | 12·5              | 9·20                      | 4·6            | 13·95             | 9·35                      | 4·2            | 13·47             | 9·27                      | 4·6            | 13·81             | 9·21                      |
|              | Last,        | 4·1            | 13·21             | 9·11                      | 5·2            | 14·29             | 9·09                      | 5·5            | 14·48             | 8·98                      | 6·3            | 15·1              | 8·80                      |
| 13 April, M. | —            | Hind Left.     |                   |                           | Hind Right.    |                   |                           | Fore Left.     |                   |                           | Fore Right.    |                   |                           |
|              | Fore,        | ·5             | 9·72              | 9·22                      | ·7             | 10·1              | 9·40                      | ·8             | 10·4              | 9·60                      | 1·2            | 10·7              | 9·50                      |
|              | Middle,      | 3·0            | 12·35             | 9·35                      | 3·4            | 12·7              | 9·30                      | 2·3            | 11·78             | 9·48                      | 3·0            | 12·34             | 9·34                      |
|              | Last,        | 3·5            | 12·68             | 9·18                      | 4·3            | 13·39             | 9·09                      | 3·3            | 12·59             | 9·29                      | 4·3            | 13·5              | 9·20                      |
| 14 April, M. | —            | Hind Left.     |                   |                           | Hind Right.    |                   |                           | Fore Left.     |                   |                           | Fore Right.    |                   |                           |
|              | Fore,        | 1·0            | 10·34             | 9·34                      | ·8             | 10·1              | 9·30                      | 1·0            | 10·33             | 9·33                      | 1·1            | 10·46             | 9·36                      |
|              | Middle,      | 3·5            | 12·88             | 9·38                      | 2·8            | 12·01             | 9·21                      | 2·8            | 12·2              | 9·40                      | 3·0            | 12·13             | 9·13                      |
|              | Last,        | 4·8            | 13·92             | 9·12                      | 4·3            | 13·2              | 8·90                      | 4·3            | 13·32             | 9·02                      | 3·4            | 12·12             | 8·72                      |
| 14 April, E. | —            | Hind Left.     |                   |                           | Hind Right.    |                   |                           | Fore Left.     |                   |                           | Fore Right.    |                   |                           |
|              | Fore,        | 2·8            | 11·6              | 8·00                      | 2·4            | 11·52             | 9·12                      | 3·1            | 12·38             | 9·28                      | 3·5            | 12·71             | 9·21                      |
|              | Middle,      | 4·7            | 13·89             | 9·19                      | 4·5            | 13·65             | 9·15                      | 3·8            | 13·09             | 9·29                      | 4·1            | 13·43             | 9·33                      |
|              | Last,        | 4·4            | 13·51             | 9·11                      | 4·6            | 13·78             | 9·18                      | 4·8            | 13·75             | 8·95                      | 3·8            | 12·8              | 9·00                      |
| 15 April, M. | —            | Fore Left.     |                   |                           | Fore Right.    |                   |                           | Hind Left.     |                   |                           | Hind Right.    |                   |                           |
|              | Fore,        | ·7             | 10·49             | 9·79                      | —              | —                 | —                         | ·9             | 10·58             | 9·68                      | ·9             | 10·72             | 9·82                      |
|              | Middle,      | 2·7            | 12·39             | 9·69                      | 3·2            | 12·82             | 9·62                      | 3·9            | 13·42             | 9·52                      | 4·2            | 13·79             | 9·59                      |
|              | Last,        | 6·0            | 15·14             | 9·14                      | 6·0            | 15·14             | 9·14                      | 4·3            | 13·35             | 9·05                      | 5·8            | 15·29             | 9·49                      |
| 15 April, E. | —            | Hind Left.     |                   |                           | Fore Right.    |                   |                           | Fore Left.     |                   |                           | Hind Right.    |                   |                           |
|              | Fore,        | 2·7            | 11·6              | 8·90                      | 3·6            | 12·7              | 9·10                      | 3·5            | 12·71             | 9·21                      | 3·9            | 12·92             | 9·02                      |
|              | Middle,      | 4·4            | 13·28             | 8·88                      | 4·7            | 13·77             | 9·07                      | 4·3            | 13·29             | 8·99                      | 4·3            | 13·29             | 8·99                      |
|              | Last,        | 5·0            | —                 | —                         | 5·6            | 14·48             | 8·88                      | 5·0            | 14·0              | 9·00                      | 8·0*           | —                 | —                         |

\* Small quantity

TABLE 1.—COW 23.

RETURNS FROM THE INDIVIDUAL QUARTERS (TEATS) OF THE UDDER.

*Order of Milking from Left to Right.*

| Date.        | Milk Sample. | Per cent. Fat. | Per cent. Solids. | Per cent. Solids-not-Fat. | Per cent. Fat. | Per cent. Solids. | Per cent. Solids-not-Fat. | Per cent. Fat. | Per cent. Solids. | Per cent. Solids-not-Fat. | Per cent. Fat. | Per cent. Solids. | Per cent. Solids-not-Fat. |
|--------------|--------------|----------------|-------------------|---------------------------|----------------|-------------------|---------------------------|----------------|-------------------|---------------------------|----------------|-------------------|---------------------------|
| 16 April, M. | —            | Hind Left.     |                   |                           | Fore Right.    |                   |                           | Fore Left.     |                   |                           | Hind Right.    |                   |                           |
|              | Fore,        | ·7             | 9·68              | 8·98                      | ·8             | 10·22             | 9·42                      | 1·0            | 10·65             | 9·65                      | 1·0            | 10·47             | 9·47                      |
|              | Middle,      | 3·5            | 12·73             | 9·23                      | 3·5            | 12·87             | 9·37                      | 2·6            | 11·97             | 9·37                      | 3·9            | 13·22             | 9·32                      |
|              | Last,        | 4·0            | 12·97             | 8·77                      | 5·0            | 14·03             | 9·03                      | 5·5            | 14·4              | 8·90                      | 4·0            | 12·48             | 8·48                      |
| 16 April, E. | —            | Hind Right.    |                   |                           | Fore Right.    |                   |                           | Fore Left.     |                   |                           | Hind Left.     |                   |                           |
|              | Fore,        | 2·7            | 12·2              | 9·50                      | 3·5            | 13·05             | 9·55                      | 3·3            | 12·8              | 9·50                      | 3·7            | 13·29             | 9·59                      |
|              | Middle,      | 4·2            | 13·7              | 9·50                      | 4·4            | 13·82             | 9·42                      | 4·4            | 13·82             | 9·42                      | 4·7            | 13·93             | 9·23                      |
|              | Last,        | 4·7            | 13·92             | 9·22                      | 5·5            | 14·78             | 9·28                      | 5·2            | 14·52             | 9·32                      | 4·0            | 13·1              | 9·10                      |
| 17 April, M. | —            | Hind Right.    |                   |                           | Fore Right.    |                   |                           | Fore Left.     |                   |                           | Hind Left.     |                   |                           |
|              | Fore,        | ·6             | 10·25             | 9·65                      | ·6             | 10·38             | 9·78                      | 1·0            | 10·73             | 9·73                      | 1·4            | 11·2              | 9·80                      |
|              | Middle,      | 2·8            | 12·62             | 9·83                      | 2·6            | 12·2              | 9·6                       | 1·8            | 11·7              | 9·90                      | —              | —                 | —                         |
|              | Last,        | 4·1            | 13·31             | 9·21                      | 3·1            | 12·55             | 9·45                      | 3·1            | 12·68             | 9·58                      | 3·3            | 12·49             | 9·19                      |
| 17 April, E. | —            | Fore Right.    |                   |                           | Fore Left.     |                   |                           | Hind Right.    |                   |                           | Hind Left.     |                   |                           |
|              | Fore,        | 1·7            | 11·5              | 9·80                      | 2·5            | 12·45             | 9·95                      | 2·9            | 12·94             | 10·04                     | 2·9            | 12·8              | 9·90                      |
|              | Middle,      | 4·2            | 14·19             | 9·99                      | 4·1            | 13·90             | 9·80                      | 4·9            | 14·55             | 9·65                      | 5·0            | 15·3              | 10·30                     |
|              | Last,        | 5·0            | 14·67             | 9·67                      | 6·5            | 15·82             | 9·32                      | 5·1            | 14·55             | 9·45                      | 4·5            | 13·57             | 9·07                      |
| 18 April, M. | —            | Fore Right.    |                   |                           | Fore Left.     |                   |                           | Hind Right.    |                   |                           | Hind Left.     |                   |                           |
|              | Fore,        | ·7             | 10·6              | 9·90                      | 1·5            | 11·56             | 10·06                     | 1·3            | 11·31             | 10·01                     | 1·7            | 11·51             | 9·81                      |
|              | Middle,      | 3·5            | 13·44             | 9·94                      | 2·9            | 12·86             | 9·96                      | 3·5            | 13·3              | 9·80                      | 3·4            | 13·01             | 9·61                      |
|              | Last,        | 5·3            | 14·9              | 9·60                      | 6·1            | 15·47             | 9·37                      | 4·2            | 13·7              | 9·50                      | 4·0            | 13·2              | 9·20                      |
| 18 April, E. | —            | Fore Left.     |                   |                           | Fore Right.    |                   |                           | Hind Left.     |                   |                           | Hind Right.    |                   |                           |
|              | Fore,        | 3·3            | 12·93             | 9·63                      | 2·9            | 12·62             | 9·72                      | 3·0            | 12·88             | 9·88                      | 3·3            | 13·24             | 9·94                      |
|              | Middle,      | 3·9            | 12·98             | 9·08                      | 4·1            | 14·2              | 10·10                     | 3·8            | 13·4              | 9·60                      | 3·9            | 13·82             | 9·92                      |
|              | Last,        | 5·2            | 14·9              | 9·70                      | 4·5            | 14·25             | 9·75                      | 3·8            | 13·1              | 9·30                      | 4·2            | 13·90             | 9·70                      |
| 20 April, M. | —            | Fore Left.     |                   |                           | Fore Right.    |                   |                           | Hind Left.     |                   |                           | Hind Right.    |                   |                           |
|              | Fore,        | ·7             | 10·45             | 9·75                      | ·6             | 10·6              | 10·00                     | ·8             | 10·27             | 9·47                      | ·7             | 10·45             | 9·75                      |
|              | Middle,      | 3·1            | 13·03             | 9·93                      | 3·4            | 13·02             | 9·62                      | 3·6            | 13·1              | 9·50                      | 3·4            | 13·15             | 9·75                      |
|              | Last,        | 6·4            | 15·68             | 9·28                      | 7·4            | 16·5              | 9·10                      | 6·0            | 14·95             | 8·95                      | 6·8            | 16·05             | 9·25                      |
| 20 April, E. | —            | Hind Right.    |                   |                           | Hind Left.     |                   |                           | Fore Right.    |                   |                           | Fore Left.     |                   |                           |
|              | Fore,        | 3·0            | 12·37             | 9·37                      | 2·9            | 12·24             | 9·34                      | 4·3            | 13·52             | 9·22                      | 4·0            | 13·2              | 9·20                      |
|              | Middle,      | 6·1            | 15·3              | 9·20                      | 6·3            | 15·3              | 9·00                      | 7·0            | 16·13             | 9·13                      | 6·3            | 15·58             | 9·28                      |
|              | Last,        | 6·1            | 15·07             | 8·97                      | 5·4            | 14·1              | 8·70                      | 7·0            | 15·9              | 8·90                      | 7·0            | 15·9              | 8·70                      |

TABLE 1.—COW 15.

RETURNS FROM THE INDIVIDUAL QUARTERS (TEATS) OF THE UDDER.

*Order of Milking from Left to Right.*

| Date.        | Milk Sample. | Per cent. Fat. | Per cent. Solids. | Per cent. Solids-not-Fat. | Per cent. Fat. | Per cent. Solids. | Per cent. Solids-not-Fat. | Per cent. Fat. | Per cent. Solids. | Per cent. Solids-not-Fat. | Per cent. Fat. | Per cent. Solids. | Per cent. Solids-not-Fat. |
|--------------|--------------|----------------|-------------------|---------------------------|----------------|-------------------|---------------------------|----------------|-------------------|---------------------------|----------------|-------------------|---------------------------|
| 24 April, E. | —            | Hind Left.     |                   |                           | Hind Right.    |                   |                           | Fore Left.     |                   |                           | Fore Right.    |                   |                           |
|              | Fore,        | 2·3            | 11·25             | 8·95                      | 1·5            | 10·7              | 9·2                       | 2·8            | 12                | 9·40                      | 3·3            | 12·6              | 9·30                      |
|              | Middle,      | 4·1            | 13·29             | 9·19                      | 3·5            | 12·85             | 9·35                      | 4·7            | 13·75             | 9·05                      | 4·1            | 13·3              | 9·20                      |
|              | Last,        | 9·0            | —                 | —                         | 8·0            | 16·75             | 8·75                      | 7·8            | 17·1              | 9·30                      | 5·8            | —                 | —                         |
| 25 April, M. | —            | Hind Left.     |                   |                           | Hind Right.    |                   |                           | Fore Left.     |                   |                           | Fore Right.    |                   |                           |
|              | Fore,        | 1·1            | 10·0              | 8·90                      | 1·0            | 10·03             | 9·03                      | 1·2            | 10·12             | 8·92                      | 1·3            | 10·4              | 9·10                      |
|              | Middle,      | 3·0            | 11·8              | 8·80                      | 3·2            | 12·02             | 8·82                      | 2·1            | 10·7              | 8·60                      | 2·3            | 10·95             | 8·65                      |
|              | Last,        | 3·7            | 12·12             | 8·42                      | 5·2            | 13·93             | 8·73                      | 3·8            | 12·5              | 8·70                      | 4·6            | 13·33             | 8·73                      |
| 25 April, E. | —            | Hind Right.    |                   |                           | Hind Left.     |                   |                           | Fore Right.    |                   |                           | Fore Left.     |                   |                           |
|              | Fore,        | 2·8            | 11·8              | 9·00                      | 3·1            | 12·3              | 9·20                      | 4·1            | 13·23             | 9·13                      | 3·2            | 12·30             | 9·10                      |
|              | Middle,      | 4·3            | 13·36             | 9·06                      | 4·0            | 13·0              | 9·00                      | 4·8            | 13·82             | 9·02                      | 4·7            | 13·58             | 8·88                      |
|              | Last,        | 5·7            | 14·67             | 8·97                      | 5·3            | 14·19             | 8·89                      | 6·3            | 15·0              | 8·70                      | 6·2            | 15·02             | 8·82                      |
| 26 April, E. | —            | Fore Right.    |                   |                           | Fore Left.     |                   |                           | Hind Right.    |                   |                           | Hind Left.     |                   |                           |
|              | Fore,        | 1·8            | 10·75             | 8·95                      | 2·0            | 10·87             | 8·87                      | 2·2            | 11·23             | 9·03                      | 2·4            | 11·35             | 8·95                      |
|              | Middle,      | 4·9            | 13·71             | 8·81                      | 5·8            | 14·56             | 8·76                      | 4·9            | 13·72             | 8·82                      | 4·7            | 13·49             | 8·79                      |
|              | Last,        | 7·3            | 15·98             | 8·68                      | 7·2            | 15·72             | 8·52                      | 5·6            | 14·3              | 8·70                      | 6·5            | 15·12             | 8·62                      |
| 29 April, E. | —            | Fore Right.    |                   |                           | Hind Left.     |                   |                           | Hind Right.    |                   |                           | Fore Left.     |                   |                           |
|              | Fore,        | 2·3            | 11·52             | 9·22                      | 2·8            | 12·12             | 9·32                      | 3·3            | 12·6              | 9·30                      | 3·0            | 12·37             | 9·37                      |
|              | Middle,      | 4·4            | 13·65             | 9·25                      | 4·7            | 13·63             | 8·93                      | 4·2            | 13·4              | 9·20                      | 4·7            | 13·77             | 9·07                      |
|              | Last,        | 5·5            | 14·72             | 9·22                      | 6·0            | 15·10             | 9·08                      | 5·2            | 14·23             | 9·03                      | 6·8            | —                 | —                         |

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THE SYSTEM n-BUTYL ALCOHOL-ACETONE-  
WATER.

JUN 15 1920

BY

JOSEPH REILLY, M.A., D.Sc., F.R.C.Sc.I.,

AND

EDGAR W. RALPH.

[COMMUNICATED BY PROFESSOR SYDNEY YOUNG, D.Sc., F.R.S.]

[*Authors alone are responsible for all opinions expressed in their Communications.*]

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## XLIII.

## THE SYSTEM n-BUTYL ALCOHOL—ACETONE—WATER.

BY JOSEPH REILLY, M.A., D.Sc., F.R.C.Sc.I.,

AND

EDGAR W. RALPH.

(COMMUNICATED BY PROFESSOR SYDNEY YOUNG, D.Sc., F.R.S.)

Read APRIL 15. Published JUNE 4, 1919.

THE production of a mixture of acetone and n-butyl alcohol on an industrial scale by a fermentation process has rendered desirable a knowledge of the system n-butyl alcohol—acetone—water. The literature fails to reveal any previous work on this ternary mixture, although several density determinations for both acetone and n-butyl alcohol have been recorded.

## ACETONE.

| Density.                               | Density calculated to $\frac{20^\circ}{4^\circ}$ | Observer.  |
|--|--|--|
| 0.79945 - $\frac{13.9^\circ}{0^\circ}$ | 0.7926   | Kopp (Annalen, 1847, <b>64</b> , 215),                           |
| 0.81858 - $\frac{0^\circ}{4^\circ}$    | 0.7962   | Thorpe (Trans. Chem. Soc., 1880, <b>37</b> , 212).               |
| 0.8179 - $0^\circ$                     | 0.7954   | Pritram (Monatsch, 1881, <b>2</b> , 675).                        |
| 0.7920 - $19.8^\circ$                  | 0.7918   | Zander (Annalen, 1882, <b>214</b> , 173).                        |
| 0.78669 - $\frac{25^\circ}{25^\circ}$  | 0.7901   | Perkins (Trans. Chem. Soc., 1884, <b>45</b> , 478).              |
| 0.79197 - $\frac{20^\circ}{4^\circ}$   | 0.79197  | McElroy (J. Am. Chem. Soc., 1894, <b>16</b> , 618).              |
| 0.786988 - $\frac{25^\circ}{25^\circ}$ | 0.7903   | Squibb (J. Am. Chem. Soc., 1895, <b>17</b> , 187).               |
| 0.79705 - $\frac{15^\circ}{4^\circ}$   | 0.7914   | Saposchnikow (J. Russ. Phys. Chem. Soc., 1896, <b>28</b> , 229). |

## n-BUTYL ALCOHOL.

|                                      |         |  |
|--------------------------------------|---------|--|
| 0.8108 - $20^\circ$                  | 0.8107  | Lieben & Rossi (Annalen, 1871, <b>158</b> , 137).              |
| 0.8099 - $\frac{20^\circ}{4^\circ}$  | 0.8099  | Bruhl (Annalen, 1880, <b>203</b> , 16).                        |
| 0.8233 - $0^\circ$                   | 0.8095  | Zander (Annalen, 1884, <b>224</b> , 80).                       |
| 0.80978 - $\frac{20^\circ}{4^\circ}$ | 0.80978 | Zoubow (J. Russ. Phys. Chem. Soc., 1898, <b>30</b> , 926).     |
| 0.82393 - $\frac{0^\circ}{4^\circ}$  | 0.8103  | Atkins & Wallace (Trans. Chem. Soc., 1913, <b>103</b> , 1469). |

As doubt exists with regard to the purity of the material employed by some of the earlier workers, much attention has been given to the preparation of a pure material for density determination. The choice of dehydrating agents in removing the last traces of water was limited to substances which did not cause any condensation of the acetone to more complex compounds. Recovered acetone obtained from the manufacture of cordite, and containing only small traces of aldehydic or ketonic compounds other than acetone, was converted into the bisulphite compound, from which the more soluble impurities were removed by washing with small quantities of water. Decomposition of this addition-compound by means of sodium carbonate solution followed by a fractional distillation, gave acetone containing some water and a small amount of carbon dioxide in solution. The acidity was removed by shaking with dilute aqueous potassium hydroxide. The acetone obtained after another fractional distillation was allowed to stand over anhydrous calcium chloride for several days and then re-distilled, the fraction 55-57° C. being collected. This portion was again dehydrated with anhydrous calcium chloride and fractionated, using an eight-section Young "evaporator" still-head, and collecting between 56-56.5° C. This operation was repeated three times, in the last fractionation the portion boiling at 56.3° C/760 mm. being collected. The pure acetone had a specific gravity of  $0.79091 \frac{20^\circ}{4^\circ}$ , which, corrected for buoyancy, was 0.79123. Submission to a further purification process did not alter this boiling point or the density. The acetone was tested and shown to be free from all traces of carbon dioxide, volatile or fixed acids, and alkalinity. There were no compounds of an alcoholic nature present. The absence of readily oxidisable impurity was shown by the addition of a small quantity of dilute potassium permanganate solution when the characteristic red colour obtained persisted for several days.

Pure n-butyl alcohol was obtained from the crude fermentation alcohol by dehydration over anhydrous potassium carbonate followed by repeated fractionation. The fraction boiling between 117-118° C. was heated under reflux for several hours with pure freshly-burnt calcium oxide. The dried alcohol was distilled, the fraction boiling at 117.6° C. being collected. The pure n-butyl alcohol boiled at 117.6° C/763 mm., and had a specific gravity of  $0.80953 \frac{20^\circ}{4^\circ}$  which, when corrected to vacuum, was 0.80974.

*Determination of densities of mixtures.*

The densities of the pure liquids and of the mixtures were obtained by means of Perkin's modification of a Sprengel tube in which a bulb had been blown above the mark to permit of expansion of the liquid (Trans. Chem. Soc.,

1884, 45, 444). Densities were obtained at 20° C. and then calculated to  $\frac{20^\circ}{4^\circ}$ . Only in the case of pure liquids were the densities reduced to vacuum. The method adopted was to correct to vacuum each of the weighings (cf. Reilly and Rae, *Science Progress*, 1918, 47, 434). The densities of the air at the times of the three weighings were found by interpolation from the table given by Wade and Merriman (*Trans. Chem. Soc.*, 1912, 103, 2429). In all the densities recorded, the method of double weighing was adopted. The determinations were usually carried out in duplicate, the average variation in the results being only two or three units in the fifth place.

Several quantities of pure n-butyl alcohol were prepared during the period of this investigation, and the following densities were obtained with separate freshly-made portions:—0.81097, 0.81099, 0.81096 at  $\frac{20^\circ}{20^\circ}$ . The densities agree within the limits of experimental error.

#### *Preparation of mixtures.*

The samples of both n-butyl alcohol and acetone set aside for the preparation of mixtures were kept in a large desiccator over anhydrous calcium chloride. Distilled water, which had stood for several days in a partial vacuum to remove dissolved air, was used in making up the mixtures. All mixtures were made with weighed quantities of the components, the calculated quantities being run into the weighing flask from burettes fitted with calcium chloride tubes to prevent the possible addition of moisture to the acetone or alcohol.

In preparing tables of densities of acetone, alcohol, and water mixtures, the following procedure was adopted:—To a mixture of pure acetone and water in known proportions, a definite measured quantity of n-butyl alcohol was added. By varying the proportions of any of the constituents a series of mixtures was obtained. For the purpose, however, of obtaining a homogeneous mixture, the proportions were so arranged that there was no separation into two layers. The densities of these mixtures are given in table I, and a series of curves was plotted (fig. 1) by interpolation from these results. These results were also plotted with triangular co-ordinates (fig. 2) from which for any observed densities direct readings of possible mixtures of n-butyl alcohol, acetone, and water can be obtained. A knowledge of the density alone of a mixture of n-butyl alcohol–acetone–water cannot be used to determine its constitution. When, however, the proportion of one of the constituents is known, the composition of the mixture can be settled by a reference to the densities plotted in fig. 2.

TABLE I. Mixtures of n-Butyl Alcohol, Acetone and Water.

| Acetone. | Water. | n-Butyl Alcohol. | Density $\frac{20^\circ}{4^\circ}$ |
|----------|--------|------------------|------------------------------------|
| 9.93     | 90.07  | —                | 0.98588                            |
| 9.44     | 85.63  | 4.93             | 0.97903                            |
| 8.92     | 80.95  | 10.13            | 0.97087                            |
| 19.31    | 80.69  | —                | 0.97307                            |
| 18.33    | 76.61  | 5.06             | 0.96668                            |
| 17.36    | 72.54  | 10.10            | 0.95837                            |
| 16.38    | 68.44  | 15.18            | 0.94947                            |
| 15.40    | 64.36  | 20.24            | 0.93976                            |
| 29.62    | 70.38  | —                | 0.95779                            |
| 26.59    | 63.19  | 10.22            | 0.94255                            |
| 24.01    | 57.05  | 18.94            | 0.92763                            |
| 21.12    | 50.13  | 28.70            | 0.91155                            |
| 37.49    | 62.51  | —                | 0.94499                            |
| 33.69    | 56.17  | 10.14            | 0.93079                            |
| 29.86    | 49.80  | 20.34            | 0.91421                            |
| 26.11    | 43.53  | 30.36            | 0.89916                            |
| 22.37    | 37.30  | 40.33            | 0.88498                            |
| 50.03    | 49.97  | —                | 0.92057                            |
| 45.01    | 44.95  | 10.04            | 0.90754                            |
| 39.84    | 39.79  | 20.37            | 0.89434                            |
| 35.06    | 35.01  | 29.93            | 0.88264                            |
| 30.02    | 29.98  | 40.00            | 0.87080                            |
| 28.23    | 22.20  | 49.57            | 0.86012                            |
| 57.46    | 42.54  | —                | 0.90469                            |
| 51.53    | 38.15  | 10.32            | 0.89338                            |
| 45.85    | 33.95  | 20.20            | 0.88211                            |
| 40.06    | 29.68  | 30.26            | 0.87153                            |
| 34.41    | 25.46  | 40.13            | 0.86157                            |
| 22.92    | 16.95  | 60.13            | 0.84291                            |
| 71.10    | 28.90  | —                | 0.87219                            |
| 63.56    | 25.83  | 10.61            | 0.86467                            |
| 56.80    | 23.09  | 20.11            | 0.85980                            |
| 49.89    | 20.22  | 29.89            | 0.85059                            |
| 42.60    | 17.31  | 40.09            | 0.84366                            |
| 35.50    | 14.43  | 50.07            | 0.83741                            |
| 79.92    | 20.08  | —                | 0.85020                            |
| 63.81    | 16.02  | 20.17            | 0.84026                            |
| 47.51    | 12.19  | 40.30            | 0.83107                            |
| 31.95    | 8.02   | 60.03            | 0.82300                            |
| 15.97    | 4.01   | 80.02            | 0.81559                            |
| 89.58    | 10.42  | —                | 0.82222                            |
| 80.55    | 9.37   | 10.08            | 0.82045                            |
| 71.75    | 8.35   | 19.90            | 0.81880                            |
| 62.72    | 7.30   | 29.98            | 0.81705                            |
| 54.11    | 6.30   | 39.59            | 0.81559                            |
| 44.81    | 5.21   | 49.98            | 0.81423                            |
| 35.85    | 4.17   | 59.98            | 0.81321                            |
| 18.01    | 2.09   | 79.90            | 0.81111                            |
| 95.10    | 4.90   | —                | 0.80690                            |
| 30.86    | —      | 69.14            | 0.80360                            |
| 50.00    | —      | 50.00            | 0.79976                            |
| 70.47    | —      | 29.53            | 0.79637                            |





The methods available for the estimation of the water are limited to the use of a reagent which reacts or combines with the water alone without action on the other two constituents. Such a reagent as calcium carbide or an anhydrous salt might be used; a method involving the use of these reagents has been worked out for the mixture under investigation, but is not described in this paper. A much simpler and more accurate procedure is to estimate the acetone by one of the methods available after suitably diluting with water. Of these, a modification of the method suggested

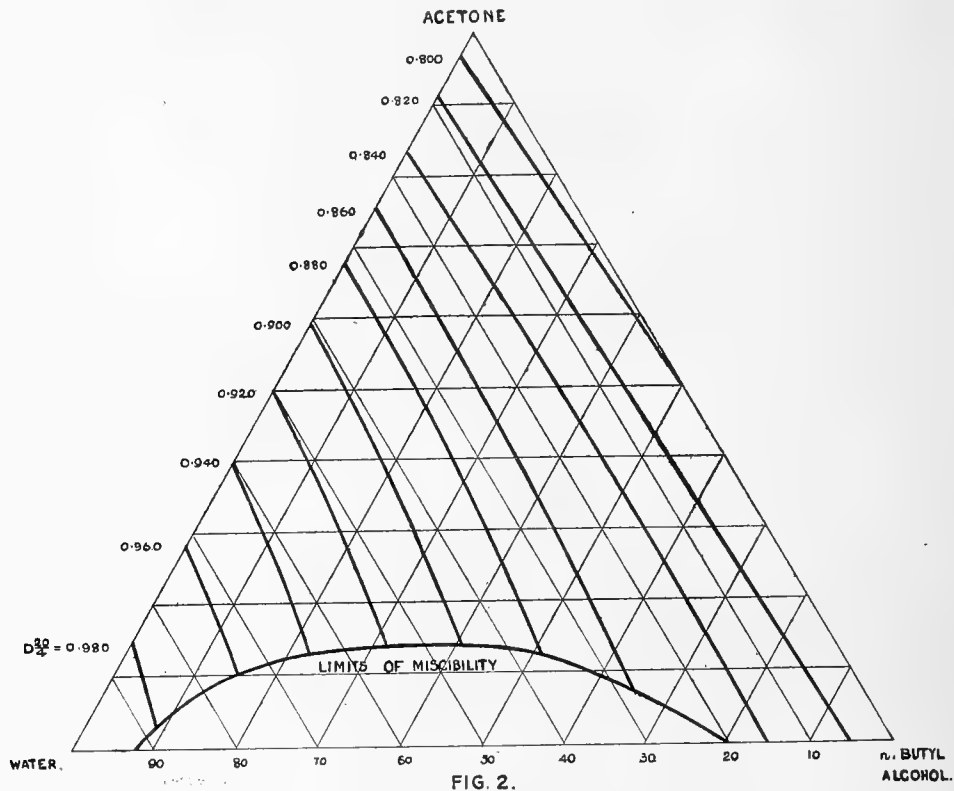


FIG. 2.

by Messinger (Ber. 1888, **21**, 3366), or by Denige (Comp. rend. 1898, **127**, 963), is convenient, and gives good results. The estimation of the n-butyl alcohol requires a longer time, and is not so reliable. Although the estimation of n-butyl alcohol alone can be rapidly carried out by a method involving the use of an acyl anhydride [as that suggested by Verley and Bolsing for hydroxyl estimation (Ber. 1901, **34**, 3354)], complications arise when the alcohol is mixed with other substances. The presence of water, especially in any appreciable quantity, is objectionable. It is probable that a large amount of water prevents the esterification from readily proceeding to completion. A method which gives satisfactory results has been devised

involving extraction with xylene. It was found, however, using the method of Verley and Bolsing, that a longer period of heating is required before the alcohol is completely esterified if an indifferent solvent be present. In order to aid the extraction of the alcohol, and to reduce the presence of the water to a minimum, the addition of a substance such as anhydrous sodium sulphate is advantageous.

To a known weight of the "n-butyl alcohol, acetone, and water" mixture anhydrous sodium sulphate was added in proportion to the water present (approximately estimated from the density), and the mixture extracted several times with xylene. The hydrocarbon extract was made up to a known volume. A measured amount was heated gently on a sandbath, with an excess of a pyridine solution of acetic anhydride, contained in a large flask fitted with a reflux condenser. Two hours' heating is usually sufficient to complete the esterification. The excess of acetic anhydride remaining was estimated in the usual way, and the n-butyl alcohol content ascertained.

An investigation of the boiling-point of mixtures of these components has been carried out, and it is found that, with the aid of this additional physical constant, it is possible to determine quickly the composition of mixtures to a fair degree of accuracy without any chemical analysis. Details of this work will be given later.

*Investigation of miscibility limits of the mixture.*

The limits of miscibility of the components of the mixtures of acetone, n-butyl alcohol, and water have also been determined. Acetone and water are miscible in all proportions, as also are acetone and n-butyl alcohol. Water and n-butyl alcohol are only partially miscible, and it was necessary in the first place to determine the miscibility limits of these at 20° C., and then to ascertain the effects of the addition of acetone to two-layer mixtures of the alcohol and water.

The miscibility limits of n-butyl alcohol and water were determined in the following manner. A saturated solution of n-butyl alcohol in water was prepared as follows:—A quantity of n-butyl alcohol was mixed with an excess of water in a stoppered separating funnel. This was immersed in a thermostat at 20° C. for several hours, and was frequently shaken. When equilibrium had been attained, portions of the two layers were removed for density determinations.

From extrapolation on a previously prepared curve of densities of solutions of n-butyl alcohol in water at 20° C., the amount of n-butyl alcohol present in a saturated solution was found to be 7.9 grams to 100 grams of mixture. A n-butyl alcohol-water mixture was therefore prepared containing this amount

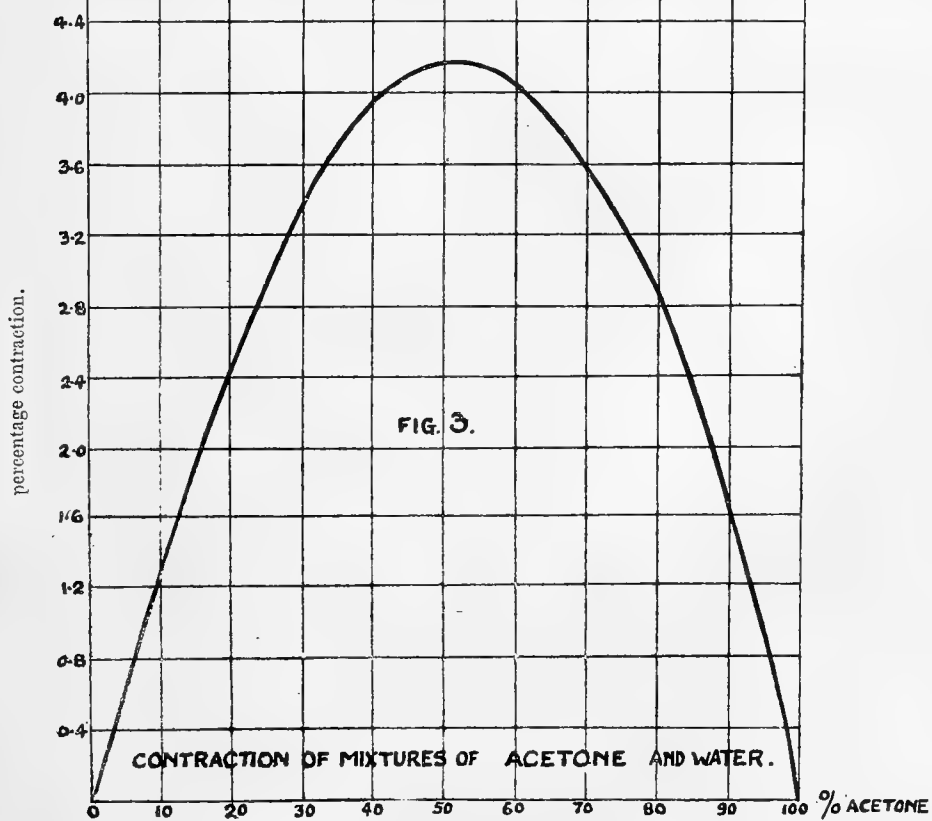
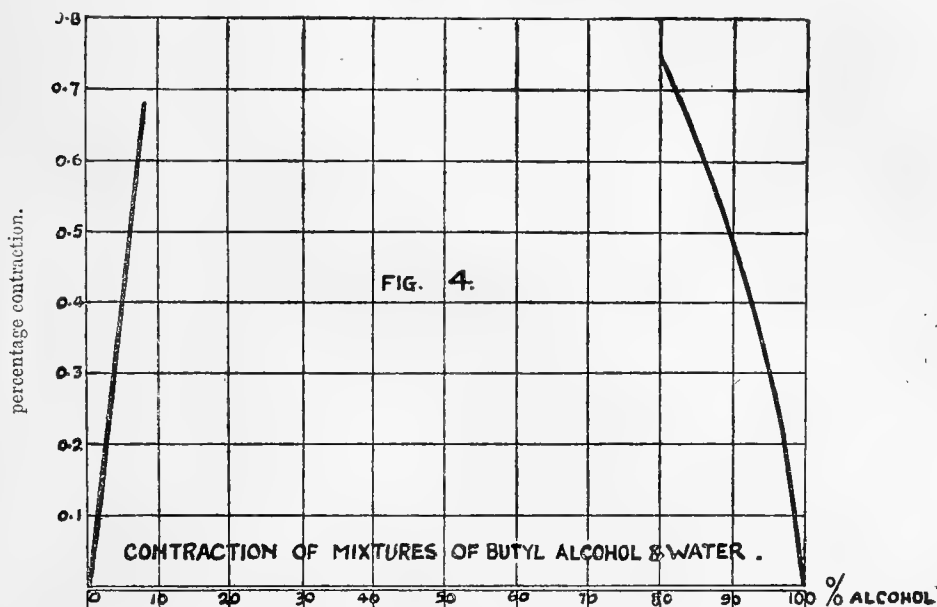
of n-butyl alcohol. It was found to be slightly cloudy, but on raising the temperature to a very small extent, a clear solution was obtained, a result which confirms the above value for the solubility. Similarly the maximum solubility of water in n-butyl alcohol at 20° C. was found to be 20 grams of water in 100 grams of the mixture.

As a further check upon these figures a saturated solution of water in n-butyl alcohol was taken and a small known weight of the alcohol added. The specific gravity of this new solution was found, and, from a graph of densities, the amount of alcohol present was determined. From the known weight of n-butyl alcohol added the original weight of alcohol was calculated and consequently the percentage weight of water. This method gave a result of 20.03 per cent. as compared with 20.06 by extrapolation of specific gravity of saturated solution. In this way the limits of the isotherm for 20° C. were obtained. Other points on the binodal or boundary curve shown in fig. 2 were found by an experimental method described below.

A mixture containing a slight excess of n-butyl alcohol over saturation was taken in a long-necked flask of 50 c.c. capacity, fitted with a burette having a long delivery tube reaching almost to the level of the liquid. The flask was immersed in a thermostat, regulated to 20° C.  $\pm$  .005° and acetone run in drop by drop with frequent shaking until the cloudy mixture just became clear on standing. From the increased weight the relative proportions of n-butyl alcohol, acetone, and water were calculated. From a series of these determinations (table II), the boundary curve was plotted both by the composition and also by the density of the mixture. It will be noted that only a comparatively small percentage of acetone (13.4 per cent.) is needed to make n-butyl alcohol and water miscible in all proportions at 20° C.

TABLE II. Saturated Solutions of Acetone, n-Butyl Alcohol, and Water.

| n-Butyl Alcohol. | Acetone. | Water. | $D \frac{20^\circ}{4^\circ}$ |
|------------------|----------|--------|------------------------------|
| 7.90             | —        | 92.10  | .9869                        |
| 12.00            | 9.26     | 78.74  | .9670                        |
| 18.64            | 11.62    | 69.74  | .9484                        |
| 24.68            | 12.65    | 62.67  | .934                         |
| 28.15            | 12.95    | 58.90  | .9260                        |
| 36.91            | 13.42    | 49.67  | .9071                        |
| 47.02            | 13.10    | 39.88  | .8874                        |
| 53.86            | 11.65    | 34.49  | .8764                        |
| 63.68            | 8.28     | 28.04  | .8633                        |
| 79.94            | —        | 20.06  | .8477                        |



## Contraction on mixing.

From the density determinations of acetone-water mixtures and n-butyl alcohol-water mixtures, the percentage of contraction on mixing has been calculated in the following way:—

Using the formula

$$\frac{W_1 + W_2}{D} = \frac{W_1}{D_1} + \frac{W_2}{D_2}$$

(in which  $W_1$  and  $W_2$  represent the percentage composition by weight of the two components, and  $D$ ,  $D_1$  and  $D_2$  are respectively the densities of the mixture and the separate components), and neglecting contraction, the calculated density was obtained. Then from the observed and calculated densities the volume of one gram was calculated. The difference between the observed and calculated volumes of a gram, expressed as a percentage of the latter, is given as the contraction. Tables III and IV show the values so obtained, and curves plotted from them are given in figs. 3 and 4. It will be noticed that the curve of contractions for acetone-water mixtures is very regular, approximating to a straight line for mixtures containing up to 30 per cent. of acetone. The maximum contraction is reached when there is about 52–54 per cent. acetone present. The descending curve is also very regular. These results agree substantially with the contractions observed by McElroy (*loc. cit.*) on mixing acetone with water (allowing for the fact that he used slightly denser acetone). He states that the contraction on mixing these liquids appears to reach its maximum when the weights of acetone and water are equal.

TABLE III. Table of Densities and Contractions of Mixtures of Acetone and Water.

| Acetone per cent. | D $\frac{20^\circ}{20^\circ}$ found | D $\frac{20^\circ}{4^\circ}$ found | D $\frac{20^\circ}{4^\circ}$ calc. | Vol. 1 gram found | Vol. 1 gram calc. | Con- tractions per cent. |
|-------------------|-------------------------------------|------------------------------------|------------------------------------|-------------------|-------------------|--------------------------|
| 100               | 0.79231                             | 0.79091                            | 0.79091                            | 1.26437           | 1.26437           | —                        |
| 94.98             | 0.80832                             | 0.80689                            | 0.79923                            | 1.2393            | 1.2512            | 0.951                    |
| 89.58             | 0.82367                             | 0.82221                            | 0.80841                            | 1.2162            | 1.2370            | 1.681                    |
| 79.92             | 0.85171                             | 0.85020                            | 0.82535                            | 1.1762            | 1.2116            | 2.922                    |
| 71.10             | 0.87370                             | 0.87215                            | 0.84154                            | 1.1466            | 1.1883            | 3.509                    |
| 57.46             | 0.90629                             | 0.90469                            | 0.86753                            | 1.1054            | 1.1527            | 4.103                    |
| 50.03             | 0.92220                             | 0.92057                            | 0.88250                            | 1.0863            | 1.13315           | 4.134                    |
| 37.49             | 0.94667                             | 0.94499                            | 0.90893                            | 1.0581            | 1.1002            | 3.827                    |
| 29.62             | 0.95949                             | 0.95779                            | 0.92635                            | 1.0441            | 1.0795            | 3.279                    |
| 19.31             | 0.97480                             | 0.97307                            | 0.95012                            | 1.0277            | 1.0525            | 2.356                    |
| 9.93              | 0.98707                             | 0.98532                            | 0.97290                            | 1.0149            | 1.02785           | 1.260                    |

TABLE IV. Densities and Contractions of Mixtures of n-Butyl Alcohol and Water.

| n-Butyl Alcohol per cent. | D $\frac{20^\circ}{20^\circ}$ found | D $\frac{20^\circ}{4^\circ}$ found | D $\frac{20^\circ}{4^\circ}$ calc. | Vol. of 1 gram found | Vol. of 1 gram calc. | Contraction per cent. |
|---------------------------|-------------------------------------|------------------------------------|------------------------------------|----------------------|----------------------|-----------------------|
| 100                       | 0.81097                             | 0.80953                            | 0.80953                            | 1.2353               | 1.2353               | —                     |
| 98.93                     | 0.81318                             | 0.81174                            | —                                  | —                    | —                    | —                     |
| 97.89                     | 0.81538                             | 0.81394                            | 0.81277                            | 1.2286               | 1.2304               | 0.143                 |
| 96.96                     | 0.81731                             | 0.81586                            | —                                  | —                    | —                    | —                     |
| 95.97                     | 0.81935                             | 0.81790                            | —                                  | —                    | —                    | —                     |
| 95.06                     | 0.82108                             | 0.81962                            | 0.81716                            | 1.2201               | 1.2238               | 0.302                 |
| 93.98                     | 0.82234                             | 0.82088                            | —                                  | —                    | —                    | —                     |
| 93.02                     | 0.82513                             | 0.82367                            | 0.82036                            | 1.2141               | 1.2190               | 0.402                 |
| 91.97                     | 0.82689                             | 0.82543                            | —                                  | —                    | —                    | —                     |
| 90.96                     | 0.82883                             | 0.82736                            | —                                  | —                    | —                    | —                     |
| 89.96                     | 0.83066                             | 0.82919                            | 0.82522                            | 1.2060               | 1.2118               | 0.479                 |
| 89.26                     | 0.83216                             | 0.83068                            | —                                  | —                    | —                    | —                     |
| 88.06                     | 0.83436                             | 0.83288                            | —                                  | —                    | —                    | —                     |
| 83.03                     | 0.84345                             | 0.84196                            | 0.83633                            | 1.1877               | 1.1957               | 0.666                 |
| 80.64                     | 0.84777                             | 0.84627                            | —                                  | —                    | —                    | —                     |
| 79.94                     | 0.84917                             | 0.84770                            | 0.84140                            | 1.1797               | 1.1885               | 0.740                 |
| 7.90                      | 0.98862                             | 0.98687                            | 0.98018                            | 1.0133               | 1.0202               | 0.676                 |
| 7.32                      | 0.98946                             | 0.98771                            | 0.98164                            | 1.0124               | 1.0188               | 0.628                 |
| 7.06                      | 0.98968                             | 0.98793                            | —                                  | —                    | —                    | —                     |
| 6.11                      | 0.99111                             | 0.98936                            | 0.98421                            | 1.0108               | 1.0160               | 0.511                 |
| 5.05                      | 0.99244                             | 0.99068                            | —                                  | —                    | —                    | —                     |
| 3.95                      | 0.99382                             | 0.99202                            | 0.98913                            | 1.00805              | 1.0110               | 0.291                 |
| 3.05                      | 0.99532                             | 0.99356                            | —                                  | —                    | —                    | —                     |
| 2.27                      | 0.99651                             | 0.99474                            | —                                  | —                    | —                    | —                     |
| 2.00                      | 0.99678                             | 0.99502                            | 0.99364                            | 1.0050               | 1.0064               | 0.139                 |
| 1.61                      | 0.99742                             | 0.99566                            | —                                  | —                    | —                    | —                     |
| 1.04                      | 0.99830                             | 0.99653                            | —                                  | —                    | —                    | —                     |
| 0.61                      | 0.99888                             | 0.99711                            | 0.99681                            | 1.0029               | 1.0032               | 0.030                 |

n-Butyl alcohol and water being miscible only within certain limits at 20°C., the curve of contraction on mixing is incomplete. It bears out the observation of Young and Fortey (Trans. Chem. Soc. 1902, **81**, 717) that the contraction, on mixing alcohol with water, diminishes with the rise in molecular weight of the alcohol. The contraction for n-butyl alcohol-water mixtures at 20°C. rises to a maximum of 0.7 per cent. for a mixture containing 80 per cent. alcohol. On the other hand, n-butyl alcohol and acetone do not contract on mixing, but rather show a slight expansion.

*Summary.*

1. The densities of a series of acetone, n-butyl alcohol, and water mixtures were obtained, and curves with rectangular and triangular co-ordinates prepared.

2. The composition of an unknown mixture is readily obtained, with a fair degree of accuracy, by a density determination in conjunction with an estimation of one of the constituents.

3. The curve of limiting miscibility in the system was determined, the end points giving the limits of solubility at 20°C. of n-butyl alcohol in water (7.9%), and water in n-butyl alcohol (20%).

4. The maximum contraction for mixtures of n-butyl alcohol and water within the limited range of solubility at 20°C. was found to be 0.74%.

5. Acetone and n-butyl alcohol were found to be miscible in all proportions, there being a slight increase of volume on mixing.

# SCIENTIFIC PROCEEDINGS.

## VOLUME XV.

1. The Subsidence of Torsional Oscillations and the Fatigue of Iron Wires when subjected to the Influence of Alternating Magnetic Fields of Frequencies up to 250 per second. By WILLIAM BROWN, B.SC. (January, 1916.) 6*d*.
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THE DETERMINATION OF THE RATE OF  
SOLUTION OF ATMOSPHERIC NITROGEN  
AND OXYGEN BY WATER.

PART II.

BY

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## XLIV.

THE DETERMINATION OF THE RATE OF SOLUTION OF  
ATMOSPHERIC NITROGEN AND OXYGEN BY WATER.

## PART II.

By W. E. ADENEY, D.Sc., A.R.C.Sc.I., F.I.C.,

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AND

H. G. BECKER, A.R.C.Sc.I., Research Student.

[Read MAY 27. Published SEPTEMBER 8, 1919.]

## I.—INTRODUCTION.

IN the first part of this communication<sup>1</sup> a method of studying the rate of solution of air by water was described, and some results were given, which showed that, when the water was kept thoroughly mixed and the water-air surface unbroken, the phenomenon took place in accordance with the general equation

$$\frac{dw}{dt} = a - bw,$$

in which  $a$  represents the initial rate of solution, and  $bw$  the rate of escape of the gas from the water,  $b$  being a constant depending on the conditions of the experiment.

The method of experimenting consisted in enclosing a large bubble of air, of known volume, in a narrow tube containing de-aerated water, and allowing the bubble to pass up through the water repeatedly until saturation was reached. The pressure in the bubble was measured after each double passage up the tube by means of a water manometer, and this gave data for calculating the absorption which took place step by step to saturation.

With the object of reducing the observations to unit area and volume, experiments have been continued along these lines, and the results are given in this communication. The apparatus employed for these later experiments has been modified in a manner which experience showed was necessary ; and the determinations have been extended to include oxygen and nitrogen as pure gases.

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<sup>1</sup> Scientific Proc., R.D.S., vol. xv, 1918, p. 385.

## II.—TEMPERATURE CONTROL.

In the experiments previously recorded the temperature of the apparatus was maintained constant by providing a large reservoir of water, and allowing the water to run through the water-jacket of the apparatus while the observations were being made. This method only allowed of the maintenance of a steady temperature for a few hours, and experiments could not be repeated at the same temperature at will, nor could higher temperatures than that of the room be obtained.

In order to bring the temperature under control, it was decided to use a thermostat, and circulate the water from it through the water-jacket of the apparatus. To provide the circulation of water a small centrifugal pump was designed, patterns were made and castings obtained from the Engineering Department of the College, while the machining was completed in the workshop attached to the Chemical Department.

This pump maintained a rapid stream of water through the water-jacket at a constant rate; and no difficulty was experienced in keeping the temperature constant to within  $0.1^{\circ}\text{C}$ . A further advantage was that any desired temperature within fairly wide limits could be attained, and experiments could be repeated as often as desired at the same temperature on different days.

## III.—EXPERIMENTS TO DETERMINE THE EFFECT OF THE AREA OF THE BUBBLE ON THE RATE OF SOLUTION.

*(a) Measurement of the lengths of different bubbles in motion.*

Bubbles of five different volumes were measured at  $25^{\circ}\text{C}$ . while in motion up the tube. Arrangements were made for photographing each bubble and the scale in close proximity to each other, through the water-jacket, by providing a scale ruled on thin tracing-paper, and cementing this to the inner tube with Canada balsam. This scale was almost transparent, and the image of the bubble was orthographically projected on to it by means of a beam of parallel light from an arc lamp. The camera was focussed sharply on the scale, and the shutter was released just as the bubble passed behind the scale, so that on the negative the scale lines were superimposed upon the image of the bubble.

These negatives were measured by means of a travelling microscope, and the measurements referred to the paper scale, the errors of which were determined by means of a standard scale both before and after use. The length of each bubble, when at rest, was measured with a mirror scale, which was also

compared with the standard scale, and the area of the bubble was calculated from the formula deduced in the first part of this communication. The results of the measurements are given in Tables I and II.

TABLE I.  
MEASUREMENTS OF BUBBLES OF DIFFERENT VOLUMES.

| Temperature. | Volume.   | Length in Motion. | Length at rest. |
|--------------|-----------|-------------------|-----------------|
| 25° C.       | 15·0 c.c. | 15·98 cm.         | 13·25 cm.       |
| „            | 12·5 „    | 13·61 „           | 11·10 „         |
| „            | 10·0 „    | 11·11 „           | 8·85 „          |
| „            | 7·5 „     | 8·48 „            | 6·70 „          |
| „            | 5·0 „     | 5·90 „            | 4·45 „          |

TABLE II.  
CALCULATION OF AREAS.

| Volume.   | Diameter. |           | Thickness of wall. | Area. |
|-----------|-----------|-----------|--------------------|-------|
|           | External. | Internal. |                    |       |
| 15·0 c.c. | 1·20 cm.  | 1·099 cm. | ·050 cm.           | 56·33 |
| 12·5 „    | „         | 1·091 „   | ·055 „             | 47·58 |
| 10·0 „    | „         | 1·086 „   | ·057 „             | 38·85 |
| 7·5 „     | „         | 1·078 „   | ·061 „             | 29·63 |
| 5·0 „     | „         | 1·058 „   | ·071 „             | 20·52 |

(b) *Effect of temperature on the length of the bubble in motion.*

A number of measurements was also made of the length of the 15 c.c. bubble at different temperatures, and the results are recorded here; for, although they appear to have no direct bearing on the object of the inquiry, they may be of use in throwing light on the nature of the motion of the bubble up the tube.

A 15 c.c. bubble was drawn into the tube at each of the temperatures given, and allowed to attain atmospheric pressure at that temperature by opening the tap connecting it with the air. The tube was then inverted several times and the tap opened after each inversion to make sure that the pressure in the bubble was atmospheric. The bubble was then photographed, and the negative measured in each case.

TABLE III.

MEASUREMENTS OF 15 C.C. BUBBLE AT DIFFERENT TEMPERATURES.

| Temperature. | Length. |
|--------------|---------|
| 11° C.       | 16.15   |
| 25°          | 15.98   |
| 30°          | 15.91   |
| 35°          | 15.85   |
| 40°          | 15.81   |

These measurements show that the length of the bubble decreases with rise in temperature; but since the volume must be constant, the diameter must increase as the length diminishes, hence the area will not be affected appreciably by this change in length.

(c) *Effect of the area of the bubble on the rate of solution.*

To determine the effect of the area of the bubble on the rate of solution a series of five duplicate experiments was carried out at 25° C., using bubbles of 5, 7.5, 10, 12.5, and 15 c.c. The experiments with the first two bubbles were made in a tube of 50 cm. length, as it was thought that too large a fraction of the whole volume of air in the bubble would be absorbed in one double passage up the 100 cm. tube. From these experiments, the values of  $a$  and  $b$  were calculated, as described previously,<sup>1</sup> from the graph obtained by plotting the rate of solution against air content.

The observations were reduced to a uniform volume of 100 c.c., and the lines

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<sup>1</sup> Part I of this communication.

representing the mean of each pair of experiments are given in fig. 1. It will be seen that they tend to meet in a point on the  $x$ -axis, this point representing the saturation value of the water for the temperature of the experiment. The agreement between the different values for this quantity is shown in the column headed " $w_0$ " in Table IV.

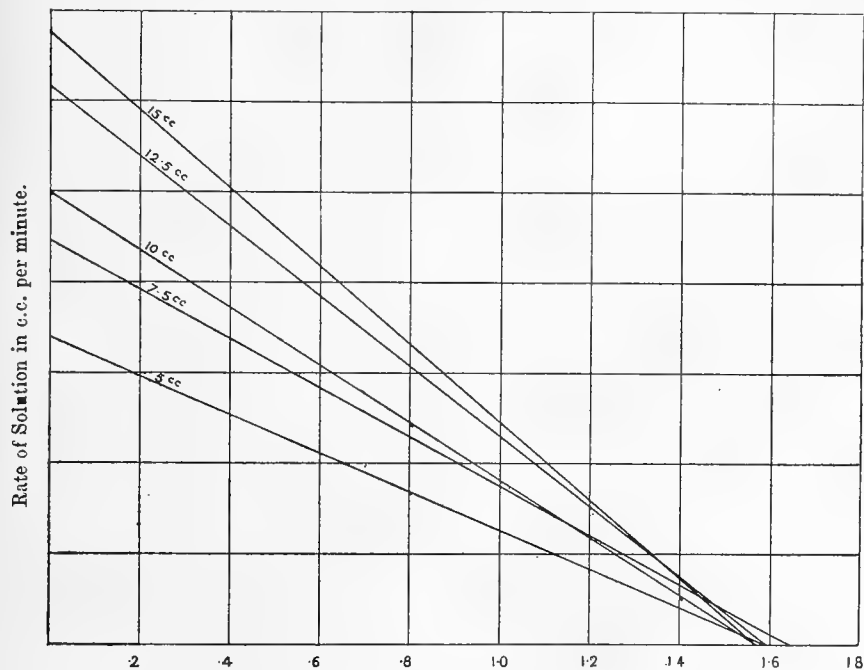


FIG. 1.—Air-content in c.c.

TABLE IV.

RESULTS OF EXPERIMENTS WITH AIR IN BUBBLES OF DIFFERENT VOLUMES AT 25° C.

| Volume. | Area.          | Value of $a$ . | Value of $w_0$ . | Value of $b$ . |
|---------|----------------|----------------|------------------|----------------|
| 5 c.c.  | 20.52 sq. c.m. | .342           | 1.59             | .215           |
| 7.5 „   | 29.63 „        | .450           | 1.64             | .274           |
| 10 „    | 38.85 „        | .497           | 1.57             | .317           |
| 12.5 „  | 47.58 „        | .620           | 1.59             | .390           |
| 15.0 „  | 56.33 „        | .680           | 1.57             | .433           |



When the values of  $b$  are plotted against the area, as in fig. 2, a straight line graph is obtained which intersects the axis of  $x$  in a point lying to the left of the origin. Hence the absorption is not directly proportional to the area of the bubble. This appears to be due to the fact that the conditions which apply to the cylindrical portion of the bubble do not hold for the hemispherical head. The rate at which the water streams past the head of the bubble is much less than that at which it passes down the cylindrical portion of it; hence the absorption due to the head of the bubble is greater than might be expected from its area. These two effects are differentiated by measuring the rate of absorption for a number of different bubbles;

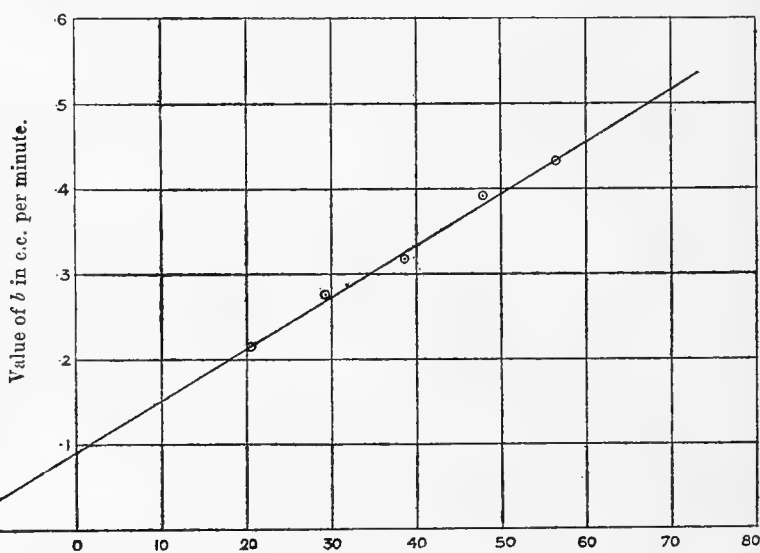


FIG. 2.—Area in sq. cm.

Values of  $b$  plotted against area of bubble.

because, since the effect of the head of the bubble is the same in each case, the variation in absorption must be due to variation in the area of the cylindrical portion. Hence the graph shows the rate at which the value of  $b$  increases with increasing cylindrical area. By producing the graph until it cuts the  $x$ -axis we obtain a constant correction for the head of the bubble, which, when added to the calculated area of the bubble, gives the effective area when the absorption is uniform all over the surface.

The value of the intercept on the  $x$ -axis is 15 sq. cm.; hence this amount must be added to the area of each bubble.

TABLE V.

| Volume. | Calculated Area. | Effective Area. |
|---------|------------------|-----------------|
| 5 c.c.  | 20.52 sq. cm.    | 35.52 sq. cm.   |
| 7.5 „   | 29.63 „          | 44.63 „         |
| 10 „    | 38.85 „          | 53.85 „         |
| 12.5 „  | 47.58 „          | 62.58 „         |
| 15 „    | 56.33 „          | 71.33 „         |

IV.—EXPERIMENTS TO DETERMINE THE EFFECT OF TEMPERATURE ON THE RATE OF SOLUTION OF ATMOSPHERIC AIR.

A series of seven duplicate experiments was made within a temperature range of 3.6° to 38.4° C. with atmospheric air in a 15 c.c. bubble. These experiments were carried out by the method described in the first part of this communication, with slight modifications, and the results are given in Table VI and fig. 3.

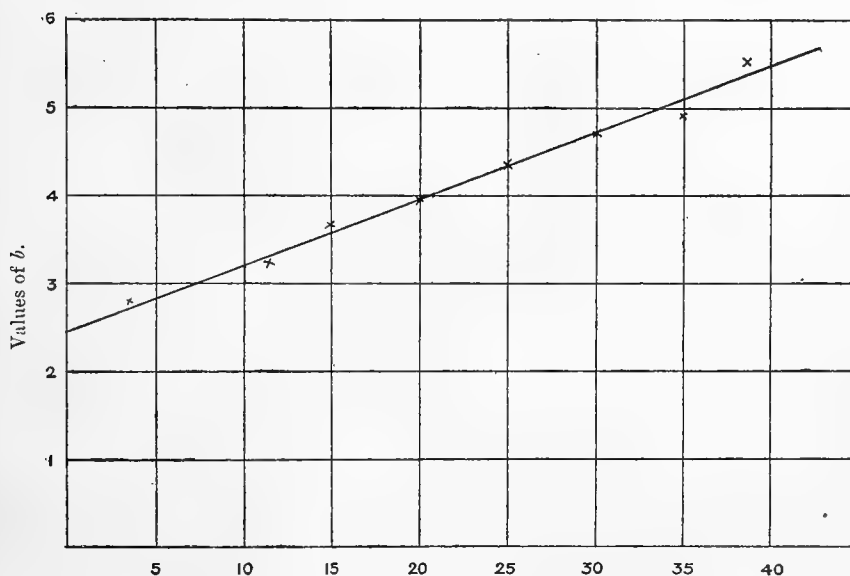


FIG. 3.—Temperature in degrees centigrade.

Values of  $b$  for air plotted against temperature.

$$\text{Formula : } -b = .0075 (T - 240.1).$$

Examination of these results showed that, when the temperature of the

water-jacket was widely different from that of the room, this method did not give sufficiently accurate values for the saturation-point.

In fig. 3, the mean values of  $b$  are plotted against temperature, giving a straight line with the formula  $b = \cdot 0075 (T - 240\cdot 1)$ . This will be referred to when finally considering the results.

TABLE VI.  
RESULTS OF EXPERIMENTS WITH ATMOSPHERIC AIR.

| Temperature,<br>°C. | Values from log<br>graph. |       | Values from $W_0$ graph. |         |       | Saturation Values. |                     | Mean<br>Value of<br>$b$ . |
|---------------------|---------------------------|-------|--------------------------|---------|-------|--------------------|---------------------|---------------------------|
|                     | $t$ .                     | $b$ . | $a$ .                    | $W_0$ . | $b$ . | Dittmar.           | Sum of<br>Readings. |                           |
| 3·6°                | 71                        | ·266  | ·750                     | 2·720   | ·296  | 2·534              | 2·682               | ·281                      |
| 11·4                | —                         | —     | ·645                     | 2·060   | —     | —                  | 2·074               | —                         |
| 11·3                | 54                        | ·336  | ·675                     | 2·115   | ·312  | 2·126              | 2·131               | ·324                      |
| 15·0                | —                         | —     | ·695                     | 1·730   | —     | —                  | 1·806               | —                         |
| 15·0                | 47                        | ·397  | ·650                     | 1·640   | ·338  | 1·988              | 1·614               | ·367                      |
| 20·0                | —                         | —     | ·700                     | 1·640   | —     | —                  | 1·663               | —                         |
| 20·0                | 44                        | ·431  | ·640                     | 1·500   | ·368  | 1·818              | 1·484               | ·399                      |
| 25·0                | —                         | —     | ·720                     | 1·570   | —     | —                  | 1·573               | —                         |
| 25·0                | 40                        | ·459  | ·650                     | 1·380   | ·411  | 1·672              | 1·381               | ·435                      |
| 29·6                | —                         | —     | ·640                     | 1·265   | —     | 1·555              | 1·267               | —                         |
| 29·3                | 36                        | ·523  | ·660                     | 1·320   | ·421  | 1·564              | 1·300               | ·472                      |
| 34·2                | —                         | —     | ·585                     | 1·060   | —     | 1·457              | 1·017               | —                         |
| 34·4                | 32                        | ·580  | ·595                     | 1·010   | ·406  | 1·453              | 0·934               | ·493                      |
| 38·5                | —                         | —     | ·630                     | 0·865   | —     | —                  | 0·845               | —                         |
| 38·6                | 28                        | ·665  | ·585                     | 0·785   | ·446  | 1·360              | 0·787               | ·555                      |

V.—IMPROVEMENTS IN METHODS OF EXPERIMENTING.

When the form of apparatus, described in Part I of this communication was employed in experiments at temperatures much above or below room-temperature, a number of possible sources of error might be expected to affect the results, viz. :—

1. Difference of temperature between the water-jacket and the air drawn in to renew bubble,

2. Absorption of air during periods of manipulation.

3. Difference in temperature between the air in the bubble and that in the air-space of the manometer.

Of these it seemed that No. 1 was the most important; No. 3 was extremely small; while subsequent experiments have shown that No. 2 is negligible, with a narrow tube, such as was used in these experiments.

In order to eliminate these errors it was decided to make a new form of apparatus, suitable for use with a pure gas, such as nitrogen or oxygen; and to work with air-free water.

(a) *Preparation of Air-free Water.*

In order to ensure that the water was air-free, it was necessary to boil it in the vacuum of the mercury pump, and then transfer it to the experimental tube without allowing it to come in contact with the air. At first it was thought that it would be sufficient to heat the water until its vapour-pressure was great enough to force it over into the tube, but it was found that this necessitated much too high a temperature. It was decided to displace the water with mercury, but this introduced such a narrow tube between the flask and condenser that the condensed vapour blocked it.

The difficulty was finally solved by providing a second tube to allow the water condensed to flow back into the flask. It was thus possible to boil the water in vacuo as long as might be necessary, without any appreciable loss by evaporation.

The diagram (fig. 4) shows the form of apparatus used, and the mode of operation is as follows:—The water in *A* is heated to a fairly high temperature by means of a water-bath, and the mercury pump is then worked until a very low pressure is reached. In this way most of the gas is extracted in the first violent ebullition, and the remainder is removed by continued boiling under the reduced pressure. During the latter part of the operation the water bumps very violently, with the result that some of it is thrown over into the vessel *E*; but this returns to the flask immediately by the tube *B*, as also does any water dripping from the condenser. When all the air is extracted, the pinch-cocks *B* and *C* are closed, and *D* is opened, when the mercury flows in and displaces the water into the experimental tube, which has been previously filled with mercury, and connected to the flask *A* by another tube not shown in the drawing. All the rubber stoppers used were protected from leakage by mercury traps, and the rubber tubing was varnished with shellac to prevent diffusion.

*(b) Modified form of Experimental Tube used.*

Owing to the difficulty in obtaining apparatus, it was decided to make the required modification of the experimental tube in the laboratory. It was designed and made as shown in the diagram (fig. 5). At the upper end of the tube there is a hollow stopper *A* ground in, which controls the connexion to the manometer *D* and the gas reservoir *C*. This stopper also has a stopcock *F*, fused on to it at the top to permit of the tube being filled with

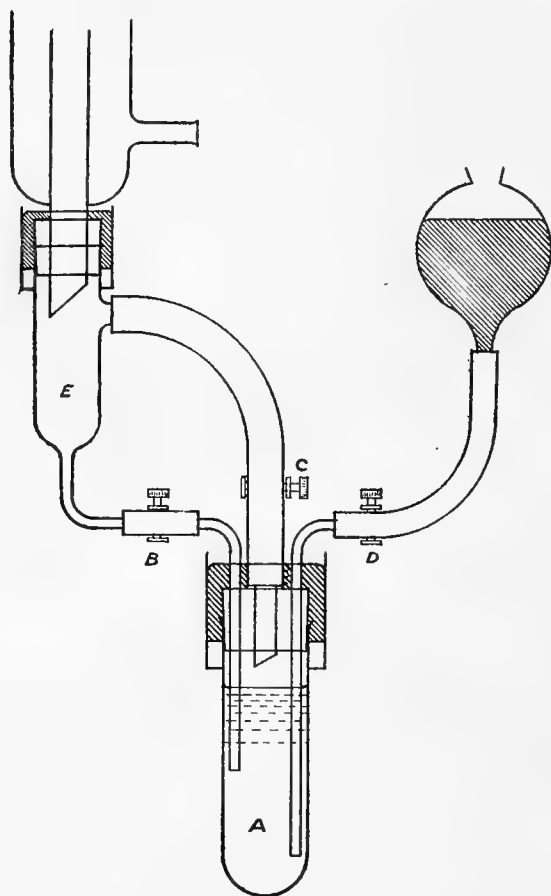


FIG. 4.

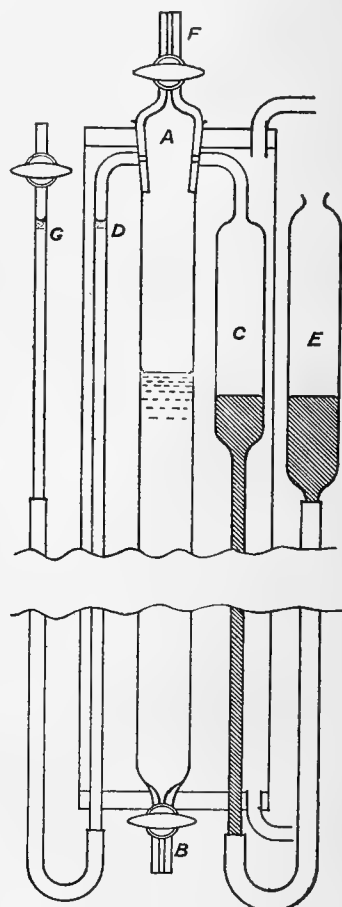


FIG. 5.

water when used in conjunction with another stopcock *B*, fused on to the lower end of the tube. The manometer *D* and the gas reservoir *C* are fused on to the tube in such positions that the openings correspond with the holes in the stopper. The whole apparatus is provided with a water-jacket as shown, through the bottom of which the ends of the gas reservoir and the manometer project, in order to allow them to be connected by rubber tubing with the mercury reservoir *E* and the tube *G*, respectively.

The manipulation involved in an experiment was as follows:—After the whole apparatus had been carefully cleaned, the manometer was filled with water and the tube filled with mercury by connecting on a temporary reservoir at *B*; at the same time the gas reservoir *C* was filled with mercury by raising *E*. The water-level in *D* was also raised to the hollow stopper, which was then turned so as to close all the side tubes. The tube was then connected to the boiling apparatus just described, by a capillary tube joined to stopcock *F*. The air was displaced from this connexion by forcing a little mercury over from the temporary reservoir. The water was then boiled until all the air was extracted, when the water was displaced over into the experimental tube, by lowering the reservoir of mercury attached to it, and raising that attached to the laboratory flask.

When the tube was quite full it was disconnected from the laboratory flask, and water from the thermostat was circulated through the jacket until the required temperature was attained. When a steady state was reached the stopcock *F* was connected to the reservoir of gas in use, and the stopcock *B* to a standard burette, and the correct volume of bubble drawn in. The gas reservoir *C* was then filled with the gas by turning the stopper so as to connect it with the bubble, and lowering the reservoir *E*; the manometer space was likewise filled by again turning the stopper and lowering the manometer tube *G*. The tap at *F* was then disconnected from the gas reservoir and opened and shut several times so as to bring the manometer to zero and the pressure in the bubble to that of the atmosphere. (The pressure in the bubble before this operation was always slightly *above* atmospheric, so that no air could enter.)

The tube was then ready for the observations which were made as usual after each double inversion. During the inversion the stopper was turned so as to shut all side tubes, and it was so arranged that after inversion the bubble could be connected to the manometer alone, to read the pressure, and then to the manometer and gas reservoir simultaneously, to allow of the pressure being re-adjusted to atmospheric, by manipulating the mercury reservoir *E* until the manometer went back to zero.

By means of this apparatus the difficulty about the temperature and vapour-pressure of the replenishing gas was overcome, because the gas was contained in the reservoir *C* at the same temperature as that of the bubble, and there was sufficient moisture in the reservoir to keep the gas saturated with aqueous vapour at that temperature.

When the observations were completed, the lower tap *B* was connected to the gas pipette described in Part I of this communication, by means of a piece of rubber tubing filled with mercury, and the water in the tube was run

into the pipette to allow of its transfer to the pump for the determination of its gas content without exposure to the atmosphere.

Using this apparatus, a number of experiments were made with both nitrogen and oxygen, the results of which are given below.

## VI.—EXPERIMENTS WITH PURE GASES.

### (a) *Experiments with Nitrogen.*

The nitrogen used was prepared according to a method recommended by Knorre,<sup>1</sup> and said to give no oxides of nitrogen.

A mixture of 30 grams sodium nitrite, 30 grams potassium bichromate, and 45 grams ammonium sulphate, was dissolved in about 500 c.c. water, and placed in a litre retort. This was connected to three bulb tubes, the first containing a mixture of 5 vols. of a saturated solution of potassium bichromate to 1 vol. strong sulphuric acid; the second, dilute potassium permanganate solution; and the third, alkaline pyrogallol.

The whole apparatus was exhausted with a water-pump, and the liquid warmed until the pressure rose to that of the atmosphere, when it was again exhausted, and the process repeated. In this way the air in the apparatus was very completely removed. The gas was collected over water which had been boiled for some time, and allowed to cool out of contact with air.

A series of experiments over a range of 35° was made with this gas, and the results are given below.

The experimental figures were treated graphically in two ways. In one case the rate of solution was plotted against the mean value of the gas content, and in the other the logarithms of the absorptions were plotted against the time intervals. Each set of graphs gave values for *a* and *b*, which are given in Table VII, and the mean of the values of *b* in each case is plotted against temperature in fig. 6.

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<sup>1</sup> Chem. Centr. 1903 (i), 125.

TABLE VII.  
RESULTS OF EXPERIMENTS WITH NITROGEN.

| Temperature,<br>°C. | Values from log graph. |       | Values from $W_0$ graph. |         |       | Saturation Values. |          |       | Mean Value of $b$ . |
|---------------------|------------------------|-------|--------------------------|---------|-------|--------------------|----------|-------|---------------------|
|                     | $t$ .                  | $b$ . | $a$ .                    | $W_0$ . | $b$ . | Adeney and Becker. | Winkler. | Bohr. |                     |
| 3.5°                | 52                     | .270  | .644                     | 2.440   | .264  | 2.230              | 2.180    | 2.240 | .267                |
| 11.1                | —                      | —     | .568                     | 1.800   | —     | 1.830              | 1.822    | 1.922 | —                   |
| 11.3                | 44                     | .310  | .558                     | 1.830   | .310  | 1.860              | 1.816    | 1.881 | .310                |
| 15.0                | —                      | —     | .562                     | 1.660   | —     | 1.735              | 1.682    | 1.785 | —                   |
| 15.1                | 40                     | .344  | .533                     | 1.640   | .332  | 1.741              | 1.689    | 1.780 | .338                |
| 20.1                | 35.5                   | .403  | .630                     | 1.660   | .380  | 1.556              | 1.530    | 1.625 | .401                |
| 24.8                | —                      | —     | .646                     | 1.480   | —     | 1.476              | 1.416    | 1.490 | —                   |
| 24.8                | 33                     | .435  | .569                     | 1.590   | .394  | 1.488              | 1.416    | 1.490 | .414                |
| 30.4                | 32                     | .440  | .600                     | 1.360   | .441  | 1.330              | 1.299    | 1.335 | .440                |
| 35.1                | 29                     | .499  | .608                     | 1.260   | .482  | 1.235              | 1.203    | 1.220 | .490                |

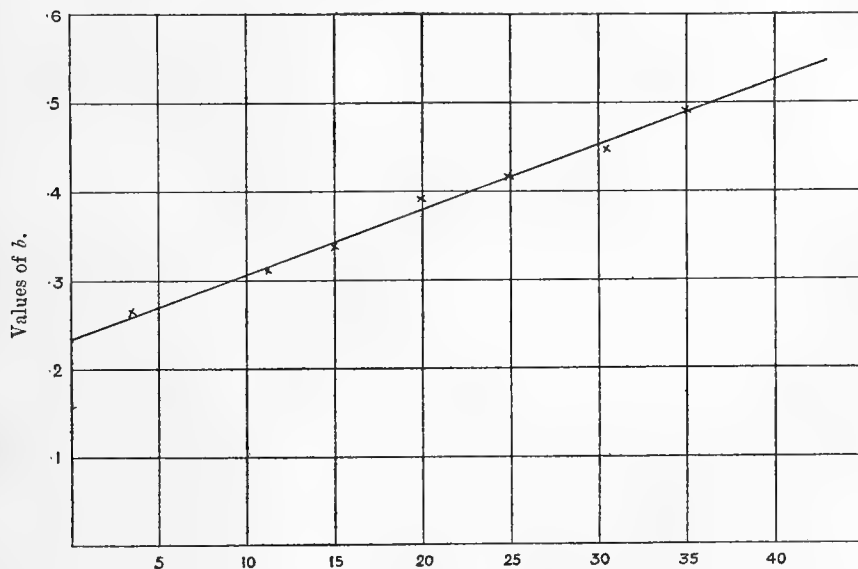


FIG. 6.—Temperature in degrees centigrade.

Values of  $b$  for Nitrogen plotted against temperature.

Formula:— $b = .00727 (T - 240.8)$ .



*(b) Experiments with Oxygen.*

The oxygen was prepared by heating potassium permanganate in a hard glass tube, and washing the gas with caustic potash to remove any traces of carbon dioxide which might be formed. The apparatus was exhausted several times with a water-pump to wash out the last traces of air. The gas was collected over water which had been boiled for some time and cooled out of contact with air.

A series of experiments was made over a range of temperature of 35°, and the results treated by the two methods as mentioned in the case of nitrogen. The results are contained in Table VIII, and the variation of *b* with temperature is shown in fig. 7.

TABLE VIII.

## RESULTS OF EXPERIMENTS WITH OXYGEN.

| Temperature,<br>°C. | Values from log graph. |            | Values from $W_0$ graph. |         |            | Saturation Values. |          |       | Mean Value of <i>b</i> . |
|---------------------|------------------------|------------|--------------------------|---------|------------|--------------------|----------|-------|--------------------------|
|                     | <i>t</i> .             | <i>b</i> . | <i>a</i> .               | $W_0$ . | <i>b</i> . | Adeney and Becker. | Winkler. | Bohr. |                          |
| 2.5                 | 77                     | .252       | 1.235                    | 4.47    | .276       | 4.450              | 4.600    | 4.690 | .264                     |
| 8.8                 | 64                     | .310       | 1.230                    | 3.910   | .315       | 3.814              | 3.970    | 4.080 | .313                     |
| 15.5                | 59                     | .336       | 1.140                    | 3.330   | .342       | 3.254              | 3.372    | 3.450 | .339                     |
| 20.2                | 54.5                   | .356       | 1.150                    | 2.950   | .390       | 2.970              | 3.040    | 3.110 | .373                     |
| 25.2                | 51                     | .392       | 1.150                    | 2.810   | .410       | 2.812              | 2.810    | 2.880 | .411                     |
| 30.3                | 46                     | .437       | 1.080                    | 2.450   | .432       | 2.485              | 2.510    | 2.575 | .434                     |
| 35.1                | 43                     | .477       | 1.120                    | 2.250   | .498       | 2.323              | 2.355    | 2.400 | .487                     |

In the above series of experiments the water in the tube at the end of each experiment was analyzed for dissolved gases, using the extraction pump and measuring apparatus described in Part I of this communication. The solubilities of oxygen and nitrogen at the given temperatures as calculated from these analyses are given in Table IX, as are also the values obtained by Bohr and Winkler by absorptiometric methods.

TABLE IX.

| NITROGEN. |          |        |                    | OXYGEN.   |          |        |                    |
|-----------|----------|--------|--------------------|-----------|----------|--------|--------------------|
| Temp. °C. | Winkler. | Bohr.  | Adeney and Becker. | Temp. °C. | Winkler. | Bohr.  | Adeney and Becker. |
| 3.5       | .02139   | .02200 | .02203             | 2.5       | .04540   | .04625 | .04390             |
| 11.2      | .01738   | .01890 | .01820             | 8.8       | .03866   | .03965 | .03710             |
| 15.0      | .01654   | .01757 | .01701             | 15.5      | .03323   | .03405 | .03206             |
| 20.1      | .01505   | .01598 | .01549             | 20.2      | .03019   | .03089 | .02955             |
| 24.8      | .01392   | .01461 | .01456             | 25.2      | .02733   | .02805 | .02732             |
| 30.4      | .01276   | .01312 | .01322             | 30.3      | .02488   | .02552 | .02465             |
| 35.1      | .01183   | .01200 | .01220             | 35.1      | .02302   | .02347 | .02270             |

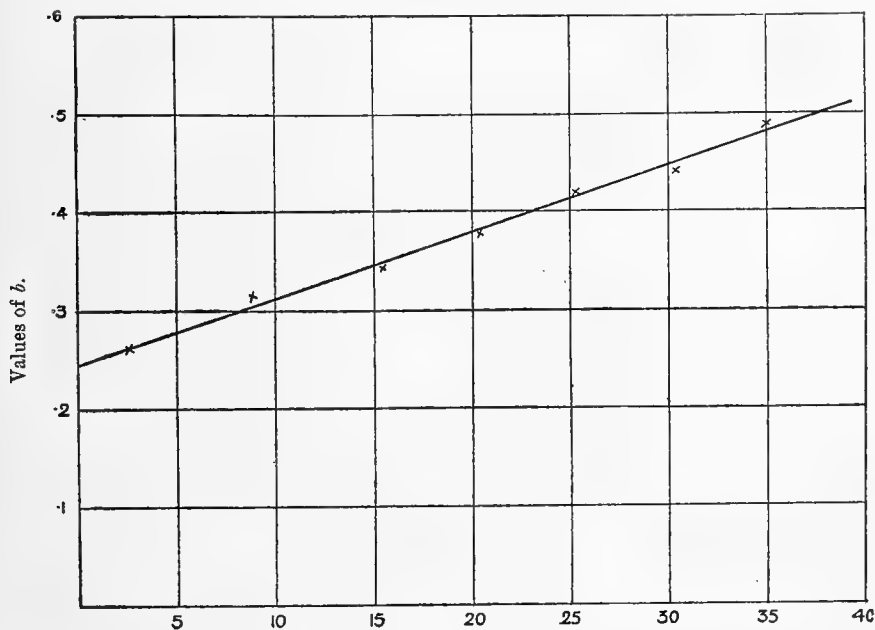


FIG. 7.—Temperature in degrees centigrade.

Values of *b* for Oxygen plotted against temperature.

Formula :— $b = .00672 (T - 236.5)$ .

VII.—REDUCTION OF RESULTS TO UNIT AREA AND VOLUME TO OBTAIN FUNDAMENTAL CONSTANTS.

The results have been shown to be in agreement with the general formula

$$\frac{dw}{dt} = SAp - f \frac{A}{V} w$$

where *w* = total quantity of gas in solution at any moment, *S* = the initial rate

of solution per unit area,  $f$  = the coefficient of escape of the gas from the liquid per unit area and volume,  $A$  = area of surface, and  $p$  = pressure of the gas.

The values of  $b$  for different temperatures and different gases have been found for various temperatures using a volume of water of 101.8 c.c.s. and an exposed area of 71.3 sq. cms. ; hence since

$$b = f \frac{A}{V},$$

we can calculate the values of  $f$ . The values are given in the second column of Table X, and when they are plotted against temperature in each case, three straight lines lying very close together are obtained, as shown in fig. 8.

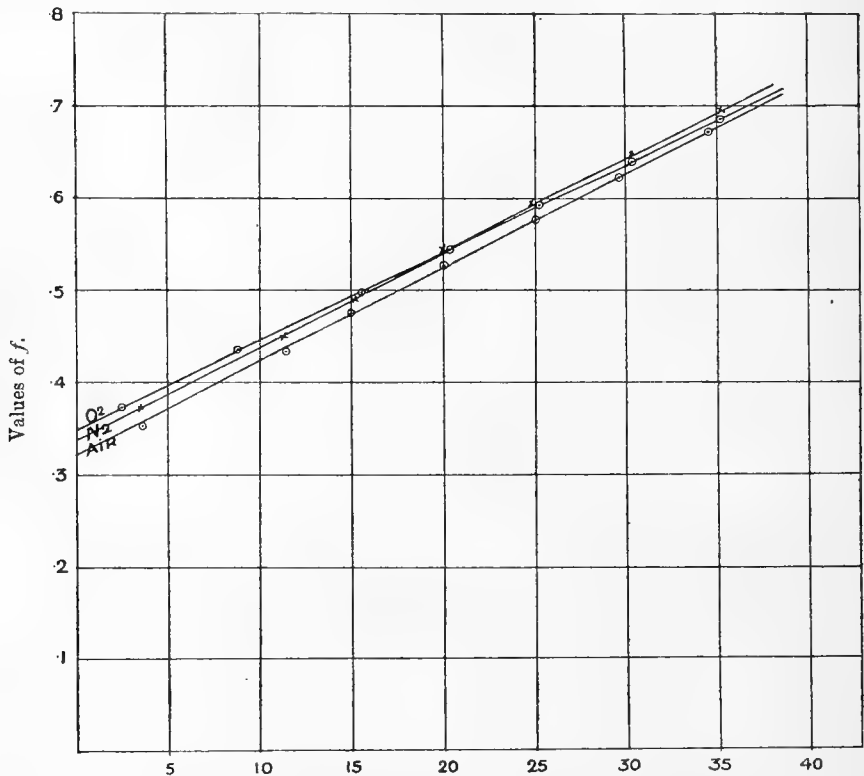


FIG. 8.—Temperature in degrees centigrade.

Values of  $f$  plotted against temperature.

Formulae :— $f = .0096 (T - 236.5)$  for Oxygen.

$f = .0103 (T - 240.0)$  for Nitrogen.

$f = .0099 (T - 239.3)$  for Air.

When the values of  $f$  for any gas are multiplied by the corresponding solubilities, the product gives the initial rate of solution in each case, since  $S = fs$ . It will be seen by reference to Table X that the value of  $S$  is practically a constant over the range of temperature given.

The value of  $S$  is approximately proportional to the solubility, being about twice as great for oxygen as it is for nitrogen; and if  $\frac{4}{5}$  of the value for nitrogen be added to  $\frac{1}{5}$  of that for oxygen, a value for air is obtained which agrees fairly closely with the actual figures thus:— $\frac{4}{5}$  of  $\cdot 0083 + \frac{1}{5}$  of  $\cdot 0160 = \cdot 00665 + \cdot 00320 = \cdot 00985$ , while the mean experimental figure is =  $\cdot 0100$ .

TABLE X.

| OXYGEN.   |      |                         |          |
|-----------|------|-------------------------|----------|
| Temp. °C. | $f$  | $s$                     | $S = fs$ |
| 2.5       | .373 | from analysis<br>.04390 | .0164    |
| 8.8       | .434 | .03710                  | .0161    |
| 15.5      | .499 | .03206                  | .0160    |
| 20.2      | .545 | .02955                  | .0161    |
| 25.2      | .591 | .02732                  | .0161    |
| 30.3      | .641 | .02465                  | .0158    |
| 35.1      | .687 | .02270                  | .0156    |
| NITROGEN. |      |                         |          |
| 3.5       | .372 | .02203                  | .0082    |
| 11.2      | .448 | .01820                  | .0081    |
| 15.0      | .490 | .01701                  | .0083    |
| 20.2      | .543 | .01549                  | .0084    |
| 24.2      | .593 | .01456                  | .0086    |
| 30.4      | .647 | .01322                  | .0085    |
| 35.1      | .696 | .01220                  | .0085    |
| AIR.      |      |                         |          |
|           |      | (Dittmar.)              |          |
| 3.6       | .352 | .02700                  | .0095    |
| 11.4      | .441 | .02260                  | .0099    |
| 15.0      | .476 | .02120                  | .0100    |
| 20.0      | .525 | .01930                  | .0101    |
| 25.0      | .574 | .01780                  | .0102    |
| 29.6      | .623 | .01660                  | .0103    |
| 34.3      | .672 | .01550                  | .0104    |

## VIII.—STATEMENT OF RESULTS.

From the figures given in the previous section it is possible to calculate the rate of solution of the gases dealt with, for any conditions of area exposed, depth, or degree of saturation, provided that the water is kept uniformly mixed.

The expression can be put either in the form

$$\frac{dw}{dt} = a - bw$$

which gives the rate of solution at any instant, or in the form  $w = (w_0 - w_1)(1 - e^{-bt})$ , which gives the amount dissolved at the end of any given time when  $w_0 =$  saturation value and  $w^1 =$  amount of gas in solution initially. For practical purposes it is most convenient to work in percentages of saturation; hence the latter equation becomes  $w = (100 - w_1)(1 - e^{-bt})$ , and since

$$b = f \frac{A}{V}$$

by substitution

$$w = (100 - w_1)(1 - e^{-f \frac{A}{V} t})$$

as the general equation for any given temperature, and since  $f$  varies with temperature according to the equations

$$\text{Oxygen} \quad f = \cdot 0096 (T - 237)$$

$$\text{Nitrogen} \quad f = \cdot 0103 (T - 240)$$

$$\text{Air} \quad f = \cdot 0099 (T - 239),$$

the corresponding general equation for each gas by substituting these expressions in the formulæ is obtained, thus:—

$$\text{for Oxygen} \quad w = (100 - w_1) \left[ 1 - e^{-\cdot 0096 (T - 237) \frac{A}{V} t} \right]$$

$$\text{,, Nitrogen} \quad w = (100 - w_1) \left[ 1 - e^{-\cdot 0103 (T - 240) \frac{A}{V} t} \right]$$

$$\text{,, Air} \quad w = (100 - w_1) \left[ 1 - e^{-\cdot 0099 (T - 239) \frac{A}{V} t} \right].$$

As an example of the use of these formulæ, consider the question of the dissolved oxygen in 1000 c.c.s. water, area exposed being 100 sq. cms., temp.  $2\cdot 5^\circ \text{C}$ ., and initial gas content = 40 per cent. of saturation. How much gas will be dissolved in an hour?

$$t = 60 \text{ minutes,}$$

$$w = 60 \left( 1 - e^{-\frac{\cdot 373}{10} t} \right) = 60 (1 - e^{-\cdot 222}) = 60 (1 - \cdot 1991) = 60 \times \cdot 8009 \\ = 48 \text{ per cent. of saturation.}$$

Hence after an hour the water will have risen to 88 per cent. of saturation.

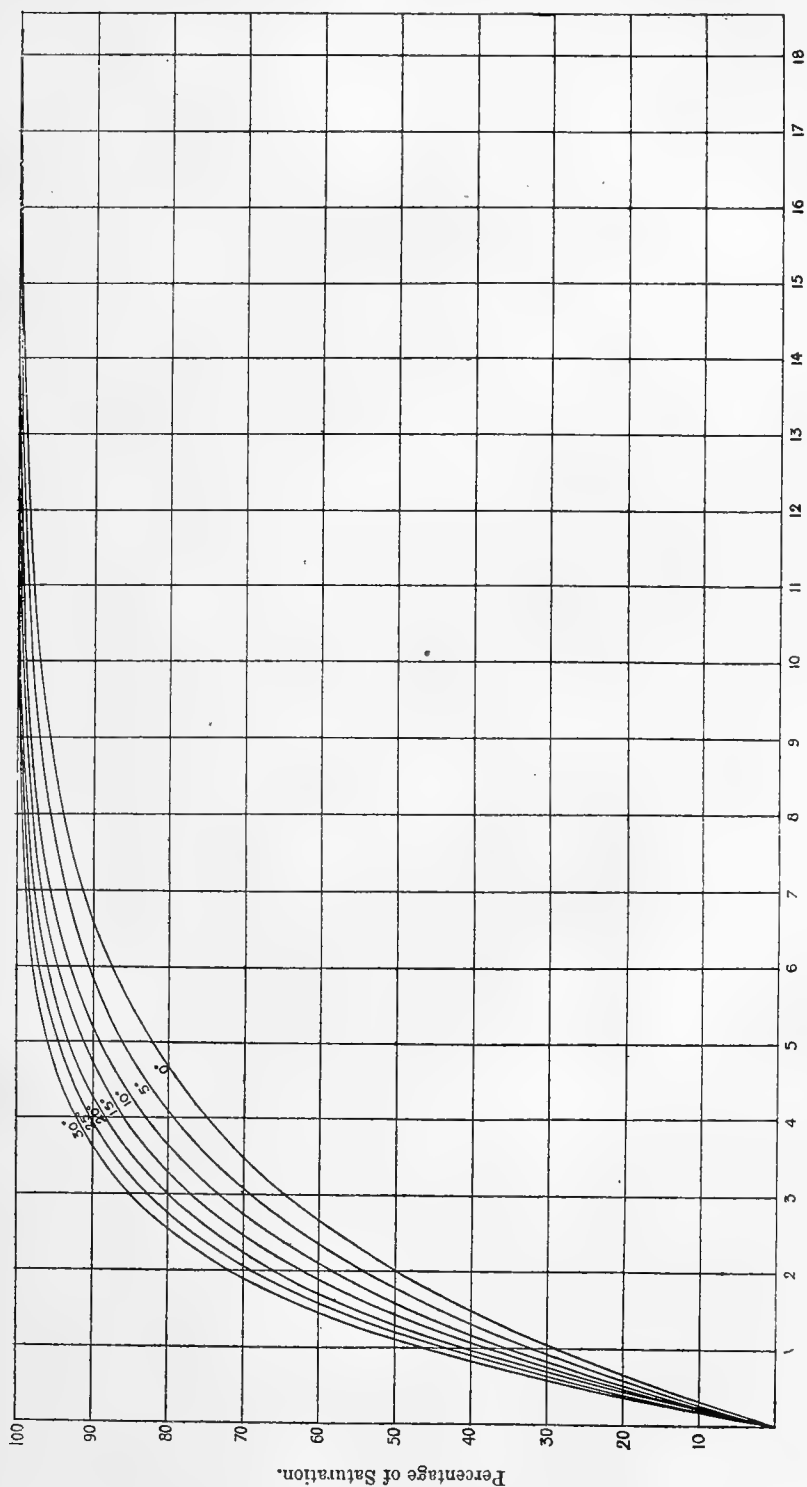


FIG. 9.—Time in Minutes.

Curves for Oxygen, showing the variation of the gas-content of the water with time.  
Volume of water 1 c.c. Area exposed 1 sq. cm.

These equations can also be used to calculate curves showing the rate of solution in water of the different gases under different conditions, and as an example the curves for oxygen between  $0^{\circ}$  C. and  $30^{\circ}$  C. have been calculated in percentages of saturation, and are shown in fig. 9. It is noteworthy that when expressed in percentages of saturation, the curves for the three gases lie very close to each other, those for oxygen and nitrogen being practically identical.

The authors desire to express again their indebtedness to Dr. Hacket (Lecturer in Physics in this College) for the interest he has taken in this investigation, and the valuable assistance he has generously given in the mathematical treatment of the subject.

CHEMICAL DEPARTMENT,

ROYAL COLLEGE OF SCIENCE FOR IRELAND.

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AN ANALYSIS OF THE PALÆOZOIC FLOOR OF  
NORTH-EAST IRELAND, WITH PREDICTIONS  
AS TO CONCEALED COAL-FIELDS.

BY

W. B. WRIGHT, B.A., F.G.S.

[COMMUNICATED BY PERMISSION OF THE DIRECTOR OF THE GEOLOGICAL SURVEY OF IRELAND.]

(PLATE LIV.—MAP.)

[*Authors alone are responsible for all opinions expressed in their Communications.*]

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## XLV.

## AN ANALYSIS OF THE PALÆOZOIC FLOOR OF NORTH-EAST IRELAND, WITH PREDICTIONS AS TO CONCEALED COAL-FIELDS.

BY W. B. WRIGHT, B.A., F.G.S.

[Communicated by permission of the Director of the Geological Survey of Ireland.]

(PLATE LIV.—MAP.)

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IN September, 1917, the Geological Survey of Ireland forwarded to the Department for the Development of Mineral Resources, Ministry of Munitions, a memorandum setting forth certain geological considerations, which point to the probable existence of extensive concealed coal-fields in the north-east of Ireland. A scheme of exploration was also outlined, and sites were selected for putting down boreholes.<sup>1</sup> As a result of this the Department decided to take action in the matter, and an agreement having been entered into with the proprietors of the mineral rights, the first bore was started on December the 17th, 1918, and arrangements are now being made with regard to a site for the second.

In the meantime new evidence has been brought to bear on the problem, and it is now considered possible not only to define more accurately the original areas in which the Survey regarded coal as likely to be found, but to extend the reasoning to the prediction of a further extensive coal-field in the north of Antrim and the adjoining portion of Londonderry. The complete discussion of the subject is set forth in the following paper.

*General Statement of the Problem.*

For the purpose of this paper it is sufficient to consider the stratified rocks of the British Isles as composed of two subdivisions to which we propose to refer for simplicity as the Palæozoic floor and the Mesozoic cover.

<sup>1</sup> This scheme, which was first outlined by the author in a lecture before the Royal Dublin Society in February, 1917, was brought to the attention of the Department for the Development of Mineral Resources by Mr. E. H. Cunningham-Craig.

It is recognized of course that these terms are not comprehensive, since the Palæozoic floor contains also metamorphic and igneous rocks, and the Mesozoic cover is itself overlain in places by Cainozoic sediments and lavas. They are, however, expressive of the fact that the British Isles are composed of a platform of older rocks on which newer strata have been laid down unconformably, and emphasize the great period of folding and denudation which separated the Palæozoic and Mesozoic Periods.

The Carboniferous strata form the uppermost member of the Palæozoic sequence. At the end of Carboniferous times came the great period of folding and faulting known as the Hercynian. The consequent uplift resulted in sub-aerial erosion and denudation, and a peneplain was cut across the upturned edges of the Palæozoic strata. The Coal Measures, being the uppermost member of the Carboniferous formation, were in general only preserved in the synclinal basins, where they escaped denudation. On this peneplain were laid down the Mesozoic and Cainozoic sediments, which at one time covered a much wider area than at present. In Miocene times there occurred another great episode of folding and faulting, with uplift and consequent denudation. This denudation stripped off a good deal of the Mesozoic cover, exposing the Palæozoic floor below and denuding it in turn.

It is important to realize that it was this latter period of denudation which was largely responsible for the difference that exists between England and Ireland as regards the scarcity of coal. It is generally considered that it was not until the Miocene period that the North Atlantic oceanic basin was formed. During the Hercynian uplift high land lay to the north and west of Ireland, which stood, relatively to the base level of erosion, in as favourable a position as England, and probably at the end of the peneplanation contained just as many coal-basins. After the Miocene uplift, on the contrary, a powerful drainage was initiated towards the Atlantic basin. At this period were formed the submerged fjords and rias of western Europe, and valleys were excavated to considerable depths below the present sea-level. These valleys have been cut in the Eocene lavas as well as in the older rocks, so that it is clear that they are not referable to any previous epoch. Ireland, being nearer the edge of the Continental shelf, suffered, as a consequence, far more heavily than England. To the Miocene denudation, therefore, we owe, not only the stripping off of the Mesozoic cover, but also the removal of much of the Palæozoic floor itself with its contained coal-basins. The practical conclusion to be drawn from this is that, where the Mesozoic cover is preserved, we might reasonably expect the Palæozoic floor to be as rich in coal-basins as it is in corresponding parts of Great Britain.

Turning now to the consideration of the problem before us, we find it is

this. We have a certain area of the Mesozoic cover preserved in the north-east of Ireland. It owes its preservation to the outpouring on its surface in Eocene times of many hundred feet of highly resistant lava-flows. Beneath it we may expect to find the Palæozoic floor in a state of preservation comparable with corresponding parts of Great Britain. We have now to consider whether there is any reason to suppose that coal-basins may occur on this portion of the floor, and if so, to try and devise means of locating them.

Previous writers on the coal-fields of Ireland have not, of course, refrained entirely from speculating on the possibility of the extension of the exposed coal-field of Tyrone beneath this area of Mesozoic rocks. Kelly in 1857<sup>1</sup> and 1868,<sup>2</sup> Hardman in 1877,<sup>3</sup> Kinahan in 1878,<sup>4</sup> Professor Cole in 1902,<sup>5</sup> Hull in 1905,<sup>6</sup> Alexander M'Henry in an unpublished report in 1906, and finally Professor Cole and Mr. Lyburn in 1913,<sup>7</sup> all discuss the question. The most general opinion seems to have been that the concealed area has no great extent, and is not likely to reach the shores of the lake. Kelly, Kinahan, and M'Henry are notable exceptions. The latter expresses his belief that Coal Measures will be found stretching from Coal Island beneath the Lough in the direction of Belfast, but gives no reasons for this belief. Kinahan believed they extended under the west side of the Lough, and occurred again to the north-east of the town of Antrim. Into his arguments I do not propose to enter here. They are not supported by facts. Kelly, on the contrary, as will appear from the passages quoted on pp. 633 and 634, fully realized the bearing on the problem of two important points; namely, that the Lowland Valley of Scotland, which contains the coal-basins of that country, is continued into Ireland, and that the synclinal basin of Lough Neagh, which is situated within it, very probably marks the site of a further extensive coal-basin. The present paper is merely an elaboration and extension of Kelly's argument.

<sup>1</sup> John Kelly: On the Subdivision of the Carboniferous Formation in Ireland. Journ. Geol. Soc. Dublin, vol. vii, p. 247, 1857.

<sup>2</sup> John Kelly: On the Geology of the County of Antrim, with parts of the adjacent Counties. Proc. Royal Irish Acad., vol x, p. 234, 1868.

<sup>3</sup> E. T. Hardman: Geology of the Tyrone Coalfield and surrounding Districts. Mem. Sheet 35 Geol. Survey of Ireland, p. 65, 1877.

<sup>4</sup> G. H. Kinahan: Geology of Ireland. London, 1878, p. 128.

<sup>5</sup> Ireland Industrial and Agricultural. Article I. Grenville A. J. Cole: The Topography and Geology of Ireland, 1902, p. 18.

<sup>6</sup> Edward Hull: The Coalfields of Great Britain. London, 1905, p. 253.

<sup>7</sup> The Coal Resources of the World. Geol. Congress, 1913. The estimate of the concealed area of the Tyrone coalfield published in this work was intentionally conservative.

*Methods available for locating concealed Coal Basins.*

Given a series of Mesozoic and Cainozoic rocks known to rest upon a varied Palæozoic floor, there are several sources from which we may obtain evidence on which to base conclusions as to the composition, structure, and form of the floor. The most obvious is to study the Palæozoic rocks in adjoining areas where they are exposed, and laying off in these areas the formations and structural lines, project them as far as we dare into the concealed areas. This has its limitations, however, for structural lines do not go on for ever, nor do they necessarily follow straight lines or logical curves which can be depended upon. We have recourse next to the principle of posthumous folding. This principle, first put forward by Godwin-Austin,<sup>1</sup> and used by him in his prediction of the Dover Coalfield, embodies the idea that the lines of folding in the newer rocks tend to follow along similar lines of folding in the older rocks of the floor, syncline generally following on syncline and anticline on anticline. I use the expression "tend to follow" with deliberation, because, to assume that every synclinal basin in the newer rocks marks the site of an older syncline in the Palæozoic floor, would be equivalent to assuming that folding never takes up new lines on the earth's surface, which is obviously absurd. Where the principle comes in most usefully is in the case in which an anticline or syncline in an exposed portion of the Palæozoic floor can be traced beneath the Mesozoic cover, and its course beneath the cover can be shown to be marked by a corresponding anticline or syncline in the Mesozoic rocks above. The further course of the post-Mesozoic fold can then be relied on to indicate with fair certainty the course of the older fold, on which it has been shown to have followed posthumously. It was a case of this kind of which Godwin-Austin availed himself in the prediction of the Dover field.

A further source from which conclusions can be drawn is the variation as regards thickness and composition in the Mesozoic sediments. Elevation along an old anticlinal axis or depression along a syncline, continued during deposition, leads in the one case to local thinning of the sediments and in the other to local thickening. Hence when we observe, in the successive members of a series of strata, either thickening or thinning, we may draw conclusions as to synclinal or anticlinal movement, which may be posthumous on an old axis of depression or elevation. Further, the coming in of coarse or conglomeratic beds in a given direction may indicate the contemporaneous

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<sup>1</sup> R. Godwin-Austin: On the possible Extension of Coal Measures beneath the South-Eastern Part of England. *Quart. Journ. Geol. Soc.*, vol. xi, p. 533, 1855, and *Rep. Coal Commission*, 1871, vol. ii, p. 424.

exposure of portion of the Palæozoic floor in that direction, even though such portion may no longer be exposed. In this way buried ridges may be located, and some idea of their composition might in certain cases be also obtained. These last methods have been employed by Professor Kendall in his speculations as to the structure of the Palæozoic floor of England.<sup>1</sup>

*The Basaltic Plateau of Antrim and the extension of the Lowland Valley of Scotland into Ireland.*

The only extensive area in Ireland where the Palæozoic rocks are concealed by a covering of newer strata is, as we have stated, the basalt plateau of the north-east, embracing portions of the counties of Londonderry, Antrim, Tyrone and Armagh. The cover in this instance consists of Cainozoic lavas and clays and Mesozoic strata belonging to the Cretaceous, Jurassic and Triassic, which have been preserved from denudation beneath the lavas. This concealed area is a rectangle about fifty miles long from north to south and thirty miles wide. The Mesozoic sediments are in general only poorly exposed around the margins of the basalt, so that little can be effected in the way of a study of their thickness and character, with a view to drawing conclusions as to the form of the floor on which they have been laid down. Fortunately the evidence from the other two sources mentioned above is remarkably good, and enables very definite conclusions to be drawn as to the areas in which concealed coalfields will most probably be found.

The most outstanding fact regarding this area is that it is traversed by the south-westerly continuation of the central trough-valley of Scotland which separates the Highlands from the Southern Uplands, and contains the valuable coalfields of Fife, the Lothians, Lanark, and Ayrshire. The extension of this remarkable feature into Ireland has long been recognized, but its bearing on the probable existence of concealed coalfields beneath the newer strata of Antrim has, I venture to think, hardly been appreciated. Kelly, writing in 1857,<sup>2</sup> has, indeed, the following remarkable passage:—

“This valley [i.e. the trough-valley of Scotland and Ireland] appears to have existed before the deposition of the Carboniferous formation, and was a natural depression, in which that formation was deposited. The S.W. strike of the valley of the Clyde is fair across the channel to the county of Antrim, where the coal rocks reappear, and no doubt are under the permian and chalk formations below the great basin of Lough Neagh. They emerge again at Coal Island in Tyrone, . . .”

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Final Report of the Coal Commission, Part ix, p. 18, 1905.

<sup>2</sup> John Kelly: On the Subdivision of the Carboniferous Formation in Ireland. Journ. Geol. Soc. Dublin, vol vii, p. 247, 1857.



And again in 1867<sup>1</sup> he says:—

“The Antrim [i.e. Ballycastle] coal district appears to be a prolongation of the coal field of the Forth and Clyde valley in Scotland. They are in the same strike and position with regard to the older adjacent rocks; and as no one can doubt that the whole of the Carboniferous formation of the British Islands was deposited at the same period, it is likely that at Antrim and Glasgow, two places not very far distant, there would be a typical likeness in the rocks which compose them both, as to lithological character and succession. The valley of the Forth and Clyde, which is in the Carboniferous rocks, may be prolonged on the map of Great Britain and Ireland. It passes through Ballycastle, across Lough Neagh, by Dungannon, Caledon, and Clogher to the Connaught coal district about Lough Allen. This shows that the limestone at Ballycastle, as well as the coal rocks there, forms a part of the great band stretching between the Firth of Forth and the Connaught coal district.”

These passages show that Kelly thoroughly appreciated the bearing of the extension of the trough-valley into Ireland on the question of the possibility of the occurrence of coal beneath the basalts. What is more, he appears to have realized that the basin of Lough Neagh was a likely point within this valley for the preservation of Coal Measures. Curiously enough, however, he failed to perceive that the Antrim [Ballycastle] coalfield lies outside the trough-valley, and belongs to a more or less distinct Carboniferous basin.

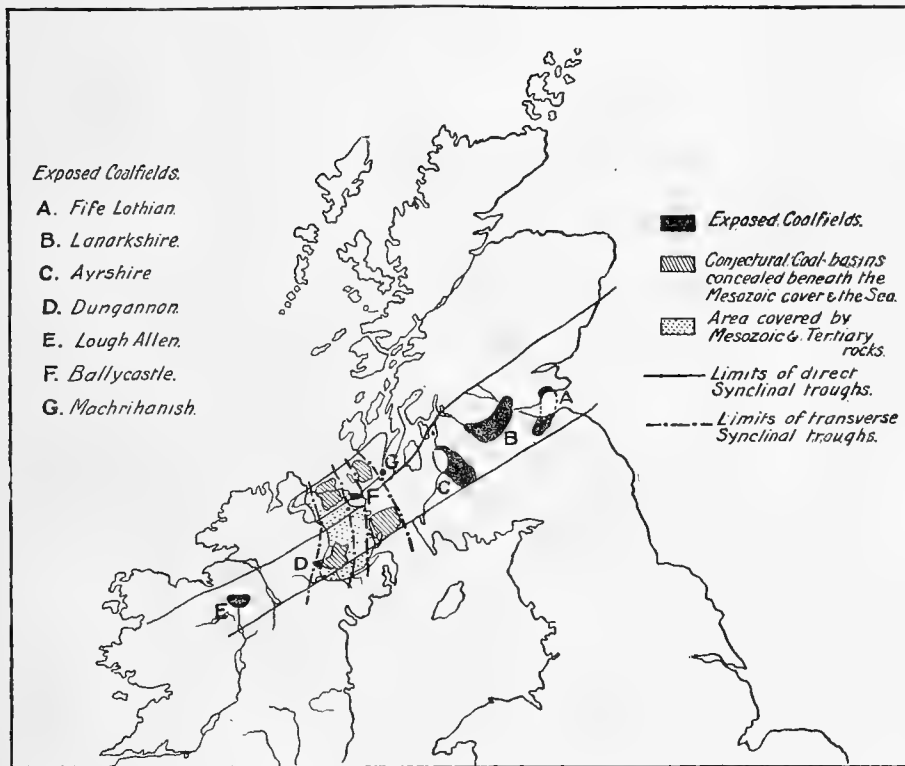
The 25-mile-to-the-inch map of the British Isles, published by the Geological Survey, shows the course of the rift-valley very clearly, from the North Sea to the Clyde, and from Dungannon south-west into the centre of Ireland. The boundaries of this trough, where seen, are lines of such remarkable straightness that it is easy to predict their course in the areas where they are concealed beneath the sea, or buried beneath newer rocks. Thus the northern boundary, where the Old Red Sandstone of the trough abuts against the Highland schists, follows a line of remarkable straightness from Stonehaven to the coast of Arran. Here it is locally deflected by the Tertiary granite intrusion of Arran, but it can be picked up again in Kintyre, where it takes a somewhat more southerly course, and at Cushendall, where it tends to resume its normal south-westerly direction before disappearing beneath the basalt plateau of Antrim. It emerges again at Draperstown, in Co. Londonderry, and is well defined throughout Co. Tyrone. Its further course towards the extreme west of Ireland is probably indicated by the southern flank of the gneissose range of the Ox Mountains.

The southern boundary, where the Carboniferous and Old Red Sandstone

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<sup>1</sup> John Kelly: On the Geology of the County of Antrim, with parts of the adjacent Counties. Proc. Royal Irish Academy, vol. x, p. 234, 1868.

are brought up against the Ordovician rocks of the Southern Uplands, and of counties Down, Monaghan, and Cavan is also remarkably straight where visible. The gap, where it is concealed beneath the sea and beneath the Mesozoic and Cainozoic rocks of Antrim, extends from the coast of Scotland to the neighbourhood of Armagh, and is much greater than in the case of the northern boundary. The continuation to the south-west of Armagh is, however, a line of remarkable straightness, which can be projected into the concealed area with a fair amount of confidence.



We are enabled, therefore, to lay off the limits of the trough-valley beneath the sea and the basalt plateau with some approach to accuracy, and the Palaeozoic floor between these limits may reasonably be expected to be composed, as it is in Scotland, on the one hand, and Ireland on the other, largely of Carboniferous and Old Red Sandstone strata. When we come to consider, however, what portions of this floor are most likely to contain coal-bearing strata, we find it necessary to further restrict the limits, for it will be seen from the 25-mile map that a wide belt along the north-western side of the trough, in the Lowlands of Scotland and in Co. Tyrone, is occupied by Old

Red Sandstone. The continuation of this belt beneath the basalt plateau of Antrim is less likely to be productive than the rest of the trough, so that it becomes necessary to draw a new line cutting off the belt of sandstone, and consider this as the north-westerly limit of probable coal-fields. In a later paragraph it will be necessary to consider the evidence in favour of a modification of this line allowing of the possible occurrence of coal-bearing strata further to the north-west; but in all preliminary exploration it should be accepted as a limit, as the probability of finding coal is undoubtedly much greater to the south of it.

*Arrangement of Coal-Basins along the Trough-Valley.*

Now, considering the lowland valley of Scotland once more, we see that the Coal Measure basins lie at intervals along it, and are separated from one another by arches of older Carboniferous and Old Red Sandstone rocks. The basin which lies nearest to Ireland, the Ayrshire coalfield, is a well-defined trough, having a north-westerly axis across the course of the central valley, and is bounded on either side by equally well-defined ridges of older rocks, having a similar trend. The other fields, the Lanarkshire and Fife and Lothian basins, are more irregular, but bear out the idea that the coal-basins are dispersed at intervals along the trough-valley of the Lowlands. We may, therefore, reasonably expect similar basins along the south-westerly continuation of this valley. Indeed, had we no further grounds for locating these basins, we should have a fair degree of probability on our side if we merely marked them off at regular intervals. We might thus locate one under the North Channel; a separating arch, possibly, under the eastern part of Antrim; and a second, of which we see the south-western edge at Dungannon and Coal Island, under Lough Neagh.

*Evidence available for locating the concealed Basins.*

There are, however, other considerations which indicate that the Lough Neagh area is one of these basins. In the first place, the Lough clearly occupies a synclinal basin in the Tertiary lavas and the underlying Mesozoic rocks, which dip in towards it on all sides. On the principle of posthumous folding, according to which the synclines and anticlines in the newer rocks tend to follow along the lines of much more pronounced synclines and anticlines in the older rocks, we would be led to expect beneath the Lough a synclinal basin bringing in the upper beds of the Carboniferous formation. The axis of this basin runs in a S.S.E. direction along the valley of the River Bann, and along the length of the Lough, towards Armagh. This axis, though it

does not maintain a constant direction throughout its course, is approximately parallel to the axis of the Ayrshire coalfield, and should be taken as the line along which the greatest thickness of Carboniferous strata is to be expected.

The nearest exposed Carboniferous strata, moreover, afford confirmatory evidence that there is a dip inwards towards the axis. This is apparent along the whole western border of the basalt plateau in the Lower Carboniferous Rocks, and, of course, in the trough-valley itself there are the Coal-Measures of Dungannon and Coal Island dipping steadily towards the Lough, and, as far as they can be seen, continually taking on higher beds in this direction.

The courses of this transverse synclinal trough and of the flanking anticlines are surprisingly well defined throughout the whole of the basaltic plateau, but more especially outside the limits of the trough-valley to the north. On the northern edge of the trough-valley the schist hills of Knocklayd and Torr Head limit it to the east, these schist hills owing their elevation and consequent exposure to the eastern limiting anticline. Similarly on the west we have the schist hills of Coolcoscreaghan and Moneyran, the eastern outliers of the Sperrin Mountains. These hill-masses are the points where the transverse anticlines intersect the schist-ridge of the Highland Larder; and in the intervening synclinal basin of the Bann this ridge is depressed, and sinks beneath the lavas and Mesozoic rocks.

#### *Course of the Western Anticline.*

The western limiting fold appears to be somewhat isoclinal in character, the dip off its eastern flank being much more pronounced than that on the west, at least as regards its effect on the Carboniferous rocks. In a broad way it appears to be responsible for the elevation of the Sperrin Mountains, which are flanked on the north-east and south-west by Carboniferous rocks, and also within the normal limits of the rift-valley itself for the exposure of the ancient gneissose axis of Tyrone and the anticlinal area of Silurian rocks at Pomeroy. All along its eastern side, from the north coast of Antrim to the Silurian rocks of Armagh, the Carboniferous strata are brought in rapidly by the dip and accompanying faulting in the direction of the Bann Valley depression. Above them follow the Mesozoic rocks and the Tertiary Lavas, with a similar but less pronounced descent in the same direction. In the southern part of the rift-valley we have on the one hand the nearly horizontal strata of the Millstone Grit forming the hills around Slievebeagh, and on the other the steeply dipping rocks of similar age in the neighbourhood of Dungannon. The further course of the fold in the Silurian strata to the south is not readily traceable.

*Course of the Eastern Limiting Anticline.*

The tracing of the eastern anticline southward from the Torr Head area is a much more difficult problem, as the older rocks do not show on this side, and we have only the much less definitely marked posthumous deformation of the lavas and Mesozoic rocks to guide us. One is tempted at first to regard this axis as parallel to the coast of Antrim, but on closer examination of the evidence this does not seem to be the case. It is a remarkable fact regarding the basalt of Antrim that the chalk is, throughout three-quarters of the periphery at least, continuously preserved beneath it. This chalk is, geologically speaking, a mere film, being seldom more than 100 feet in thickness, and only at one point reaching 200 feet. In pre-basaltic times this "film" was subjected to subaerial denudation, as is proved by its piped and flint-covered surface beneath the basalt. Nevertheless, it has not been to any extent dissected by river valleys, as the basalt does not trench down into the softer rocks beneath. This fact seems to me to indicate that it was laid down horizontally, and maintained an approximately horizontal or at the most a gently inclined position till the lavas were spread over it. If this assumption be correct, then the contours of the chalk will give an indication of the lines followed by the post-Cretaceous deformation. At the two northern angles of the basalt plateau it reaches high altitudes (750 feet to 1600 feet), where, as we have shown above, the transverse anticlines intersect the elevated axis of the Highland border. At the south-west corner it is not preserved. At the south-east corner it reaches altitudes of 650 to 720 ft. over a belt about six miles wide around Divis Mountain, due west of Belfast. This is where I consider the easterly transverse anticline intersects the escarpment over the Lagan Valley, and that escarpment lies along the margin of the southern uplands as defined by the projected edge of the trough-valley.

As regards the course of the eastern anticline between the Torr Head schist area and Divis Mountain the evidence is not quite so definite. The high levels of the chalk-outcrop along the coast as far south as Glenarm seem to indicate that the axis of elevation follows the coast for this distance. Here, however, it appears to take a slightly more southerly course, passing inland, and leaving to the east areas where the faulting and dip bring the chalk to progressively lower levels, and by the time Divis Mountain is reached its course appears to run almost due south. We have no means of tracing it further across the valley of the Lagan into the Silurian area of Co. Down.

*Course of the Bann Valley Syncline.*

As regards the course of the intervening syncline, we have a fair amount of evidence. It may be regarded as embracing on the northern coast the stretch between Downhill and White Park Bay, throughout which the chalk is at or below sea-level. The western limit is defined by the line of high hills of basalt stretching south by east from Magilligan, along the western escarpment of which the chalk occurs at heights of over 1000 feet. This is also the direction of the valley of the Bann, and appears to be the direction of the synclinal axis in this portion of the basalt plateau. The limits are next defined by the north-eastern schist hills of Cooloscreaghan and Moneyoran. South of these the course of the trough seems to swing south towards the northern end of Lough Neagh; and its western limit is here well defined by the elevated outlier of chalk on the summit of Slieve Gallion. The relatively low-lying chalk of Moneymore is to be regarded as lying within the trough.

The actual lake basin itself, being probably due to quite late subsidence along the line of the syncline, helps to indicate by its outline the actual course of the latter, which here runs first due south and then a little west of south. This is true whether we consider the present lake or its former extension as indicated by the clays. Finally, this westward deflection of the syncline is confirmed by the series of lobes and outliers of Basalt, Trias and Permian preserved in it, and extending over the Carboniferous and Silurian Rocks towards Caledon, Armagh, Markethill, and Poyntz Pass. The form and trend of the most southerly of these outliers indicate a return to a direction slightly east of south in crossing the Silurian axis.

*Existence of the Transverse Trough in Pre-Mesozoic Times.*

We have up to the present spoken of the transverse syncline mainly as affecting the Mesozoic and Tertiary rocks. It must, of course, affect to an equal extent the Palæozoic strata beneath. To be assured of the existence of a coal basin beneath, we want something more than this. We need, in fact, to know that the post-Tertiary folding and faulting along this axis are only the last manifestations of more pronounced folding in pre-Mesozoic times. Without evidence to this effect we would still have a presumption in our favour; but with it we attain to a very high degree of probability. Fortunately such evidence is forthcoming. Along the whole western margin of the basalt plateau the effect of the Bann Valley syncline on the Carboniferous strata can be clearly seen. They are brought in by both dip and faulting in the direction of this axis of depression. The dip of the Lower

Carboniferous beds along this belt can in some cases be proved to be greater than that of the overlying Mesozoic rocks, as, for instance, in the Coal Island area, where the Coal Measures have been reached by shafts sunk through the Triassic sandstones. Much of the faulting which affects the Carboniferous formation is, moreover, clearly pre-Mesozoic; and even in those cases where a fault is continued in the Mesozoic rocks, it can be shown to displace them to a much smaller extent than it does the Carboniferous strata. For example, the great fault, which limits the Coal Island field on the north, and has, according to Hardman, a throw of over 2000 feet, when continued to the east into the Mesozoic rocks and lavas, displaces them at the most about 1000 feet. The cumulative effect of the folding and faulting in the Carboniferous rocks along the western margin of the plateau is to cause them to take on cover in the direction of the Bann syncline at a much greater rate than would be the case if they were merely affected by the post-Mesozoic folding and faulting. We can see, in fact, one side of the pre-Mesozoic syncline, and are thus assured of its existence. We merely use the posthumous folding along the same line as an indication of its limits where it is concealed.

We may, therefore, take the established limits of the post-Tertiary trough to indicate the existence of an extensive coal-basin, of which we see a mere fragment in the exposed field of Coal Island. The general position and outer limits of this coal-basin have already been indicated. The centre of the basin and the greatest thickness of coal-bearing strata lie beneath Lough Neagh, where the median line of the transverse syncline crosses the trough-valley. It is situated most probably in the south-east of the trough-valley, the north-western half, which is elsewhere occupied by Old Red Sandstone, being less likely to contain Coal Measures. We have seen, however, that in this particular area the Lower Carboniferous strata transgress the area of Old Red Sandstone, and there is at least a chance that, in the very centre of the transverse syncline, the Coal Measures may do so too. Search should, however, in the first instance be confined to the south-eastern portion of the area.

It is not perhaps to be expected that the indicated area will everywhere contain Coal Measures right up to its margins. Owing to the highly faulted character of the ground, blocks of Lower Carboniferous strata will probably come to the surface of the Palæozoic floor here and there. Indeed the south-western corner of the area, which is partly exposed, contains a large proportion of these lower beds. We see therefore that to have the greatest chance of success the first bore-holes should be located as near to the centre of the depressed block as is possible under the circumstances. Were it not for the engineering difficulties, the best site for boring would be in the centre of the

lake. Failing this, it is necessary to select sites as near this ideal as possible, that is, along its shores; and before doing so it is desirable to consider the faulting of the area.

*Consideration of the effects of faulting.*

The northern limit of the Coal Island field is an E.N.E. fault having an upthrow to the north of 2000 feet, and bringing the Carboniferous Limestone into juxtaposition with the Coal Measures. This fault is continued to the north-east into the Mesozoic rocks, in which, however, it has a much smaller throw, probably not more than some 1000 feet. It is clear, therefore, that there has been movement along it at, at least, two periods, the main displacement being pre-Mesozoic, and the posthumous post-Mesozoic displacement being relatively slight. The realization of this fact is of the greatest importance, for, the greater part of the displacement having taken place previous to the pre-Mesozoic denudation, the Coal Measures will be preserved over a much wider area to the south of the fault, as indeed we see to be the case at Coal Island.<sup>1</sup> We should then in the first trials keep to the south of this fault. For instance, on the west side of the lake, Washing Bay is a better site for boring than Arboe Point, although the latter is a little nearer the centre of the trough. This is more especially the case as, on this side of the lake, there are, to the north of the Coal Island boundary fault, two other faults parallel to it, both with an upthrow to the north, so that we might expect the coal-basin to be progressively contracted towards the north.

Now, coming to the eastern side of the lake we find only one such fault, or at any rate only one has been recognized. This is the Templepatrick fault, which has a north-easterly course and an upthrow to the north of about 500 feet. This fault is in a direct line with the Coal Island boundary fault, and is believed to be a continuation of it. It should therefore, as at Coal Island, have a much greater throw in the Palæozoic rocks beneath, and Coal Measures are more likely to be preserved to the south of it. For exploration purposes, therefore, Lennymore Bay is, for instance, a better site than Ardmore Point. If coal should be found here and at Washing Bay, the exploration of the rest of the district will follow in logical sequence, which need not be elaborated at present.

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<sup>1</sup> I am indebted to Mr. Ernest Williams, Engineer to the Department for the Development of Mineral Resources, Ministry of Munitions, for bringing home to me the vital importance of this fault; and indeed the discussion of the problem as a whole owes much to his criticism.



*Possible existence of a Coalfield at Larne and beneath the North Channel.*

On page 638 it has been pointed out that the easterly bounding anticline of the Lough Neagh basin follows the coast southward as far as Glenarm, but at this point passes inland, leaving to the east an area in which the chalk is faulted down to progressively lower levels. This depressed area is probably the margin of a transverse synclinal trough similar to that of the Bann Valley and Lough Neagh, occupying the bed of the North Channel. That such a synclinal exists is borne out by the gap in the Highland border ridge between Torr Head and the Mull of Kintyre. It is impossible to go further than this in defining the course of this basin, but its western limit on the land may be taken as roughly indicated by a line joining McAuley's Head near Glenarm to Carrickfergus. In the neighbourhood of Larne there is a belt of land some five miles wide to the east of this line, and it is well worth while to consider the possibility of the occurrence of Coal Measures within this area, because of the ease with which coal could be shipped from this excellent seaport. Moreover its discovery would open up possibilities of access to an extensive field extending seaward beneath the Channel, and in the event of a tunnel to Scotland ever being constructed, it might not be beyond the skill of the engineers of that date to work the North Channel coalfield from that tunnel.

Now, as to the probability of the occurrence of coal in this area, it must be remembered that we have no evidence of its existence at all comparable to that yielded by the Lough Neagh basin. It is entirely a matter of analogy. It is true that in a boring at Duncrue, north of Carrickfergus, and just within the limits of the supposed basin, strata, which appear from the borer's description to be almost certainly Carboniferous, were found beneath the Trias at a depth of 836 feet. There is no certainty, however, that these beds belonged to the Coal Measures, but it is something to be assured of the existence of any Carboniferous beds in this position. Their presence there renders it fairly probable that some miles further into the basin at Larne or Island Magee actual Coal Measures might be found. It cannot be denied, however, that this field, if it exists, would be difficult to work on account of its highly faulted character. If explorations are ever undertaken, the first boring should be located as far to the north-east as is possible; the best site being probably the small outcrop of chalk on the coast of Island Magee opposite the Isle of Muck.

*Probability of concealed Coalfields in the North of Antrim.*

We have now discussed all the possibilities of concealed coalfields within the trough-valley. We know, however, that, to the north of the Highland border ridge, there is another coal-bearing area, of which the exposed coalfield of Ballycastle forms portion. The possibility of a concealed extension of this coalfield occurred to the mind of Alexander McHenry of the Geological Survey of Ireland, and he has suggested in an unpublished report that it will be found to the west, in the direction of Londonderry. He, however, gives no reason for this supposition, and does not suggest any means of locating the best site for exploration. An analysis of the structure of the Palæozoic floor of this part of the basalt plateau enables us to make such a prediction with a fair amount of confidence.

It should not be forgotten in connexion with the discussion of matters relating to the Ballycastle field that the coals found in it are in no sense the equivalent of the coals of Dungannon and Coal Island. The strata in which they occur are of Lower Carboniferous age, and are stratigraphically far beneath the horizon of the Coal Measures proper. These strata are, as Hull pointed out in 1871,<sup>1</sup> the equivalent of the Lower Limestone of the central parts of Ireland, and are comparable with the so-called "limestone-coals" of Scotland.

The typical Lower Limestone of Ireland is well developed at Dungannon, but when followed northward along the west side of the basalt plateau it becomes gradually intercalated with sandstones and shales, until these predominate to the almost entire exclusion of the limestone. In the Dungiven area small coal streaks also appear, and when we pass east to Ballycastle we find a sandstone and shale series, with well-developed coals, and only a few thin bands of limestone. A similar change probably takes place to the north-east of Dungannon, along the concealed trough-valley, for when we reach the Glasgow district we find a series of shales and sandstones with coals and thin limestones, which can be seen there to occupy a stratigraphical position beneath the Coal Measures and Millstone Grit, similar to that filled by the Carboniferous Limestone in Ireland.

The Ballycastle field, therefore, contains only Lower Carboniferous coals,

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<sup>1</sup> Edward Hull: On the Geological Age of the Ballycastle Coalfield and its relations to the Carboniferous Rocks of the West of Scotland. *Journ. R. Geol. Soc., Ireland*, vol. ii, pt. iii, 1871, p. 260.

and in considering the problem of a possible concealed extension of this field we have three things to think of:—

1. Where, according to the tectonic structure of the district, is such an extension likely to occur?
2. Are the coals likely to have deteriorated in this extension?
3. Are the Coal Measures proper likely to occur above the Ballycastle series in such an extension?

In the first place, it is important to realize that the exposed portion of the Ballycastle field is only a portion of a much larger field, extending to the north, beneath the sea. This fact is apparent to anyone who has examined the fine coast-sections which form its northern limit, and is borne out by the fact that a similar series with coals and limestones occurs at Machrihanish, near Campbelltown, in a position on the north side of the Highland border ridge, very similar to Ballycastle. One gets the impression, therefore, that there is an extensive coal-basin to the north-west of this ridge. In order to form an idea of its structure we must follow the ridge throughout its course, and see what takes place to the north of it.

*The Ballycastle-Dungiven and Lough Foyle Synclines.*

In the first place, the Ballycastle coalfield is in the form of a syncline, the strata dipping north off the schist ridge, and rising again towards the coast. When we pass west, across the transverse synclinal trough of the Bann Valley, to the western escarpment of the basalt plateau, we find a similar syncline lying to the north of the ridge at Dungiven. To the north of this, at Ardmore, between Dungiven and Limavady, is an anticline of schist, and then comes the larger Carboniferous syncline of Lough Foyle, bounded to the north by the schist ridge of Inishowen, the rocks of which correspond to those of Islay and Jura in Scotland. We thus get the impression of the basin, as being made up of two synclines and an intervening anticline, all with their axis parallel to the Highland border ridge, the Ballycastle syncline and the Dungiven syncline being probably portions of the same tectonic feature. Along the same line, further west, occurs the very marked synclinal Carboniferous basin of Donegal Bay, which corresponds to one or both of the Co. Derry synclines.

We have now to consider the effect on these synclinal basins where they are crossed by the transverse synclines and anticlines described above in connexion with the Lough Neagh and Larne coal-basins in the trough-valley. In the first place, it is to be noted that the Ballycastle coalfield occurs just

where the eastern limiting anticline of the Lough Neagh basin crosses the first of these synclines, that is to say, in a position where we should not expect any great thickness of strata to be preserved. This would be very remarkable if we were dealing with true Coal Measures; but, as we have already pointed out, these beds are Lower Carboniferous, and even the highest beds in Ballycastle are probably not much more than 3000 feet above the base of the formation. Two conclusions may be drawn from their occurrence in this position: first, that similar beds are likely to occur along the greater part of the Dungiven-Ballycastle syncline; and, secondly, that where that syncline is crossed by the transverse syncline of the Bann Valley much higher beds are likely to be found than those which occur at Ballycastle. The course of the area defined by the intersection of these two synclines is roughly indicated by the Ballycastle Railway between Armoy and Ballymoney, the Midland Railway between Ballymoney and Macfinn Junction, and the Derry Central Railway between Macfinn and Garvagh.

To the north of the Dungiven-Ballycastle syncline lies the Ardmore anticline. This is only exposed on the western side of the basalt, and we have to presume that its course in the concealed area is parallel to that of the Dungiven-Ballycastle syncline. It is possible that posthumous elevation along this axis has brought to their relatively elevated position the extensive areas of chalk exposed at Ballintoy and Church Bay in Rathlin. This anticline should, with certain qualifications which we shall specify later, be avoided in all preliminary exploration; but it is not unlikely that in the centre of the Bann syncline the Ballycastle coals will be found to pass over it without a break.

North of the Ardmore anticline is the Lough Foyle syncline, which, being double the width of the Dungiven syncline, shows correspondingly greater promise. Unfortunately a large part of it lies beneath the sea, and is consequently inaccessible. Its southern limit might be taken as a line joining Limavady Junction to Port Ballintrae, near the Causeway. It is thus possible to explore by boring the southern side of the syncline all along this stretch of coast, and in one place, on Magilligan sands, to get right into the heart of it. The most promising portion of this syncline is that where it is intersected by the Bann trough, so that the earliest explorations should be made along the coast between Castlerock and Bengore Head. Portrush would probably be about the best site.

*Consideration of the Effect of Faulting in Northern Antrim.*

There is a point in the structure of the Ballycastle coal-field which needs to be taken into consideration in selecting a site for exploring the basin formed

by the intersection of the direct and transverse synclines to the west. This is the occurrence of the fault known as the Great Gaw, which has an approximately east and west course from Murlough Bay to Ballycastle. This fault has an immense downthrow to the north, certainly well over 1000 feet, but probably as much as 2000 feet. All the really valuable seams occur only to the north of it. Its extension to the west from Ballycastle follows the line of the Ballycastle Railway for about two miles, and then turns west again by Moss-side towards Coleraine. In this part of its course it serves to bring in the area of Upper Basalt between Coleraine and Ballycastle. Its throw in the Mesozoic and Tertiary rocks is not so great as in the Carboniferous. Thus at Murlough Bay it only displaces the chalk about 100 feet. South-west of Ballycastle it has a downthrow of about 700 feet to the north-west, as shown by the displacement of the chalk and basalt. Further west its throw is difficult to determine, but is probably not as great as this. It is clear, however, that the post-Basaltic displacement is only the result of posthumous movement along the fault, and probably indicates a much greater throw in the Carboniferous beds beneath. The main portion of the displacement, having therefore taken place previously to the pre-Mesozoic denudation of the Palæozoic floor, tends to the preservation of a greater thickness and area of coal-bearing strata to the north. A similar incoming of higher Carboniferous strata probably accompanies the parallel fault running from White Park Bay to Port Ballintrae, which also has a downthrow to the north. These faults, it will be noted, are not parallel to the Dungiven-Ballycastle and Lough Foyle synclines, but cross them obliquely in exactly the same manner as the Coal Island and Templepatrick fault and those parallel to it cross the trough-valley. In this instance, however, they have downthrows to the north, so that it is desirable, having due consideration for the other factors involved, to keep as far north as possible in all preliminary explorations. This makes the northern or Lough Foyle syncline a decidedly better proposition than the Dungiven-Ballycastle one. It also makes it worth our while to consider the anticlinal area between Coleraine and Ballintoy as a possible coal-bearing area.

As regards the Dungiven-Ballycastle syncline, which lies, except in the northern part of the Ballycastle field, to the south of the fault, I am nevertheless inclined to take a very optimistic view; for although the strata seen in this syncline at Dungiven, and at Ballycastle to the south of the fault, contain only small coals, and are stratigraphically undoubtedly beneath the richer seams, yet, if we can judge from what takes place at Coal Island, covering strata will be taken on at such a rate when we pass into the area of intersection with the Bann transverse trough, that the higher beds containing the thicker seams are very likely to be preserved,

*Possibility of deterioration of the Lower Carboniferous Coals  
to the South-West.*

We have yet to consider whether there is any chance of the deterioration of the Ballycastle coals either in quality or thickness as they pass south-west into these predicted areas, and it has to be admitted at once that there is a distinct chance of this. I do not consider that much is indicated by the fact that the seams in the Carboniferous rocks exposed at Dungiven are mere coal-smuts, because they are in the very lowest beds of the formation, and the same might be said of the lower strata of the Ballycastle coalfield. We must remember, however, that between Ballycastle and Dungannon there is a gradual passage from estuarine to clear-sea conditions, and that in proportion as the estuarine conditions are replaced the coal must fail. At Maghera, just south of the Highland border ridge, there is still a fairly thick mass of the Lower Limestone above the sandstone and shale series, and we cannot see what happens to the north-east of this. We can only hope that perhaps the Highland border ridge itself has in some way formed a line of demarcation between the predominantly estuarine conditions on the north and the predominantly open sea conditions on the south. Again, in view of this possibility of deterioration I see a preference in favour of the Lough Foyle syncline as compared with the Dungiven-Ballycastle syncline.

*Possibility of the occurrence of true Coal Measures in N. Antrim.*

No strata of Upper Carboniferous age are known anywhere within the North Antrim basin, but this is hardly to be wondered at in view of the very few exposures even of the Lower Carboniferous. The latter strata we know were deposited here, and we can prove their continuity with the Lower Carboniferous strata of the trough-valley by the series of exposures along the western margin of the basalt plateau. If the sea in which the Lower Carboniferous beds were laid down did not everywhere cover the Highland border ridge, it at least broke through it in one place and occupied the basin to the north. Now the Coal Measures are everywhere conformable to the Lower Carboniferous, so that it is highly probable that the estuarine waters in which they were deposited covered the same area as the Lower Carboniferous sea, and even, in view of the progressive submergence during Carboniferous times, a much greater area. We may therefore assume that the North Antrim basin once contained Coal Measures, and it remains to be considered whether any of them have escaped the pre-Mesozoic denudation and are preserved as portion of the Palæozoic floor.

Now, once more reverting for purposes of comparison to the Coal Island

district, as being the only place along the margin of the Bann transverse syncline where we can see the Coal Measures, we find that by means of dip and faulting we can pass from the very base of the Carboniferous to areas where the Coal Measures are preserved in the fault blocks in a distance of about eight miles. This rate of taking on cover is the only measure we have of the rate of the descent towards the centre of the Bann syncline. It is estimated parallel to the trough valley; so that any dip or faulting downwards from the sides of the latter towards the centre is left out of account. Now, applying this to the North Antrim basin, we find, to say the least of it, that there is a considerable area in the centre of the Bann transverse syncline where true Coal Measures may be expected to occur at the points of intersection with the direct synclines. This may sound rather speculative, but it should be remembered that it is not proposed to bore here in search of true Coal Measures, but for the Lower Carboniferous coals, the probability of the occurrence of which is on a different plane altogether. Should the true Coal Measures occur, or should even the higher beds of the Lower Carboniferous Series be present, the area might be many times richer than any estimate from the known seams of Ballycastle would indicate. Should there be no seams in the area but what are found at Ballycastle, nevertheless the Main Coal, the Hawks Nest Coal, and the Blackband Ironstone are in themselves well worth searching for.

*Effect of the North Channel Trough on the North Antrim Field.*

The N.N.W. faults which cross the Ballycastle field and are well seen in the fine coast-sections have almost all their up-throw to the east. The result of this is that the Main Coal, which is 260 feet below sea-level near Ballycastle, is 400 feet above it south of Fair Head. This is the crest of the rise, however, for on the east side of the Head there is a powerful fault throwing down to the east. I take this to be the first of a series of faults similar to those in the Larne district, by which the descent into the transverse synclinal basin of the North Channel is brought about; and I would expect that no very great distance out to sea to the north-east of Murlough the Main Coal must again occur at low levels beneath the sea, and that still higher strata and possibly even the Coal Measures may be found forming the floor of the Channel in this direction. I do not think that this conclusion is of any economic importance, for, to reach this area from the land, a highly faulted region would have to be traversed, involving difficulties in working which would most certainly be fatal to any enterprise of the kind. Moreover, I hardly fancy a tunnel will ever be run from Fair Head to the Mull of Kintyre, as neither place could be described as a desirable destination.

*Summary of Conclusions.*

We have thus found by studying the structure of the Palaeozoic floor outside the basalt plateau of north-eastern Ireland, projecting the lines of folding and faulting into the interior of the plateau and correlating them with lines of posthumous folding and faulting in the lavas and Mesozoic rocks, that there are three principal areas where coal-bearing strata may be expected to occur. These lie at the intersections of the transverse synclinal troughs of the Bann Valley and North Channel with the trough valley and the parallel synclines to the north of the Highland border ridge. The chief of these doubly depressed basins is undoubtedly that beneath Lough Neagh. We already know that it contains Coal Measures, and our analysis merely helps to show the probable extent of these, and indicate the localities where boring is most likely to be successful. The seams which have been worked near their outcrops at Coal Island are numerous, of considerable thickness, and for the most part of excellent quality. There are altogether twelve seams of 2 feet and over, aggregating altogether 43 feet of coal in 900 feet of strata in the upper series of coals, and lower down two coals of over 4 feet at considerable intervals. This is undoubtedly an exceptionally rich series of coals; and if they are found over even a quarter of the area which the analysis seems to indicate, the resulting output will be sufficient to revolutionize the whole industrial life of Ulster. One thing only seems to mar the splendour of the prospect. The exposed portion of the field is greatly broken up by faults, and a faulted field is difficult to work at great depths. Mr. Williams, engineer to the Department for the Development of Mineral Resources, is, however, of opinion, and I concur with him in this, that the faulting will be far less severe and complicated in the middle of the basin than it is at the margin.

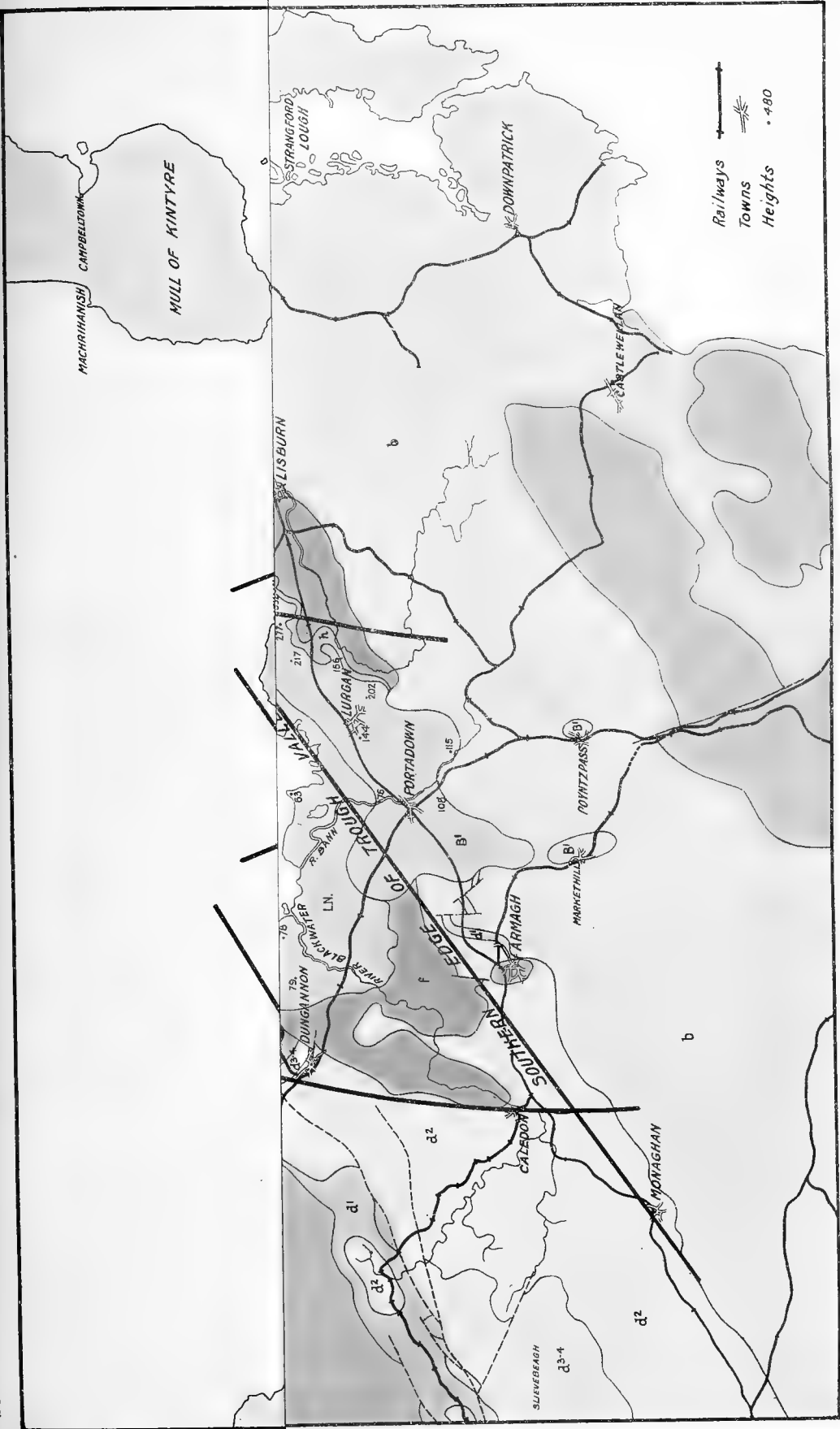
The area of Larne, where there is a possibility of the occurrence of Coal Measures, is also highly faulted, and as here it is impossible to get beyond the margin of the trough, the likelihood that this field can be developed in the near future is not so great. In this connexion it should, however, be kept in mind that Carboniferous strata appear to have been reached at a depth of only 836 feet north of Carrickfergus.

The North Antrim field does not promise a richness at all comparable with that of the Lough Neagh basin, unless, indeed, it is found that the Coal Measures proper are preserved there as well as the limestone coals. However, even if only these latter are found, the presence of a four-foot seam of as good quality as the Main Coal of Ballycastle over the very considerable area indicated by the geological evidence would amply repay exploitation. It



should also be remembered that the Ballycastle section may represent merely the lower portion of the limestone coal series, so that there is a fair likelihood that other seams may be discovered.

Should success attend the present operations in the neighbourhood of Lough Neagh, there can be little doubt that the exploration of the other areas will follow without much difficulty. In the event of their failure from one cause or another, it is well in conclusion to issue a word of warning. Two holes should not be regarded as sufficient evidence on which to condemn the search as hopeless. To the individual the expense of deep boring may seem great; but from a national point of view it is, in comparison with the issues involved, almost negligible. This is not an occasion on which to enter into the relative merits of State and individual enterprise; but it should be remembered that there are more things to follow on the discovery of extensive coalfields in Ireland than a mere accession of wealth to certain landowners and capitalists.

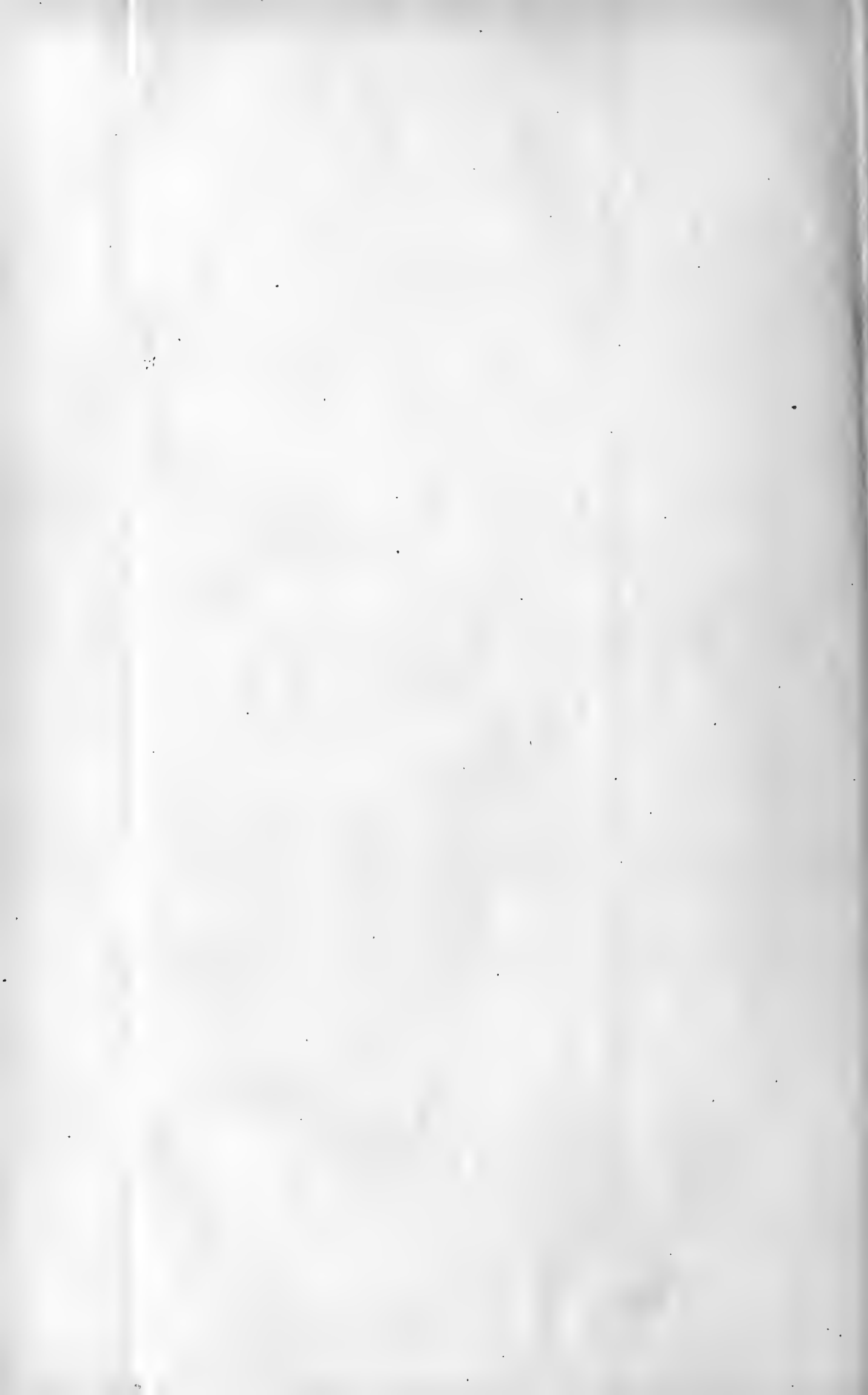


Geological Map, illustrating the probable location of concealed Coalfields in the North-East of Ireland. The black lines show the more or less conjectural limits of the synclinal troughs, at the intersection of which coal-basins are expected to occur.

WRIGHT: PALEOZOIC FLOOR OF N. E. IRELAND.







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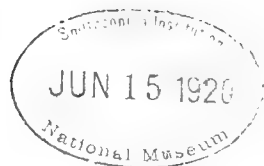
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ON SOME FACTORS AFFECTING THE CONCENTRATION OF ELECTROLYTES IN THE LEAF-SAP OF *SYRINGA VULGARIS*.

BY

T. G. MASON, Sc.B., M.A.



[*Authors alone are responsible for all opinions expressed in their Communications.*]

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## XLVI.

ON SOME FACTORS AFFECTING THE CONCENTRATION OF  
ELECTROLYTES IN THE LEAF-SAP OF *SYRINGA VULGARIS*.

BY T. G. MASON, Sc.B., M.A.

Read NOVEMBER 25. Published DECEMBER 12, 1919.

CONSIDERABLE fluctuations in the concentrations of electrolytes, as shown by conductivity observations, have been recorded by Dixon and Atkins (4) in the leaf-sap of *Syringa vulgaris* from different localities. It was hoped that a more extended examination might throw some light on the factors responsible for these fluctuations, and possibly contribute something to an appreciation of their physiological significance. A distinction between the electrolyte content and ash content must be drawn, since the former is mainly due to inorganic salts in solution in the cell-sap, whereas the latter embraces not only the mineral elements in solution in the sap, but also those constituents which have been removed from solution in the course of metabolism.

Some doubt was felt as to the value of observations of the conductivity of the sap as a means of determining the amount of electrolytes present, unless the effect of viscosity was taken into consideration. Consequently some preliminary experiments on this subject were undertaken.

It has been established that for most organic solvents the mobility of the ion varies inversely with the viscosity; and though this is only approximately true for salts in aqueous solution, it is clear that allowance for this factor would add considerably to the precision with which the amount of electrolytes in the sap could be determined. In order to gauge the value of this relationship for the sap, the following experiments were made:—

*Method.*

The method adopted was to observe the conductivity of a certain concentration ( $\frac{N}{10}$ ) of potassium chloride dissolved in the sap, and by comparing this with the conductivity of the same concentration in aqueous solution the loss due to the viscosity of the sap could be determined.<sup>1</sup> A viscosimeter of the Ostwald type was employed in making determinations of the viscosity of the sap; the results of these determinations are expressed as relative viscosities.

<sup>1</sup> This is not strictly true, since ( $\frac{N}{10}$ ) potassium chloride is not as completely dissociated in the sap; the magnitude of this error will depend on the concentration of potassium and chlorine ions present in the sap.

For observing the electrical conductivities a Kohlrausch apparatus (by Kohler of Leipzig) was used. Both viscosity and conductivity determinations were made at 0° C.

Dixon's (5) thermo-electric method was employed to ascertain the freezing-points of the sap.

*The Application of the Viscosity Correction to the Conductivity of the Leaf-Sap of Aucuba japonica.*

In Table I the results are recorded of an experiment which was carried out on the leaf-sap of *Aucuba japonica*. The leaves from which the saps were extracted were gathered from shrubs growing in the Botanical Gardens and grounds of Trinity College, Dublin, the former located in the inner suburbs and the latter in the city. Experiments 1-6 were made on leaves from the College grounds, and 7-9 from the Botanical Gardens. In order to render the protoplasm permeable, the leaves were frozen at approximately -16° C; the sap was then extracted by pressing the leaves between silver discs.

About 350 c.c. were extracted for each experiment; after filtration, which occupied several hours, 1.8625 gm. of potassium chloride was dissolved in 250 c.c. of the sap; an aqueous solution of this concentration ( $\frac{N}{10}$ ) has a conductivity at 0° of 0.00715. In Table I the following nomenclature has been employed:—

$V$  = the relative viscosity of the sap.

$C_s$  = the conductivity of the sap.

$C_{s+KCl}$  = the conductivity of the sap in which the potassium chloride was dissolved.

$C_{KCl}$  = the conductivity shown by the potassium chloride dissolved in the sap, and is numerically equal to  $C_{s+KCl} - C_s$ .

$C_{KCl}^v$  =  $C_{KCl}$  after the application of the linear correction for the viscosity of the sap, and should, if the correction is justified, approximate to the conductivity of an aqueous decinormal solution of potassium chloride, viz., to 0.00715.

$C_s^v$  = the conductivity of the sap to which a similar correction for viscosity has been applied.

$\Delta_e$  = the depression of the freezing-point, which would be produced by a potassium chloride solution, having a conductivity equal to that of  $C_s^v$ , thus affording an *approximate* index of the contribution of the electrolytes to the total depression, and so of course to the osmotic pressure.

$\Delta$  = the depression of the freezing-point of the sap.

$\Delta - \Delta_e$  = the depression due to the non-electrolytes of the sap, e.g. sugars.

The value of the viscosity correction may be seen from an inspection of the conductivities recorded under  $C_{KCl}^v$ ; the mean of this column is 0.00695, and the maximum deviation + 0.00044.

TABLE I.  
*Aucuba japonica*, July, 1919.

| No. of Exp. | $V$  | $C_s$<br>$\times 10^5$ | $C_{s+KCl}$<br>$\times 10^5$ | $C_{KCl}$<br>$\times 10^5$ | $C_{KCl}^v$<br>$\times 10^5$ | $C_s^v$<br>$\times 10^{5-}$ | $\Delta_e$ | $\Delta - \Delta_e$ | $\Delta$ |
|-------------|------|------------------------|------------------------------|----------------------------|------------------------------|-----------------------------|------------|---------------------|----------|
| 1           | 1.17 | 450                    | 1017                         | 567                        | 663                          | 526                         | 0.263°     | 0.556°              | 0.819°   |
| 2           | 1.28 | 364                    | 912                          | 548                        | 701                          | 466                         | 0.233°     | 0.735°              | 0.968°   |
| 3           | 1.29 | 350                    | 860                          | 510                        | 659                          | 451                         | 0.225°     | 0.691°              | 0.916°   |
| 4           | 1.31 | 339                    | 891                          | 552                        | 723                          | 444                         | 0.222°     | 0.773°              | 1.005°   |
| 5           | 1.34 | 345                    | 1093                         | 498                        | 667                          | 462                         | 0.230°     | 0.853°              | 1.083°   |
| 6           | 1.35 | 346                    | 864                          | 518                        | 699                          | 467                         | 0.233°     | 0.861°              | 1.094°   |
| 7           | 1.37 | 317                    | 816                          | 499                        | 685                          | 434                         | 0.217°     | 0.930°              | 1.147°   |
| 8           | 1.41 | 312                    | 819                          | 507                        | 715                          | 440                         | 0.220°     | 0.909°              | 1.129°   |
| 9           | 1.41 | 325                    | 849                          | 524                        | 739                          | 458                         | 0.229°     | 0.931°              | 1.160°   |

A tendency for the electrolyte content of the sap ( $\Delta_e$ ) to diminish as the concentration of non-electrolytes ( $\Delta - \Delta_e$ ) increases may be also noticed.

*The Nature of the Non-Electrolytic Solutes of the Sap.*

In order to ascertain the part played by electrolytes and non-electrolytes in the production of osmotic pressure, Dixon and Atkins (4) determined both the freezing-points and conductivities of the sap. They were thus enabled, by assigning a depression of the freezing-point which a potassium-chloride solution having a conductivity equal to that shown by the sap would produce, to determine approximately the contribution of the electrolytes and non-electrolytes to the total depression.

Chandler (3) adopted a similar method in order to discriminate between the electrolytes and non-electrolytes of the cell, but also endeavoured to ascertain the nature of the contribution of the sugars to the total depression of the sap. He found that generally more than half the depression of the sap was due to neither electrolytes nor sugars. Unfortunately he omitted in estimating the electrolytes to make any allowance for the viscosity of the sap; had this been done, there can be little doubt that his estimate of the part played by the electrolytes would have been considerably augmented.

In Table I a more accurate estimate of the contribution of the electrolytes ( $\Delta_e$ ) to the total depression of the sap has been determined, so that it

is possible to consider to what extent the freezing-points recorded under  $\Delta - \Delta_e$  are due to sugars. A  $n$  one per cent. sucrose solution has a freezing-point of  $-0.054^\circ$ , whereas a 1 per cent. solution of dextrose or levulose has one equal to  $-0.106^\circ$ . In Expt. 9 of Table I it will be seen that  $\Delta - \Delta_e = 0.931^\circ$ ; a depression of this magnitude would be produced by approximately a 12 per cent. solution of mixed sugars (6 per cent. sucrose and 6 per cent. hexoses). So far as the writer can ascertain, sugars in concentrations approaching this have never been encountered in the leaf-sap.

It would appear, therefore, that Chandler was at least partially correct, and consequently it must be assumed on this line of argument that the freezing-points shown under  $\Delta - \Delta_e$  are not mainly due to sugars, but are due to solutes, whose presence in the sap has been hitherto apparently unsuspected.

With a view to ascertaining if a sugar solution, with a depression of the freezing-point equal to that shown by  $\Delta - \Delta_e$ , could produce a viscosity equivalent to that recorded for the sap, a few determinations were made of the relative viscosities at  $0^\circ$  of some equimolecular sugar solutions.

TABLE II.

| Sugar     | No. of gms.<br>per<br>100 gms. water | $\nu$ | $\Delta$<br>approximately |
|-----------|--------------------------------------|-------|---------------------------|
| Sucrose,  | 15.000                               | 1.49  | 0.78                      |
| Maltose,  | 15.000                               | 1.48  | 0.78                      |
| Dextrose, | 7.895                                | 1.21  | 0.78                      |

An inspection of Tables I and II clearly shows that mixed sugars [sucrose, maltose, and the hexoses] in concentrations equivalent to  $\Delta - \Delta_e$  are capable of producing viscosities as great as those observed in the sap. Viscosity observations alone, therefore, give no reason to suspect that solutes other than sugars are concerned in the production of the depressions recorded under  $\Delta - \Delta_e$ .

The discrepancy between the concentrations of sugars which chemical analysis reveal, and that indicated by  $\Delta - \Delta_e$ , is probably to some extent to be explained as follows:—In assigning a depression of the freezing-point to the conductivity of the sap it has been assumed that the salts and acids in solution in the cell-sap are not only dissociated to the same extent as potassium chloride, but that their ionic mobilities are of the same magnitude; these assumptions are, as Miss Haynes (6)<sup>1</sup> points out, not justified.

<sup>1</sup> Miss Haynes' paper only came to hand when this work was ready for press.

The depressions recorded under  $\Delta_e$  in Table I, so far as affected by these considerations, are too low, and that of the non-electrolytes correspondingly high. It is clearly impossible to apply a correction for these factors without a knowledge of the nature and concentrations of the sap ions. The error thus introduced into work of a comparative nature on the leaf-sap of a single species is not, it is believed, of the first importance. The results obtained by the adoption of this method of discriminating between the part played by electrolytes and non-electrolytes are, however, necessarily of a preliminary nature.

*The Application of the Viscosity Correction to the Conductivity of the Leaf-Sap of Syringa vulgaris.*

In Table III are recorded the results of some experiments which were carried out on *Syringa vulgaris* in order to determine the validity of the application of the linear viscosity correction to the conductivity of the sap of this plant. The material for the first five experiments was gathered from trees growing in the grounds, and the last two in the Botanical Gardens of Trinity College, Dublin.

TABLE III.  
*Syringa vulgaris*, June-July, 1919.

| No. of Exp. | $V$  | $C_s$<br>$\times 10^5$ | $C_{s+KCl}$<br>$\times 10^5$ | $C_{KCl}$<br>$\times 10^5$ | $C_{KCl}^v$<br>$\times 10^5$ | $C_s^v$<br>$\times 10^5$ | $\Delta_e$ | $\Delta - \Delta_e$ | $\Delta$ |
|-------------|------|------------------------|------------------------------|----------------------------|------------------------------|--------------------------|------------|---------------------|----------|
| 1           | 1.44 | 1002                   | 1493                         | 491                        | 707                          | 1443                     | 0.695      | 0.740               | 1.435    |
| 2           | 1.44 | 1113                   | 1600                         | 487                        | 701                          | 1603                     | 0.772      | 0.696               | 1.468    |
| 3           | 1.51 | 812                    | 1300                         | 488                        | 737                          | 1227                     | 0.591      | 0.862               | 1.353    |
| 4           | 1.56 | 898                    | 1367                         | 469                        | 732                          | 1464                     | 0.705      | 0.754               | 1.459    |
| 5           | 1.57 | 923                    | 1391                         | 468                        | 735                          | 1449                     | 0.698      | 0.804               | 1.502    |
| 6           | 1.65 | 835                    | 1279                         | 444                        | 733                          | 1378                     | 0.664      | 0.984               | 1.648    |
| 7           | 1.75 | 793                    | 1240                         | 447                        | 782                          | 1388                     | 0.669      | 1.156               | 1.825    |

As in *Aucuba japonica* (Table I), the concentration of electrolytes [ $\Delta_e$ ] tends to diminish with a rise in the non-electrolyte content [ $\Delta - \Delta_e$ ]. It will be seen also that the sap extracted from leaves from the Botanical Gardens has somewhat higher viscosity and non-electrolyte content, and a smaller concentration of electrolytes than that from the grounds of the College.

A tendency to over-correction is shown by the figures recorded in the  $C_{KCl}^v$  column. [Conductivity of  $\frac{N}{10}$  aqueous  $KCl = .00715$ ].

TABLE IV.  
*Syringa vulgaris.*

| Locality                                     | Date        | Time      | Exposure                  | V    | C<br>× 10 <sup>5</sup> | C <sup>3</sup><br>× 10 <sup>5</sup> | Δ     | Δ <sub>e</sub> | Δ - Δ <sub>e</sub> |
|--|-------------|-----------|---------------------------|------|------------------------|-------------------------------------|-------|----------------|--------------------|
| The Grounds of<br>Trinity College,<br>Dublin | August 29th | 7.20 p.m. | N.                        | 1.61 | 1122 (15)              | 1804 (14)                           | 1.655 | 0.896          | 0.759              |
|  | Sept. 9th   | 5.30 p.m. | S.                        | 1.73 | 1041 (14)              | 1783 (13)                           | 1.737 | 0.886          | 0.851              |
| Botanical Gardens                            | August 29th | 6.30 p.m. | S.                        | 1.63 | 1147 (16)              | 1869 (16)                           | 1.517 | 0.928          | 0.589              |
|  | Sept. 9th   | "         | S.                        | 1.86 | 996 (13)               | 1842 (15)                           | 1.730 | 0.915          | 0.815              |
| Scalp  | August 29th | 6.30 p.m. | S.                        | 1.69 | 975 (12)               | 1647 (12)                           | 1.643 | 0.818          | 0.825              |
|  | Sept. 2nd   | 4.30 p.m. | S.W.                      | 1.97 | 802 (9)                | 1584 (10)                           | 1.630 | 0.791          | 0.841              |
|  | Sept. 9th   | "         | N.E.                      | 1.71 | 942 (11)               | 1611 (11)                           | 1.508 | 0.800          | 0.708              |
|  | Sept. 9th   | 6.30 p.m. | N.<br>top of tree<br>S.E. | 2.14 | 702 (7)                | 1502 (7)                            | 1.746 | 0.745          | 1.001              |
| Milltown                                     | August 29th | 6.10 p.m. | W.                        | 1.89 | 652 (6)                | 1232 (1)                            | 1.652 | 0.612          | 1.040              |
|  | August 29th | "         | W.<br>shaded              | 1.61 | 807 (10)               | 1299 (4)                            | 1.928 | 0.645          | 0.883              |
| Island Bridge                                | August 29th | 5.20 p.m. | N.                        | 2.44 | 511 (1)                | 1247 (2)                            | 1.932 | 0.619          | 1.313              |
|  | August 29th | "         | S.                        | 2.43 | 526 (3)                | 1278 (3)                            | 1.918 | 0.635          | 1.283              |
|  | Sept. 9th   | 5.30 p.m. | S.                        | 2.45 | 631 (5)                | 1545 (8)                            | 1.783 | 0.767          | 1.016              |
|  | Sept. 10th  | "         | N.                        | 2.64 | 521 (2)                | 1375 (5)                            | 1.776 | 0.683          | 1.093              |
|  | Sept. 10th  | 11 a.m.   | S.                        | 2.70 | 584 (4)                | 1577 (9)                            | 1.924 | 0.788          | 1.136              |

The figures in brackets indicate the order of magnitude of the conductivities.

As this matter is more fully dealt with in subsequent experiments, it is possible to proceed now to a consideration of the nature and magnitude of the fluctuations in electrolyte content encountered in the leaf-saps of a number of *Syringa vulgaris* trees growing in different parts of the County Dublin, and to briefly describe the five localities referred to in Table IV.

*On the Variations in the Concentration of Electrolytes in the Leaves of Syringa vulgaris.*

Of these areas, only the grounds and Botanical Gardens of Trinity College are exposed to town conditions; the latter is not exposed to quite the same amount of smoke as the former, but in both cases there is of course a considerable reduction in the intensity of the light available for carbon assimilation.

The third area, the Scalp, is situated among the hills about ten miles south of the city; carbon assimilation may be here possibly somewhat limited by the temperature.

The Milltown and Island Bridge areas are both a few miles outside Dublin, and neither is exposed to the smoke of the city.

A survey of the figures recorded in the two conductivity columns [ $C$  the observed conductivity, and  $C^v$  the conductivity corrected for the viscosity] indicates that though the application of the viscosity correction has considerably altered the ratios, yet the order of magnitude [in brackets] of the conductivities has been only very slightly changed. It would seem from this that for comparative results, where the fluctuations are marked, the viscosity correction may be dispensed with.

It should be pointed out, however, that the corrected conductivities [ $C^v$ ] are somewhat too high; this is especially so in the Island Bridge samples. The magnitude of the over-correction will be subsequently indicated.

If the results recorded for the five areas be compared, it will be seen that those areas where a high non-electrolyte content prevails in the leaf-sap usually show a relatively low concentration of electrolytes. It may be also noticed that a similar tendency is encountered among the saps of individual areas. The Island Bridge results are, however, in this respect exceptional.

*The part played by the Colloids of the Sap in Retarding the Mobility of the Ions.*

The tendency to over-correction, to which the application of the linear viscosity-conductivity correction leads, is a subject which must now be referred to.

As a precipitate of gums was thrown down, on adding basic lead acetate or alcohol to the filtered sap, it seemed probable that the overcorrection might



be due to the presence of colloids, which, though raising the viscosity, at the same time failed to retard the movement of the ion to a corresponding extent.

An experiment carried out with a gum arabic sol will make the meaning of this clear. The conductivity of a decinormal solution of potassium chloride in the sol is shown in Table V under  $C_{KCl}$ ;  $C_g$  represents the conductivity shown by the sol, and  $C_{g+KCl}$  that of the sol to which the salt was added. The viscosities of the sol, one and four hours respectively after its preparation, are shown in the first two columns, and that after the addition of the potassium chloride in the third column. If the viscosity of the sol after the addition of the salt were inversely proportional to its conductivity, then the application of the linear viscosity correction should raise the conductivity shown by the potassium chloride in the presence of the colloid to 0.00715 [the conductivity of a decinormal aqueous solution of potassium chloride].

TABLE V.

| $V_g$<br>after 1 hour | $V_g$<br>after 4 hours | $V_{g+KCl}$<br>after addition<br>of $KCl \left(\frac{N}{10}\right)$ | $C_g$<br>$\times 10^5$ | $C_{g+KCl}$<br>$\times 10^5$ | $C_{KCl}$<br>$\times 10^5$ | $C_{KCl}^v$<br>$\times 10^5$ |
|-----------------------|------------------------|---|------------------------|------------------------------|----------------------------|------------------------------|
| 2.46                  | 2.68                   | 1.53  | 30                     | 698                          | 668                        | 1622                         |

That this figure is greatly exceeded is shown in the last column, thus demonstrating that the mobility of the ion has not been greatly retarded. It will have been noticed that an increase took place in the viscosity of the sol with age, and a decrease on the addition of the potassium chloride; as these are both characters shown by the majority of emulsoids, comment is unnecessary. It is well to remember when considering the large viscosities shown by the saps from Island Bridge that, unlike molecular solutions, great changes in the viscosity of emulsoid sols [*e.g.*, gum sols] may be brought about by a very small increase in concentration; in these cases a considerable over-correction may occur. Attention may be also drawn to the clumping of colloids by metallic ions, which takes place in nearly all saps after extraction; that electrolytes are concerned in this coagulation, and that it is the gums which are mainly acted on is indicated by the continued precipitation which takes place after killing the enzymes by boiling and filtering off the coagulated albumen.

An experiment recorded in Table VI will illustrate the insignificance of albumen as a factor in raising the viscosity of the sap. The sap was pressed from leaves taken from a tree growing at the Scalp.

TABLE VI.

| Viscosity      |                            |                  | Conductivity $\times 10^5$ |                            |
|----------------|----------------------------|------------------|----------------------------|----------------------------|
| After pressing | After pressing and boiling | After three days | After pressing             | After pressing and boiling |
| 1.97           | 1.96                       | 1.68             | 802                        | 805                        |

It will be seen that the loss in viscosity after the precipitation of the albumen by boiling is quite small. The decrease shown after three days is, doubtless, mainly associated with the clumping of the colloids, and to some extent, perhaps, to a destruction of the sugars.

In Table VII the magnitude of the error is shown, which may be introduced by the application of the linear viscosity-conductivity correction into the determination of the electrolyte content of the sap.

The following nomenclature has been adopted:—

$V_s$  = the viscosity of the sap after filtration.

$V_{s+KCl}$  = the viscosity of the filtered sap in which potassium chloride  $\left(\frac{N}{10}\right)$  is dissolved.

$C_s$  = the conductivity of the sap after filtration.

$C_{s+KCl}$  = the conductivity of the filtered sap in which the potassium chloride is dissolved.

$C_{KCl}$  = the conductivity of the potassium chloride  $\left(\frac{N}{10}\right)$  dissolved in the sap.

[The conductivity of an  $\frac{N}{10}$  *KCl* solution in water = 0.00715.]

$C_e$  = the conductivity of the sap calculated from the loss observed in the conductivity of the potassium chloride dissolved in the sap: thus  $C_e$  is closely proportional to the true electrolyte content of the sap.

$C^v$  = the conductivity of the sap obtained by the application of the linear viscosity correction.

The sap for the experiment was obtained from Island Bridge.

TABLE VII.

| $V_s$ | $V_{s+KCl}$ | $C_s$<br>$\times 10^5$ | $C_{s+KCl}$<br>$\times 10^5$ | $C_{KCl}$<br>$\times 10^5$ | $C_e$<br>$\times 10^5$ | $C^v$<br>$\times 10^5$ |
|-------|-------------|------------------------|------------------------------|----------------------------|------------------------|------------------------|
| 2.47  | 2.49        | 607                    | 996                          | 389                        | 1113                   | 1.199                  |

Comparison of the conductivities shown in the last two columns indicates that the application of the linear viscosity correction to the conductivities of the Island Bridge saps, which is recorded in Table IV, has resulted in a considerable over-estimate of the amount of electrolytes present. The decrease shown by electrolytes with increasing concentration of sugar, to which it will be remembered attention was drawn in Table IV, must be therefore greater than the figures in the table indicate.

It will have been noted that high viscosities in the sap are usually accompanied by low conductivities; as this suggested that the large viscosities shown by the saps from Island Bridge may to some extent have been associated with the failure of a small concentration of metallic ions to coagulate the gums, it was thought that by freezing these saps the disturbance introduced into the viscosity correction by the presence of gums might be partially removed. Freezing the saps of course effects an increase in the concentration of electrolytes. It is not clear why this clumping of colloids should not proceed in the sap of the living cell.

The results recorded in Table VIII will serve to illustrate the effect obtained by immersing the sap in a freezing mixture of  $-10^{\circ}$  C.

TABLE VIII.

| Viscosity after Filtration | Viscosity 2 hours later after Freezing | $C \times 10^5$ after Filtration | $C \times 10^5$ 2 hours later after Freezing |
|----------------------------|--|----------------------------------|--|
| 2.47                       | 2.73                                   | 607                              | 598  |

The results indicate that, instead of a decrease, a marked augmentation in the viscosity of the sap has been effected; it is doubtful whether this is to be associated with the freezing of the sap, or is merely due to a growth in viscosity such as occurs in emulsoids with age; it is even possible that pectase, which is normally present in the sap of *Syringa vulgaris*, may have been responsible.

As many emulsoids are extremely sensitive to mechanical treatment, it seemed possible that the intense disturbance effected by centrifuging the sap might lead to a great diminution of the viscosity of the gums.

A preliminary experiment carried out on a gum arabic sol seemed to support this view; it was found that prolonged centrifuging at high speeds considerably decreased the viscosity of this gum, and ultimately brought about some precipitation. On repeating this treatment on the sap, however, no appreciable decrease in the viscosity could be obtained.

Unless some means can be found of readily eliminating the gums without

altering the concentration of electrolytes, it is evident that the application of the linear viscosity correction as a means of ascertaining the quantity of electrolytes in the sap is liable to be misleading, and recourse must be had to ascertaining the loss in conductivity which takes place in some salt after its solution in the sap.

*The Concentration of Electrolytes in the soil solution as a factor in the determination of the variations in electrolyte content of the leaf.*

It is now possible to resume the investigation of the factors responsible for the fluctuations in the amount of electrolytes already encountered in the leaf-saps of *Syringa vulgaris*. If it be assumed that the electrolytes are mainly inorganic, and have been ultimately drawn from the soil solution, it seemed probable that an examination of the conductivities of the soils from which the material was obtained might prove of value.

The samples of soil were taken from under the trees at a depth of three inches. After the removal of the stones and coarser particles had been accomplished by passing the soils through a sieve, 250 c.c. of each sample were measured in a graduated cylinder, which was then tapped on the ground till no further shrinkage in volume could be observed. The soils were then transferred to a filter [with filter paper], and 300 c.c. of distilled water gradually added.

The conductivities of the filtrates are shown under  $C_1$ , in Table IX. The saturated soil, which remained on the filter, was centrifuged after twenty-four hours; the conductivities of the solutions thus obtained are shown under  $C_2$ . The soils were, as the moisture contents in the table indicate, at the time of sampling very dry; the drain on the soil-moisture is, of course, very great under a rapidly transpiring tree.

TABLE IX (AUGUST 19TH).

| Locality                      | $C_1$ | $C_2$ | Per cent. Moisture |
|-------------------------------|-------|-------|--------------------|
| The Grounds, Trinity College, | 28    | 28    | 9.11               |
| The Botanical Gardens,        | 103   | 45    | 8.12               |
| Milltown,                     | 15    | 18    | 10.81              |
| Island Bridge,                | 23    | 25    | 9.21               |

As it may be doubted whether the above method is capable of furnishing

results which are truly comparative, a somewhat different procedure was adopted.

The samples of soil for the next experiment, the results of which are recorded in Table X, were collected and sieved in the manner described above; they were then spread out in a thin layer for twenty hours to dry; the temperature of the room was approximately 18° C. It may be noted that Bouyoucos and McCool (2) found that air-drying did not increase the quantity of soluble materials of soils.

Samples of 250 c.c. of the air-dry soils were then placed in Buchner filters, and to each of them 120 c.c. of distilled water were gradually added. As the samples were also weighed, an inspection of their respective weights should afford an approximate index of their textures. The volumes of soil and water used were so gauged that no water dripped from the filter.

After ten minutes from 8–10 c.c. of the solution were withdrawn by pressure, and set aside for cryoscopic and conductivity determinations.

The readiness with which the solution was withdrawn from the first two samples was remarkable, and was due, of course, to the coarseness of their textures; this is quite in accord with the weights as recorded in Table X. In the last column the actual freezing-points ( $\Delta_a$ ) of the solution existing in the soil at the time of sampling have been calculated; in making this calculation the traces of moisture in the air-dry soil have been neglected.

TABLE X (SEPTEMBER 8TH, 1919).

| Locality                      | No. of<br>gms. soil<br>in 250 c cs. | Per cent.<br>Moisture. | $C \times 10^5$ | $\Delta$ | $\Delta_a$ |
|-------------------------------|-------------------------------------|------------------------|-----------------|----------|------------|
| The Grounds, Trinity College, | 244.9                               | 16.08                  | 144             | 0.054°   | 0.155°     |
| The Botanical Gardens,        | 243.0                               | 25.00                  | 419             | 0.196°   | 0.290°     |
| Milltown,                     | 263.2                               | 19.36                  | 76              | 0.036°   | 0.068°     |
| Island Bridge,                | 264.9                               | 11.66                  | 101             | 0.047°   | 0.161°     |

An inspection of the two tables (IX and X) shows that, though considerable fluctuations have occurred in the moisture-contents of the soils between the dates of sampling, yet the general order of the salt-contents of the four soils has not sensibly altered; on the other hand, there can be no doubt that considerable changes have taken place in the actual concentrations

of salts in the respective soils. It is tolerably clear, however, that the salt-content of the soil of the Botanical Gardens is uniformly great, whereas that of the Milltown area is consistently the smallest.

These experiments do not, however, afford any explanation of the concentration of electrolytes which have been encountered in the leaf-saps.

*On the Concentration of Electrolytes in the transpiration current as a factor in the determination of the electrolyte contents of the leaves.*

Dixon and Atkins' (1) work on the composition of the sap in the conducting tracts of trees suggested that some information might be obtained from observations carried out on the sap of the transpiration current.

The electrical conductivities and freezing-points of the sap obtained by centrifuging samples of wood from the base of the stem are shown in Table XI.

TABLE XI (AUGUST 28TH, 1919).

| Locality                      | $C \times 10^5$ | $\Delta$ |
|-------------------------------|-----------------|----------|
| The Grounds, Trinity College, | 62              | 0.078°   |
| The Botanical Gardens,        | 57              | 0.076°   |
| Milltown;                     | 47              | 0.094°   |
| Island Bridge,                | 61              | 0.091°   |

The conductivities recorded in the table indicate the relative concentrations of electrolytes in the sap ascending the stem; they do not, however, show the quantity of electrolytes entering the leaves with the transpiration current, for this is a function of not only the concentration of electrolytes in the ascending sap, but also of the rate of transpiration.

The saps obtained from the xylem were all slightly acid to litmus; whether this is due to the rupture of the living elements of the wood in the preparation of the material for the centrifuge buckets, or is to be regarded as the normal condition of the transpiration current in this tree, is not clear.

It will be seen from an inspection of tables X and XI that the freezing-points, and therefore the osmotic pressures of the soil-solution may be much greater than that of the ascending sap; should these conditions prevail while root-pressure is active, it is evident that the part played by the living cells of the root in producing this pressure cannot be a passive one.

It is clear, however, that the conductivities of the ascending saps bear no relationship to those recorded for the leaves in Table IV.

*Discussion.*

In what follows it has been necessary to assume, since nothing is known of the nature or concentration of the organic ions, that the fluctuations in the conductivities recorded in Table IV are mainly due to changes in the concentration of the inorganic salts dissolved in the leaf-sap; it is probable, however, that the organic constituents of the leaf-sap play only a minor part in the conductivities recorded.

The concentration of electrolytes in the leaf is mainly a function of the rate at which salts have entered with the transpiration current, and been removed in the course of metabolism. The factors on which the supply of salts entering the leaf depend are, firstly, the concentration of salts in the ascending sap, and secondly, the rate of transpiration. It has already been seen that the former is not responsible for the fluctuations encountered in electrolytes of the leaf. On the other hand, that the rate of transpiration is not the sole factor is demonstrated by the fact that in the sap pressed from leaves with a southern exposure a smaller conductivity is often met than in that of leaves from the north side of the tree, where transpiration is normally less rapid.

The factors tending to limit the concentration of electrolytes may be now considered. An ion, which takes part in the synthesis of organic molecules, will presumably be removed from solution provided the necessary concentration of sugars is present; Schimper's (7) and Zaleski's (8) investigations on protein synthesis clearly show that this is so in the case of nitrates. If, on the other hand, the ion takes no part in metabolism, its concentration in the leaf will continue to rise whether the sugar supply is large or small.

If the distribution of plants showing low conductivities and high non-electrolyte contents in the leaf were purely fortuitous, then the nature of the ions in the sap might provide the explanation of the fluctuations in the concentration of electrolytes; but, as it is in the locality where carbon assimilation is limited that a high conductivity and low non-electrolyte content is encountered, it would appear that it is in the rate of carbon assimilation that the explanation must be sought. It is significant that it is in leaves where the sugar-content is relatively low that the electrolytes assume a very prominent part in the maintenance of the osmotic pressure; in some cases even the major part.

It may be of interest to consider what might be expected to occur if the rate at which inorganic salts were removed from solution was dependent, not

on the concentration of sugars in the sap, but on the magnitude of the osmotic pressure.

Assuming, then, that the rate of carbon assimilation were for any reason retarded, a decrease in the supply of sugars entering the cell would take place, and ultimately a fall in the osmotic pressure. With this decline in the osmotic pressure of the cell, the rate at which electrolytes could be removed from solution must, by assumption, be diminished; but as the supply of electrolytes entering the cell would continue as long as the rate of transpiration was unchecked, a rise in the osmotic pressure would thus be brought about.

As a result of this, the rate of metabolism would be again accelerated, and no further accumulation of electrolytes would occur. In this manner a decrease in the rate of carbon assimilation might effect a large concentration of electrolytes. The prominent part which electrolytes play in the production of the osmotic pressure of plants growing in greenhouses, to which Dixon and Atkins have drawn attention, may provisionally, the writer considers, be explained from this point of view. The rate of carbon assimilation must be often limited by the reduction in the intensity of the illumination in greenhouses. It would not be profitable, however, to speculate further until the nature of the ions responsible for the fluctuations in conductivity have been established.

#### SUMMARY.

1. The determination of the concentration of electrolytes of the cell by means of conductivity observations has been found unsatisfactory, unless allowance is made for the viscosity of the sap. Methods of making a correction for the viscosity have been described.

2. The osmotic pressure of the cell is frequently mainly due to electrolytes; but the presence of solutes which are neither electrolytes nor sugars is not excluded.

3. Considerable fluctuations in the concentrations of electrolytes in the leaf-sap of *Syringa vulgaris* trees growing in different localities have been indicated.

4. A tendency for the concentration of electrolytes to vary inversely with that of the non-electrolytes has been found.

5. It is suggested that these fluctuations are associated with the rate of carbon assimilation, which determines the rate at which electrolytes are removed from solution in metabolism.



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The writer wishes to express his indebtedness to Professor H. H. Dixon and Major W. R. G. Atkins, at whose instigation the work was undertaken; and to Capt. N. G. Ball for his assistance in the soil analysis.

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ON BROWN'S FORMULA FOR DISTILLATION.

BY

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## XLVII.

## ON BROWN'S FORMULA FOR DISTILLATION.

BY SYDNEY YOUNG, D.Sc., F.R.S.,

University Professor of Chemistry, Trinity College, Dublin.

Read DECEMBER 16, 1919. Published JANUARY 2, 1920.

THE subject of fractional distillation was investigated by F. D. Brown during the years 1879 to 1881 (Trans. Chem. Soc., xxxv, 547; xxxvii, 49; xxxix, 304 and 517), and he arrived at the conclusion that the relation between the composition of a liquid mixture and that of the vapour evolved from it could in general be expressed by the formula

$$\frac{m'_A}{m'_B} = \frac{m_A P_A}{m_B P_B},$$

where  $m'_A$  and  $m'_B$  are the relative masses of the two substances in the vapour,  $m_A$  and  $m_B$  their relative masses in the liquid mixture, and  $P_A$  and  $P_B$  the vapour-pressures of the pure substances at the boiling point of the mixture. He considered, however, that a better agreement between the calculated and observed results was obtained by substituting a constant  $c$  for the ratio  $P_A/P_B$ .

It is frequently convenient to write the equation

$$\frac{M'_A}{M'_B} = c \frac{M_A}{M_B},$$

where  $M'_A$ ,  $M'_B$ , and  $M_A$ ,  $M_B$  are the relative number of molecules of A and B in the vapour and the liquid respectively.

As a matter of fact, Brown's experimental results did not agree by any means well with the formula

$$\frac{M'_A}{M'_B} = c \frac{M_A}{M_B},$$

but it has been pointed out by the author ("Fractional Distillation," p. 93) that the experimental evidence which so far has been obtained points to the conclusion that the formula is applicable to those liquid mixtures for which the relation  $P = mP_A + (1 - m)P_B$  holds good. [ $P$  is the vapour-pressure of the mixture, and  $P_A$  and  $P_B$  the vapour-pressures of the two pure substances at the same temperature, and  $m$  is the molar fraction of the substance A.] It also seemed probable that in such cases  $c = P_A/P_B$ .

The number of such mixtures investigated is, however, very small, and further evidence is required before definite statements can be made.

In 1903 four pairs of closely related liquids were examined by Miss E. C. Fortey and the author (*Trans. Chem. Soc.*, lxxxiii, 45). The boiling points of several mixtures of each pair of liquids were determined under pressures from about 660 to 840 mm., and by interpolation the boiling points of these mixtures under the pressures 700, 760, and 820 mm. were ascertained. Finally, the values of P in the formula  $P = mP_A + (1 - m)P_B$  were calculated from the known vapour-pressures of the pure substances at these temperatures, and it was found that the differences between the calculated and observed pressures were very small, although not negligible. The substances examined were ethyl acetate and ethyl propionate, toluene and ethyl benzene, *n*-hexane and *n*-octane, and benzene and toluene. It had previously been found by the author [*ibid.*, lxxxi, 768 (1902)] that the vapour-pressure formula is strictly applicable to mixtures of chlorobenzene and bromobenzene.

Unfortunately, in none of these cases has the relation between the composition of the liquid and that of its vapour been experimentally determined, but for benzene and toluene indirect evidence is now available.

The boiling points of mixtures of benzene and toluene observed by Miss Fortey and the author are given below:—

| Pressure<br>in mm. | Molar percentage of benzene. |        |         |
|--------------------|------------------------------|--------|---------|
|                    | 75·06                        | 50·00  | 27·54   |
| 700                | 82·97°                       | 89·57° | 96·80°  |
| 760                | 85·72°                       | 92·38° | 99·63°  |
| 820                | 88·23°                       | 94·96° | 102·22° |

The pressures P, calculated from the formula

$$P = \frac{mP_A + (100 - m)P_B}{100},$$

where m is the molar percentage of benzene and  $P_A$  its vapour-pressure, are compared with the actual pressure in the table below:—

| Actual<br>Pressure<br>in mm. | P.     |        |        |
|------------------------------|--------|--------|--------|
| 700                          | 699·88 | 701·80 | 703·96 |
| 760                          | 760·57 | 762·95 | 764·55 |
| 820                          | 819·90 | 822·90 | 823·60 |

It will be seen that the agreement is very close for the mixture richest in benzene, but that it becomes less close as the percentage of benzene decreases. At the worst, however, the agreement is fair.

Duhem (1887-1894) and Margules (1895) independently proposed the equation

$$\frac{d \log p_A}{d \log M} = \frac{d \log p_B}{d \log (1 - M)}$$

or the relation between the molar composition of the liquid mixture and the partial pressures  $p_A$  and  $p_B$  of the components in the vapour, and the formulae of Lehfeldt and of Zawidski are based on this equation.

In recent years M. A. Rosanoff and his co-workers have carried out a series of excellent experimental and theoretical researches on distillation; and in 1914 Rosanoff, Bacon, and Schulze (*J. Amer. Chem. Soc.*, xxxvi, 1993) pointed out that the method of Margules, which depends on the graphic measurement of the slope of the total pressure-curve at its two ends, is liable to yield inaccurate results.

They, therefore, sought to formulate a general relationship, even if only empirical, between the total and partial vapour-pressure curves.

They found that, in the cases examined, if a set of values of  $\frac{dP}{dM}$  were plotted against the corresponding values of  $\log [p_A (1 - M)/p_B M]$ , the result was a straight line passing through the origin of the coordinates, which indicated that the simplest possible relationship exists between the two quantities. This apparently general law is expressed by the equation

$$\frac{dP}{dM} = (1/K) \log [p_A (1 - M)/p_B M],$$

where

$$1/K = (P_A - P_B)/(\log P_A - \log P_B).$$

Therefore

$$\frac{dP}{dM} = [(P_A - P_B)/(\log P_A - \log P_B)] \log [p_A (1 - M)/p_B M] \dots \quad (\text{I})$$

The authors state that this equation is not in conflict with the thermodynamical equation of Duhem and Margules, and they show that it faithfully reproduces the experimental results in all types of cases, even when mixtures of maximum or minimum vapour-pressure are formed.

Rosanoff, Bacon, and Schulze (*loc. cit.*) have determined the vapour-pressures of mixtures of benzene and toluene at 79.70°, and find that the data are almost perfectly reproduced by the formula

$$P = 288.438 + 466.519M - 56.464M^2 + 100.281M^3 - 49.971M^4 \dots, \quad (\text{II})$$

where  $M$  is the molar fraction of benzene in the liquid mixture.



For these two substances

$$\frac{\log_{10} P_A - \log_{10} P_B}{P_A - P_B} = 0.000900;$$

therefore

$$\log_{10} [p_A(1-M)/p_B M] = 0.4198671 - 0.101635M + 0.270739M^2 - 0.179896M^3. \quad (\text{III})$$

from which equation they calculated the ratios  $p_A/p_B$  and the molar percentages of benzene in the vapour, benzene and toluene being regarded as substances of normal molecular weight.

The data obtained by Fortey and Young indicate that the vapour-pressures of mixtures of benzene and toluene are represented without serious error by the formula  $P = MP_A + (1 - M)P_B$ , and in the table below the vapour-pressures determined by Rosanoff, Bacon, and Schulze are compared with those calculated by them by the formula (II) and with those calculated by the simple formula  $P = MP_A + (1 - M)P_B$ .

| Molar per-centage of benzene in liquid. | Vapour-pressures of mixtures at 79.7° in mm. |                                       |          |  |          |
|---|--|---------------------------------------|----------|--|----------|
|   | Observed.                                    | Calculated<br>$P = MP_A + (1-M)P_B$ . | $\Delta$ | Calculated by<br>formula II of<br>R., B., & S. | $\Delta$ |
| 100                                     | 748.7  | 748.7                                 | 0        | 748.8  | + 0.1    |
| 95.65                                   | 729.0  | 728.7                                 | - 0.3    | 728.9  | - 0.1    |
| 91.89                                   | 711.4  | 711.4                                 | 0        | 711.6  | + 0.2    |
| 82.43                                   | 668.0  | 667.9                                 | - 0.1    | 667.7  | - 0.3    |
| 73.27                                   | 624.9  | 625.7                                 | + 0.8    | 625.0  | + 0.1    |
| 63.44                                   | 579.2  | 580.4                                 | + 1.2    | 579.2  | 0        |
| 54.51                                   | 537.5  | 539.4                                 | + 1.9    | 537.8  | + 0.3    |
| 43.52                                   | 487.0  | 488.8                                 | + 1.8    | 487.2  | + 0.2    |
| 33.83                                   | 443.1  | 444.2                                 | + 1.1    | 443.0  | - 0.1    |
| 22.71                                   | 392.8  | 393.0                                 | + 0.2    | 392.5  | - 0.3    |
| 11.61                                   | 341.5  | 341.9                                 | + 0.4    | 342.0  | + 0.5    |
| 0                                       | 288.5  | 288.5                                 | 0        | 288.4  | - 0.1    |

The formula of Rosanoff, Bacon, and Schulze obviously reproduces the results better than the simple formula  $P = MP_A + (1 - M)P_B$ , but the deviations in the latter case are by no means large. They are in the same direction and of the same order of magnitude as those found by Fortey and Young from their data.

As the equation (I) of Rosanoff, Bacon, and Schulze satisfactorily reproduces the percentage composition of the vapour even when the substances considered form mixtures of maximum or of minimum vapour-pressure, it may be employed with great confidence in such a simple case as that of benzene and toluene, more especially on account of the excellent agreement between the observed vapour-pressures and those calculated from the formula (II).

We may, therefore, accept the calculated molar percentages of benzene in the vapour without hesitation, although actual determinations have not been made; and we may now make use of these data in order to find whether Brown's formula is applicable without serious error to this pair of liquids. We can also find whether the constant  $c$  in Brown's formula agrees with the ratio

$$\frac{P_A}{P_B} = \frac{748.7}{288.5} = 2.5951 \text{ at } 79.7^\circ.$$

| Molar percentage of benzene in liquid. | Molar percentage of benzene in vapour, calculated by formula of |                      |          |                     |          |
|--|---|----------------------|----------|---------------------|----------|
|  | R., B., & S.  | Brown, $c = 2.5951.$ | $\Delta$ | Brown, $c = 2.589.$ | $\Delta$ |
| 95.65                                  | 98.27   | 98.28                | + 0.01   | 98.27               | 0        |
| 91.89                                  | 96.72   | 96.71                | - 0.01   | 96.70               | - 0.02   |
| 82.43                                  | 92.49   | 92.41                | - 0.08   | 92.40               | - 0.09   |
| 73.27                                  | 87.82   | 87.68                | - 0.14   | 87.65               | - 0.17   |
| 63.44                                  | 81.97   | 81.83                | - 0.14   | 81.79               | - 0.18   |
| 54.51                                  | 75.74   | 75.67                | - 0.07   | 75.62               | - 0.12   |
| 43.52                                  | 66.56   | 66.66                | + 0.10   | 66.61               | + 0.05   |
| 33.83                                  | 56.76   | 57.02                | + 0.26   | 56.97               | + 0.21   |
| 22.71                                  | 42.95   | 43.26                | + 0.31   | 43.21               | + 0.26   |
| 11.61                                  | 25.30   | 25.42                | + 0.12   | 25.38               | + 0.08   |

Taking for the constant  $c = \frac{P_A}{P_B} = 2.5951$ , the differences are considerably smaller than those between the calculated (R., B., & S.) and observed (Zawidzki) molar percentages of carbon tetrachloride in mixtures of that substance with benzene, and, were it not for their regularity, they might perhaps be regarded as within the limits of experimental error.

The best agreement is obtained by making  $c = 2.589$ —a value which differs but slightly from the ratio  $\frac{P_A}{P_B}$ .

The mean value of  $c$  calculated from the formula

$$\frac{M'_A}{M'_B} = c \frac{M_A}{M_B},$$

taking the molar percentages of benzene in the vapour calculated by Rosanoff, Bacon, and Schulze (column 2 in above table) as correct, is 2.591, but the individual values vary from 2.522 to 2.630.

It may be noted that whilst benzene is a purely aromatic compound toluene is partially aliphatic, so that the chemical relationship is not quite so close as in the case of the other pairs of liquids examined by Miss Fortey and the author. The volume and temperature changes which take place on admixture of benzene and toluene, although slight, are noticeably greater than in the other cases. It seems probable, therefore, that Brown's formula would hold as well, if not better, for the other pairs of closely related liquids.

#### *Summary.*

It is found that Brown's formula,

$$\frac{M'_A}{M'_B} = c \frac{M_A}{M_B},$$

is applicable without serious error to mixtures of benzene and toluene for which the formula  $P = mP_A + (1 - m)P_B$  gives results which are nearly, but certainly not quite, correct.

It is also found that for benzene and toluene the best value of the constant  $c$  differs but slightly from the ratio  $\frac{P_A}{P_B}$ .

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AN APPARATUS FOR THE PRODUCTION OF  
HIGH STATIC VOLTAGES.

BY

J. J. DOWLING, M.A.,

UNIVERSITY COLLEGE, DUBLIN.

*[Authors alone are responsible for all opinions expressed in their Communications.]*

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## XLVIII.

AN APPARATUS FOR THE PRODUCTION OF HIGH STATIC  
VOLTAGES.

By J. J. DOWLING, M.A.  
(University College, Dublin).

Read NOVEMBER 25, 1919. Published JANUARY 2, 1920.

IN the course of recent work I required a steady potential difference of several thousand volts, maintained between a pair of insulated plates. It was inconvenient to employ a battery of accumulators, in view of the excessive number necessary. The following apparatus was devised for the purpose, and has answered so well that it seems worth while giving a description of it:—

In principle it is the “condensing electroscope” of Volta, operated in a continuous manner by mechanical means. The same principle was employed by Einstein<sup>1</sup> in an apparatus designed for a slightly different purpose, namely, to multiply up minute potential differences so as to render them measurable with comparatively insensitive electrostatic voltmeters. I had at one time constructed an apparatus on the same lines as Einstein; but when I became aware of his paper, I did not further pursue the matter. However, when my present necessities arose, I tried my original machine to see whether it was capable of producing a sufficiently high potential for my purpose.

In this machine a brass inductor-plate, mounted on the face of an ebonite disc, was revolved *in its own plane* past a fixed plate, kept at a steady potential by a battery. Contacts were made by suitably situated springs, so as (1) to earth the inductor-plate when it passed opposite the charged plate, and (2) to connect the inductor, when it had moved away from the fixed plate, with the apparatus to be charged.

I found, however, that, in consequence of the potential of the inductor-plate rising rapidly, while the plates were still close together, there was a limit to the maximum potential obtainable. With the machine in question 1500 volts was about the highest steady potential obtainable, above which sparking set in between the plates.

<sup>1</sup> Einstein, *Phys. Zeitschr.* 9 (216–217), April 1, 1908.



The present apparatus was designed to overcome this defect. It is clear that, by moving the condenser plates apart normally, as we decrease the capacity of the system, and thus increase the potential difference, the spark-gap between the plates is increased at the same rate, or indeed somewhat more rapidly. Thus, if the plates are not within sparking distance when close together, sparking cannot occur between them in any other position.

The accompanying figure represents the machine as constructed. The earth-plate B is mounted on the end of a steel rod A, sliding freely in two uprights E, F. A is given a reciprocating motion by an eccentric I, working between two guides G, H attached to the rod A. The inductor-plate C is supported behind by an ebonite block,<sup>1</sup> attached to the upright D by four adjustment screws,<sup>1</sup> whereby C can be rendered exactly parallel to B. The opposing surfaces of B and C are, of course, as nearly plane as possible.

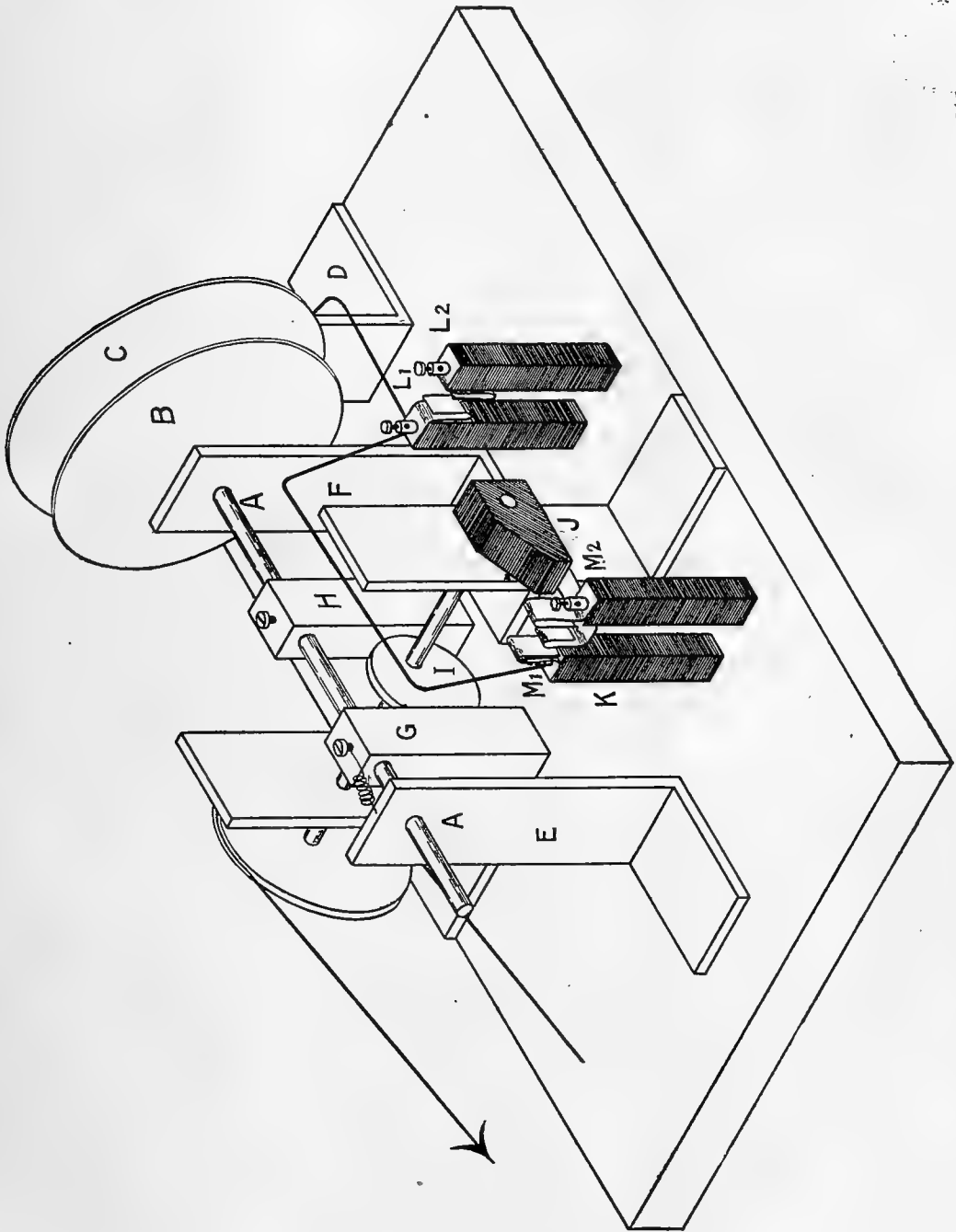
The contact-making device is attached to the eccentric shaft, which ensures that the contacts are made instantaneously at the correct moments, viz., when the moving plate is momentarily at rest at each end of its oscillation. The ebonite arm J carries a contact piece which passes between pairs of contact springs L<sub>1</sub>, L<sub>2</sub>, M<sub>1</sub>, M<sub>2</sub>, mounted on ebonite pillars. Contact is made between L<sub>1</sub>L<sub>2</sub> when the plates are closest together, and between M<sub>1</sub>M<sub>2</sub> when the plates are fully separated. L<sub>1</sub>M<sub>1</sub> are permanently joined to C, while B is permanently earthed. One pole of a battery is attached to L<sub>2</sub>, and the other pole is earthed. The high voltage is, of course, obtained at the terminal M<sub>2</sub>. The plates B, C are about 20 cms. in diameter, and B has a reciprocating motion over a range of about 5 cms. By the adjustment screws the minimum distance of C from B can be regulated, and thus the multiplying factor of the machine varied. The extent of this variation is subject to two considerations. In the first place, the minimum separation must exceed the sparking distance for the battery voltage. This consideration is of minor importance in the case of a machine of the dimensions given, because to obtain a voltage of 4000 or 5000 volts, using a battery of 800 volts, the plates need not be brought closer than a couple of millimetres. The other consideration affects the steadiness of working. This would be impaired were the back-lash of the eccentric motion comparable with the distance of minimum separation of the plates. Here again a couple of millimetres suffices to eliminate trouble.

Finally, the speed of working which I find most suitable is about five oscillations per second. At this rate the equivalent current, when multiplying 800 to 4000 volts, is of the order of half a microampere, which, of

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<sup>1</sup> These are not shown in the drawing, being behind C.

course, is ample to maintain a fairly well-insulated system charged to even the high potential mentioned.



I have no doubt that higher potentials could be obtained by increasing

the battery-voltage or by increasing the dimensions of the machine, or, again, by adopting Einstein's plan of combining the same principle more than once in the same machine. However, as my own purpose was served by a voltage of about 4000, I have not sought to extend the range further.

I may add that I have had the machine in use for several months, and I have found it most constant and reliable in its action, provided only that the ordinary precautions against dampness are taken, which precautions are inseparable from most electrostatic apparatus. Under these conditions I have been able to maintain a voltage of 4000 or 5000 constant to within 1 or 2 per cent. for several hours, the charged system consisting principally of a leyden jar of about 1000 cms. capacity, to which my other apparatus, of much smaller capacity, could be connected as desired.

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46. On some Factors affecting the Concentration of Electrolytes in the Leaf-sap of *Syringa vulgaris*. By T. G. MASON, SC.B., M.A. (December, 1919.) 1s.
47. On Brown's Formula for Distillation. By SYDNEY YOUNG, D.Sc., F.R.S. (January, 1920.) 6d.
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AWARD OF THE BOYLE MEDAL

TO

PROFESSOR JOHN A. McCLELLAND, M.A., D.Sc., F.R.S.

(UNIVERSITY COLLEGE, DUBLIN).

1917



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XLIX.

AWARD OF THE BOYLE MEDAL

TO PROFESSOR JOHN A. McCLELLAND, M.A., D.Sc., F.R.S.  
(University College, Dublin).

1917.<sup>1</sup>

REPORT OF THE SCIENCE COMMITTEE.

THE claim of Professor J. A. McClelland to receive the Boyle Medal of the Royal Dublin Society is based upon research in many branches of science, but primarily in those which deal (*a*) with ionization as resulting from addition of electrons to gaseous molecules, or to aggregates of such; and (*b*) with the more recently discovered forms of radiation associated pre-eminently with radio-activity.

In the first field McClelland in 1899-1901 did much work on the nature of flame-conduction. In 1903 the ionization of the atmosphere was dealt with, and the subject was resumed in 1912, when a study of the electric sign of rain-drops led him to important conclusions as to the nature of the larger and less mobile ions of the atmosphere. Quite recently (1916) his work on photo-electric effect advances our knowledge of a great natural source of ionization which has intimate bearing on the processes of vegetable life.

The second field of work has proved to be even more fruitful. It is not too much to claim for McClelland a high position as pioneer in investigating the nature of the radiations associated with radio-activity. So long ago as 1897 he showed that the Lenard rays, like the Cathode rays, consisted of negatively charged particles. In 1904 he showed that radium-emanation is not charged. In 1905 he proved the complex character of the secondary radiation due to  $\beta$  and  $\gamma$  rays. He recognized that negatively charged particles constitute the secondary radiation, these particles attaining very high velocities. And most suggestive of all is his discovery that secondary radiation from the elements increases in amount with the atomic weight. This work was done in 1905, and communicated to the Royal Dublin Society. It is, very evidently, of much importance. It has since

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<sup>1</sup> The presentation was made at the Scientific Meeting of the Royal Dublin Society, held on Wednesday, the 19th December, 1917, when the Medal was handed to Professor McClelland by the President, the Right Hon. Lord Rathdonnell, H.M.L.



been confirmed and extended by others. It shows primarily that secondary radiation or scattering of electrons is an atomic property. It is, in fact, additive, as McClelland proved in 1906; the elements carrying unaltered their characteristic effects into their compounds one with another. The elemental scattering follows their periodic classification as based on other physical properties. Very intimate chemical relations are attended with closely similar elemental scattering.

In 1907 McClelland, working with F. E. Hackett, showed that the periodic lay could also be traced in the absorption of  $\beta$  radiations.

McClelland's work has been attended with that inspiration which is the first attribute of secure and sound advance. His work on ionization has been used by Sir J. J. Thomson in his work on Conductivity through Gases. His discoveries on secondary radiations have been the starting-point of much similar work done, not only in England, but abroad. Most of his principal papers find a place in the Transactions of this Society.

Of McClelland's other work for the Royal Dublin Society during the many years of sustained interest in its affairs, and more especially in its scientific advancement, it is not easy to speak too highly. As a teacher his pupils speak gratefully of his devotion to their interests. His beneficial influence has extended itself to the sister Institution, the Royal Irish Academy. More recently he has served with distinction on the Advisory Council for Research instituted by the State.

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[The names in italics indicate joint authorship.]

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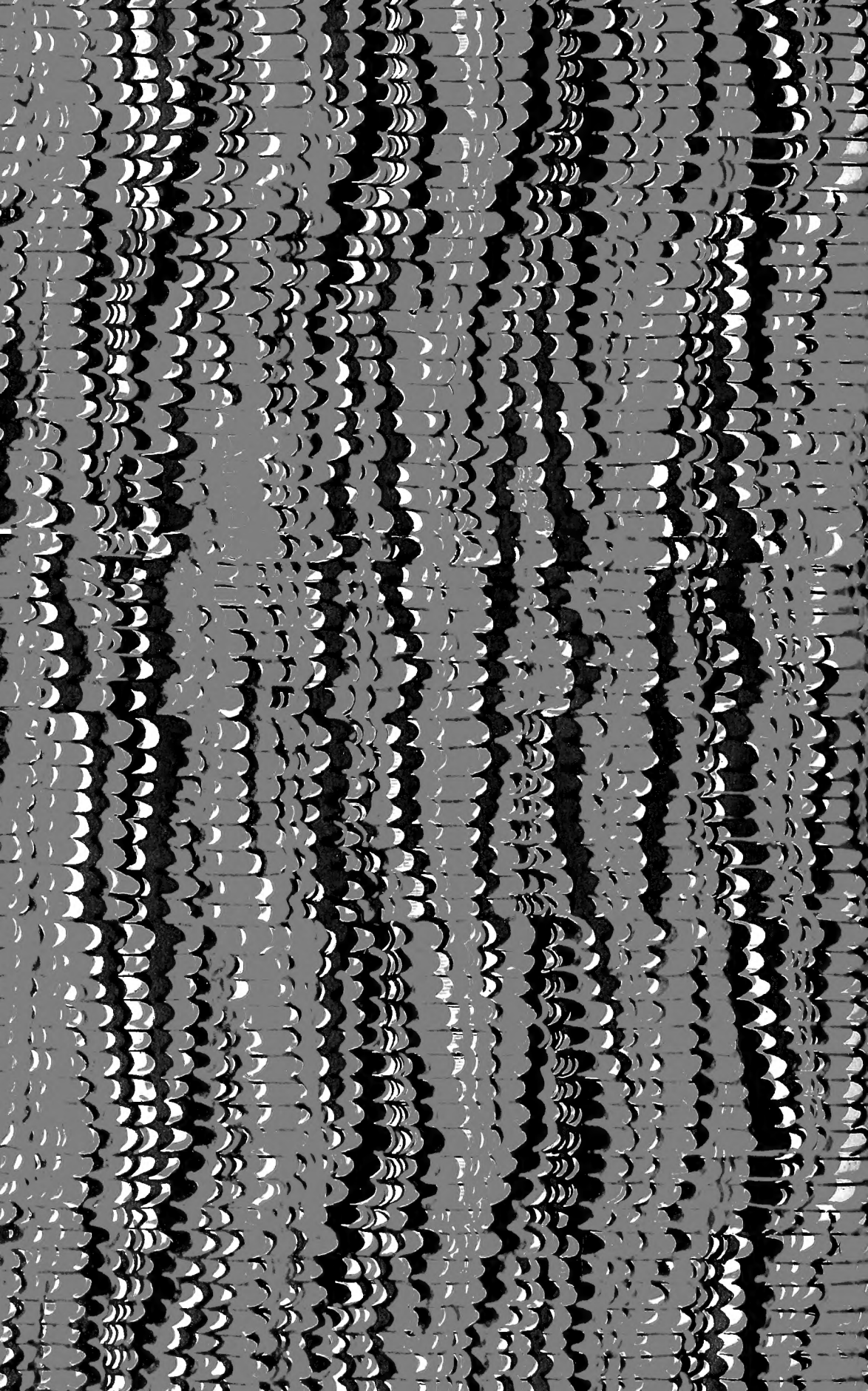




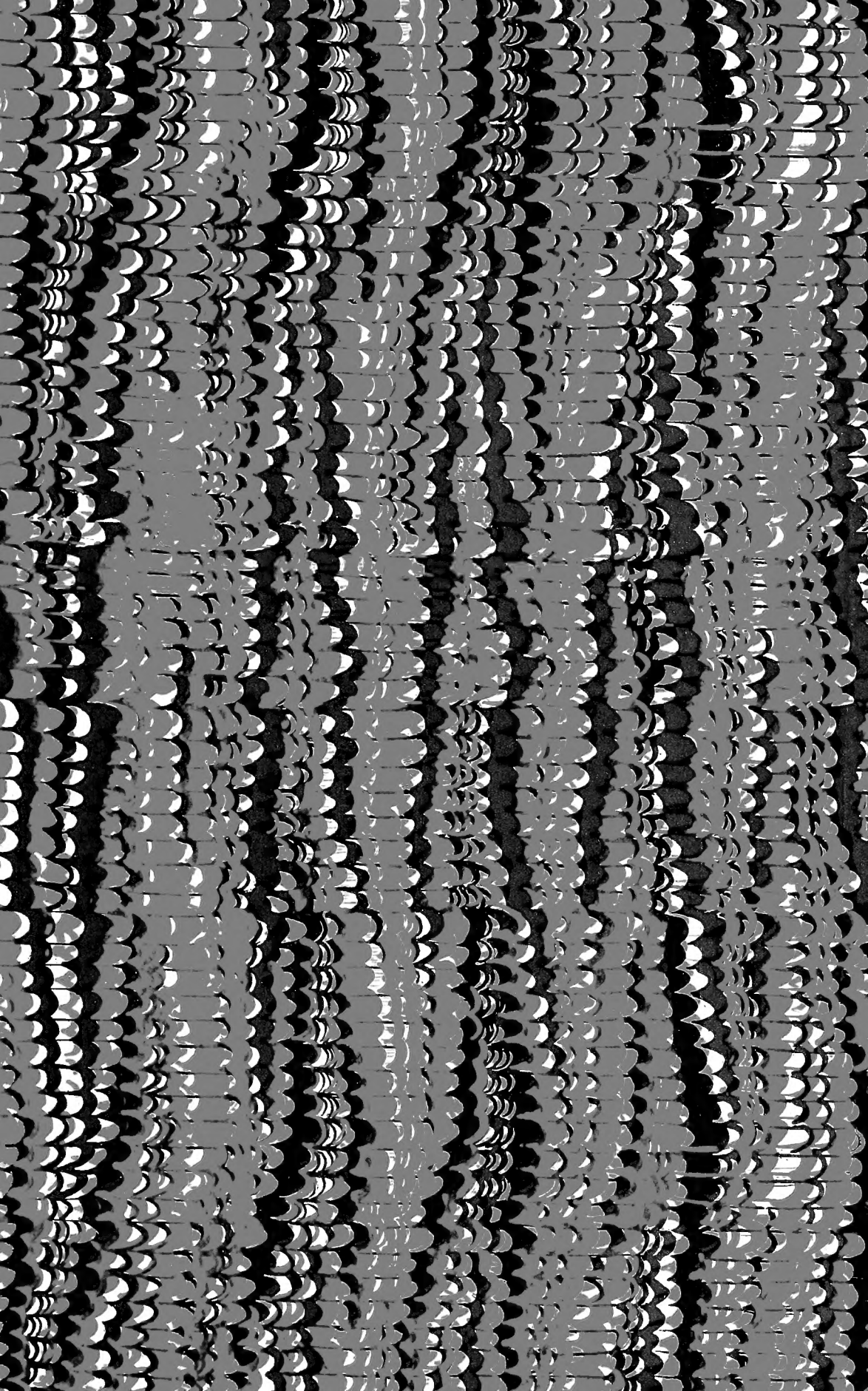














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