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THE

KANSAS UNIVERSITY SCIENCE BULLETIN.

VOL. XIII, NO. 1—MAY, 1920.

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MIOCENE LAND SHELLS FROM OREGON,
G. Dallas Hanna.

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THE KANSAS UNIVERSITY SCIENCE BULLETIN.

VOL. XIII.] MAY, 1920. [NO. 1.

Miocene Land Shells from Oregon.*

BY G. DALLAS HANNA,

Curator of Invertebrate Paleontology, California Academy of Sciences.

(Plate I.)

THE exposures of fossiliferous rocks in the valley of the John Day river in Oregon have been known as a collecting ground for mammalian remains since 1861. Many expeditions have worked there and an extensive literature exists in which numerous types have been described. Fossil mollusks were obtained by the earliest collectors and subsequently and several papers have been written about them since 1870.

In 1907 an expedition was led into the region by Mr. H. T. Martin, curator of paleontology of the University of Kansas. Numerous specimens of vertebrate animals were secured and Mr. Martin also collected the land shells which form the basis of this report. Sixteen specimens belonging to eight species were found at Cove Inlet of John Day river. Four species appear to be new and are named and described herein.

Altogether thirteen species of mollusks have been collected in the John Day deposits, eleven being land pulmonates, one a fresh-water pulmonate and a fresh-water mussel. All are species not now known to exist but no genus has been considered to be new. The preponderance of the land forms has an interesting bearing upon the question of the lacustrine, fluviatile or æolian method of deposition of the strata.†

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* Received for publication on February 2, 1920.

† For a full account of the geological, stratigraphical, and paleontological features of the region see, Merriam, "A Contribution to the Geology of the John Day Basin," University of California publications, Bulletin of the Department of Geology, vol. 2, No. 9, pp. 269-314, April, 1901. Also, same author and series, vol. 5, No. 1, pp. 1-64; December, 1906. Also, vol. 5, No. 11; Merriam and Sinclair for fairly complete bibliography, etc.; October, 1907.

The age of the beds is believed to be Miocene, a conclusion reached from a study of the fossil mammals and plants, and other geological features. A sufficient number of land and fresh-water shells has not been collected to have an important bearing on the subject. However, the long geological life of the molluscan genera found in these strata as compared with the disappearance of families and perhaps orders of mammals is a valuable commentary on the correlation of deposits elsewhere by the two classes of fossils when they are found singly. Not only have the mollusks passed through epochs of intense climatic change but they have withstood one of the most violent outflows of lava visible on the surface of the earth. Yet the genera found in the John Day and Mascall beds are represented in and near the same region to-day with closely allied species.

Ammonitella lunata Conrad.

Planorbis (*Spirorbis?*) *lunatus* Conrad, Am. Journ. Conch., vol. VI; p. 315, pl. XIII, fig. 8, 1870. Condon collection. Bridge Cr., Ore.

Planorbis (*Spirorbis?*) *lunatus* White, 3d. Ann. Rep. U. S. Geol. Surv., p. 448, pl. XXXII, figs. 24, 25, 1880-'81. Published, 1883.

Gonostoma yatesi Cooper. Stearns (in White), Bul. 18, U. S. Geol. Surv., p. 16, pl. III, figs. 8-12, 1885. Cope and Condon Coll.

Ammonitella yatesi præcursor Stearns, Proc. Wash. Acad. Sci., vol. II, p. 656, pl. XXXV, figs. 8-12, 1900. Same figures reproduced as in Bul. 18, U. S. Geol. Surv., cited above.

Ammonitella yatesi præcursor Stearns, Science, New Series, vol. XV, p. 153, 1902. University of California Collection.

Ammonitella yatesi præcursor Stearns, Univ. of Calif. Pub. Geol., vol. V, No. 3, p. 67, 1906.

Although Conrad's description is very meager, taking it together with his figures leaves no doubt that he first described the shell which seems to have been collected by many exploring parties into the John Day region. His specimens were collected by Thomas Condon, the pioneer in the field and it is stated that they came from "Bridge Creek, Oregon." The error in considering it to be a species of the fresh-water genus *Planorbis* is not strange since Cooper says of *Ammonitella yatesi* (*Am. Jour. Conch., IV, 210, 1868*): "It would have been supposed to be a *Planorbis* if found near water, and if the streams of that country (Calaveras county, California) had not been thoroughly searched by many collectors."

Stearns first identified the fossils as *A. yatesi* Cooper but later reconsidered the matter and made them a new subspecies based chiefly on size. He says: "Though the fossil specimens are considerably larger than any of the recent ones, I am unable to detect any other difference." (*Proc. Wash. Acad. Sci., vol. II, p. 657, 1900.*)

The University of Kansas expedition secured two specimens of this interesting form and although they are not perfect I am able to point out specific differences which are of sufficient importance to continue the separation of the fossil from the living form. Comparison has been made with several fossil specimens in the collection of the University of California; also with 16 excellent specimens of *Ammonitella yatesi* Cooper from the Hemphill collection which now forms a part of the museum of the California Academy of Sciences. The recent shells came from "near Murphys, California," and were collected by Henry Hemphill.

One important difference is in size. The largest *yatesi* is but 9 mm. in greatest diameter, whereas the largest *lunata* (and it is imperfect) is 15 mm. The former also has eight whorls while the latter has nine. The umbilicus of *lunata* is proportionately wider and the apex is a hollow cone. The apex of *yatesi* is truncated inside and therefore shallower. On the ventral side of *yatesi* the last whorl swings out over the one preceding, but this is not true in the best specimen of *lunata*, although figure 1 of Stearns (White) indicates that there may be some variation in this respect in the fossil species.

MEASUREMENTS.

(All measurements are in millimeters.)

	A. yatesi.	*A. lunata.*	
Greatest diameter	9.00	15.00	12.50
Least diameter	8.00	13.50	11.00
Greatest altitude	4.50	7.50	6.50

No measurements of the fossils studied by Conrad, Stearns and White have been published. Their figures show that the shell substance of the body whorl has been lost, a condition which is almost always the case. The University of Kansas specimens are in that condition, but through the kindness of Prof. Bruce L. Clark, I was permitted to examine well-preserved material in the University of California. It was learned that the shells are smooth and shining as in the recent species, with growth wrinkles barely showing on the latter part of the body whorl.

Gastrodonta imperforata Hanna. New species.

(Plate I; figures 1, 2, 3.)

Whorls six; spire high and dome-shaped; sutures moderately impressed; apex marked with fine regular growth lines; growth lines on the body whorl slightly uneven but without an approach to a ribbed condition; last whorl slightly descending at the aperture; peristome thin and acute, slightly expanded on the basal portion; umbilical region deeply impressed, the perforation being minute. Greatest diameter, 17.50. Least diameter, 16. Altitude, 13.

Type in the University of Kansas from Cove Inlet, John Day river, Oregon, collected by H. T. Martin in 1907.

A single specimen was obtained. The dome-shaped shell and thin, acute peristome prevents its being classed as *Polygyra dalli,* the species with which it is most apt to be confused. Its correct generic position cannot be stated because of minor shell differences which separate many of the groups of recent pulmonates. It resembles in general shape some of the *Gastrodontas* as *intertexta,* for instance. The fact that the lip is slightly expanded below is the chief character which casts some doubt upon its being a *Gastrodonta.* This condition is met with in *Oreohelix* and our shell resembles in form and size some of the dome-shaped varieties of *O. cooperi,* as, for instance, *apiarium* Berry. It might be placed directly in this genus were it not for the differentiating characters of the umbilicus.

The specimen is slightly defective as shown by the photographs but it is sufficiently intact it seems to make the species easily recognizable in the future.

There is a second specimen in the collection of the University of California which is similar in all respects to the type, except perhaps it is a little better preserved.

Pyramidula mascallensis Hanna. New species.

(Plate I; figures 4, 5, 6.)

Whorls six and three-fourths, rounded below and flat above; spire not greatly elevated; suture apparently channeled; last whorl carinated through the first two-thirds, the carina gradually disappearing; latter part of last whorl depressed below the carina of the one preceding; the shell substance of the apical whorls is preserved but sculpture is absent; the body whorl is an internal cast but shows on the upper side some coarse uneven growth ridges; umbilicus widely open. Greatest diameter, 33.50. Least diameter, 30.25. Altitude, 28.

Type in the University of Kansas from Cove Inlet, John Day river, Oregon, collected by H. T. Martin in 1907.

Only the type specimen was secured so that a statement of variation cannot be given. The flattened upper whorls and the apparently deeply channeled suture distinguish this shell from other species. It may represent a new generic type, but the genera of land shells were so often based upon anatomical and minor shell characters that it seems best for the present to include this under *Pyramidula,* the genus which it most resembles. Perhaps better material will eventually be secured and enable the correct genus to be determined. The specimen is not perfect. The aperture has been lost, together with the shell substance of the last two whorls. It has also been crushed but not in such a manner as to distort the shape. The original shell had over seven whorls and was considerably more elevated than the measurements given show. But the diameter was but little if any greater on account of the last whorl growing in beneath the one preceding. Also when the shell was complete the last whorl was but little angulated on the periphery, this seeming to be a character which applies only to the whorls up to and including the sixth.

It is named for the Mascall, one of the subdivisions of the John Day series.

At first it was believed that this specimen was Conrad's *Helix* (*Zonites*) *marginicola* because it was the only form found with the "spire scarcely raised above the margin of the last volution." However, he states that his shell had six whorls and was narrowly umbilicate. He gave no measurements, but his figure shows that he had a young specimen. He states further that his shell was narrowly umbilicate, a condition which would not be true in the young of *mascallensis.* There is, in my opinion, little doubt that one of the species subsequently described under another name is *marginicola,* but this cannot be recognized because of the inadequate original description. It is to be hoped that if the type specimen is in existence it will some day be fully described.

Polygyra dalli Stearns.

Helix (*Monodon*) [*error for Mesodon*] *dalli* Stearns. In White, Bul. 18, U. S. Geol. Surv., p. 14, pl. III, figs. 4-6, 1885.

Polygyra dalli Stearns, Proc. Wash. Ac. Sci., vol. II, p. 655, pl. XXXV, figs. 4-6, 1900. Same figures as above reproduced.

Polygyra dalli Stearns, Science, new series, vol. XV, p. 153, 1902.

Polygyra dalli Stearns, Univ. of Calif. Pub. Geol., vol. V, No. 3, p. 67, 1906.

One almost perfect specimen and four young and broken ones were obtained at Cove Inlet, John Day river, by Mr. Martin. A large number of specimens in the University of California indicates that this is probably the most abundant species in the region. As Stearns has shown, it is very closely related to *Polygyra columbiana* Gould, which is common in the

Pacific coast states to-day. The latter, however, is smaller; some specimens of *dalli* are almost as large as *thyroides* of Kansas and Missouri. The umbilicus of the fossil species is covered by the narrowly reflected peristome and its junction with the body whorl is deeply seated. There appears to be no tendency for the peristome to descend more or less abruptly near its outer termination with the body whorl.

Polygyra expansa Hanna. New species.

(Plate I; figures 7, 8, 9.)

Whorls about seven, somewhat flattened above and below; sutures not deeply impressed; lines of growth apparently uneven on the last whorl and broken into ridges parallel thereto; the last whorl of the type is subcarinate at its beginning due to pressure, but is flattened naturally on the lower side; axis imperforate and covered with heavy shell substance; the junction of the peristome with the body whorl in the umbilical region is marked with a distinct angular depression; it is not a gently concave depression as found in such recent *Polygyras* as *albolabris*. Greatest diameter, 32. Least diameter, 28.50. Altitude, 17.

Type in the University of Kansas from Cove Inlet, John Day river, Oregon, collected by Mr. H. T. Martin.

A single specimen was secured and it is not in as good condition as would be desired. Its characters are so distinct, however, that it cannot be referred to any known form. The imperforate axis covered with heavy callus places it in *Polygyra* rather than in *Epiphragmophora*. However, it is flattened on the base and has a tendency to be slightly carinated as some forms of *fidelis* Gray of the latter genus.

A single, and better preserved specimen in the University of California shows, in addition to the above characters, that the outer lip abruptly descends at its junction with the body whorl for a distance of 4 mm.

Polygyra martini Hanna. New species.

(Plate I; figures 10, 11, 12.)

Whorls five, well rounded, the last being conspicuously enlarged vertically; sutures moderately impressed; lines of growth very fine for a shell of this size and very regular, crossed by less impressed revolving striæ which are most noticeable on the body whorl; umbilical region deeply impressed; lip thickened by callus and reflected over almost the entire umbilicus; no indication of a noticeable deflection of the peristome at its junction with the body whorl. Greatest diameter, 34.50. Least diameter, 25. Height of body whorl, 19. Altitude without body whorl, 18. Altitude (total), 28.

Type in the University of Kansas from Cove Inlet, John Day river, Oregon, collected by Mr. H. T. Martin in 1907.

A single well-preserved specimen was secured. While it resembles in general shape some of the old world species, as *Pomatia aspera* for instance, it is believed to be more closely related to the *albolabris* group of *Polygyra*. It must be stated, however, that important differences exist. The shell is more globose than other species of this genus and the umbilical region is more deeply impressed. While most of the margin is broken away, enough remains to show that it was folded back upon itself in the basal region and the body whorl was obtusely keeled in this region.

The shell resembles in some respects the *Helix leidyi* of Hall and Meek (*White, 3d. Ann. Rep. U. S. Geol. Surv., p. 455, pl. XXXII, figs. 32, 33, 1881-'82*), but it is proportionately more elevated and the body whorl is deeper in a vertical direction. The two species belong to the same section of the genus which may be defined by the form of the lower apertural margin and the angular body whorl in the umbilical region.

The species is named in honor of Mr. Martin, an indefatigable collector of fossils.

Epiphragmophora dubiosa Stearns.

Epiphragmophora dubiosa Stearns, Science, new series, vol. XV, p. 153, 1902. (Original description.)

Epiphragmophora dubiosa Stearns, Univ. of Calif. Pub. Geol., vol. V, p. 69, figs. 3, 4, 1906. Original description repeated and figures provided.

Only one specimen of this interesting species was found. The shell is imperfect, as was the type, but enough remains to show that it is narrowly umbilicated; very flat below and spire but little elevated; whorls flattened above and sutures but little impressed; the pitting on the apex mentioned by Stearns cannot be seen, but this may be due to the worn condition of the shell substance; for the same reason the growth striæ are not well preserved. Greatest diameter, 23. Altitude, 12. Whorls, five and three-fourths.

It is not certain that the form is placed in the correct genus, but without better preserved material for study it would be useless to attempt any other disposition. Doctor Stearns states and shows in his figure that the sutures are deeply impressed. It is believed, however, that this is not natural, as the Kansas University specimen and four others seen in the University of California did not show them noticeably deepened. Snails of this group are known to be subject to considerable variation in this respect so that it would not seem to be justifiable to consider them distinct on this character when otherwise all which have been seen agree with the description and figures. Unfortunately the formation of the aperture in the species cannot be determined.

Epiphragmophora antecedens Stearns.

Helix (Aglaia) fidelis Gray. Stearns (in White) Bul. 18, U. S. G. S., p. 14, pl. III, figs. 1-3, 1885.

Epiphragmophora fidelis antecedens Stearns, Proc. Wash. Acad. Sci., vol. II. p. 653, pl. XXXV, figs. 1-3, 1900.

Epiphragmophora fidelis antecedens Stearns, Science, new series, vol. XV, p. 153, 1902.

Epiphragmophora fidelis antecedens Stearns, Univ. of Calif. Pub. Geol., vol. V, p. 67, 1906.

Four specimens which clearly belong to this species were found. One is fully grown. It shows that the umbilicus was normally completely closed and thickened with callus, a condition which does not obtain in *E. fidelis.* The umbilicus, however, is of the general form found in *Epiphragmophora* and not that which is common in *Polygyra.* The best specimen Stearns had was imperforate, but it seemed to have been caused by crushing. This is now known to be normal.

In order to complete the record the other species of mollusks known from the John Day Miocene will be mentioned. The original generic terms ascribed to them are retained. No object would seem to be gained by attempting a rearrangement at this time. The full synonomy of *Unio condoni* White has not been searched for.

1. *Unio condoni* White, Bul. 18, U. S. Geol. Surv., p. 13, pl. II, figs. 1-3, 1885.
2. *Limnæa maxima* Stearns, Science, new series, vol. XV, p. 154, 1902.
   Limnæa maxima Stearns, Univ. of Calif. Pub. Geol., vol. V, p. 70, fig. 1, 1906.
   Limnæa stearnsi Hannibal (in Baker) *Limnæidæ* of N. and Mid. Am., p. 102, pl. XVII, fig. 11, 1911. New name for *L. maxima* above, preoccupied by Collin, Ann. Soc. Mal. Belg., VII, p. 94, 1872.
3. *Helix (Zonites) marginicola* Conrad, Am. Jour. Conch., vol. VI, p. 315, pl. XIII, fig. 9, 1870. Bridge creek, Oregon. Condon, Coll.
   Helix (Zonites) marginicola White, 3d Ann. Rep. U. S. Geol. Surv., p. 453, pl. 32, fig. 34, 1880-'81.
4. *Helix (Patula) perspectiva* Say. Stearns, Bul. 18, U. S. Geol. Surv., p. 14, pl. III, fig. 7, 1885.
   Pyramidula perspectiva simillima Stearns, Proc. Wash. Acad. Sci., vol. II, p. 657, pl. XXXV, fig. 7, 1900.
   Pyramidula perspectiva simillima Stearns, Science, new series, vol. XV, p. 153, 1902.
   Pyramidula perspectiva simillima Stearns, Univ. of Calif. Pub. Geol., vol. V, p. 67, 1906.
5. *Pyramidula lecontei* Stearns, Science, new series, vol. XV, p. 154, 1902.
   Pyramidula lecontei Stearns, Univ. of Calif. Pub. Geol., vol. V, p. 68, fig. 2, 1906.

The reader is referred to a paper by Harold Hannibal (*A Synopsis of the Recent and Tertiary Mollusca of the Cali-*

fornian Province; Proc. Mal. Soc. London, vol. X, pp. 112-211, 1912) which may perhaps have references to the John Day fauna. The paper has not been favorably reviewed. (*Pilsbry, Nautilus, XXVI, 71, 1912.*) I have not seen it and cannot comment on what it contains, but apparently Hannibal, in working over the John Day material in the University of California, combined at least four species under the name *Helix marginicola* Conrad. Some of them bore Stearns' labels and probably some of them were his types.

EXPLANATION OF PLATE I.

The figures are from photographs which have been retouched. The photographs were taken with millimeter cross-section paper for a background and the scale can be obtained from this. Figure 1 is less enlarged than figures 2 and 3.

Figures 1, 2 and 3. *Gastrodonta imperforata* new species.
Figures 4, 5 and 6. *Pyramidula mascallensis* new species.
Figures 7, 8 and 9. *Polygyra expansa* new species.
Figures 10, 11 and 12. *Polygyra martini* new species.

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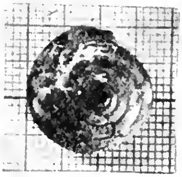

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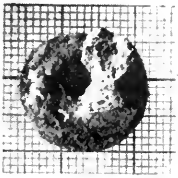

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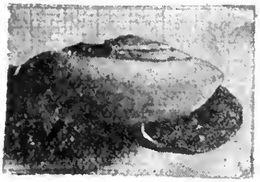

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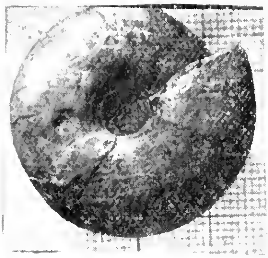

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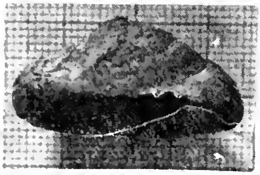

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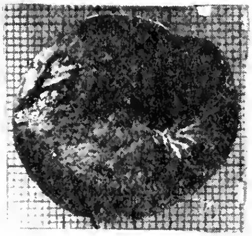

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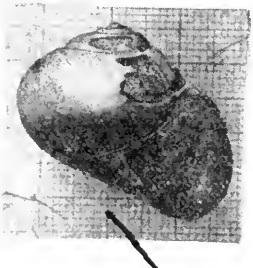

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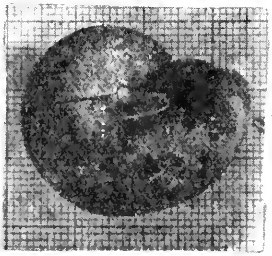

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PLATE I.


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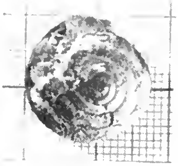
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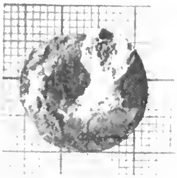
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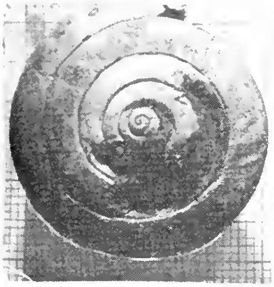
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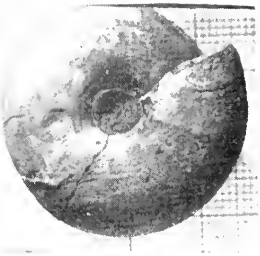
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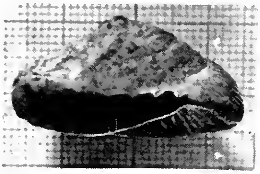
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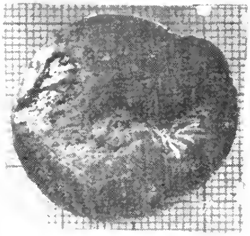
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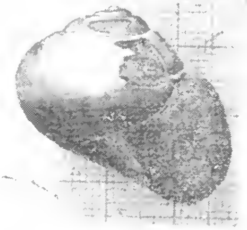
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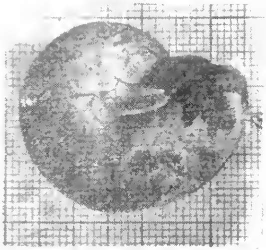
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THE KANSAS UNIVERSITY SCIENCE BULLETIN.

VOL. XIII.] MAY, 1920. [NO. 2.

Pleistocene Mollusks from Wallace County, Kansas.*

BY G. DALLAS HANNA.

Curator of Invertebrate Paleontology, California Academy of Sciences.

ONE of Mr. H. T. Martin's numerous fossil hunting expeditions for the University of Kansas took him to the Miocene mammal beds of Wallace county of that state. Here, in one locality he found some ant hills about which were numerous shells the indefatigable insects had collected. A small quantity of the general debris about the nests was preserved and the mollusks have come to me for study.

The collection, although small, is valuable because it throws more definite light upon the size and duration of the Pleistocene Kansas lake which Prof. J. E. Todd has aptly named "Kaw Lake." Some of the species of mollusks found inhabit lakes solely and since there are none of these bodies of water within a long distance of the locality at the present time, practically conclusive proof is offered of the existence of Kaw Lake before the present epoch. And since many of the species now live in northern cold waters it seems justifiable to conclude that this body of water was coexistent with the great glaciers. Probably its inhabitants lived during the deposition of the Aftonian gravels; that is, prior to the descent of the Kansan ice sheet. It seems likely that the lake was formed by the pre-Kansan ice sheets, continued through the Aftonian period and that its dam was broken by the Kansan sheet.

Kaw Lake probably existed for several hundred years. This is indicated by the presence in it of a large molluscan population which would require a very considerable number of years

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for dispersal. A cool, moist climate similar to that of northern United States or southern Canada must have accompanied it. This is shown by the land-shell species found associated with the fresh water. This was also shown by the shells found in the Phillips county Pleistocene which has been reported upon. (*Hanna and Johnson, Kan. Univ. Sci. Bul., vol. VII, No. 3, 1913.*)

That radical change took place in the climate, fauna and flora of western Kansas after the disappearance of Kaw Lake is evident from the almost complete disappearance of the land and fresh-water mollusks. A considerable number of species and at least two genera are not known from Kansas as yet except from Pleistocene fossils. Neither streams nor uplands are fitted for their existence and search must be made for them far to the north before they are located.

The ants were not particular in choosing material for their "hills." Besides the fossil shells dug from the light buff material forming the lake deposit they collected a few recent species, probably found living near at hand. There were also sand grains of large size and plant stems, seeds and roots.

LIST OF SPECIES.

Sphærium. What appear to be two species were secured. Any attempt at specific determination in this group of shells at this time would merely add to the already almost inextricable confusion.

Valvata tricarinata Say. Four specimens. I know of no published records of this species from Kansas, either living or fossil. Mr. E. C. Johnston collected a dead shell, but not a fossil, at Cameron's Bluff, above Lawrence, Kan., in 1916. No other records are available for the state.

Lymnæa humilis rustica Lea. One specimen. This form is recorded from Douglas county, Kansas, by Baker (*Lymnæidæ of N. Am., p. 269, 1911*), and is probably the same as was recorded from the Phillips county Pleistocene as *L. humilis.*

Lymnæa parva Lea. Thirteen specimens. Previously known from the marl beds of Long Island, Phillips county, and from Douglas county river debris.

Planorbis antrosus Conrad. Seven specimens.

Planorbis deflectus Say. Two specimens. Both are small and apparently not full grown. The species lives in Lake View, Douglas county and has been found in the Pleistocene of Phillips county. Baker (*Naut., XXIII, p. 93, 1909*) records it from Anthony, Kan.

Succinea avara Say. Abundant.

Succinea stretchiana Bland. Two specimens. This species lives on the plains at the present time and the two shells secured are plainly not fossils.

Vallonia pulchella Müller. Fifteen specimens. This is an addition to the list of Kansas Mollusca and since it inhabits cool, moist timbered areas it emphasizes that this was the condition in western Kansas in Pleistocene time.

Zonitoides singleyanus Pilsbry. Two specimens, not fossils.

Pupilla muscorum Linnæus. Abundant. In Pleistocene time this was a very common snail in western Kansas.

Pupoides marginatus Say. Six living shells.

Gastrocopta armifera Say. One living shell. Both this and the preceding species live in the region at the present time.

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Moisture Requirements of Germinating Seeds.*

BY RUPERT PETERS.

INTRODUCTION.

IT HAS long been recognized that a close relation exists between plant life and soil moisture. Common observation showed our ancestors that wilting occurred when the moisture content of the soil was markedly lowered and that death followed when it was long continued, but it remained for the twentieth century investigators to attempt the discovery of the moisture conditions under which plants could best flourish and those under which they wilted and died, as well as to point out definitely the boundaries between these. But, even yet, very little is to be found in the literature concerning the lower limits of soil moisture in connection with plant growth.

This paper is the record of an attempt to aid in the location of the lowest boundary at which plants may be active, and is concerned particularly with the relation of the wilting coefficient of the soil to the germination of seeds. An attempt has been made to answer the question whether seeds can germinate when the amount of soil moisture is so low that plants growing in it wilt and die.

The work was suggested by Dr. Charles A. Shull, then of the plant physiology laboratory of the University of Kansas, now of the University of Kentucky. Most of the actual work was done in the botany laboratory of the Northeast High School, Kansas City, Mo., near enough to be in frequent consultation with Doctor Shull. It is but fitting that an appreciation of his deep interest and kind suggestions be made here. Thanks

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are also due Prof. W. C. Stevens for suggestions and criticisms in the preparation of this paper.

HISTORICAL.

Although Sachs (7) recognized a wide range, from 1.5 per cent in coarse sand to 12.3 per cent in a mixture of sand and humus, in the moisture content of various soils when plants wilted, he made his tests with a single plant species (the tobacco), drew his conclusions, and then dropped this line of investigation. Few have taken it up since. Hedgecock (4) found that entire turgid plants of the same species had, at any given age, approximately the same water content, regardless of the differences in the soil or in the conditions under which they were grown. On the contrary, the water content of plants beginning to wilt varies with the soil, being always greater in clay, loess, and saline soils than in loam, humus, or sand. He also found that xerophytes could remove more water from the soil than could mesophytes or hydrophytes; the former removing all but 3 per cent, while the second named left in the same soil under the same ærial conditions at least 5 per cent. Clements (3), independently, arrived at similar conclusions.

These were the chief contributions until Briggs and Shantz (1) brought out their work on the "wilting coefficient." They proposed the term and defined it as the percentage of water (based upon the dry weight of the soil) remaining in this when wilting had progressed to such an extent that recovery by the plant was impossible even in an approximately saturated atmosphere, without the previous addition of water to the soil. In working out their results they maintained practically uniform conditions; their greenhouse had an average temperature of about 70° F. and the relative humidity was maintained at 85 per cent. Such changes as did occur in these factors were slight and gradual. A constant temperature for the soils being examined was maintained by a specially-devised water bath in which the containers were set. About twenty different soils were examined, differing widely in all characters, and giving results ranging from 1 per cent in coarse dune sand to over 30 per cent in the heaviest types of clay. For plants, over a hundred species and varieties were tried out, so selected as to give a range from extreme xerophytes to hydrophytes. In general, the amount of water remaining in any one of these soils when the plants growing in it had fully wilted, was practically constant. It made no difference as to the plants used, being a fixed quantity for that soil. Furthermore, they worked out formulæ by which this wilting coefficient for any soil could be calculated from either of four factors: its moisture equivalent, its hygroscopic coefficient, its moisture-holding capacity, or its texture as determined by mechanical analysis. Their wilting coefficient was the standard when this work was begun. Since then, the work of Caldwell (2) has come to hand. He carried on his experiments at the desert laboratory of the Carnegie Institution at Tucson, Arizona. Here, transpiration was excessive as the result of the heat, low humidity, and the hot, dry winds. When he produced conditions similar to those of Briggs and Shantz, his results tallied with theirs. When conditions were natural for his location, he found the wilting coefficient always higher (even 30 to 40 per cent) than theirs or than that calculated from their formulæ. Further, "under any set of aërial conditions the observed soil moisture content at permanent wilting is approximately a constant for each of the soils used, and its value increases with the increase in the rate of transpiration, being greater under conditions of high evaporation intensity and declining with the decrease of the evaporating power of the air. For a series of plants grown in any soil, and wilted under different aërial conditions, all with relatively high evaporation rates, as many different soil moisture contents at permanent wilting are obtained as there are sets of conditions."

Russell (6) has shown that the rate of supply of soil water is simply the speed at which water can move in the soil, and this depends upon the amount of clay and colloidal matter present. Livingstone (5) calls attention to another factor which complicates the problem still more. In a set of experiments carried on in the Johns Hopkins' greenhouses where he had plants grown with their roots in vessels of water and subjected to varying aërial conditions, he found that with the "back pull" of the soil thus cut out, temporary and even permanent wilting occurred. His conclusion is that the trouble is internal, the absorbing power of the roots is inadequate to supply moisture as fast as it is lost by evaporation. Hence, he thinks permanent wilting need not depend upon soil moisture conditions necessarily, although it frequently does. Caldwell's higher results are thus evidently due to the rapid transpiration of water from the leaves, associated with the slowness of the water movement in the soil, especially when the amount present was quite low; in other words, the water was evaporated from the leaves more rapidly than it could be absorbed from the soil, and wilting followed as the result of this back pull before the amount of water in the soil was lowered to the point reached in the corresponding tests of Briggs and Shantz.

METHODS.

Since the purpose of this investigation is to determine if germination can occur with far less moisture than is commonly thought necessary, since transpiration is not a factor in the tests (thus making them somewhat similar to those of Briggs and Shantz in that they had always a high humidity present in theirs), and since the Briggs and Shantz' figures are lower than Caldwell's, they are retained as the standard for this test. Nevertheless, it is recognized that this may not be a fixed standard for all conditions but may vary with differing atmospheric conditions whenever transpiration is a factor.

Because quartz sand and its data were available, it was used. It is designated as No. 2 o by its manufacturers, the Wausau Quartz Company, and passes over a 147-mesh screen but through a 124-mesh one, thus making the average diameter of the particles about .10 mm. It contains by analysis:

	Per cent.
Silicon dioxide	99.07
Iron oxide	0.17
Aluminum oxide	0.52
Hygroscopic moisture	0.06
Undetermined	0.18
	100.00

Its wilting coefficient, as determined at the biophysical laboratory of the bureau of plant industry, Washington, D. C., of which Mr. Briggs is director, is 1.31 per cent (8).

Two hundred grams of this sand, roughly weighed, was chosen as the unit, merely because it lacked about three centimeters of filling the common heavy glass tumblers used. The unit of sand was spread upon a glass plate and water to produce the desired percentage of moisture was added from a burette, and *thoroughly* mixed in with a spatula. Owing to varying humidity conditions in the air during mixing at different times, accuracy was approximate only, but as a rule about twenty per cent more water had to be added than was desired when mixing was complete. The wet sand was placed in the tumbler, the seeds were spaced more or less evenly about four centimeters below the surface, and the sand was settled by jarring the tumbler against the table. Enough of the melted paraffin-vaseline mixture (20 per cent vaseline in paraffin having a melting point of 45° C.) was poured over the surface to seal it effectively, and the labelled tumbler was set aside at room temperature for two weeks. As sufficient growth did not occur for photosynthesis to become a factor, light was disregarded.

In this connection, it should be stated that the first series of tests, some thirty, failed because the seeds were planted about a centimeter only below the surface of the sand. The clue was found when a sample was taken from the top and another from the bottom of the sand at the close of one of these tests, run for moisture content, and compared. That from the bottom showed a higher moisture content than the upper one, where the seeds were. A series was then run upon a tumbler machine (the one described by Shull, Bot. Gaz., 62:10-11). The bottles were half filled with the wet sand, the seeds were added, heavily shellacked corks were sealed in place, and the bottles fixed upon the wheel of the machine so that they had fifteen complete rotations a minute. This so mixed the contents of the bottles that there could be no question as to the moisture content in the various parts of the soil mass. The results were checked with another series in which the seeds were placed near the center of the sand mass, the tumblers sealed as usual, and set aside for the regular time. As results corresponded closely, the more troublesome machine method was not further used.

While filling the tumblers a carefully chosen sample of the sand was placed in a tared weighing bottle and this was immediately covered. Although this sample was taken when the tumbler was half filled, and although all speed commensurate with careful work was used, yet on dry days considerable loss of water must have occurred from the sand not yet in the tumbler and from the surface of that already in it. This sample was carefully weighed upon a standard balance sensitive to .0001 gram and was then placed with cover removed in a drying oven at 100° to 104° C. until a constant weight was obtained. Another source of error is to be noted here. The particles of dry sand were so light that unless extreme care was used in covering and uncovering the bottles, some of these particles would be carried out on air currents and so give false results upon subsequent weighings. From the two figures obtained by these weighings, the per cent of moisture in the corresponding sand was secured.

At the end of the two-week period the seal was broken and the contents of the tumbler were dumped upon a glass plate. A sample was taken quickly for determining the moisture content. Germination was noted and the seeds were separated from adhering sand grains by being gently brushed with a camel's hair brush, were at once dropped into a weighing bottle, and their loss of moisture then determined by weighing and drying to a constant weight.

Seeds were considered to have germinated when .5 cm. of the rootlet extended through the seedcoat, and to be "incipient" when a shorter length was to be seen. This is another arbitrary standard, but some such point had to be chosen.

It is realized that with no means available for controlling the soil temperatures during the tests, considerable error may have crept in, but with all allowance for such in the results following, it is felt that it would not alter the conclusions drawn.

PRELIMINARY TESTS.

An early step taken as a guide to the amount of absorption to be expected was to determine the approximate curve of water absorption of various seeds when conditions were favorable for germination. It was thought this might be used in comparison with results obtained in the tests as an indicator, suggesting nearness of approach to necessary amounts of water to be furnished. Although of little assistance in the way planned, the results later obtained tallied fairly closely. To get these, ten weighed seeds were placed upon wet sand, or on or between pads of wet cotton, in Petri dishes at room temperature (averaging 19.5° C.) and weighed at intervals until germination had taken place.

The results are shown in the following tables:

TABLE 1. Water Absorption of Corn.

Test No.	1		2		3		4	
Dry wt.	3.6270		3.7286		3.6565		3.5170	
Time in hours.	Gain.		Gain.		Gain.		Gain.	
	Grams.	Per cent.	Grams.	Per cent.	Grams.	Per cent.	Grams.	Per cent.
1	.2731	7.52						
2					.2690	7.3		
3	.3991	11.00						
4			.7215	19.3			.2496	7.0
5	.4926	13.58						
7	.5903	16.27			.5757	15.7		
8			.9848	26.4			.4146	11.2
9	.6585	18.15						
24	1.0119	27.89	1.4165	38.8	1.0834	29.9	.7241	20.5
28	1.0495	28.93	1.5142	40.0	1.1766	32.1		
32	1.1109	30.62	1.5652	41.1	1.2342	33.7	.8809	25.0
48	1.2587	34.70	1.8168	48.7	1.4037	38.3	1.0030	28.5
52	1.3111	36.14			1.4264	39.0		
56	1.3137	36.22			1.4548	39.7		
72	1.4735	40.7			1.5937	43.5	1.1198	31.8
96	2.0045	55.2			1.7588	48.1	1.2073	34.3
120							1.4661	41.1

Germination.—No. 1, all ten, rootlets averaged 2 cm.; No. 2, the same; No. 3, nine with 1.8 cm. rootlets, secondary rootlets and shoots appearing, one rot; No. 4, eight with rootlets from 1 to 3.5 cm., shoots appearing, one incipient, one rot. No. 4 was checked by setting up another test under the same conditions and taking but the initial and the final readings. Germination was complete and the per cent of gain was 41.5.

TABLE 2. Water Absorption of Legumes.

	Peas.		Navy beans.		Soy beans.	
Dry weight.	3.3909		2.7181		4.0166	
Time in hours.	Gain.		Gain.		Gain.	
	Grams.	Per cent.	Grams.	Per cent.	Grams.	Per cent.
1			1.0070	40.49	.4811	11.97
3			1.6225	59.69	.8870	22.08
4	2.8367	83.6				
5			1.9493	71.71	1.2667	31.53
7			2.1184	77.93	1.6510	41.10
8	3.9282	115.8				
9					1.9613	48.80
24	5.1386	151.5	2.5903	95.23	3.8499	95.84
27			2.6135	96.15		
28	5.2918	153.1			4.2329	105.38
30			2.6394	97.10	4.4170	109.96
32	5.3788	158.6			4.5323	112.83
48			2.8475	104.76	4.7940	119.35
52					4.8430	120.57
54			2.9528	108.62		
56					4.8823	121.55

Germination.—All peas and the navy beans had rootlets averaging 0.9 cm. One soy bean rotted, the others had 0.5 to 1.0 cm. rootlets.

The results shown in these tables are shown graphically in figure 1. They were checked by running a series of five sets each. The above are characteristic and the data for the others is omitted. The averages, however, were: Corn, 46.4 per cent; peas, 149 per cent; navy beans, 108.3 per cent; and a series of tests with wheat, 69.1 per cent.

Widtsoe (10) gives the following as the percentages of moisture contained by seeds at saturation. Wheat, 52 to 57; corn, 44 to 57; peas, 93; beans, 88 to 95. The differences between those given above and those of Widtsoe are probably due to differing end-points, or the different varieties of seeds may differ in their saturation percentages. The original papers to which he refers are not available. The results reached here will be used as the same end-point and as seeds from the same lots were used as in the tests following.

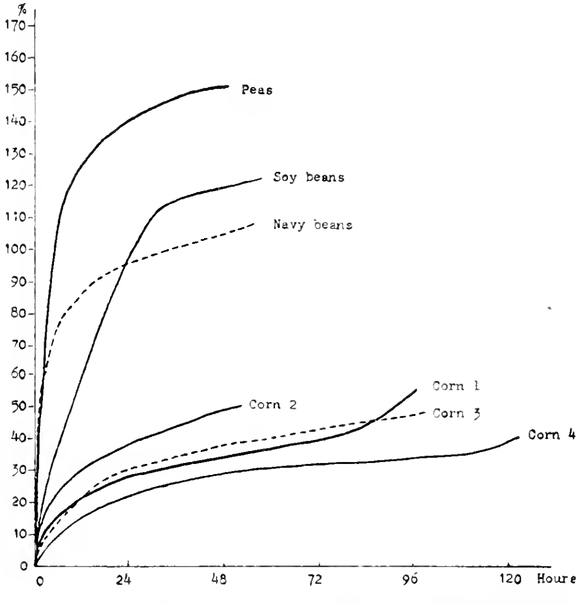

FIG. 1. Water absorption of various germinating seeds. Corn 1, navy beans and soy beans on wet cotton; peas and corn 2, between pads of wet cotton; corn 3, on sand wet with 10 per cent water; corn 4, on sand wet with 5 per cent water.

RESULTS.

At the same time this preliminary test was run, careful germination tests were made of different lots of seeds and only those were chosen for use which gave a high percentage of vitality. Corn was the first used, Boone County White, as to variety. With no arrangement to keep temperatures down, and working at first in July in a room where it at times became exceedingly warm, a number of the early tests failed because the vapor caused the seal to buckle and loss of moisture resulted. The unnoticed loss of sand particles in removing covers when placing bottles in the oven, caused on one series alone some seventy useless weighings in the endeavor to secure constant weights. But when the difficulties had been overcome, results were secured as shown in table 3, the first ones naturally being too high.

Only those tests are quoted which may be of assistance in reaching conclusions. By "weight of bottle" is meant the tare of the weighing bottle in which the particular sand sample was placed for drying. "Weight with wet sample" is the weight of this bottle and the wet sand sample before going into the oven. "Weight with dry sample" means the weight of this bottle and the sand when a constant weight had been secured by drying. "Loss of water" is the difference between the two just given. "Weight of dry sample" is the net weight of the sand sample after drying. "Per cent of water" $= \frac{\text{Loss of water}}{\text{Weight of dry sample}}$. The upper line of figures in each test is the record of the sample taken at the beginning of the test; the lower one, that at the close of it.

TABLE 3. Results of tests with corn.

No.	Weight of bottle.	Weight with wet sample.	Weight with dry sample.	Loss of water.	Weight of dry sample.	Per cent of water.	Germination.
22	15.1972 14.9436	27.2665 24.4012	27.0445 24.3547	0.2220 0.0465	11.8473 9.4111	1.87 0.48	All sprouted; tumbler filled with tangle of roots; two shoots through seal.
23	14.9436 13.1033	26.2905 22.4946	26.1013 22.4467	0.1892 0.0479	11.1577 9.3434	1.69 0.51	Four growing vigorously, 25 cm.; roots freely branched, no shoots; one rotted.
24	13.4485 11.2461	22.8234 21.7644	22.6711 21.6932	0.1523 0.0712	9.2226 10.4471	1.65 0.68	Four germinated, one incipient.
25	11.2461 13.4485	19.7670 22.9802	19.5860 22.9190	0.1810 0.0612	8.3399 9.4705	2.17 0.64	All growing freely; shoots appearing.
28	14.9436 11.2461	27.1611 20.6403	26.9926 20.5776	0.1685 0.0627	12.0490 9.3315	1.39 0.67	All germinated, roots 0.5 to 3cm., shoots forming.
29	15.7069 13.1033	28.8811 21.4845	27.7170 21.4264	0.1641 0.0581	12.0101 8.3231	1.36 0.69	All with branched roots, 5-12 cm., and with 1-3 cm. shoots.
30	15.1972 13.4485	26.4334 23.1298	26.2708 23.0806	0.1626 0.0492	11.0736 9.6321	1.46 0.51	Four with 1 cm. rootlets, 1 incipient.
33	14.9436 12.7311	27.2533 21.9564	27.0783 21.8662	0.1750 0.0902	12.1347 9.1352	1.44 0.98	All with 1 cm. rootlets.
34	15.7069 11.2461	27.4449 21.7802	27.2634 21.6694	0.1815 0.1108	11.5565 10.4233	1.59 1.06	All with 4-7 cm. roots, shoot just showing.
36	15.1972 13.1033	26.6290 22.6704	26.5158 22.6056	0.1182 0.0648	11.3186 9.5023	1.00 0.68	One with 2 cm. rootlet and with shoot showing, 4 with 1 cm. rootlets.
38	15.7069 15.7069	27.0591 27.1975	26.9420 27.1318	0.1171 0.0657	11.2351 11.4249	1.04 0.57	One fully germinated, 4 incipient.
39	12.7311 12.7311	23.0582 22.4594	22.9908 22.4195	0.0647 0.0399	10.2597 9.6884	0.65 0.41	All swollen.
41	14.9436 13.4485	28.0634 23.8692	27.9723 23.8295	0.0911 0.0397	13.0287 10.3810	0.69 0.38	One with 2 cm. rootlet; 1 incipient; 3 swollen.
42	15.1972 13.1033	26.2167 21.9365	26.1267 21.8895	0.0900 0.0470	10.9295 8.7862	0.82 0.53	Two with 1 cm. rootlets; 1 incipient, 2 swollen.
43	15.1972 13.4485	27.2890 22.8073	27.2100 22.7795	0.0790 0.0278	12.0128 9.3310	0.65 0.29	All swollen.
46	11.2461 12.7311	21.7230 22.8293	21.6416 22.8028	0.0814 0.0265	10.3955 10.0717	0.78 0.26	One with 1 cm. rootlet, the others swollen.

Navy beans were next tested. Because of their larger size and because they absorb at least their own weight of water in germinating (table 1 and fig. 1), but two seeds were used for each test lest the necessary moisture demands for germination should so exceed the amount furnished in the sand that germination would be impossible.

TABLE 4. Results of tests with navy beans.

No.	Weight of bottle.	Weight with wet sample.	Weight with dry sample.	Loss of water.	Weight of dry sample.	Per cent of water.	Germination.
58	12.7311	21.7195	21.6582	0.0613	8.9271	0.68	One somewhat swollen, one with 2 cm. rootlet.
	15.1972	27.7559	27.7136	0.0423	12.5160	0.33	
59	14.9436	26.5169	26.4262	0.0907	11.4826	0.79	One with 1 cm. rootlet, one with 0.4 cm. rootlet.
	13.1033	22.0372	22.0058	0.0314	8.9025	0.35	
60	15.1972	27.1102	26.9874	0.1228	11.7902	1.04	One with 2.4 cm. rootlet, one with 0.2 cm. rootlet.
	12.7311	22.0474	21.9928	0.0546	9.2617	0.58	
61	15.7069	27.1330	26.9881	0.1449	11.2812	1.28	One with 3 cm. rootlet, one dry and unswollen.
	13.4485	24.1932	24.1025	0.0907	10.6540	0.85	

Numbers 59 and 60 are particularly interesting as they show germination of both seeds with amounts of water supplied well below the wilting coefficient of the sand. Number 61 unfortunately had a dead seed. As a further check in this series, the beans were weighed when selected, again when the test was complete, and were then dried and the loss of water determined. In the following table "calculated absorption" is based upon the results shown in table 1 above. The actual loss of weight is in every case below the calculated absorption, even though it includes the water originally present in the seeds. This either indicates that germination can take place with less water than the amounts indicated there, or illustrates the difficulty of making transfers without the loss of water, probably the latter, although corn 4 compared with corn 3 in table 1, given originally 5 per cent and 10 per cent of water in the sand, seem to bear out the former idea, since the absorption was 4 per cent and 48 per cent, respectively.

TABLE 5. Loss of water in drying germinated beans.

No.	Original weight.	Sprouted seeds.	Dried seeds.	Loss of weight.	Calculated absorption.
58	0.5082	0.8624	0.4200	0.4424	0.5448
59	0.5618	0.9484	0.4622	0.4862	0.6067
60	0.5440	1.0178	0.4356	0.5822	0.5875
61	0.5257	0.8092	0.4634	0.3458	0.5677

The final series upon which a report can be made was run with wheat, ten grains to the test. Results follow:

TABLE 6. Result of tests with wheat.

No.	Weight of bottle.	Weight with wet sample.	Weight with dry sample.	Loss of water.	Weight of dry sample.	Per cent of water.	Germination.
101	14.9436 14.9436	28.5618 25.8592	28.4282 25.7821	0.1336 0.0771	13.4846 10.8385	0.99 0.71	5 with 0.5-1.2 cm. rootlets, 4 incipient, 1 dead.
102	11.2461 15.7069	21.2021 27.1988	21.0792 27.1070	0.1229 0.0918	9.8331 11.4001	1.25 0.80	6 incipient, 4 unchanged.
103	12.7311 12.7311	24.2885 22.9414	24.1628 22.8613	0.1257 0.0801	11.4317 10.1302	1.09 0.79	7 with 5-7 cm. rootlets, 3 incipient.
104	15.5137 15.1972	24.7871 25.9985	24.6767 25.8904	0.1104 0.1081	9.1630 10.6932	1.20 1.01	2 with 0.5-1.2 cm. rootlets, 7 incipient, 1 dead.

Of these, No. 103 gives illuminating results with Nos. 101 and 104 close seconds.

DISCUSSION.

Some interesting things are shown in these tables. Numbers 22-35 started with moisture contents above that of the wilting coefficient of this sand, 1.31 per cent; the remaining ones quoted were below it. Numbers 36, 38, 59, 60 and 103 showed satisfactory germination in a soil given less than the wilting coefficient of moisture. Others are very close, not listed simply because fewer of the seeds germinated. Some are very suggestive: Numbers 28 and 29, for example, fully germinated and with original moisture content but 0.08 and 0.05 per cent, respectively, above the limit. There seems abundant evidence in the results shown here to indicate that seeds can germinate at or below the wilting coefficient of the soil.

Why germination did not take place in some instances is still a problem. For example, in number 4, with 1.55 per cent of moisture on the start, the seeds became slightly swollen with one rotted, and 1.30 per cent of moisture remained in the sand at the close of the test. In the light of the other tests, it hardly seems that five infertile seeds were selected for this particular one.

Further, germinating seeds pull the moisture content down to surprisingly low figures, the average, as already given, being 0.584 per cent for corn, 0.42 per cent for beans, and 0.83 per cent for wheat. This evidently depends considerably upon the rapidity with which water moves through the soil, as referred to above. In this connection, while Briggs and Shantz found the same amount of moisture remaining in the soil at permanent wilting regardless of the kind of plants grown in it, results here show quite the contrary, as just pointed out. Of course their plants had root systems distributed through the soil and with very short distances, comparatively, to pull the water; transpiration was going on; and wilting gave a more or less definite end-point; while here, there were practically no roots, just as many absorbing centers as there were seeds. There was no transpiration to be a factor, and the end-point was not even approximately fixed, making this problem really in no way comparable to theirs. Yet, in a series from the corn tests where the moisture supplied was above the wilting coefficient, there remained at the close of the tests, 0.48, 0.51, 0.68, 0.67, 0.69, and 0.51 per cent, respectively, and with the crude apparatus used, with the lack of soil temperature control, and with the variations in the end-points reached, these do not really differ a great deal.

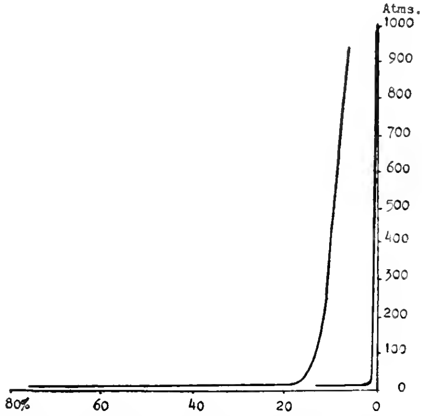

FIG. 2. Curves showing increase in the surface forces of soils as drying proceeds; to the left, for subsoil of the Oswego silt loam: to the right, for No. 2/0 sand.

But, in contrast, in those tests which started with just about this amount of water, the corn grains showed absorptive power sufficient to pull the water down to 0.29, 0.38, and 0.41 per cent, respectively. Dead plants, as shown by Briggs and Shantz (1), would have done this, or more, if extending through the seal, but here it went into the seeds. This is especially interesting in view of the fact shown by Shull (8) in his graph reproduced here, that the soil forces tending to retain moisture increase enormously as the soil becomes drier and drier, especially when approaching air-dry conditions. In these three instances there is shown a tremendous absorptive power which is evidently not present in the six cases given above, or they would have pulled more moisture from the sand.

But Shull (9) also found that air-dry seeds of the cocklebur (hygroscopic moisture, 7 per cent) had an internal attractive force for water of 965 atmospheres, or over 14,000 pounds per square inch, and that when these seeds had absorbed an additional 7 per cent of water this force had dropped to less than 400 atmospheres. The absorptive power shown by the three instances referred to in the paragraph above seems to bear out his findings. In the case of the other six, there was evidently sufficient water in the sand to allow an equilibrium to be reached between the opposing external and internal forces before the percentage of water present was pulled to the low figure reached by the other set.

Another way of looking at the results mentioned above, numbers 39, 41, and 43 were given about the same amount of water each, practically half that required for the wilting coefficient of this sand, and the results are practically the same. By calculation, disregarding that removed in sampling, each tumbler contained a total water content of about 1.3 grams. Of this, the seeds absorbed about half, 0.48, 0.62, and 0.72 grams, respectively. According to table 1, 41 per cent of the weight of the corn seed is the minimum for fair germination when conditions are favorable. Forty-one per cent here is 0.73 gram. The maximum used as shown in the table is 55 per cent, or, that would be here, 1 gram. With 0.48 to 0.72 gram of water used here, with 0.73 to 1 gram used when conditions are favorable for absorption, with the weight of the seeds practically the same, and with the moisture content of the soil pulled down to 0.29-0.41 per cent, it would seem that when the lower limit of possible water absorption from the surrounding soil was reached by these seeds in the cases quoted, they had been unable to secure water enough for germination. The lower limit is probably somewhere about 0.75 to 0.85 per cent.

In comparison, number 36 used but about 0.64 gram of water for complete germination, and when this was complete, as much water remained in the sand as each of the three mentioned had to start with. But why should number 36 germinate when it had absorbed 0.64 gram of water and number 43 fail to do so when it absorbed 0.72 gram? Has the rate of absorption or the amount remaining in the soil anything to do with it?

CONCLUSIONS.

1. Seeds can germinate when supplied with amounts of water which are below the wilting coefficient for the particular soil used.

2. A uniform water content remaining in the soil when permanent wilting occurs in the plants growing in it, regardless of species, does not hold true for seeds germinating in such a soil even when the amount supplied could have been used in germination.

3. While the amount of water used by seeds for germination may be more or less constant when moisture is abundant, they may germinate with far smaller quantities when the supply is scanty.

4. When the supply of moisture is scanty, the time required for germination is correspondingly lengthened.

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Army service interrupted this work and it is not now convenient to resume it. Its imperfections are realized, but it is hoped that it adds something to our knowledge in this field and that it may suggest further investigation.

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A Special Riemann Surface.*

BY H. H. CONWELL.

(Plates II to V.)

THE purpose of this paper is to consider in detail, for elliptic functions and briefly for hyper-elliptic functions, a special Riemann surface in three space obtained as the projection of the intersection of two hyper-surfaces in four space.

It will be seen that the surface investigated here is of advantage in the fact that it can be easily identified, from the point of view of analysis situs, with a double-faced disk having p holes; where $p = \left[\frac{n-1}{2}\right]$†, n being the degree of the function. In Riemann's real representation this is obtained only after an artificial and somewhat complicated dissection of the surface, in which the determination of the branch points is a very important factor. In a sense this difficulty may be said in our case to have been merely shifted from such a dissection to the construction of a certain real surface from its equation in three space. This construction can, however, be made very simple. In the ordinary Riemann surface the actual location of the branch points is difficult at best, and is useless so far as the investigations bearing on the surface are concerned. The actual construction of the surface under consideration will be avoided except in the simplest case, and then only as much of its outline as is necessary will be obtained. This construction will be found to be comparatively simple.

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* Received for publication on April 29, 1920.

† $\left[\frac{n-1}{2}\right]$ is understood to mean the greatest integer in $\frac{n-1}{2}$.

Let $f(w, z) = O$ be an irreducible polynomial in the two complex variables w and z, with either real or imaginary constant coefficients. Substituting $w = u + iv$ and $z = x + iy$ in the above relation we obtain the equation,

$$P\ (x, y, u, v) + iQ\ (x, y, u, v) = 0 \qquad (1)$$

Whence,

$$P\ (x, y, u, v) = 0 \qquad (2)$$

$$Q\ (x, y, u, v) = 0 \qquad (3)$$

The last two equations represent real three dimensional manifolds in the real four space (x, y, u, v). Their intersection in four space will be the surface Φ. Assume that $w = w_0$ when $z = z_0$. It is then possible, in the neighborhood z_0, w_0, to expand $(w - w_0)$ in powers of $(z - z_0)$ and by analytical continuation to go from the neighborhood of z_0 to the neighborhood of z_1. As z changes from z_0 to z_1, w will change from w_0 into one of the values w_1 corresponding to z_1. If this process be continued until z by a continuous succession of values returns to z_0, w may or may not return to w_0. In the first case the representative point on Φ corresponding to a pair of values (w, z) will describe a closed path, while in the second case the path will be open. The obvious one to one correspondence between points of the surface Φ and sets of values (w, z) shows that this surface can play the same role as the ordinary Riemann surface.

If between equations (2) and (3) v is eliminated there arises the relation,

$$F\ (x, y, u) = 0 \qquad (4)$$

which represents in the three space (x, y, u), a surface F, viz., the projection of Φ in that space. This surface F, as well as Φ, can be used as a Riemann image, this being the configuration to be investigated in this paper. We shall limit ourselves, as before stated, to the hyper-elliptic case. It is evident that the x, y or u projection of Φ would serve the same purpose as F.

Before proceeding with the general cubic a special cubic will be considered in detail, and enough of the resulting surface constructed to show its properties as a Riemann image. (This special cubic is chosen on account of its adaptability to cross-section representation.)

Consider the equation

$$w^2 = z^3 - 31z - 30 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

from which

$$P \equiv u^2 - v^2 - (x^3 - 3xy^2 - 31x - 30) = 0 \quad \ldots \quad (6)$$

and

$$Q \equiv 2uv - (3x^2y - y^3 - 31y) = 0 \quad \ldots\ldots\ldots\ldots \quad (7)$$

The intersection of $P = 0$ and $Q = 0$ in four space is the surface Φ. The v projection of Φ in three space has for its equation

$$F\ (x, y, u) = 4u^4 - 4u^2\ (x^3 - 3xy^2 - 31x - 30) - (3x^2y - y^3 - 31y)^2 = 0 \ldots. \quad (8)$$

This surface is symmetric to both the XU and XY planes. The trace on the XU plane is the XX axis and the real curve

$$u^2 = x^3 - 31x - 30 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (9)$$

representing all the real pairs (w, z) satisfying the original equation. The curve represented by (9) consists of an infinite branch and an oval (see fig. I). The XY trace consists of the XX axis and the hyperbola (see fig. II).

$$3x^2 - y^2 = 31 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (10)$$

This hyperbola and the XX axis are the only double curves of the surface.

From equation (4) we obtain,

$$u = \pm \frac{\sqrt{2}}{2} \left[S + (S^2 + T^2)^{1/2} \right]^{1/2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (11)$$

where

$$S = x^3 - 3xy^2 - 31x - 30 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (12)$$

and

$$T = 3x^2y - y^3 - 31y \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (13)$$

In this expression for u only positive values of the inner radical are considered as only real points on the surface F are to be investigated. Investigations of (11) show that when $y = 0$, $\frac{\partial u}{\partial y} = 0$ for all values of x except 6, -1 and -5, where it is infinite. For values of $x \leqq \sqrt{\frac{31}{3}}$ and $y > 0$, $\frac{\partial u}{\partial y}$ is positive or negative according to whether u is positive or negative, while for negative values of y it is positive or negative according to whether u is negative or positive. Hence for all sections of the surface parallel to the YU plane, where $x \leqq \sqrt{\frac{31}{3}}$ there will be either both a maximum and minimum point, or a double point, for y equal zero and for no other finite value of y. For $x > \sqrt{\frac{31}{3}}$, there are other maximum and minimum points and double points, and the curves all pierce the XY plane along the curve represented by equation (10). From the preceding discussion and an inspection of equation (9) and figure I it is evident that the orthogonal projection of F upon the XU plane will be nowhere within the oval, and hence that there is a hole in F for which the oval is the central section.

It is obvious that the surface F is composed of two sheets (see figs. I-VII) which hang together along the XX axis from $-\infty$ to -5, from -1 to $+6$ and pass through each other along the branch of the double curve $T=0$ which lies to the right of the YY axis.

Sections parallel to the XU plane give curves composed of two branches which cut each other in points on one branch of the double curve $T=0$ and nowhere else. Each branch continues to infinity and there unites parabolically with the other. The YU sections also unite parabolically at infinity, and hence the two sheets of the surface F merge into each other everywhere at infinity.

The surface F may be reduced to a double-faced disk with one hole as follows: For all values of $x > \sqrt{\frac{31}{3}}$ deform the surface by pulling the sheets through each other in such a way that instead of cutting in two distinct points on $T=0$ for each value of x they will cut each other in two coincident points. This deformation will be continuous and approach zero in magnitude as x approaches $\sqrt{\frac{31}{3}}$ and will nowhere produce a tear in the surface. Having made this deformation, project the surface upon the XU plane and the result will be a double-faced disk with one hole.

Starting at a point P in sheet I and continuing in any direction on the surface F we can always return to P. This closed path may be all in sheet *I* or in both sheets *I* and *II*. It may or may not pass through or around the oval. In the latter case the circuit can always be reduced to zero while in the former it cannot be so reduced, unless there be an even number of such passages and they be in opposite directions. Hence any closed circuit on F can be reduced to zero or to sums of multiples of two irreducible circuits. These facts show the elliptic function to be doubly periodic over F.

THE GENERAL ELLIPTIC CASE FOR WHICH $f(z)$ HAS REAL ROOTS.

We shall now extend the preceding discussion to a general elliptic function of the type

$$u^2 = z^3 - pz + q \quad \dots\dots\dots\dots \quad (14)$$

where p is positive and q either positive or negative, and where the roots of

$$z^3 - pz + q = 0 \quad \dots\dots\dots\dots \quad (15)$$

are all real. It will be shown that the resulting surface $F(x, y, u) = 0$ has properties identical with those of the special case already investigated, if judged from the point of view of the investigations of this paper.

We obtain at once, as in the preceding case,

$$F(x, y, u) = 4u^4 - 4u^2S - T^2 = 0 \quad \dots\dots\dots \quad (16)$$

where

$$S = x^3 - 3xy^2 - px + q \quad \dots\dots\dots\dots \quad (17)$$

and

$$T = 3x^2y - y^3 - py \quad \dots\dots\dots\dots \quad (18)$$

The similarity of the XU and XY traces to those in the preceding case is obvious. From (16) we obtain,

$$\frac{\partial u}{\partial y} = \frac{\sqrt{2}\, y[-6x(S^2 - T^2)^{1/2} + 3x^4 + 6x^2y^2 - 6qx + 3y^4 + 4py^2 - p^2}{4\,(S^2 - T^2)^{1/2}\,[S + (S^2 + T^2)^{1/2}]^{1/2}}.$$

For $y = 0$, $\frac{\partial u}{\partial y} = 0$ for all values of x except the roots of $x^3 - px + q = 0$, where it is infinite. For all negative values of $x \leqq \sqrt{\frac{p}{3}}$, $\frac{\partial u}{\partial y}$ is positive or negative for values of $y > 0$, according to whether u is positive or negative, and negative or positive for $y < 0$ according as u is positive or negative. Hence for all sections parallel to the YU plane, where $x \leqq \sqrt{\frac{p}{3}}$ there will be a maximum and minimum point for y equal zero and for no other finite value of y. Since the sum of the roots of (15) are zero, at least one root must be negative and at least one positive. It is also evident that the oval passes through the two smaller roots of (15). Let r_1, r_2, r_3, be the roots of (15), where $r_3 > r_2 > r_1$; then $r_1 + r_2 + r_3 = 0$ and $-r_1 r_2 r_3 = q$. From the last relation and the fact that $\frac{2}{3}p\sqrt{\frac{p}{3}} > q$ it is evident that $\frac{2}{3}p\sqrt{\frac{p}{3}} > 2r_2^3$ and therefore $\sqrt{\frac{p}{3}} > r_2$; in other words, $x = \sqrt{\frac{p}{3}}$ does not lie within the oval.

For $x > \sqrt{\frac{p}{3}}$ there are other maximum and minimum points or double points than for y equal zero. As in the simpler case these sections are parabolic in nature.

These investigations show that this surface has no important characteristics, from our point of view, not common to the more special case and is therefore always reducible to a double-faced disk with one hole.

THE GENERAL ELLIPTIC CASE.

Up to this point the investigations have been confined to the type, $w^2 = z^3 - pz + q$, where p and q were both real, p positive and the roots all real. It will now be shown that no generality is lost by this restriction.

Consider the general elliptic case,

$$w^2 = f(z) \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad (20)$$

where

$$f(z) = a_0(z - r_1)(z - r_2)(z - r_3)(z - r_4) \quad \dots (21)$$

and a_0, r_1, r_2, r_3, r_4, are real or imaginary constants. The elliptic integral resulting from this form may by a well known transformation of $f(z)$ be made to depend upon an integral of the type,

$$g(z) = b_0(z^3 - a_2 z - a_3).^{*} \quad \dots\dots\dots\dots\dots\dots \quad (22)$$

No generality is therefore lost by replacing $f(z)$ by $g(z)$. The constants of (22) may be positive or negative, real or imaginary. If a_2 and a_3 are arbitrarily changed the surface F will undergo a deformation. The only matter of interest in the present paper is whether such a deformation increases or decreases the number of holes in F. It is of course evident that if the number of holes is diminished as a_2 and a_3 assume the

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* Boehm, Elliptische Functionen, Zweiter Teil, page 128.

values a^0_2 and a^0_3, that as a_2 and a_3 approach a^0_2 and a^0_3 in value, one or more holes in the surface must be continually decreasing in size in such a way that when a^0_2 and a^0_3 are reached the surface has a node at the point (x_0, y_0, u_0) on F and *vice versa*. If (x_0, y_0, u_0, v_0) is the corresponding point on Φ, the latter will also have a node at this point. Therefore corresponding to nodes on F are nodes on Φ. At such nodes the tangent hyper-planes to

$$P\ (x, y, u, v) = 0$$

and

$$Q\ (x, y, u, v) = 0$$

are coincident. In order to investigate the nature of F at such places write the equations of the tangent hyper-planes to P and Q at the point (x_0, y_0, u_0, v_0), and the conditions for their coincidence. The equations in question are,

$$(x-x_0)\,P'_{x_0}+(y-y_0)\,P'_{y_0}+(v-v_0)\,P'_{e_0}+(u-u_0)\,P'_{u_0}=0, \quad (23)$$

and

$$(x-x_0)Q'_{x_0}+(y-y_0)Q'_{y_0}+(u-u_0)Q'_{u_0}+(v-v_0)Q'_{v_0}=0 \ \ldots (24)$$

The conditions for these two hyper-planes to be coincident is that

$$\frac{P'_{x_0}}{Q'_{x_0}}=\frac{P'_{y_0}}{Q'_{y_0}}=\frac{P'_{u_0}}{Q'_{u_0}}=\frac{P'_{v_0}}{Q'_{v_0}}.$$

It is evident, however, from the relation

$$P\,(x, y, u, v)+i\,Q(x, y, u, v)=0$$

that

$$P'_{x_0}=Q'_{y_0},\ P'_{y_0}=\ -Q'_{x_0},\ P'_{u_0}=Q'_{v_0}, \text{ and } P'_{v_0}=\ -Q'_{u_0}.$$

Hence

$P^{2\prime}_{x_0}+Q^{2\prime}_{x_0}=0, P^{2\prime}_{y_0}+Q^{2\prime}_{y_0}0, =P^{2\prime}_{u_0}+Q^{2\prime}_{u_0}=0$ and $P^{2\prime}_{v_0}+Q^{2\prime}_{e_0}=0$

and therefore

$$Px'_0=P'_{y_0}=P'_{u_0}=P_{v_0}=Q'_{x_0}=Q'_{y_0}=Q'_{u_0}=Q'_{v_0}=0.$$

In the above relations

$$P=u^2-v^2-s\ (x, y)$$

and

$$Q=2uv-t\ (x, y),$$

therefore it follows that $u=0$ and $v=0$ and therefore that $g\ (z)=0$. Moreover, since

$$P'_{x_0}+i\,Q'_{x_0}=0 \text{ and } P'_{y_0}+i\,Q'_{y_0}=0$$

it follows that

$$s'x_0 + it'x_0 = 0 \text{ and } s'y_0 + it'y_0 = 0.$$

Therefore $g'(z_0) = 0$, showing that z is a double root of $g(z) = 0$. It is evident therefore that the surfaces P and Q, and hence F, may be deformed in any way we please without affecting its analysis situs properties provided that during this deformation $g(z) = 0$ never acquires any double roots. These conditions allow a deformation that will change complex roots into real and unequal roots without any two roots becoming equal in the process. Hence we may in this manner transform $g(z)$ into $j(z)$, where the roots of $j(z)$ are real and unequal.

The above conclusions show that no generality is lost in considering the simpler case and thereby avoiding the difficult task of dealing with imaginary coefficients. The difficulty introduced by imaginary coefficients is that due to the lack of symmetry with respect to the XU plane.

It is evident now that the surface constructed from the simplest possible relation is sufficient for a complete exposition of the Riemann surface properties of the most general elliptic function.

A NUMERICAL EXAMPLE OF THE HYPER-ELLIPTIC CASE.

As an introduction to the general hyper-elliptic function we will consider briefly a simple numerical example of the same. The details of the surface F will be considered sufficiently to show that the preceding discussion can be applied in all its essential details to the higher form. For this purpose consider the equation

$$w^2 = (z - 5)(z - 1)(z + 1)(z + 2)(z + 3).$$

The surface $F(x, y, u) = 0$ will be represented by

$$4u^4 - 4u^2S - T^2 = 0,$$

where

$$S = x^5 - 10x^3y^2 + 5xy^4 - 20x^3 + 60xy^2 - 30x^2 + 30y^2 + 19x + 30$$

and

$$T = 5x^4y - 10x^2y^3 + y^5 - 60x^2y + 20y^3 - 60xy + 19y.$$

The surface F is symmetric to the XU and XY planes. The trace on the XU plane is the XX axis and the real curve

$$v^2 = (x - 5)(x - 1)(x + 1)(x + 2)(x + 3)$$

representing all the real pairs (w, z) satisfying the original equation. The latter consists of two ovals and an infinite branch. The trace on the XY plane is the double curve represented by the equation $T^2 = 0$. This curve is composed of the XX axis and four infinite branches which are hyperbolic in form and coaxial (see fig. VIII).

Sections parallel to the XU plane give rise to curves which have double points on the branches I and III of the double curve, as shown in the figure, and nowhere else. This is shown by an investigation of the value of S in the neighborhood of these branches. For the two branches to hang together or intersect each other, it is necessary that T be equal to zero and S be negative or zero. Every pair of values (x, y) on one of these infinite branches reduces T to zero, but none of these pairs on branch II or IV will cause S to be negative or zero. Therefore the two sheets of the surface F do not cut through each other along either of these branches. The two sheets hang together along the XX axis from $-\infty$ to -3, -2 to -1, from $+1$ to $+5$ and cut each other along the two branches I and III of $T = 0$. To prove, as in the elliptic case, that the two sheets never hang together for any finite value of y except zero would be very complicated, and so another method is employed. It is easily seen that any section parallel to the YU plane will give rise to a curve which has a number, say d, double points. But this curve is composed of two branches which intersect in d points in the XY plane. If d is odd the two branches are odd and hence each branch stretches off to infinity in both directions. If d is even, each branch is even and hence cuts the line at infinity in an even number of places and is accordingly a closed curve. In the first case (d odd) the XX axis must be composed of intersection points, while in the latter it is not. This leads to the conclusion that all sections which cut the curve $u = f(x)$, $y = 0$ give rise to even branches and all others to odd. Hence the former are always reducible to traces of the form, fig. V or fig. VI, while the latter are always reducible to branches of the form fig. VII. From this will follow, as in the elliptic case, that F is two-sheeted and contains two holes. By a deformation similar to the one described in the example of the elliptic case, it may be brought into the form of a double-faced disk with two holes. Hence all closed circuits on F may be reduced to zero or to sums of multiples of four irreducible circuits.

Having considered the elliptic case in detail and investigated briefly a special hyper-elliptic function, we now proceed to the most general hyper-elliptic function, $w = R(z)$, where $R(z)$ is of degree n.

Forming the equation of the surface F in the usual manner, there arises the equation $F(x, y, u) = 0$, where F is of degree $2n$ in (x, y, u). $F(x, y, u) = 0$ may always be put in the form,

$$4u^4 - 4u^2S - T^2 = 0,$$

where S and T are polynomials in x and y of degree n. As has been shown in the preceding considerations, $R(z)$ may be assumed to have only real roots. Hence the surface F is symmetric to the XU and XY planes. The XU trace will consist of the XX axis and a curve representing all real pairs (w, z) satisfying the original equation. The latter curve will consist of one or two infinite branches, according to whether n is odd or even, and p ovals. The XY trace will be a double curve represented by $T = 0$ and consisting of the XX axis and a curve represented by an equation of degree $(n - 1)$. This double curve represents all the real double points of the surface F.

The surface F is composed of two sheets which hang together everywhere along the XX axis except for values of x which satisfy the equation $u = R(x), y = 0$, and cut each other along certain branches of the double curve $T = 0$. Corresponding to the p ovals there will be p holes in F. All closed circuits on F may be reduced to sums of multiples of $2p$ irreducible circuits.

DOUBLE CURVES.

The double curves of the surface F arise as the result of projecting the surface Φ from four space into three space, the center of projection being at infinity. Whenever a projecting line cuts Φ in two places a double point occurs on F. If the two points on Φ be real the double point on F will be a real double point connected with the surface F, but if the two points on Φ be imaginary the resulting double point on F will be isolated. This gives rise to two classes of double curves, one being on the surface F and the other being related to the surface but isolated from it.

In the elliptic case the double curves consisted of the XX axis and an hyperbola. That part of the XX axis included by the real part of the curve $u = f(x)$, $y = 0$ is isolated. Of the hyperbola, that branch lying to the left of the YU plane is isolated.

In the hyper-elliptic example the double curve consists of the XX axis and four infinite branches. What was said of the XX axis for the elliptic case holds here also. Of the four infinite branches two are isolated (see fig. VIII), and two are curves of intersection of the two sheets of the surface.

The same conditions will exist in the general hyper-elliptic case, the XX axis always being a double curve with the same law as to isolated points as in the simpler cases. The other double curves will be partly isolated and partly curves of intersection of the two sheets of the surface. The isolated curves separate themselves from the other class in that they always pass through one or more of the ovals, while the curves of intersection of sheets never do.

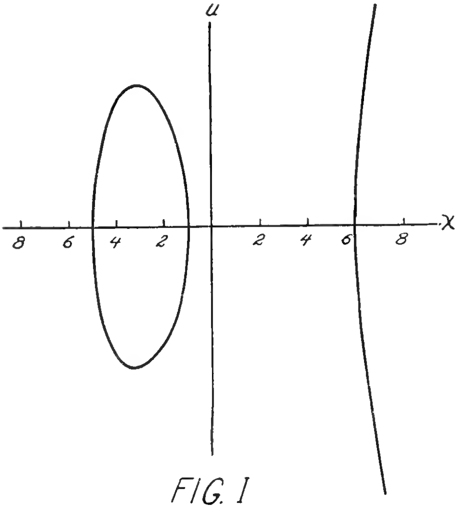

FIG. I

$F(x,y,u)=0,\ y=0$

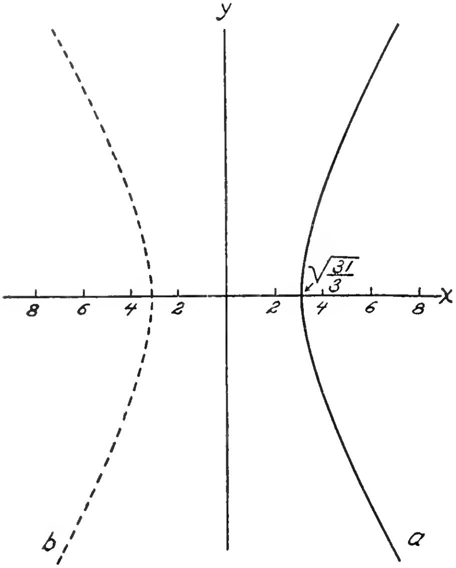

FIG. II

$F(x,y,u)=0,\ u=0$, (b) isolated

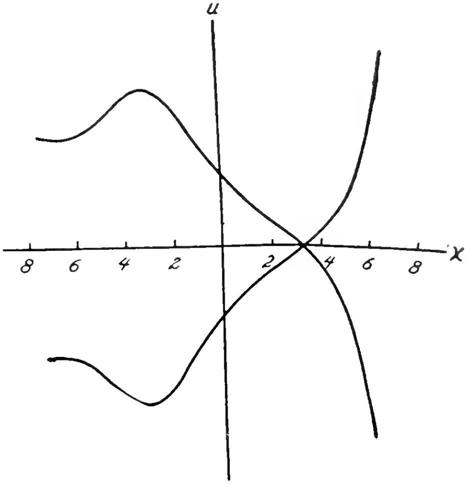

FIG. III

$F(x, y, u) = 0, y = 1$

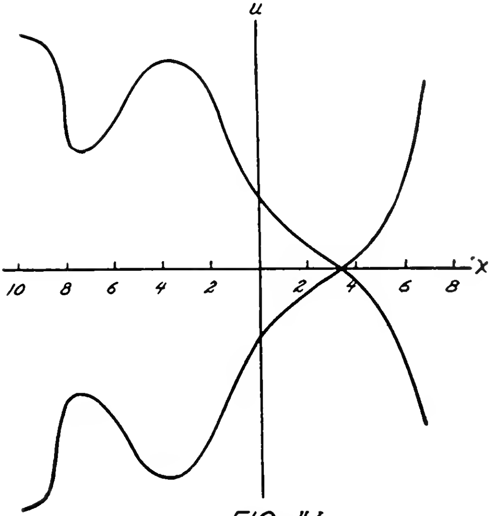

FIG. IV

$F(x, y, u) = 0, y = 2$

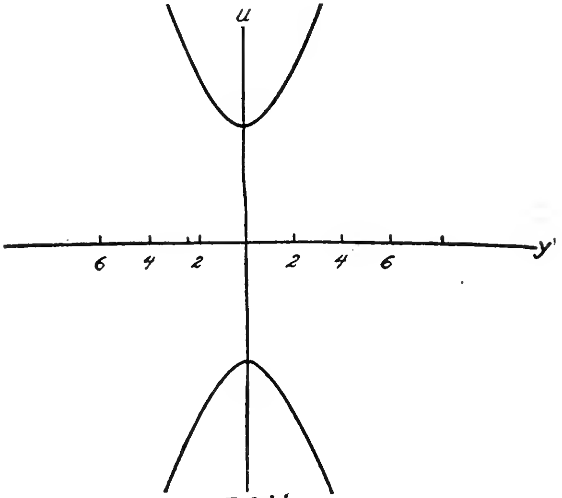

FIG. V
F(x,y,u)=0, x=-2

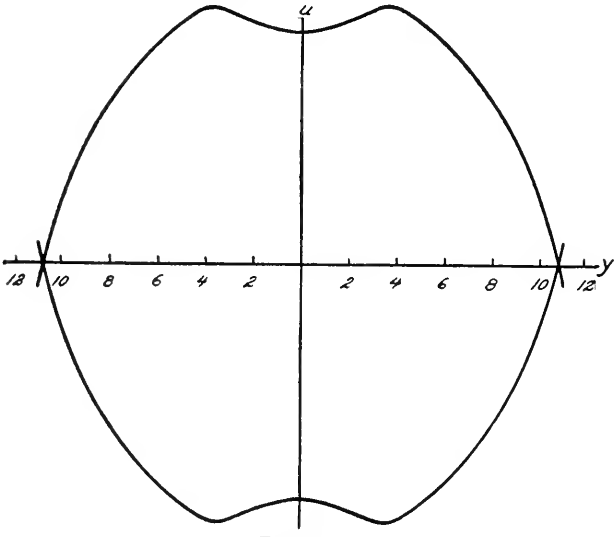

FIG VI
F(x,y,u)=0, x=7

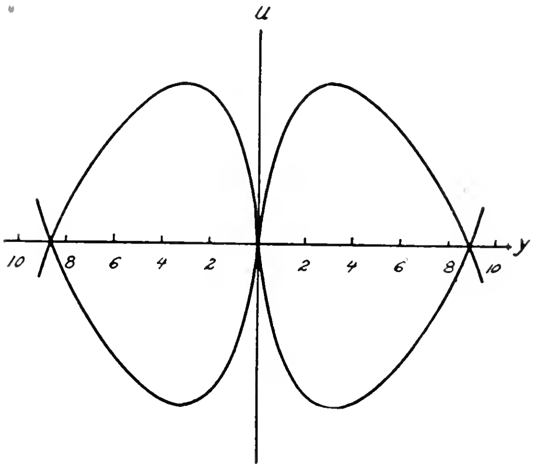

FIG. VII

F(x,y,u)=0, x=6

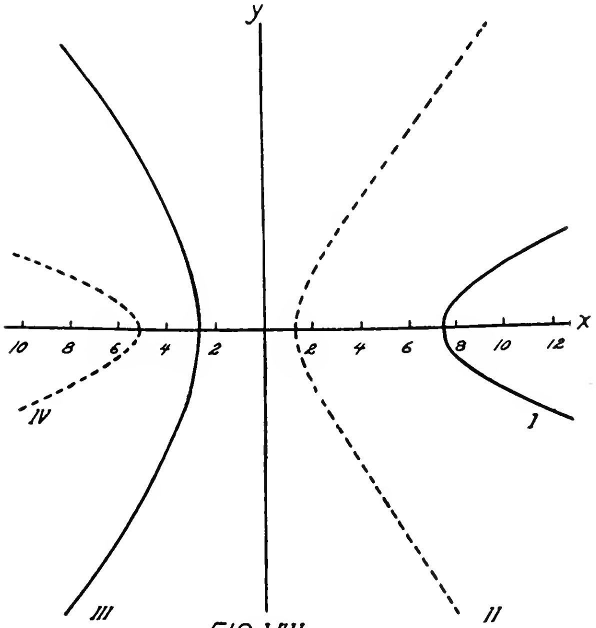

FIG. VIII

F(x,y,u)=0, u=0 II and IV isolated.

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CONTENTS:

A CALCULATION OF THE INVARIANTS AND COVARIANTS FOR RULED SURFACES,

E. B. Stouffer.

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THE KANSAS UNIVERSITY SCIENCE BULLETIN.

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A Calculation of the Invariants and Covariants for Ruled Surfaces.*

BY E. B. STOUFFER.

IN Wilczynski's *Projective Differential Geometry of Curves and Ruled Surfaces* † it is shown that the projective differential properties of a non-developable ruled surface may be studied by means of a system of differential equations of the form ‡

$$(A)\left\{\begin{aligned} y''+2p_{11}y'+2p_{12}z'+q_{11}y+q_{12}z&=0,\\ z''+2p_{21}y'+2p_{22}z'+q_{21}y+q_{22}z&=0,\end{aligned}\right.$$

where p_{ik} and q_{ik} are functions of the independent variable x. The most general transformations leaving (A) unchanged in form are given by the equations

$$(1)\left\{\begin{aligned} y&=\alpha_{11}\bar{y}+\alpha_{12}\bar{z},\\ z&=\alpha_{21}\bar{y}+\alpha_{22}\bar{z},\end{aligned}\right.\qquad \triangle\equiv\alpha_{11}\alpha_{22}-\alpha_{12}\alpha_{21}\neq 0,$$

$$(2)\qquad \xi=\xi(x),$$

where α_{ik} and ξ are arbitrary functions of x.

A function of the coefficients of (A) and their derivatives and of the dependent variables and their derivatives which remains unchanged in value by the transformation (1) is called a *semi-covariant* and if it remains unchanged in value also by the transformation (2) it is called a *covariant*. Semi-covariants or covariants which do not involve the dependent variables or their derivatives are called *seminvariants* or *invariants*, respectively. The invariants and covariants of system (A) are used in the study of the

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* Received for publication May 10.

† Teubner, Leipzig, 1906.

‡ Wilczynski writes his system without the factor 2 in the coefficients of y' and z'. Its introduction makes some of the results appear in simpler form.

properties of ruled surfaces. Their calculation as given by Wilczynski involves the solution of several rather complicated systems of partial differential equations. It is the purpose of this paper to obtain the same results by much shorter methods.

In 1915 Green published a paper* in which he obtains the invariants and covariants of the general form of the system of partial differential equations associated with curved surfaces from the invariants and covariants of a canonical form of these equations. Green points out that his general method is of wide application. This scheme of making the calculations first for a simplified system and then transforming to the coefficients of the original system is used in the present paper.

The results in this paper carry the same label as do the corresponding results in Wilczynski's book but there are differences in numerical coefficients and in signs because of the introduction of the binomial coefficients in equations (A) and because of a change of sign in the defining expression for u_{ik}.

1. The Semi-Canonical Form.

Let us make the transformation (1) upon the system (A). There immediately results the system

$$(3)\quad \begin{cases} a_{11}\bar{y}'' + a_{12}\bar{z}'' + 2\,(a'_{11} + p_{11}\,a_{11} + p_{12}\,a_{21})\bar{y}' + \\ \qquad\qquad 2\,(a'_{12} + p_{11}\,a_{12} + p_{12}\,a_{22})\,\bar{z}' \\ \quad + (a''_{11} + 2\,p_{11}\,a'_{11} + 2\,p_{12}\,a'_{21} + q_{11}a_{11} + q_{12}\,a_{21})\,\bar{y} \\ \quad + (a''_{12} + 2\,p_{11}\,a'_{12} + 2\,p_{12}\,a'_{22} + q_{11}\,a_{12} + q_{12}\,a_{22})\,\bar{z} = 0, \\ a_{21}\bar{y}'' + a_{22}\bar{z}'' + 2\,(a'_{21} + p_{21}\,a_{11} + p_{22}\,a_{21})\,\bar{y}' + \\ \qquad\qquad 2\,(a'_{22} + p_{21}\,a_{12} + p_{22}\,a_{22})\bar{z}' \\ \quad + (a''_{21} + 2\,p_{21}\,a'_{11} + 2\,p_{22}\,a'_{21} + q_{21}\,a_{11} + q_{22}\,a_{21})\,\bar{y} \\ \quad + (a''_{22} + 2\,p_{21}\,a'_{12} + 2\,p_{22}\,a'_{22} + q_{21}\,a_{12} + q_{22}\,a_{22})\bar{z} = 0. \end{cases}$$

If a_{ik} are so chosen that

$$(4)\quad a'_{ik} = -\sum_{j=1}^{2} p_{ij}\,a_{jk}, \quad (i, k = 1, 2),$$

the coefficients of $\bar{y}'$ and $\bar{z}'$ in (3) vanish. Such a solution for a_{ik} is always possible since it is equivalent merely to choosing (a_{11}, a_{21}) and (a_{12}, a_{22}) as two distinct pairs of solutions of the system of differential equations

$$\begin{aligned} \rho' &= -\,(p_{11}\,\rho + p_{12}\,\sigma) \\ \sigma' &= -\,(p_{21}\,\rho + p_{22}\,\sigma). \end{aligned}$$

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*G. M. Green, *On the Theory of Curved Surfaces, and Canonical Systems in Projective Differential Geometry.* Transactions of the American Mathematical Society, Vol. 16 (1915), pp. 1-12.

The substitution from (4) into (3) now gives

$$(5)\quad \begin{cases} \alpha_{11}\bar{y}'' + \alpha_{12}\bar{z}'' + (u_{11}\alpha_{11} + u_{12}\alpha_{21})\bar{y} + (u_{11}\alpha_{12} + u_{12}\alpha_{22})\bar{z} = 0, \\ \alpha_{21}\bar{y}'' + \alpha_{22}\bar{z}'' + (u_{21}\alpha_{11} + u_{22}\alpha_{21})\bar{y} + (u_{21}\alpha_{12} + u_{22}\alpha_{22})\bar{z} = 0, \end{cases}$$

where*

$$(6)\quad u_{ik} = q_{ik} - p'_{ik} - \sum_{j=1}^{2} p_{ij}\,p_{jk}, \quad (i, k = 1, 2).$$

The system (5) may be put into the form

$$(B)\quad \begin{cases} \bar{y}'' + \bar{q}_{11}\bar{y} + \bar{q}_{12}\bar{z} = 0, \\ \bar{z}'' + \bar{q}_{21}\bar{y} + \bar{q}_{22}\bar{z} = 0, \end{cases}$$

if we write

$$(7)\quad \triangle\,\bar{q}_{ik} = \sum_{l=1}^{2}\sum_{j=1}^{2} A_{ji}\,\alpha_{lk}\,u_{jl}, \quad (i, k = 1, 2),$$

where A_{ji} is the algebraic minor α_{ji} in the determinant of the transformation (1). Wilczynski calls (*B*) the semi-canonical form of the system (A).

The differentiation of equations (7) gives

$$(8)\quad \triangle\bar{q}'_{ik} = \sum_{l=1}^{2}\sum_{j=1}^{2} [A_{ji}\,\alpha_{lk}\,u'_{jl} + A_{ji}\,\alpha'_{lk}\,u_{jl} + A'_{ji}\,\alpha_{lk}\,u_{jl}] - \triangle'\bar{q}_{ik}, \quad (i, k = 1, 2).$$

By the use of (4) we find

$$\sum_{j=1}^{2} A'_{ji}\,u_{jl} = \sum_{j=1}^{2} A_{ji}\,[-(p_{11} + p_{22})\,u_{jl} + \sum_{m=1}^{2} p_{jm}\,u_{ml}],$$

$$\triangle' = -(p_{11} + p_{22})\triangle,$$

whence it follows at once that

$$(9)\quad \triangle\,\bar{q}'_{ik} = \sum_{l=1}^{2}\sum_{j=1}^{2} A_{ji}\,\alpha_{lk}\,v_{jl}, \quad (i, k = 1, 2),$$

where

$$(10)\quad v_{ik} = u'_{ik} + \sum_{j=1}^{2} (p_{ij}\,u_{jk} - p_{jk}\,u_{ij}), \quad (i, k = 1, 2).$$

It follows without calculation that

$$(11)\quad \triangle\,\bar{q}''_{ik} = \sum_{l=1}^{2}\sum_{j=1}^{2} A_{ji}\,\alpha_{lk}\,w_{jl}, \quad (i, k = 1, 2),$$

where

$$(12)\quad w_{ik} = v'_{ik} + \sum_{j=1}^{2} (p_{ij}\,v_{jk} - p_{jk}\,v_{ij}), \quad (i, k = 1, 2).$$

---

*The expression here used for u_{ik} differs in sign as well as in numerical coefficients from that used by Wilczynski.

Let us rewrite transformations (1) and (2) in the form

$$(13)\quad \begin{cases} \bar{y} = \beta_{11}\, Y + \beta_{12}\, Z, \\ \bar{z} = \beta_{21}\, Y + \beta_{22}\, Z, \end{cases} \qquad \beta_{11}\,\beta_{22} - \beta_{12}\,\beta_{21} \neq 0.$$

$$(14)\quad \xi = \xi\,(x),$$

and find the most general nature which these transformations may have and still leave (B) in the semi-canonical form. By these transformations (B) is converted into

$$(15)\quad \begin{cases} \beta_{11}\,(\xi')^2 \dfrac{d^2 Y}{d\,\xi^2} + \beta_{12}\,(\xi')^2 \dfrac{d^2 Z}{d\,\xi^2} + (\beta_{11}\,\xi'' + 2\,\beta'_{11}\,\xi')\dfrac{d\,Y}{d\,\xi} + \\ \qquad (\beta_{12}\,\xi'' + 2\,\beta'_{12}\,\xi')\dfrac{d\,Z}{d\,\xi} + (\beta''_{11} + \bar{q}_{11}\beta_{11} + \bar{q}_{12}\beta_{21})\,Y + \\ \qquad\qquad (\beta''_{12} + \bar{q}_{11}\,\beta_{12} + \bar{q}_{12}\,\beta_{22})\,Z = 0\,, \\ \beta_{21}\,(\xi')^2 \dfrac{d^2 Y}{d\,\xi^2} + \beta_{22}\,(\xi')^2 \dfrac{d^2 Z}{d\,\xi^2} + (\beta_{21}\,\xi'' + 2\,\beta'_{21}\,\xi')\dfrac{d\,Y}{d\,\xi} + \\ \qquad (\beta_{22}\,\xi'' + 2\,\beta'_{22}\,\xi')\dfrac{d\,Z}{d\,\xi} + (\beta''_{21} + \bar{q}_{21}\,\beta_{11} + \bar{q}_{22}\,\beta_{21})\,Y + \\ \qquad\qquad (\beta''_{22} + \bar{q}_{21}\,\beta_{12} + \bar{q}_{22}\,\beta_{22})\,Z = 0. \end{cases}$$

This system is in the form of system (B) if and only if

$$\beta_{ij}\,\xi'' + 2\,\beta_{ij}\,\xi' = 0, \quad (i, j = 1, 2),$$

that is, if

$$(16)\quad \beta_{ij} = \frac{b_{ij}}{\sqrt{\xi'}}, \quad (i, j = 1, 2),$$

where b_{ij} are constants. If these values for β_{ij} are substituted into (15) that system may be written in the form

$$(C)\quad \begin{cases} \dfrac{d^2\,Y}{d\,\xi^2} + Q_{11}\,Y + Q_{12}\,Z = 0, \\ \dfrac{d^2\,Z}{d\,\xi^2} + Q_{21}\,Y + Q_{22}\,Z = 0, \end{cases}$$

if we put

$$(17)\quad D\,Q_{ik} + \frac{1}{(\xi')^2} \sum_{j=1}^{2} B_{ji}\,[\,(\tfrac{1}{4}\eta^2 - \tfrac{1}{2}\eta')\,b_{ik} + \sum_{l=1}^{2} b_{lk}\bar{q}_{jl}\,], \quad (i, k = 1,2),$$

where $\eta = \dfrac{\xi''}{\xi'}$ and where B_{ji} is the minor of b_{ji} in the determinant $D \equiv b_{11}\,b_{22} - b_{12}\,b_{21}$.

The transformations

$$(18)\quad \begin{cases} \bar{y} = \dfrac{b_{11}}{\sqrt{\xi'}} Y + \dfrac{b_{12}}{\sqrt{\xi'}} Z, \\ \bar{z} = \dfrac{b_{21}}{\sqrt{\xi'}} Y + \dfrac{b_{22}}{\sqrt{\xi'}} Z, \\ \xi = \xi(x). \end{cases}$$

which leave B unchanged in form may be considered as consisting of the transformation

$$(19)\quad \begin{cases} \bar{y} = b_{11} Y + b_{12} Z, \\ \bar{z} = b_{21} Y + b_{22} Z, \end{cases} \qquad D \equiv b_{11} b_{22} - b_{12} b_{21} \neq 0,$$

in which $\xi = x$, and of the transformations

$$(20)\quad \begin{cases} \bar{y} = \dfrac{1}{\sqrt{\xi'}} Y, \\ \bar{z} = \dfrac{1}{\sqrt{\xi'}} Z, \\ \xi = \xi(x), \end{cases}$$

in which $b_{11} = b_{22} = 1$ and $b_{12} = b_{21} = 0$.

2. THE SEMINVARIANTS.

Let us first find those functions of the coefficients of (B) and their derivatives which remain unchanged in value by the transformation (19). Equations (17) show that (19) converts $\bar{q}_{ik}$ into Q_{ik} where

$$(21)\quad D Q_{ik} = \sum_{l=1}^{2} \sum_{j=1}^{2} B_{ji} b_{lk} \bar{q}_{jl}, \quad (i, k = 1, 2).$$

If the transformation (19) is made infinitesimal by putting $b_{ii} = 1 + \varphi_{ii}\,\delta t$ and $b_{ij} = \varphi_{ij}\,\delta t$, $(i \neq j)$, where φ_{ij} are arbitrary constants and δt an infinitesimal, the infinitesimal transformations of $\bar{q}_{ik}$ are found from (21) to be

$$(22)\quad \delta \bar{q}_{ik} = \sum_{j=1}^{2} (\varphi_{jk} \bar{q}_{ij} - \varphi_{ij} \bar{q}_{jk})\,\delta t, \quad (i, k = 1, 2).$$

In accordance with the Lie theory the desired functions must satisfy the system of partial differential equations.

$$(23)\quad U_{rs} f \equiv \sum_{l=1}^{2} \left(\bar{q}_{lr} \frac{\partial f}{\partial \bar{q}_{ls}} - \bar{q}_{sl} \frac{\partial f}{\partial \bar{q}_{rl}}\right) = 0, \quad (r, s = 1, 2).$$

Between these four equations there are the two relations

$$(24)\quad U_{11} + U_{22} = 0,$$

$$(25) \qquad \bar{q}_{12} U_{12} + \bar{q}_{21} U_{21} + \bar{q}_{11} U_{11} + \bar{q}_{22} U_{22} = 0.$$

Since the system contains four variables there are just two solutions. These are easily seen to be

$$I = \bar{q}_{11} + \bar{q}_{22}, \quad J = \bar{q}_{11}\bar{q}_{22} - \bar{q}_{12}\bar{q}_{21}.$$

Since the coefficients in (19) are constants the transformations of the various derivatives of $\bar{q}_{ik}$ will be of exactly the same form as the transformations of $\bar{q}_{ik}$. The differential equations for the functions involving $\bar{q}'_{ik}$ as well as $\bar{q}_{ik}$ are simply (23) with terms of the same form in $\bar{q}'_{ik}$ added. The relations (25) ceases to hold so that there are just three more solutions. These are evidently

$$I', J', K = \bar{q}'_{11}\bar{q}'_{22} - \bar{q}'_{12}\bar{q}'_{21}.$$

In the system of equations for the functions involving also $\bar{q}''_{ik}$ there are just three independent equations and four more variables so that there are four more solutions. These are evidently

$$I'', J'', K', L = \bar{q}''_{11}\bar{q}''_{22} - \bar{q}''_{12}\bar{q}''_{21}.$$

A continuation of this process shows that all the desired functions involving higher derivatives of $\bar{q}_{ik}$ can be obtained by forming the successive derivatives of I, J, K, L.

Let us now substitute in I, J, K, L and their derivatives the expressions for $\bar{q}_{ik}, \bar{q}'_{ik}, \bar{q}''_{ik}$ given in (7), (9) and (11). A comparison of these equations with (21) and its derivatives shows that $\bar{q}_{ik}$ is expressed in terms of u_{ik}, $\bar{q}'_{ik}$ in terms of v_{ik}, and $\bar{q}''_{ik}$ in terms of w_{ik} in exactly the same way that Q_{ik} is expressed in terms of $\bar{q}_{ik}$, Q'_{ik} in terms $\bar{q}'_{ik}$, and Q''_{ik} in terms of $\bar{q}''_{ik}$, respectively, except of course that a_{ik} replaces b_{ik}. If now in I, J, K, L or in their derivatives we replace $\bar{q}_{ik}, \bar{q}'_{ik}, \bar{q}''_{ik}$ by $Q_{ik}, Q'_{ik}, Q''_{ik}$ respectively, we obtain the original functions of $\bar{q}_{ik}, \bar{q}'_{ik}, \bar{q}''_{ik}$. It follows therefore that if in I, J, K, L and their derivatives we replace $\bar{q}_{ik}, \bar{q}'_{ik}, \bar{q}''_{ik}$ by u_{ik}, v_{ik}, w_{ik}, respectively, we obtain the result of substituting (7), (9), (11) into these functions. In other words

$$(26) \begin{cases} I = u_{11} + u_{22}, & J = u_{11}u_{22} - u_{12}u_{21}, \\ I' = v_{11} + v_{22}, & J' = u_{11}v_{22} + u_{22}v_{11} - u_{12}v_{21} - u_{21}v_{12}, \\ I'' = w_{11} + w_{22}, & J'' = 2K + u_{11}w_{22} + u_{22}w_{11} - u_{12}w_{21} - u_{21}w_{12}, \\ K = v_{11}v_{22} - v_{12}v_{21}, & L = w_{11}w_{22} - w_{12}w_{21}, \\ K' = v_{11}w_{22} + v_{22}w_{11} - v_{12}w_{21} - v_{21}w_{12}. & \end{cases}$$

The expressions (26) and their derivatives are all seminvariants of the system (A) and moreover they form a complete system of seminvariants for the system (A). To show these facts let us suppose that we have two systems of form (A) which are equivalent under a transformation of form (1). Each of these systems may be reduced to a semi-canonical form and these must be equivalent under a transformation of form (19). A seminvariant expression, $\bar{q}_{11} + \bar{q}_{22}$, say, formed for these two semi-canonical forms must be equal and each is equal to the expression $u_{11} + u_{22} = I$ formed for its corresponding original system. Therefore the two expressions for I are equal and I must be a seminvariant. The same reasoning applies to the other expressions (26). That we have a complete system of seminvariants is obvious from the fact that every seminvariant of (A) must have a semi-canonical form which remains unchanged by transformations which leave the semi-canonical form invariant.

3. The Semi-Covariants.

We shall now find the semi-covariants of (A) by finding first the semi-canonical form of these semi-covariants. The transformation (1) when solved for $\bar{y}$ and $\bar{z}$ has the form

$$(27)\quad \begin{cases} \triangle \bar{y} = a_{22}\, y - a_{12}\, z, \\ \triangle \bar{z} = -\, a_{21}\, y + a_{11}\, z. \end{cases}$$

When the coefficients of this transformation are subjected to the conditions (4) we find

$$(28)\quad \begin{cases} \triangle \bar{y}' = a_{22}\, \rho - a_{12}\, \sigma, \\ \triangle \bar{z}' = -\, a_{21}\, \rho + a_{11}\, \sigma. \end{cases}$$

where

$$(29)\quad \rho = y' + p_{11}\, y + p_{12}\, z, \quad \sigma = z' + p_{21}\, y + p_{22}\, z.$$

Evidently semi-covariants need contain no higher derivatives of y and z than the first.

The semi-canonical form of the semi-covariants will be found by subjecting (B) to the transformation (19). Since the coefficients in (19) are constants

$$(30)\quad \begin{cases} \bar{y}' = b_{11}\, Y' + b_{12}\, Z', \\ \bar{z}' = b_{21}\, Y' + b_{22}\, Z', \end{cases}$$

and it follows at once that

$$(31)\quad P = \bar{y}\, \bar{z}' - \bar{y}'\, \bar{z}$$

is a semi-covariant.

The system of differential equations for the semi-canonical form of the semi-covariants is the same as the system for the semi-canonical form of the seminvariants except that each equation contains more terms and there are four more variables. The relations (24) and (25) both cease to hold so that there are three semi-covariants or four relative semi-covariants.

Equations (19) and (21) show that the expressions $\bar{q}_{11}\bar{y}+\bar{q}_{12}\bar{z}$ and $\bar{q}_{21}\bar{y}+\bar{q}_{22}\bar{z}$ are transformed cogrediently with $\bar{y}$ and $\bar{z}$, respectively. The same is of course true of $\bar{q}'_{11}\bar{y}+\bar{q}'_{12}\bar{z}$ and $\bar{q}'_{21}\bar{y}+\bar{q}'_{22}\bar{z}$, respectively. It follows at once that the three expressions

$$(32)\begin{cases} C=(\bar{q}_{11}\bar{y}+\bar{q}_{12}\bar{z})\,\bar{z}-(\bar{q}_{21}\bar{y}+\bar{q}_{22}\bar{z})\,\bar{y}, \\ E=(\bar{q}'_{11}\bar{y}+\bar{q}'_{12}\bar{z})\,\bar{z}-(\bar{q}'_{21}\bar{y}+\bar{q}'_{22}\bar{z})\,\bar{y}, \\ O=(\bar{q}_{11}\bar{y}+\bar{q}_{12}\bar{z})\,\bar{z}'-(\bar{q}_{21}\bar{y}+\bar{q}_{22}\bar{z})\,\bar{y}', \end{cases}$$

are independent relative semi-covariants. A comparison of (19) and (30) with (27) and (28) shows that the semi-covariants (31) and (32) can be expressed in terms of the original variables and coefficients if $\bar{y}$ is replaced by y, $\bar{z}$ by z, $\bar{y}'$ by ρ and $\bar{z}'$ by σ at the same time that $\bar{q}_{ik}$ and $\bar{q}'_{ik}$ are replaced by u_{ik} and v_{ik}, respectively. Thus we have

$$(33)\begin{cases} P=y\sigma-z\rho, \\ C=(u_{11}y+u_{12}z)\,z-(u_{21}y+u_{22}z)\,y, \\ E=(v_{11}y+v_{12}z)\,z-(v_{21}y+v_{22}z)\,y, \\ O=(u_{11}y+u_{12}z)\sigma-(u_{21}y+u_{22}z)\,\rho. \end{cases}$$

By the same argument as in the case of seminvariants these four semi-covariants are known to form a complete system for (A).

4. THE CANONICAL FORM AND THE INVARIANTS.

We shall now proceed to find those functions of the seminvariants in their semi-canonical form which remain unchanged except for a factor $\frac{1}{(\xi')^m}$ by the transformation (20). We shall thus obtain the functions of the coefficients of (B) and their derivatives which remain unchanged by (18), except for the factor $\frac{1}{(\xi')^m}$.

Equation (17) shows that (20) converts (B) into a new system whose coefficients Q_{ik} are given by the equations

$$(34)\quad \begin{cases} Q_{ii} = \dfrac{1}{(\xi')^2}\left(\frac{1}{4}\eta^2 - \frac{1}{2}\eta' + \bar{q}_{ii}\right), & (i = 1, 2), \\ Q_{ik} = \dfrac{1}{(\xi')^2}\,\bar{q}_{ik}, & (i, k = 1, 2;\ i \neq k). \end{cases}$$

We notice that

$$Q_{11} + Q_{22} = \frac{1}{(\xi')^2}\left(\tfrac{1}{2}\eta^2 - \eta' + \bar{q}_{11} + \bar{q}_{12}\right),$$

so that $Q_{11} + Q_{22} = 0$, provided that

$$(35)\qquad I \equiv \eta' - \tfrac{1}{2}\eta^2 = \bar{q}_{11} + \bar{q}_{22}.$$

From equations (34) we have at once, if (35) is satisfied,

$$(36)\quad \begin{cases} Q_{ii} = \dfrac{1}{(\xi')^2}\left(\bar{q}_{ii} - \frac{1}{2}I\right), & (i = 1, 2), \\ Q_{ik} = \dfrac{1}{(\xi')^2}\,\bar{q}_{ik}, & (i, k = 1, 2;\ i \neq k), \end{cases}$$

whence

$$(37)\quad \begin{cases} Q'_{ii} = \dfrac{1}{(\xi')^3}\left[\bar{q}'_{ii} - \frac{1}{2}I' - 2\eta\left(\bar{q}_{ii} - \frac{1}{2}I\right)\right], \\ Q''_{ii} = \dfrac{1}{(\xi')^4}\left[\bar{q}''_{ii} - \frac{1}{2}I'' + I^2 - 2I\bar{q}_{ii} - 5\eta\left(\bar{q}'_{ii} - \frac{1}{2}I'\right) + \right. \\ \qquad\qquad\qquad\qquad\qquad\qquad \left. 5\eta^2\left(\bar{q}_{ii} - \frac{1}{2}I\right)\right], \\ Q'_{ik} = \dfrac{1}{(\xi')^3}\left(\bar{q}'_{ik} - 2\eta\,\bar{q}_{ik}\right), \quad (i, k = 1, 2;\ i \neq k), \\ Q''_{ik} = \dfrac{1}{(\xi')^4}\left(\bar{q}''_{ik} - 2I\,\bar{q}_{ik} - 5\eta\,\bar{q}'_{ik} + 5\eta^2\,\bar{q}_{ik}\right). \end{cases}$$

Let us now assume that (B) has been converted into

$$(D)\quad \begin{cases} \bar{y}'' + Q_{11}\bar{y} + Q_{12}\bar{z} = 0, \\ \bar{z}'' + Q_{21}\bar{y} + Q_{22}\bar{z} = 0, \end{cases}$$

where Q_{ik} have the values (36) so that $Q_{11} + Q_{22} = 0$. The system (D) is called the canonical form of (A).

If the seminvariants for (D) corresponding to I, J, K, L for (B) are denoted by I_1, J_1, K_1, L_1, respectively, equations (37) show that

$$
(38)\quad\left\{
\begin{aligned}
& I_1 = 0,\ J_1 = \frac{1}{(\xi')^4}\left[J - \tfrac{1}{4} I^2\right],\\
& J'_1 = \frac{1}{(\xi')^5}\left[\frac{d}{dx}(J - \tfrac{1}{4} I^2) - 4\eta(J - \tfrac{1}{4} I^2)\right],\\
& J''_1 = \frac{1}{(\xi')^6}\left[\frac{d^2}{dx^2}(J - \tfrac{1}{4} I^2) - 4I(J - \tfrac{1}{4} I^2) - \right.\\
& \qquad\qquad \left. 9\eta\frac{d}{dx}(J - \tfrac{1}{4} I^2) + 18\eta^2(J - \tfrac{1}{4} I^2)\right],\\
& K_1 = \frac{1}{(\xi')^6}\left[K - \tfrac{1}{4}(I')^2 - 2\eta\frac{d}{dx}(J - \tfrac{1}{4} I^2) + \right.\\
& \qquad\qquad \left. 4\eta^2(J - \tfrac{1}{4} I^2)\right],\\
& K'_1 = \frac{1}{(\xi')^7}\left[\frac{d}{dx}\left\{K - \tfrac{1}{4}(I')^2\right\} - 2I\frac{d}{dx}(J - \tfrac{1}{4} I^2) - \right.\\
& \qquad 6\eta\left\{K - \tfrac{1}{4}(I')^2\right\} - 2\eta\left\{\frac{d^2}{dx^2}(J - \tfrac{1}{4} I^2) - \right.\\
& \qquad \left. 4I(J - \tfrac{1}{4} I^2)\right\} + 15\eta^2\frac{d}{dx}(J - \tfrac{1}{4} I^2) - \\
& \qquad \left. 20\eta^3(J - \tfrac{1}{4} I^2)\right],\\
& I_1 = \frac{1}{(\xi')^8}\left[L - \tfrac{1}{4}(I'')^2 + 4I\left\{K - \tfrac{1}{4}(I')^2\right\}\right.\\
& \qquad - 2I\frac{d^2}{dx^2}(J - \tfrac{1}{4} I^2) + 4I^2(J - \tfrac{1}{4} I^2)\\
& \qquad - 5\eta\left\{\frac{d}{dx}[K - \tfrac{1}{4}(I')^2] - 2I\frac{d}{dx}(J - \tfrac{1}{4} I^2)\right\}\\
& \qquad + 5\eta^2\left\{\frac{d^2}{dx^2}(J - \tfrac{1}{4} I^2) - 4I(J - \tfrac{1}{4} I^2)\right\}\\
& \qquad + 15\eta^2\left\{K - \tfrac{1}{4}(I')^2\right\} - 25\eta^3\frac{d}{dx}(J - \tfrac{1}{4} I^2)\\
& \qquad \left. + 25\eta^4(J - \tfrac{1}{4} I^2)\right].
\end{aligned}
\right.
$$

The system (D) is left in the canonical form by the transformation (20) provided that $\mu = 0$. We shall now seek those functions of the seminvariants in their semi-canonical form which are left unchanged in value by the transformation (20) subject to the condition $\mu = 0$.

From (34) or by direct substitution we find that (20) with $\mu = 0$ converts Q_{ik} into

$$(39)\qquad \overline{Q}_{ik} = \frac{1}{(\xi')^2} Q_{ik}, \quad (i, k = 1, 2),$$

whence it follows that

$$(40)\begin{cases} \bar{Q}'_{ik} = \dfrac{1}{(\xi')^3}(Q'_{ik} - 2\,\eta\,Q_{ik}), & \\ & (i, k = 1, 2), \\ \bar{Q}''_{ik} = \dfrac{1}{(\xi')^4}(Q''_{ik} - 5\,\eta\,Q'_{ik} + 5\,\eta^2\,Q_{ik}). & \end{cases}$$

These results show by direct substitution and by differentiation that J_1, K_1, L_1, and their derivatives for the transformed equations have the values

$$(41)\begin{cases} \bar{J}_1 = \dfrac{1}{(\xi')^4}\,J_1, \bar{J}'_1 = \dfrac{1}{(\xi')^5}(J'_1 - 4\,\eta\,J_1), \\ \bar{J}''_1 = \dfrac{1}{(\xi')^6}(J''_1 - 9\,\eta\,J'_1 + 18\,\eta\,J_1), \\ \bar{K}_1 = \dfrac{1}{(\xi')^6}(K_1 - 2\,\eta\,J'_1 + 4\,\eta^2\,J_1), \\ \bar{K}'_1 = \dfrac{1}{(\xi')^7}(K'_1 - 6\,\eta\,K_1 - 2\,\eta\,J''_1 + 15\,\eta^2\,J'_1 - 20\,\eta^3\,J_1), \\ \bar{L}_1 = \dfrac{1}{(\xi')^8}(L_1 - 5\,\eta\,K'_1 + 5\,\eta^2\,J''_1 + 15\,\eta^2\,K_1 - 25\,\eta^3\,J'_1 \\ \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad + 25\,\eta^4\,J_1). \end{cases}$$

If the transformation (20) is made infinitesimal by putting

$$\xi = x + \varphi\,(x)\,\delta t$$

where $\varphi(x)$ is an arbitrary function of x and δt is an infinitesimal, the infinitesimal transformations of J_1, K_1, L_1, and their derivatives are found by direct substitution in (41) to be

$$(42)\begin{cases} \delta J_1 = -4\,\varphi'\,J_1\,\delta t, \\ \delta J'_1 = (-5\,\varphi'\,J'_1 - 4\,\varphi''\,J_1)\,\delta t, \\ \delta J''_1 = (-6\,\varphi'\,J''_1 - 9\,\varphi''\,J'_1)\,\delta t, \\ \delta K_1 = (-6\,\varphi'\,K_1 - 2\,\varphi''\,J'_1)\,\delta t, \\ \delta K'_1 = (-7\,\varphi'\,K'_1 - 6\,\varphi''\,K_1 - 2\,\varphi''\,J''_1)\,\delta t, \\ \delta L_1 = (-8\,\varphi'\,L_1 - 5\,\varphi''\,K'_1)\,\delta t. \end{cases}$$

The resulting system of partial differential equations whose solutions are invariants of (D) under the transformation (20) with $\mu = 0$ contains two independent equations. There are therefore four such absolute invariants involving the variables J_1, J'_1, J''_1, K_1, K'_1, L_1. The five relative invariants may be taken to be

$$(43)\begin{cases} \bar{\theta}_4 = J_1, \bar{\theta}_{4.1} = 9\,(J'_1)^2 - 8\,J_1\,J''_1, \\ \bar{\theta}_{10} = (J'_1)^2 - 4\,J_1\,K_1, \bar{\theta}_{15} = 5\,\bar{\theta}_{10}\,J'_1 - 2\,\bar{\theta}'_{10}\,J_1, \\ \bar{\theta}_{18} = \{\,(J'_1)^2 - 4\,J_1\,K_1\,\}\,L + K_1\,(J''_1 - 2\,K_1)^2 + J_1\,(K'_1)^2 \\ \qquad\qquad\qquad\qquad\qquad\qquad\qquad - J'_1\,K'_1\,(J''_1 - 2\,K_1). \end{cases}$$

The system of equations for the invariants involving also the next higher derivatives of J_1, K_1, L_1, contains no more equations but three more variables. The three solutions may be taken to be

$$(44)\quad \begin{cases} 4\,J_1\,\overline{\theta}'_{4.1} - 9\,J'_1\,\overline{\theta}_{4.1}, \\ 4\,J_1\,\overline{\theta}'_{15} - 15\,J'_1\,\overline{\theta}_{15}, \\ 4\,J_1\,\overline{\theta}_{18} - 18\,J'_1\,\overline{\theta}_{18}. \end{cases}$$

The invariants involving the next higher derivatives of J_1, K_1, L_1, may obviously be obtained by combining J_1 and J'_1 with the invariants (44). A continuation of this process evidently gives all the independent relative invariants.

The invariants (43) may be expressed in terms of I, J, K, L, and their derivatives by means of (38). However, a comparison of (38) and (41) shows that this substitution can be made, except for a factor $\frac{1}{(\xi')^{m}}$, by replacing in (43) J_1 by $J - \frac{1}{4}I^2$, J'_1 by $\frac{d}{dx}(J - \frac{1}{4}I^2)$, J''_1 by $\frac{d^2}{dx^2}(J - \frac{1}{4}I^2) - 4I\,(J - \frac{1}{4}I^2)$, K_1 by $K - \frac{1}{4}(I')^2$, K'_1 by $\frac{d}{dx}\{K - \frac{1}{4}(I')^2\} - 2I\frac{d}{dx}(J - \frac{1}{4}I^2)$ and L_1 by $L - \frac{1}{4}(I'')^2 + 4I\,\{K - \frac{1}{4}(I')^2\} - 2I\,\frac{d^2}{dx^2}(J - \frac{1}{4}I^2) + 4\,I^2\,(J - \frac{1}{4}I^2)$. The results of these substitutions are as follows:

$$(45)\quad \begin{cases} \theta_4 = J - \frac{1}{4}I^2, \\ \theta_{4.1} = 9\,(\theta'_4)^2 - 8\,\theta_4\,\theta''_4 + 32\,I\,\theta_4^2, \\ \theta_{10} = (\theta'_4)^2 - 4\,\theta_4\,\{K - \frac{1}{4}(I')^2\}, \\ \theta_{15} = 5\,\theta_{10}\,\theta'_4 - 2\,\theta'_{10}\,\theta_4, \\ \theta_{18} = \theta_{10}\,[L - \frac{1}{4}(I'')^2 + 4\,I\,\{K - \frac{1}{4}(I')^2\} - 2\,I\,\theta''_4 + \\ \qquad 4\,I^2\,\theta_4] + \{K - \frac{1}{4}(I')^2\}\,\{\theta''_4 - 4I\theta_4 - 2K + \frac{1}{2}(I')^2\}^2 \\ \qquad + \theta_4\,(K' - \frac{1}{2}I'\,I'' - 2\,I\,\theta'_4)^2 - \\ \qquad \theta'_4\,(K' - \frac{1}{2}I\,I'' - 2\,I\,\theta'_4)\,\{\theta''_4 - 4\,I\,\theta_4 - 2\,K + \frac{1}{2}(I')^2\} \\ \quad = \theta_{10}\,\{L - \frac{1}{4}(I'')^2\} + \{K - \frac{1}{4}(I')^2\}\,(J'' - \frac{1}{2}I\,I'' - 2\,K)^2 \\ \qquad + \theta_4\,(K' - \frac{1}{2}I\,I'')^2 - \theta'_4\,(K' - \frac{1}{2}I\,I'')\,(J'' - \frac{1}{2}I\,I'' - 2K). \end{cases}$$

The same reasoning as in the case of the seminvariants shows that the expressions (45) are invariants of (A) and that all independent invariants of (A) are obtained in this way.

There is another expression for an invariant which is easily obtained and which is of geometrical interest. From equation (21) we easily deduce the equations

$$\begin{aligned} D(Q_{11}-Q_{22}) &= (b_{11}b_{22}+b_{12}b_{21})(\bar{q}_{11}-\bar{q}_{22})+2b_{21}b_{22}\bar{q}_{12}-2b_{12}b_{11}\bar{q}_{21}, \\ DQ_{12} &= b_{12}b_{22}(\bar{q}_{11}-\bar{q}_{22})+b_{22}^2\bar{q}_{12}-b_{12}^2\bar{q}_{21}, \\ DQ_{21} &= -b_{21}b_{11}(\bar{q}_{11}-\bar{q}_{22})-b_{21}^2\bar{q}_{12}+b_{11}^2\bar{q}_{21}, \end{aligned}$$

and exactly similar equations involving derivatives of any order. Thus we know at once that the determinant

$$(46) \qquad \begin{vmatrix} \bar{q}_{11}-\bar{q}_{22} & \bar{q}_{12} & \bar{q}_{21} \\ \bar{q}'_{11}-\bar{q}'_{22} & \bar{q}'_{12} & \bar{q}'_{21} \\ \bar{q}''_{11}-\bar{q}''_{22} & \bar{q}''_{12} & \bar{q}''_{21} \end{vmatrix}$$

is the semi-canonical form of a seminvariant. Furthermore equations (39) and (40) show that it is the semi-canonical form of an invariant. The expression in terms of the original coefficients for this invariant is

$$(47) \qquad \theta_9 = \begin{vmatrix} u_{11}-u_{22} & u_{12} & u_{21} \\ v_{11}-v_{22} & v_{12} & v_{21} \\ w_{11}-w_{22} & w_{12} & w_{21} \end{vmatrix}$$

5. THE COVARIANTS.

Let us now return to the semi-canonical form of the semi-covariants and assume that they have been written down for equations (D). If they are denoted by P_1, C_1, B_1, O_1, equations (39) and (40) show that their values for the equations obtained by transforming (D) by (20) with $\mu = 0$ are as follows:

$$\bar{P}_1 = P_1, \quad \bar{C}_1 = \frac{1}{\xi'}C_1,$$

$$\bar{E}_1 = \frac{1}{(\xi')^2}(E_1 - 2\eta C_1), \; \bar{O}_1 = \frac{1}{(\xi')^2}(O_1 + \tfrac{1}{2}\eta C_1).$$

Therefore four relative covariants in their canonical form are

$$P_1, C_1, E_1 + 4O_1, 2J_1E_1 - C_1J'_1.$$

By converting these expressions into the original coefficients and variables we find the complete system of covariants for (A) to be

$$P, C, C_3 = E + 4(O - \tfrac{1}{2}IP) = E + 2N, C_7 = 2\theta_4 E - \theta'_4 C.$$

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Possible Methods of Classifying White, Yellow and Orange Staphylococci.*

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INTRODUCTION.

STAPHYLOCOCCI were first found in pus by Pasteur[1] (1880). Ogston[2] confirmed Pasteur's work a year later (1881), and in 1883 Becker[3] was able to isolate staphylococci in pure culture. Rosenback[4] (1884) described *staphylococcus pyogenes*, dividing it into two varieties corresponding to the orange and white pigmentation, calling them var. *aureus* and var. *albus*. In 1908 the Winslows[5] based their classification upon growth, pigment production and liquefaction of gelatin.

Dudgeon[6] (1908) found *staphylococcus albus* commonly in normal tissue while *staphylococcus aureus* was usually obtained from pathogenic sources. He was interested in the interchangeability of these two varieties and worked upon a classification of these organisms, using glucose, lactose, maltose, glycerin, cane sugar, raffinose, erythrite, salacin, litmus milk and neutral red. He finally concluded that they all belonged to the same species.

Winslow, Rothberg and Parsons[7] (1920) studied 180 cultures of white and orange staphylococci to determine their action upon the sugars, glucose, lactose, sucrose, maltose, raffinose, mannitol, dulcitol, salacin and inulin. They used two different media, the dehydrated bacto nutrient broth prepared by

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the Digestive Ferments Company, and the peptone media of Clark and Lubs. They found that: "The action of the staphylococci upon glucose, maltose, sucrose and lactose would seem to offer a possible basis of classification, although the marked differences due to the effect of the medium would suggest the use of this property as a differential test might prove of doubtful value."

They were able to divide the organisms into three main groups. Group I, organisms fermenting all four sugars; group II, organisms fermenting glucose, maltose and sucrose, but not lactose. In group III they classified all the rest of the strains and stated that it was a "highly heterogeneous agglomeration."

They found that "gelatin liquefaction was slightly but distinctly more common among the active fermenters," and that "white and orange pigments were fairly evenly divided among the various fermentative groups with a slightly greater preponderance of vigorous fermenters in the orange than in the white group." Their tests for indol were all negative and nitrate broth gave almost uniformly positive results showing reduction.

Winslow, Rothberg and Parsons, after this extensive work upon various sugars, nitrates, indol chromogenesis and gelatin liquefaction, state that: "Fundamentally we are inclined to agree with Dudgeon in considering the whole group a reasonably homogeneous one, and it seems clear the central type of the whole genus is the orange-pigment forming, vigorously fermenting, gelatin liquefying, somewhat actively pathogenic *St. aureus*. As we depart from this type there is a progressive weakening of the various biochemical activities of this more vigorous form. The loss of one characteristic of the *St. aureus* type tends in some degree to be associated with the loss of others. Thus the white chromogens are less actively pathogenic than the orange forms, less actively gelatinolytic and slightly less vigorous in fermentation action. The forms which fail to liquefy gelatin also tend to be less active fermenters than the liquefiers."

The object of the present paper was to obtain white, yellow and orange staphylococci from as many different sources as possible and to see whether the group would lend itself to rational or satisfactory subdivision making use of fermentation, pigmentation, hemolysis, proteolysis on milk agar plates, liquefaction of gelatin, blackening of lead acetate agar, and the determining of limiting hydrogen ion concentrations of each strain in dextrose broth. I hoped to see if there was a correlation of any of these with source and pathogenicity.

In order to do this, I have subdivided this work under six headings, as follows:

1. Assuming as Dudgeon that staphylococci seemed to be one species and disregarding the characteristic of pigment production and liquefaction of gelatin, is it possible to subdivide staphylococci in general upon a basis of fermentation of carbohydrates. In determining data for this question, I have asked myself to note the following questions: Does the classification by fermentation reaction offer any correlation with pigment production, liquefaction of gelatin, with pathogenicity, with source? and, Is there a correlation between rapidity of fermentation and of pigment production and pathogenicity as suggested by Winslow?

2. After studying staphylococci as a whole from the standpoint of fermentation reactions, it was next decided to assume pigmentation as the primary differentiation into subgroups of white, yellow and orange staphylococci and attempt the subdivision of each of these by means of fermentation reaction. The borderline yellows and orange pigment producers were placed in their respective groups of yellow or orange.

3. The next step was to assume, as before, pigmentation as a primary differentiation into white, yellow and orange staphylococci then to attempt a subdivision of each of these by means of blood agar plates, placing the hemolizers and nonhemolizers in separate groups as has been done for streptococci, these were again subdivided upon the basis of fermentation reactions. In the work on hemolysis, a comparative study was made using different kinds of blood, such as rabbit, sheep and human.

4. A similar study of staphylococci in which pigmentation was made use of for primary subdivision of each group, subdivided again in accordance with the ability of various strains in that group to produce proteolysis upon milk agar plates. This gave proteolytic and nonproteolytic subdivision. These were further divided upon the basis of fermentation. It was necessary to study the reationship between reaction of media and degree of proteolysis in obtaining data for this work.

5. To study the ability of the various staphylococci to produce hydrogen sulphide, all staphylococci were first inoculated into both one per cent peptone broth agar containing lead acetate, and three per cent peptone broth agar containing lead acetate to see whether there was any correlation between the blackening of lead acetate and any other characteristics. I might say there was noted apparently a correlation between pathogenicity and blackening of three per cent peptone lead acetate agar.

6. Lastly, it was thought worth while to determine the limiting hydrogen ion concentrations of all these various staphylococci in dextrose dipotassium phosphate broth to see whether there exist high and low

ratio groups and whether these correlate with any other characteristics and data.

In all, 75 strains of staphylococci were studied. These were obtained from pathological conditions, in various foods and three strains from the American Museum of Natural History. My tentative definition for staphylococci was cocci in which the division was in two planes giving rise to flat sheets of cells and irregular masses.

TECHNIQUE.

All organisms used in this work were freshly isolated and were first grown upon agar, + 1 to phenolphthalein, then inoculated into plain broth to determine morphology.

In studying fermentation, the organisms were inoculated into one per cent sugar broth solutions of dextrose, lactose, saccharose, mannite, maltose, salacin, dulcite, inulin, raffinose, glycerin, galactose and xylose, and tested in 48 to 72 hours with litmus.

For confirmation, the organisms were inoculated into Hess's semisolid medium containing Andrede as an indicator plus the following carbohydrates—dextrose, lactose, saccharose and mannite.

One per cent peptone lead acetate agar and three per cent peptone lead acetate agar were made according to directions given by Jordan.

Litmus milk, one per cent peptone gelatin, Dunham's peptone, nitrate broth were made according to directions in Standard Methods of Water Analysis.

Gram stains were made from cultures after 24 hours' growth upon an agar slant, using carbol gentian violet as the primary stain and counterstaining with an aqueous solution Bismarck brown.

The chromogenic power was determined by spreading a portion of a culture two weeks old upon white paper, as suggested by Winslow.

Blood agar plates were made by adding 3 cc. of whole defibrinated blood to 100 cc. of agar neutral to phenolphthalein. Sheep, rabbit and human blood were used. The sheep blood was all obtained from the same animal, three different rabbits were bled, and human blood was obtained from several individuals.

Milk plates were made by adding 10 cc. of milk to 100 cc. of agar. The agar was adjusted to + 2, + 1, 1, and — 1 to phenolphthalein.

The chlorimetric or indicator method was used in determining the hydrogen ion concentration. Buffers were made up according to Cole.[8] Methyl red, Phenol red and brom cresol purple were used as indicators as suggested by Clark and Lubs.[9]

The synthetic media used contained .5 per cent Bacto peptone (Digestive Ferments Company), .5 per cent dextrose and .5 per cent K_2HPO_4 titrated neutral to methyl orange. The media was sterilized at 10 pounds for 15 minutes, in order not to destroy the vitamines. After sterilization the hydrogen ion concentration of the broth was 7.3.

As previously mentioned, the first division of this work was a study of the fermentation reaction of all strains of staphylococci, especially with regard to dextrose, lactose, saccharose and mannite. As a matter of supplying additional information maltose, galactose, xylose, salacin are included in the report.

The summary of this data is included in table I.

Nomenclature was taken from Winslow's Systematic Relationship of *Coccaceæ*.

TABLE I.

CLASS 1—Organisms fermenting dextrose, lactose, saccharose and mannite.

No.	SOURCE.	Pigm.	Dex.	Lac.	Sach.	Man.	Malt.	Gal.	Xyl.	Sal.	Glyc.	Milk.*	Milk.**	Gel.	K_2PO_4 Broth.	Nitr.	Lead Acet.	Gram Stain.
5	Pus from ear	White	+	+	+	+	+	+	—	+	+	+	Pep	+	+	—	—	+ Albus.
30	Boil (Acalia)	O	+	+	+	+	+	+	+	—	—	+	+	+	+	+	+	+ Aureus.
31	Boil (Johnson)	O	+	+	+	+	+	+	+	—	—	+	+	+	+	+	+	+ Aureus.
38	Rabbit sore	White	+	+	+	+	+	+	+	—	—	+	+	+	+	+	+	+ Albus.
48	Oyster	Clear	+	+	+	+	+	+	—	+	—	+	Pep	+	+	+	—	+ Albus.
17	H. Urine (Flu)	White	+	+	+	+	+	+	+	+	—	+	Pep	—	+	—	—	+ Albus.
49	Oyster	Clear	+	+	+	+	+	+	—	+	—	+	Pep	+	+	—	—	+ Albus.
16	L. Urine (Flu)	White	+	+	+	+	+	+	+		—	+	Pep	+	—	—	—	+ Albus.
6	Milk	Y	+	+	+	+	+	+	+	—	—	—	+	+	+	+	—	+ Citreus.
12	Milk	White	+	+	+	+	+	—	+	—	—	+	Cog	+	—	+	+	+ Albus.
20	Rabbit Abscess	White	+	+	+	+	+	—	+	—	—	+	Cog	+	—	+	+	+ Albus.
27	Throat	White	+	+	+	+	+	—	—	+	—	+	+	+	+	+	+	+ Albus.
39	T. B. Infection	O	+	+	+	+	+	+	+	—	—	+	+	+	+	+	+	+ Aureus.
40	Infected Tooth	White	+	+	+	+	+	+	—	—	+	+	+	—	—	—	—	+ Albus.
57	Sore Throat	O	+	+	+	+	+	+	—	—	—	+	+	+		+	+	+ Aureus.
7	Milk	Y	+	+	+	+	+	+	+	—	—	+	Cog	+	—	+	+	+ Citreus.
3	Air	White	+	+	+	+	+	—	—	—	—	+	+	—	—	+	—	+ (?)
8	Milk	White	+	+	+	+	+	—	—	—	—	+	Pep	+	—	+	—	+ Albus.
9	Milk	O	+	+	+	+	+	—	—	—	—	—	Pep	+	+	+	+	+ Aureus.
55	Chronic Eye Infection	O	+	+	+	+	+	—	—	—	—	+	Pep	—	+	+	+	+ Aurantiacii.
58	J. P	W	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	Variable Epidermidis.
59	Boil	O	+	+	+	+	+	+	+	—	—	+	+	+	+	+	+	Aureus.
61	—	O	+	+	+	+	+	+	+	—	—	+		+	+	+	—	+ Aureus.
62	—	O	+	+	+	+	+	+	—	—	—	+	+	+	+	+	+	+ Aureus.
63	—	O	+	+	+	+	+	+	+	—	—	+	+	+	+	+	+	+ Aureus.
64	—	O	+	+	+	+	+	+	+	—	—	+	Pep	+	+	+	—	+ Aureus.
65	—	W	+	+	+	+	+	+	—	—	—	+	Cog. pep.	+	+	+	+	+ Albus.
66	—	W	+	+	+	+	+	+	+	—	—	+	+	+	+	+	+	+ Albus.
67	—	W	+	+	+	+	+	—	+	—	—	+	+	+	+	+	+	+ Albus.
68	—	O	+	+	+	+	+	+	+	—	—	+	+	+	+	+	—	+ Aureus.
72	Aureus	O	+	+	+	+	—	+	—	—	+		Cog. pep.	+	+	+	—	+ Aureus.
76	Milk	O	+	+	+	+	+	+	—	—	—	+	Pep	+	+	+	+	+ Aureus.
78	Boil	O	+	+	+	+	+	+	—	—	—	+	+	+	+	+	+	+ Aureus.
83	313	O	+	+	+	+	+	+	—	—	—	+	Cog	+	+	+	—	+ Aureus.
84	348	O	+	+	+	+	+	+	—	+	—	+	Pep	—	—	+	+	+ Aurantiacii.
85	457	O	+	+	+	+	+	—	—	—	—	+	—	—	+	+	+	+ Aurantiacii.
86	Boil	O	+	+	+	+	+	+	—	—	—	+	+	+	+	+	—	+ Aureus.
87	Pus	O	+	+	+	+	+	+	—	—	—	+	+	+	+	+	+	+ Aureus.
88	Pus	O	+	+	+	+	+	+	—	—	—	+	+	+	+	+	+	+ Aureus.
89	Pus	O	+	+	+	+	+	+	—	—	—	+	+	+	+	—	+	+ Aureus.
90	Pus	O	+	+	+	+	+	+	—	—	—	+	+	+	+	+	+	+ Aureus.
91	Pus	O	+	+	+	+	+	—	—	—	—	+	+	+	+	+	+	+ Aureus.

O = Orange; W = White; Y = Yellow, C = Clear

TABLE I—CONTINUED.

CLASS 2—Organisms Fermenting Dextrose, Lactose, Saccharose but not Mannite.

No.	Source.	Pigm.	Dex.	Lac.	Sach.	Man.	Malt.	Gal.	Xyl.	Sal.	Glyc.	Milk.	Milk.	Gel.	K_2PO_4 Broth.	Nitr.	Lead.	Milk plates, Gram stain.
29	Acne	White	+	+	+	—	+	+	+	—		+	Cog	+	+	+	—	+ Epidemus.
34	Milk	White	+	+	+	—	+	+	+	—		+	+	+	—	+	+	+ Epidemus.
37	Arm Infection	White	+	+	+	—	+	+	+	—		—	—	+	+	+	—	+ Epidemus.
35	Milk	White	+	+	+	—	+	+	+	—		+	+	+	+	—	+	+ Albus.
28	Acne	White	+	+	+	—	+	+	+	—		+	+	+	+	+	—	+ Epidemus.
2	Skin of Nose	White	+	+	+	—	+	+	—	—		+	Cog	+	+	+	—	+ Epidemus.
41	Butter	White	+	+	+	—	+	+	—	—		+	+	—	—	+	—	+ Candidus.
43	Oleomargarine	Y	+	+	+	—	+	+	—	—		+	+	—	—	+	—	— Luteus.
46	Butter	Y	+	+	+	—	+	+	—	—		+	+	+	—	+	—	+ Citreus.
47	Infected Tooth	White	+	+	+	—	+	+	—	—		+	Pep	+	—	+	—	+ Epidemus.
26	Throat	White	+	+	+	—	+	—	—	—		+	+	—	—	—	+	+ Candidus.
52	Tonsil	O	+	+	+	—	+	—	—	—		+	Pep	+	—	+	+	— Aureus.
33	Sneeze	White	+	+	+	—	+	—	—	—		+	+	—	—	—	—	+ Candidus.
69	—	White	+	+	+	—	+	+	+	—	—	+		+	—	—	+ +	+ Albus.
70	—	O	+	+	+	—	+	+	—	—	—	+		+	—	—	+ —	+ Aureus.
77	Milk	Y	+	+	+	—	+	+	+	+	—	+		+	—	+	+ +	+ Citreus.
80	Hamberger	Y	+	+	+	—	—	—	—	—	—	+		+	—	—	— +	+ Flavus.
81	Nose	W	+	+	+	—	+	+	—	—	—	+		+	+	+	— +	+ Epidermidis
82	Nose	W	+	+	+	—	+	+	—	—	—	+		+	+	+	— +	+ Epidermidis

TABLE I—CONTINUED.

CLASS 3—Organisms Fermenting Dextrose and Saccharose but not Lactose or Mannite.

No.	Source.	Pigm.	Dex.	Lac.	Sach.	Man.	Malt.	Gal.	Xyl.	Sal.	Milk.	Milk.	Gel.	Red.	Mit.	Lead.	Gram Stain.
4	Air	White	+	—	+	—	+	—	—	—	—	Pep	+	—	—	+	+ Albus.
53	Tonsil	O	+	+	+	—	+	—	—	—	—	—		—	+	+	+
32	Sneeze	Y	+	—	+	—	+	—	—	—	—	—	—	—	—	—	— Luteus.
15	Scalp	Y	+	—	+	—	+	—	—	—	—	—	—	—	—	+	+ Luteus.

TABLE I—CONTINUED.

CLASS 4—Organisms not Fermenting Dextrose, Lactose, Saccharose or Mannite.

No.	SOURCE.	Pigm.	Dex.	Lac.	Sach.	Man.	Malt.	Gal.	Xyl.	Sal.	Milk.	Milk.	Gel.	Red.	Mit.	Lead.	Gram Stain.
21	Feces (Flu)	Light Yellow	—	—	—	—	—	—	—	—	—	—	+	—	+	—	+ Citreus.
25	Milk	Light Yellow	—	—	—	—	—	—	—	—	—	—	+	+	—	+	+ Flavus.
22	Feces (Flu)	Light Yellow	—	—	—	—	—	—	—	—	—	—	—	—	—	+	+ Luteus.
54	Infected Tooth	White	—	—	—	—	—	—	—	—	—	—	—	—	—	—	+
50	Oyster	White	—	—	—	—	—	—	—	—	—	Pep	—	—	—	—	+
51	Sore Throat	Orange White	—	—	—	—	—	—	—	—	—	—	—	—	—	+	+ Aurantiacus.

TABLE I—CONCLUDED.

CLASS 5—Irregular Organisms.

No.	SOURCE.	Pigm.	Dex.	Lac.	Sach.	Mau.	Malt.	Gal.	Xyl.	Sal.	Milk.	Milk.	Gel.	Red.	Mit.	Lead.	Gram Stain.
11	Milk	Orange-White	+	—	+	+	+	—	—	—	—	Pep	+	+	+	+	+ Aureus.
23	Unknown	White	+	—	+	+	—	—	—	+	—	Pep	+	+	+	+	+ Epidermidis.
14	Pus from Rabbit	Light Yellow	+	—	—	—	—	—	—	—	—	—	—	—	—	—	+ Luteus.
45	Air	Light Yellow	+	—	—	—	—	—	—	—	—	Pep	+	—	—	+	+ Flavus.

It will be observed that results in table I have divided all of the staphylococci into five classes. Class I, those staphylococci which ferment all four of the sugars, dextrose, lactose, saccharose and mannite; class II, those that ferment dextrose, lactose, saccharose, but are negative upon mannite; class III, those fermenting dextrose and saccharose but negative upon lactose and mannite; class IV, includes all staphylococci which failed to produce acid in any of the four sugars; and class V, includes four strains that are irregular.

It can readily be seen that there is no correlation between these classes in source, pathogenicity or pigmentation. For this reason, classifying staphylococci purely on fermentation reactions, disregarding pigment production and liquefaction of gelatin, does not seem to give a satisfactory classification.

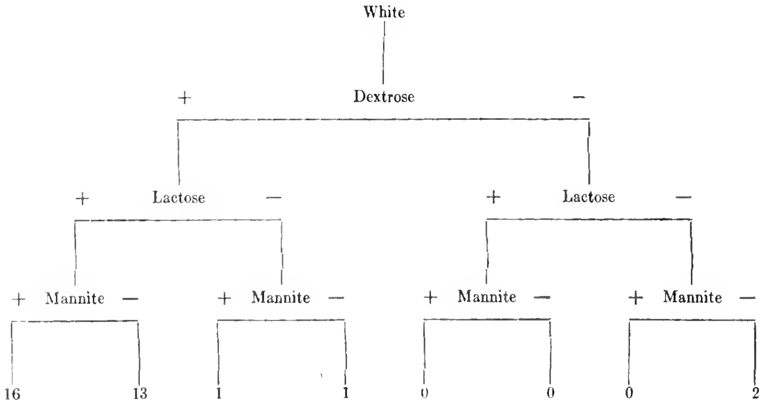
The second phase was to assume pigmentation as a primary classification, using white, yellow and orange, and subdividing each of these, making use of the fermentation reaction of the sugars. In doing this, I have assumed that dextrose, lactose and mannite are of importance in the order named and have developed the classifications which are shown in table II.

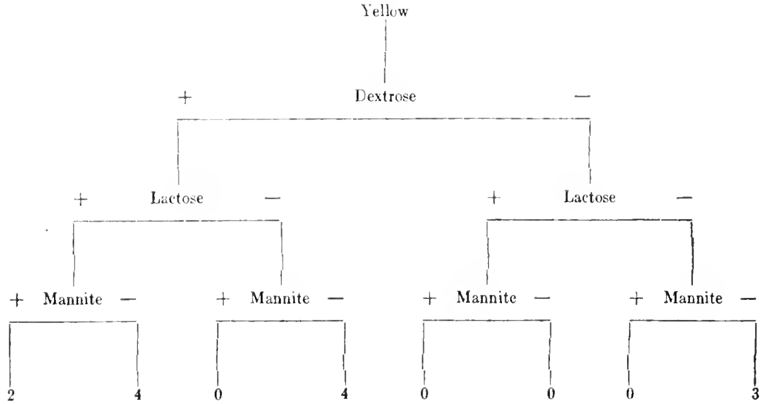
Again it can be seen that there is no apparent correlation between these fermentation reactions and pigmentation or source or pathogenicity.

Subdivision 3 of this problem comprises an application of the phenomena of hemolysis to subdivision of various pigmented types of staphylococci. There are various and conflicting statements in literature as to most suitable kind of blood for determining hemolysis by staphylococci. It is quite generally recommended that a washed suspension of red blood cells be used, but for routine laboratory work this process is not ordinarily followed, largely because of the lack of facilities and the desire for speed. In order to duplicate ordinary laboratory methods, I have made use of blood agar prepared by adding defibrinated blood to melted agar cooled to 45° C.

Before attempting this work I tried the hemolytic properties of these organisms for rabbit, sheep and human bloods to determine which gave the most positive and fairly consistent results. These are embodied in table III.

TABLE II.


White
+ Dextrose −
+ Lactose −
+ Lactose −
+ Mannite −
+ Mannite −
+ Mannite −
+ Mannite −
16
13
1
1
0
0
0
2


Yellow
+ Dextrose −
+ Lactose −
+ Lactose −
+ Mannite −
+ Mannite −
+ Mannite −
+ Mannite −
2
4
0
4
0
0
0
3

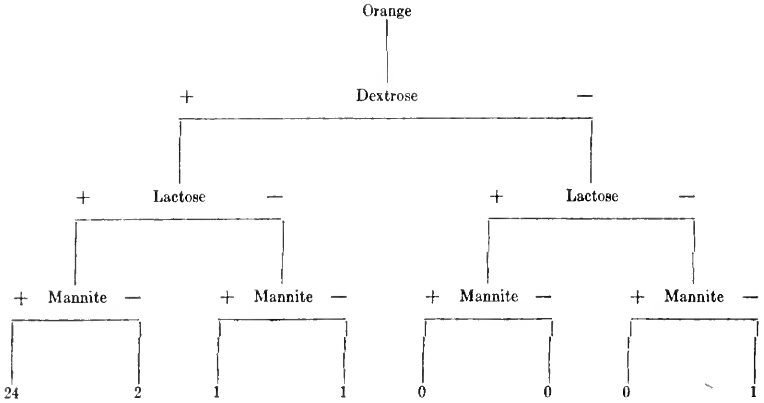

Orange
+ Dextrose −
+ Lactose −
+ Lactose −
+ Mannite −
+ Mannite −
+ Mannite −
+ Mannite −
24
2
1
1
0
0
0
1

TABLE III.

SOURCE.	Strain and Group No.	Pigm.	Rabbit Blood Hemolysis +	Rabbit Blood Hemolysis —	Sheep Blood Hemolysis +	Sheep Blood Hemolysis —	Human Blood Hemolysis +	Human Blood Hemolysis —	Milk Plates Proteolysis +	Milk Plates Proteolysis —
Air	3^1	White		—		—		—		—
Milk	8^1	White		—	+		+		+	
Milk	12^1	White		—		—		—		—
Urine F	17^1	White		—		—		—		—
Rab. Absc.	20^1	White		—	+		+			—
Throat	27^1	White	+		+		+		+	
Rab. Sore	38^1	White	+			—	+			—
Urine F	16^1	White		—		—	+		+	
Inf. Tooth.	40^1	White	+		+		+			—
Pus—ear.	5^1	White				—		—	+	
Oyster	48^1	Clear		—		—		—	+	
Oyster	49^1	Clear		—	+		+		+	
—	65^1	White		—	+		+		+	
G. P. Autopsy	58^1	White	+		+		+			—
—	66^1	White	+	—		—	+			—
—	67^1	White		—		—	+		+	
Acne	29^2	White		—		—		—	+	
Milk	34^2	White	+		+		+		+	
Arm. Inf.	37^2	White		—		—		—	+	
Milk	35^2	White	+		+		+			—
Acne	28^2	White		—		—		—	+	
Skin—nose.	2^2	White		—		—		—		—
Butter	41^2	White		—		—		—	+	
Inf. Tooth.	47^2	White		—	+		+		+	
Throat	26^2	White	+			—		—		—
Sneeze	33^2	White		—		—		—		—
—	69^2	White	+		+		+		+	
None	81^2	White		—		—		—	+	
None	82^2	White	+			—	+		+	
—	54^3	Lost								
Oyster	50^3	Lost		—		—		—		—
	4^4	Lost								
	23 ir	Lost								
Milk	6^1	Y. White	+			—	+			—
Milk	7^1	Y. White		—		—		—		—
Oleomargarine	43^2	Y. White		—	+		+		+	
Butter	46^2	Y. White		—		—		—		—
Milk	77^2	Yellow		—	+		+		+	
Hamburger	80^2	Yellow		—		—	+		+	
Feces	21^3	Yellow	+		+		+		+	
Milk	25^3	Yellow	+		+		+		+	
Feces	22^3	Yellow	+		+		+		+	
Rab. Pus	14^3	Yellow		—		—		—		—
Air	45^3	Yellow	+		+		+		+	
Scalp	15^4	Yellow		—		—	+		+	
Milk	9^1	Orange		—		—		—	+	
Boil	30^1	Orange		—	+		+			—
Boil	31^1	Orange		—		—		—	+	
T. B. Inf.	39^1	Orange		—		—	+			—
Sore Throat	57^1	Orange		—	+		+		+	
Eye	55^1	Orange	+		+		+		+	
Boil	59^1	Orange		—	+		+		+	
—	61^1	Orange	+		+		+		+	
—	62^1	Orange		—	+		+		+	
—	63^1	Orange	+		+		+		+	
—	64^1	Orange	+		+		+			—
—	68^1	Orange		—		—	+		+	
Lab. St.	72^1	Orange	+		+		+			—
Boil	78^1	Orange		—	+		+		+	
Aureus	83^1	Orange		—		—	+			—
Aurientiacus,	84^1	Orange	+		+		+		+	
Aurientiacus,	85^1	Orange		—	+		+		+	
Boil	86^1	Orange	+		+		+			—
Boil	87^1	Orange	+		+		+		+	
Boil	88^1	Orange	+		+		+		+	
Boil	89^1	Orange	+		+		+		+	
Boil	90^1	Orange	+		+		+		+	
Boil	91^1	Orange	+		+		+		+	
Milk	76^1	Orange		—		—	+			
Tonsil	52^2		+		+		+		+	
—	70^2	Orange		—		—		—		—
Sore Throat	51^3	Orange		—	+		+			—
Milk	11 ir	Orange	+		+		+		+	
Tonsil	53^4	Orange	+		+		+		+	

It is quite evident that human blood gave the most positive results.

I decided, as mentioned above, to use pigmentation as the primary method of division and blood agar plates secondarily, subdividing each of these into hemolytic and nonhemolytic staphylococci, and the fermentation reactions as described in table II were made use of for further subdivision. The results of this are summarized in table IV.

It will be observed that the white staphylococci were evenly divided between hemolytic and nonhemolytic strains, 16 strains were hemolytic and 14 strains were nonhemolytic. This condition shows a gradual change as you go through the yellow and orange staphylococci. For example, out of 13 yellow staphylococci, one was lost before hemolytic properties were determined and of the remaining 12, 9 were hemolytic and 3 were nonhemolytic. Among the orange staphylococci, 26 strains were hemolytic and 3 nonhemolytic. Of these 26 hemolytic orange staphylococci, 19 were from the animal body as compared with one among the three of the nonhemolyzers. Of the 19 from the animal body, 16 were positive in all sugars. Among the yellow, only one was from the animal body and that one was nonhemolytic and fermented dextrose but not lactose or mannite. Among the white hemolytic staphylococci, 7 were from the animal body and of these 7, 6 fermented all sugars. Among the 14 nonhemolyzers, 2 were from the animal body. This suggests that in general staphylococci associated with the animal body seem to be hemolyzers. The history of organisms obtained from the air and various foods is not known further than the source mentioned.

As the fourth phase of this problem, we have attempted to study a possible classification of staphylococci, making use of pigment as a primary division and next the ability of the staphylococci to produce proteolysis or conversely failure to produce proteolysis. This is followed by making use of carbohydrates as in previous tables. It will be observed that the only difference between this and the third phase is that proteolysis is substituted for hemolysis.

Very little work has been published showing the use of milk agar plates in the attempt to classify any kinds of bacteria at all. As a preliminary it was found necessary to determine the optimum reaction of media for proteolysis. Accordingly, studies were made on milk plates + 2, + 1, 1, and — 1 to phenolphthalein. The results are summarized in table V.

TABLE IV.

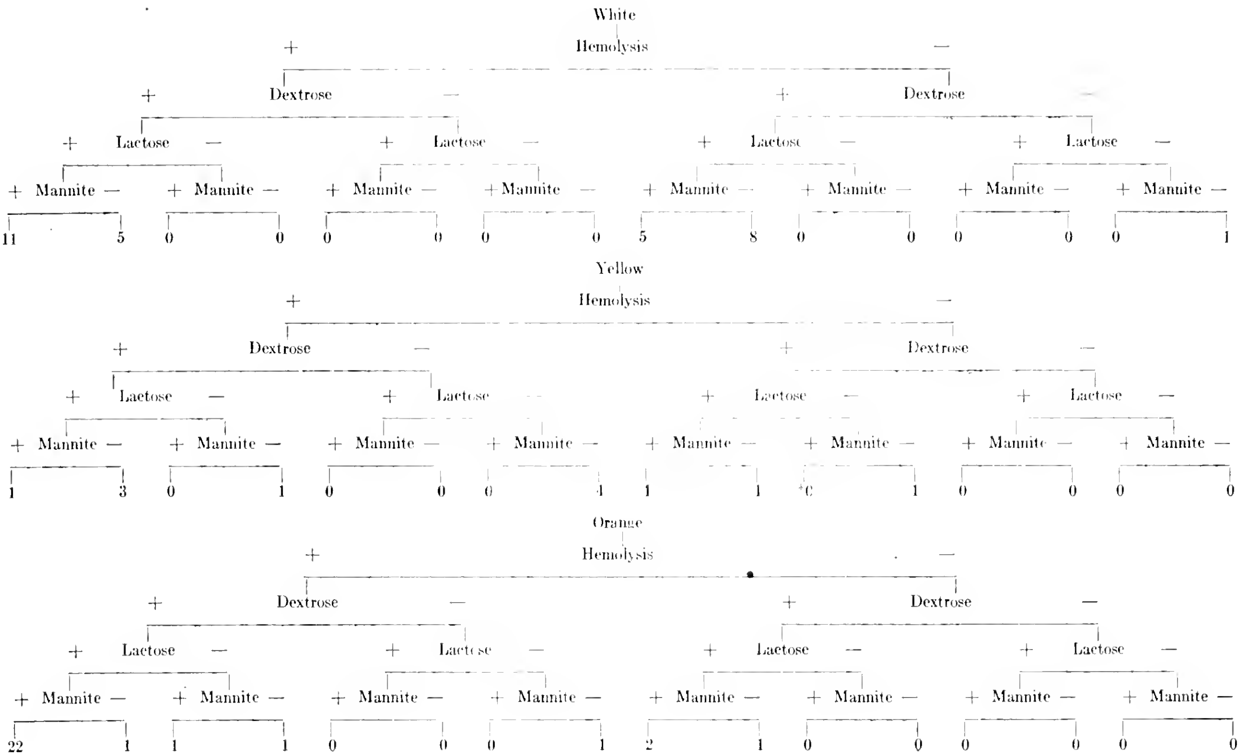

White
Hemolysis
+ Dextrose —
+ Dextrose —
+ Lactose —
+ Lactose —
+ Lactose —
+ Lactose —
+ Mannite —
11 5 0 0 0 0 0 0 5 8 0 0 0 0 0 1
Yellow
Hemolysis
+ Dextrose —
+ Dextrose —
+ Lactose —
+ Mannite —
1 3 0 1 0 0 0 4 1 1 0 1 0 0 0 0
Orange
Hemolysis
+ Dextrose —
+ Dextrose —
+ Lactose —
+ Mannite —
22 1 1 1 0 0 0 1 2 1 0 0 0 0 0 0

TABLE V.—Effect of Reaction of Media on Proteolysis on Milk Agar Plates.

PIGMENT.	Total number of strains.	Reaction of media and number of strains showing proteolysis.															
		+ 2 to phenolphthalein.				+ 1 to phenolphthalein.				1 to phenolphthalein.				1 to phenolphthalein.			
		None.	Trace.	Fair.	Good.	None.	Trace.	Fair.	Good.	None.	Trace.	Fair.	Good.	None.	Trace.	Fair.	Good.
White	30	18	4	0	8	16	6		8	14	4	2	10	15	5	1	9
Yellow	12	7	2	0	3	7	2		3	6	0	0	6	6	4	0	2
Orange	29	15	6	3	5	14	4	6	5	12	3	9	5	10	11	5	3

It is quite evident that the best reaction was neutral to phenolphthalein, the end point was a pronounced end point and corresponded to a P_h of about 8.8.

Applying this in the same manner as blood agar plates in table IV, I have summarized the data in table VI.

Of the white staphylococci, it will be observed that 17 were proteolytic and 12 nonproteolytic. Of the 17 proteolytic, it was rather interesting to note that only 3 were body organisms. In comparing results with hemolysis in table IV, it was noted that on milk agar plates there were 17 proteolytic staphylococci and 12 nonproteolytic, whereas there were 16 hemolyzers to 13 nonhemolyzers. While the total number found proteolytic compares very closely with the total found hemolytic, it is an interesting observation that organisms that are proteolytic are not necessarily the same ones that are hemolytic. For example, of the 11 hemolyzers that fermented all sugars, only 8 are proteolytic. Of the 9 proteolytic organisms that ferment dextrose and lactose but do not ferment mannite, 5 are hemolytic, 4 failing to show hemolysis. Thus it is quite evident that proteolysis and hemolysis are not consistent in their actions although about the same number of staphylococci were proteolytic as were hemolytic.

Among the yellow staphylococci it is observed that 8 were proteolytic and 4 nonproteolytic and that 9 were hemolytic and 3 nonhemolytic. The one hemolyzer which fermented all sugars was not proteolytic and one of the two proteolytic organisms that fermented dextrose, lactose and mannite was not hemolytic, which was very similar to the observations made on white staphylococci.

Among the orange staphylococci, it was previously observed that 26 were hemolytic and three nonhemolytic. Using milk agar plates, we observed that there were 21 proteolytic and 8 nonproteolytic. In other words, 4 of 22 of the hemolytic orange staphylococci that fermented all of the sugars were not proteolytic and one of the 2 proteolytic orange staphylococci that fermented dextrose but failed to ferment lactose or mannite was not hemolytic.

Now as to source, it will be observed that 14 of the 21 proteolytic staphylococci were obtained from the animal body. The percentage of organisms associated with the animal body was greater with the nonproteolytic than with the nonhemolytic orange staphylococci.

TABLE VI.

Proteolysis	+	+	+	+	+	+	+	+	—	—	—	—	—	—	—	—
Dextrose	+	+	+	+	—	—	—	—	+	+	+	+	—	—	—	—
Lactose	+	+	—	—	+	+	—	—	+	+	—	—	+	+	—	—
Mannite	+	—	+	—	+	—	+	—	+	—	+	—	+	—	+	—
White	8	9	0	0	0	0	0	0	8	4	0	0	0	0	0	1
Yellow	0	3	0	2	0	0	0	3	2	1	0	1	0	0	0	0
Orange	18	1	0	2	0	0	6	1	0	0	0	0	0	0	0	1

The fifth subdivision of this paper has to do with the action of all staphylococci upon lead acetate agar. A summary of this data is embodied in table I. It will be observed that, with two exceptions, all staphylococci isolated from pus or boils blackened lead acetate agar. I doubt, however, that this could be depended upon to denote pathogenicity.

In regard to the sixth subdivision of the paper applying to the various hydrogen ion concentrations, I hope to do more extensive work in the future. I selected 6 from class 1, table I, 6 from class 2, 2 from class 3, and 4 from class 4, and grew them in dextrose dipotassium phosphate broth, as described in the paragraph on technique, and determined the hydrogen ion from day to day for a period of five days.

These results suggest the possibility of dividing staphylococci into subdivisions depending upon the limiting P_h. This is analogous to the attempt to subdivide the coliærogenes group. It might be of some value if used with pigment production as a basis of classification and the high ratio determined for white, yellow and orange separately.

I have also considered the value of the group number system as suggested in the descriptive chart of the American Association of Bacteriology, but have decided not to include the various group numbers of the various staphylococci in question.

SUMMARY AND CONCLUSIONS.

That disregarding pigmentation and liquefaction of gelatin staphylococci may be arranged into five types according to their ability to ferment dextrose, lactose, saccharose and mannite. These types do not correlate with any other observed characteristics such as source, pathogenicity, pigmentation or liquefaction of gelatin. It would seem that this method of classifying staphylococci would only lead to confusion and offers nothing of basic value.

That while routine laboratory work might warrant only the data on morphology, gram stain, type of growth and pigment production on plain agar slants, yet it would seem advisable, at least from the standpoint of comparison when reporting upon staphylococci in the literature, to follow some such plan as follows: Gram stain, pigment production, liquefaction of gelatin, action on blood agar plates where kind of blood, amount and P_h of medium are given, and the fermentation reaction in dextrose, lactose and mannite. Instead of blood agar plates it would seem that for comparison milk agar plates might equally well be substituted and perhaps prove equally reliable. In either proteolysis or milk agar plates or hemolysis, it is apparently important to have an optimum and known hydrogen-ion concentration in the medium. This is very easily a source of discrepancies. The blackening of lead acetate agar might also be worth including.

There does not seem to be any uniform correlation between the property of proteolysis of milk agar plates and hemolysis on blood agar plates.

Apparently most staphylococci from the animal body are hemolytic.

Contrary to frequent statements in the literature, human blood seemed to be superior to either rabbit or sheep blood.

As might well be expected, hydrogen-ion determinations show that staphylococci can rightly be grouped into at least two groups with respect to some one indicator such as methyl red, and into more groups if desired. I do not know that this is consistent or will prove of value.

Acknowledgment is hereby made to two members of the department of bacteriology of the University of Kansas, Prof. N. P. Sherwood and Miss Cornelia M. Downs, for many valuable suggestions and criticisms of my work.

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THE
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CONTENTS:

ANGUILLAVUS HACKBERRYENSIS.
H. T. Martin.

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9-860

THE KANSAS UNIVERSITY
SCIENCE BULLETIN.

VOL. XIII.] MAY, 1920. [NO. 7.

Anguillavus hackberryensis.*

A new species and a new genus of fish from the Niobrara Cretaceous of Kansas.

BY H. T. MARTIN.

(Plate VI.)

ALTHOUGH not a new genus of fish in the proper sense of of the word (the generic name having been given by Hay† to similar forms from the Upper Cretaceous of Mount Lebanon, Syria), this is the first time so far as the writer is aware that this genus has been reported from the Niobrara Cretaceous of Kansas, hence the term.

The species I have named for the locality in which the specimen was found, a locality made famous by the early discoveries of Williston and Mudge.

It is rather strange that, after fifty years of collecting by as many parties, not a single fragment has been found referable to this genus. Yet one would naturally expect that among the thousands of fossil fishes that have been collected from the deposits of this once great inland sea some member of this group would have been recognized.

The specimen here figured and described was found by the writer during the University Expedition of 1919, on Hackberry creek, Gove county, Kansas, six miles east of Gove City.

When found the specimen was weathered out and fully exposed as shown in the plate. The process of weathering had unfortunately carried away the greater part of the front portion of the skeleton, leaving only one or two bones of the skull,

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* Received for publication on May 18, 1921.

† On a collection of Upper Cretaceous fishes from Mount Lebanon, Syria, with descriptions of four new genera and nineteen new species, p. 439, by O. P. Hay.

with impressions where other parts had been washed away. The only part of the head remaining was a fragment of one dentary and one quadrate.

From all indications the skull was disarticulated and scattered over quite an area, while the hinder part of the skeleton was missing from the level of the sixty-fifth vertebra backward. The vertebræ remaining are connected in series which has made possible the retaining of the dorsal and anal fin in position. In size the Kansas specimen greatly exceeds those described by Hay from Mount Lebanon.

DESCRIPTION.

Ventral Fin.

The ventral fin is represented by two separate and distinct groups of four or five small irregular oblong plates, which are evidently the baseost bones of the fins. These plates and portions of the girdle appear at the level of the thirtieth vertebra in line with the well-defined outline of the body. The plates are 3 mm. wide and 4 mm. long. As the basal plates may have moved from their original position it is not certain that the ventral fins commenced at the thirtieth vertebra, although they appear to have done so.

Anal Fin.

The anal fin commences at the thirty-fifth vertebra or just behind the baseost bones of the ventral fin and continues without break to the last vertebra remaining in the preserved series.

Dorsal Fin.

Owing to the weathering away of the matrix towards the front part of the specimen, the dorsal fin does not show distinctly its whole length, the rays being disassociated and scattered, but in such a way that the fin appears to have commenced at or very near the occipital. From the thirty-fifth vertebra backward they are in position to the last vertebra remaining.

Vertebræ.

From the position made clear by impressions in the matrix, where the first vertebra occurred, to the eighteenth, the vertebræ are missing. The nineteenth, twentieth, twenty-first and twenty-second are represented by a half of each vertebra, the twenty-second to the thirty-seventh are missing entirely, but from here on to the sixty-fifth the vertebræ connected with the dorsal and anal fins are perfect. Twenty-five vertebræ here measure 100 mm. All vertebræ are very constricted in their center and are a little wider than long.

The entire specimen is crushed laterally, leaving the dorsal and anal fins in their natural position. The average distance across from the upper edge of the dorsal fin to the lower edge of the anal fin is 22 mm. At one point where the matrix has flaked away there appear six or seven delicate ribs attached to the underside of the vertebræ.

The following measurements have been made: Length of specimen from impression of first vertebra to the sixty-fifth and last remaining vertebra, 255 mm.; length of quadrate, 6 mm.

DESCRIPTION OF PLATE VI.

FIG. 1. Photograph of entire specimen as preserved in the matrix.

df. = Dorsal fin.
af. = Anal fin.
Bp. of Vf. = Basal plates of ventral fins.
X. = Impressions of first vertebræ.
Qd. = One quadrate 6 mm. long.
Dent. = Portion of dentary.

FIG. 2. Section of the hinder portion of the specimen, about natural size.

df. = Dorsal fin.
af. = Anal fin.
Br. of Vf. = Basal plates of ventral fins.

ANGUILLAVUS HACKBERRYENSIS.
H. T. Martin.

PLATE VI.

FIG. 1.

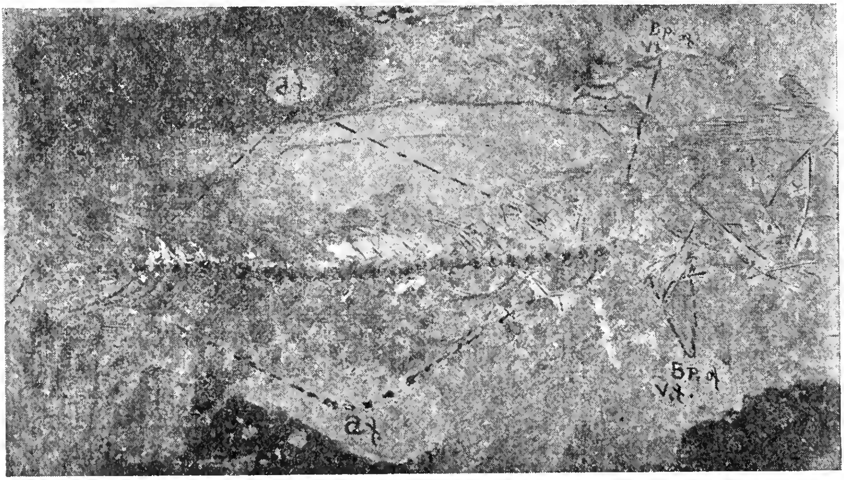

FIG. 2.

THE

KANSAS UNIVERSITY SCIENCE BULLETIN.

VOL. XIII, NO. 8—MAY, 1920.

CONTENTS:

CONTINUATION OF INVESTIGATION OF A POSSIBLE RAINFALL PERIOD EQUAL TO ONE-NINTH THE SUN-SPOT PERIOD,
Dinsmore Alter.

PUBLISHED BY THE UNIVERSITY,
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THE KANSAS UNIVERSITY SCIENCE BULLETIN.

VOL. XIII.] MAY, 1920. [NO. 8.

Continuation of Investigation of a Possible Rainfall Period Equal to One-ninth the Sun-spot Period.*

BY DINSMORE ALTER.

IN THE *Monthly Weather Review* for February, 1921, is published a preliminary report of the investigation of all the state averages of rainfall for the whole United States. Certain conclusions are reached tentatively, subject to further investigation. These are that there is evidence tending to show the existence of a correlation between rainfall and sun spots and that the rainfall follows a period of one-ninth the sun-spot period, varying its length always to keep in step with the sun-spot cycle. In this paper it is assumed that the reader is familiar with the previous discussion and only very brief reference will be made to any point discussed there. As stated in the conclusion of the other paper, the work has been continued in an attempt to fix more definitely the probability of the phenomenon.

The first continuation of the work was to answer definitely the question whether it might be that excessive rainfall or severe droughths in a very few of the months under discussion had produced the variations noted in the means of the two halves of the time as recorded in the previous paper. To do this, it was necessary to obtain the percentages of rainfall through each of the cycles for which data are available. For the eastern group state averages from two states are available beginning January, 1883, and for all states from the latter nineties. These averages give us twenty-four consecutive

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* Received for publication August 5, 1921

cycles. In investigating individual cycles it is necessary to eliminate the seasonal effect from each individual month. This has, therefore, been done for each month and each state by dividing the actual rainfall of each state for each month by the normal of that state and month. As stated in the first paper, this method is as reliable as the former one, except on the extreme western coast of the country where normals are practically zero for certain months, and where these zero months are thus given an equal weight with months of heavy normal rainfall. The results for these twenty-four consecutive cycles are tabulated as table 1. The attention of the reader is called to the fact that in twenty-two cycles there are only two in which the percentage of rainfall, for months when the cycle calls for a minimum, has actually been above normal. Each of these cycles is strictly independent of any other and their lengths are dependent only upon extra-terrestial causes. For the maximum phase it is to be noted that sixteen are above normal, seven below and one exactly normal. The author believes that this table establishes the probability much more strongly than the previous treatment, so strongly in fact that only very strong definite negative evidence can combat it.

California, western Washington and western Oregon are, as shown in the preceding paragraph, not available for treatment by individual cycles unless the summer months are entirely disregarded. It has been felt best, therefore, to treat, instead of the whole Pacific group of the first paper, the states of eastern Washington and Oregon, Idaho, Montana, Utah and Nevada as a unit. For these states there are available eighteen consecutives cycles. The results are shown as table 2. For the minimum phase fifteen of the eighteen are found to be below normal and for the maximum phase thirteen out of the eighteen are above normal.

As shown in the first paper, it is impossible to continue the varying period beyond the last date which is followed by both a sun-spot maximum and sun-spot minimum. This is 1913. The tables previously referred to are based on Wolfer's estimate of May, 1913, as epoch of minimum. This has been revised by him, placing the minimum nearly three months later.[1]

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[1] Prof. A. Wolfer. *Monthly Weather Review*, July, 1915, p. 314; August, 1920, pp. 459-461.

However, since the effect of changing this one date would affect only the latter part of tables 1 and 2, and since they were computed before the new estimate became available, I have merely inspected them to see approximately what the result of the shift in the latter cycles will be. The reader can see by such an inspection that this will make the results slightly more striking than they are at present.

It is desirable to make some use of the rainfall data since 1913 if possible. Since it is impossible to use the period which actually applies, it is only possible to use a constant periodicity and thus get some approximation to the truth, although some of the amplitude is certain to be damped. Every indication from the sun spots and rainfall was that the period averaged approximately fourteen months since the last sun-spot minimum. I have, therefore, plotted all the data of these two sections on the basis of such a constant periodicity. The results are given as table 3. These show once more the regularity with which the phases hold for each cycle, although, since the constant period is, of course, only an approximation to the true variable one, the same accuracy cannot be expected as has been found before. It should be noted that should the investigator be engaged in the entirely different problem of hunting for a possible date of a future minimum instead of, as in this paper, justifying the assumption of existence of the period, he would no longer be bound by this constancy, but could adjust the lengths as seemed best to fit the data in hand.

The mathematical reason for the greater reliability of minima in comparison with maxima is shown at once by table 10 of the first paper. The 15-month primary period has its minimum at phase 13.4 and its maximum at 5.9 in the Eastern group. The second harmonic has minima at 13.3 and at 5.8, with maxima at 2.0 and 9.5. The third harmonic has minima at 13.4, 8.4 and 3.4, with maxima at 10.9, 5.9 and 0.9. It is, therefore, evident that amplitude variation between these harmonics will have very little effect on the principal minimum, but that changes in relative intensity will shift the principal maximum from phase 6, its normal value, whenever the second harmonic gains in relative strength sufficiently, to a principal maximum between phases 1 and 2.

TABLE 1.—Eastern Group. Rainfall data for twenty-four consecutive cycles ending 1913. Sun-spot minimum occurs in phase 4.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
74	258	64	129	127	122	110	71	66	224	149	116	94	184	117
89	99	110	118	60	109	109	103	60	110	127	68	28	92	92
89	102	84	148	96	144	144	108	80	115	87	102	90	90	120
114	73	98	102	102	55	146	86	85	85	158	69	91	78	77
91	93	93	73	73	113	76	131	106	106	89	132	64	124	124
89	78	134	137	137	133	130	85	114	71	71	69	72	101	124
138	68	68	117	75	163	64	119	138	130	97	132	91	83	124
146	159	63	86	121	149	137	71	59	98	106	119	59	66	136
96	121	79	94	111	124	132	105	98	89	36	125	79	70	138
102	136	101	70	99	102	120	100	88	83	117	72	98	91	80
76	123	108	71	95	134	48	82	98	84	96	90	54	64	116
113	65	122	82	77	109	132	76	121	77	138	49	94	131	122
87	88	117	82	46	68	129	112	98	92	96	93	88	108	142
101	169	105	98	120	132	66	81	80	95	83	83	96	82	88
144	101	110	82	141	99	75	82	120	139	80	69	106	132	122
94	88	150	104	59	62	156	70	104	99	76	118	91	78	144
121	118	140	96	162	131	97	78	126	97	90	83	68	76	96
77	110	83	83	88	101	101	88	104	63	97	90	94	87	100
120	107	116	118	97	130	74	129	105	60	127	62	92	114	126
121	123	126	95	111	100	66	80	113	134	107	99	88	147	85
146	130	89	136	100	116	134	80	96	103	65	63	64	65	81
138	102	134	119	104	87	91	72	66	100	106	105	26	104	105
120	105	80	92	126	78	77	87	67	70	130	53	94	79	137
108	143	136	133	92	87	147	148	116	85	107	103	122	79	80
14	16	14	11	11	16	14	8	11	8	11	9	2	9	15 Above normal.
10	8	10	13	12	7	10	15	13	15	13	15	22	15	8 Below normal.
108	115	105	103	101	110	107	94	96	100	101	90	84	97	112 Mean.

TABLE 2.—Rainfall data of six western states September, 1889, to April, 1913. Phase numbers same as for Eastern group.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
......	......	......	*36	*255	*164	*409	200	120	146	66	106	67	38	318
114	50	14	70	45	187	105	94	147	250	215	86	128	28	46
169	62	54	106	119	127	106	85	28	30	71	122	128	69	125
156	127	47	86	44	174	113	124	94	138	116	156	91	101	82
67	109	82	30	141	150	94	85	76	69	68	43	118	26	82
116	115	62	120	149	61	126	137	88	74	198	85	80	160	118
67	119	100	55	108	146	167	138	64	87	72	161	100	76	80
63	82	86	104	116	126	91	89	86	56	211	62	151	100	79
81	70	188	86	54	45	108	115	164	113	86	123	72	86	97
78	62	74	133	78	65	120	51	141	100	104	44	173	68	54
40	154	130	117	47	100	86	84	92	112	107	82	126	63	76
190	206	93	67	69	109	67	64	103	26	96	71	69	118	97
119	109	57	53	131	98	102	65	114	98	130	109	169	134	75
162	86	57	152	171	155	132	156	98	95	181	108	180	90	83
51	139	65	91	102	66	145	132	121	110	121	190	43	68	190
127	72	69	77	109	160	157	80	188	136	110	125	73	82	70
82	84	47	140	133	148	95	148	93	62	79	111	149	61	74
161	99	92	83	108	82	104	158	111	109	174	172	94	148	85
101	88	91	......	......	......	......	......	......	......	......	......	......	......	......
10	8	2	7	12	11	13	9	9	8	11	11	9	5	4 Above normal.
8	10	15	11	6	6	5	9	9	9	7	7	8	12	14 Below normal.
108	102	74	92	101	118	113	112	107	100	122	108	112	84	102 Mean.

* These months not used in mean since only one state's data available.

TABLE 3.—Rainfall since August, 1913, plotted as constant 14-month approximate periodicity.

EASTERN GROUP.

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
93	71	89	78	121	134	87	76	79	97	83	107	56	73
86	118	73	105	91	130	144	102	44	41	130	95	114	144
100	124	97	123	111	81	77	78	112	125	138	83	87	87
74	102	108	72	127	95	86	110	102	95	95	121	31	53
60	60	58	145	95	87	75	87	113	153	99	126	92	98
116	91	146	101	112	109	65	188	138	86	98	88	107	161
86	107	102	129	107	53	124	124	75	82				
1	4	3	5	5	3	2	4	4	2	2	3	2	2 Above normal.
5	3	4	2	2	4	5	3	3	5	4	3	4	4 Below normal.
88	96	96	108	109	98	94	109	95	97	107	103	81	101 Mean.

SIX WESTERN STATES.

90	192	150	142	94	124	134	90	163	97	47	145	70	213
128	38	130	149	39	50	66	116	72	137	161	92	185	41
119	50	120	136	172	142	146	78	80	116	184	108	72	150
69	132	74	116	96	170	147	49	64	41	113	22	70	211
110	105	97	64	64	89	164	141	156	156	75	96	61	162
90	87	60	12	54	54	129	126	101	115	64	98	130	177
69	98												
3	3	3	4	1	3	5	3	3	4	3	2	2	5 Above normal.
4	4	3	2	5	3	1	3	3	2	3	4	4	1 Below normal.
96	100	105	103	86	105	131	100	106	110	107	94	98	159 Mean*.

* Since these years averaged much wetter than normal the average of the phase means is 107 instead of 100.

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Application of Marvin's Periodocrite to Rainfall Periodicity.*

BY DINSMORE ALTER.

(Plates VII and VIII.)

PROFESSOR MARVIN has recently[1] published a criterion for discrimination between real periodicities and fortuitous ones. This criterion, called by him the periodocrite, seems to me to fill a real need, and I hope that it, or a slight modification of it, may be adopted generally for such purposes.

If the data covers q of the suspected cycles they are arranged in q rows and p columns. The total number of observations is N. $\sigma_0 = \pm\sqrt{\frac{\Sigma V_n^2}{N}} = \frac{\Sigma V_n}{.7979\,N}$ is then formed. Let n be any number of the rows or cycles. The mean is taken of the n observations, in each column, and $\sigma_n = \pm\sqrt{\frac{\Sigma V^2}{n}} = \frac{\Sigma V}{.7979\,n}$ is formed. The ratios $\frac{\sigma_n}{\sigma_0}$ are plotted as ordinates and $\sqrt{\frac{1}{n}}$ as abscissæ. "When y is substantially and consistently greater than x a real periodicity is indicated of greater or less amplitude."

In the first of these two papers published here I have given two tables continuing the work of the previous paper on a rainfall period equalling one-ninth the principal sun-spot period. The first of these tables shows the percentages of normal for each phase of each of twenty-four consecutive

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* Received for publication August 5, 1921.

[1] Monthly Weather Review, March, 1921, pp. 115-124.

cycles in the eastern third of the United States. The second table shows the same for each of seventeen consecutive cycles of a large western group. These tables are peculiarly well adapted for application of Professor Marvin's Periodocrite.

In table 1 of this paper I have formed the means of the first n cycles for each column of the Eastern group table described above, allowing n to assume each integral value from one to twenty-four. These means are the tabular values printed under each phase number. From these I have computed x and y, beginning with $n=3$. In table 2 I have done the same thing for the Western group.

The last columns show the ratios y/x. Each of these thirty-five ratios is greater than one, the mean for the first table being about 1.4 and for the second about 1.2.

In plate VII I have shown these results graphically, and for purposes of comparison have copied the curves representing the annual cycles of Washington, D. C., and of Boston from the figure given by Professor Marvin in his paper.

The following has no connection with the application I have just made of the periodocrite to rainfall, but I believe that a slight modification of its graphical representation, not in any way changing its principle nor the method of analysis, will make it even more useful to discriminate between accidental and real periodicities of small amplitude.

When x is plotted as $\frac{1}{\sqrt{n}}$ the abscissæ corresponding to successive values of n become very closely crowded together, so much so that in the case of of 24 cycles the last half of them are represented by a very short portion of the curve, one easily overlooked in comparison with the much longer part representing the first half of the data. For a larger number of cycles the case becomes even worse. Yet these are the cycles in which accidental errors have been damped, to a large extent, and in which any true periodicity of small amplitude will show itself most clearly. Furthermore $\frac{\sigma_n}{\sigma_0}$ has become small, if the amplitude of a real periodicity is small, and the distance that is plotted above the line of perfect fortuity seems to the eye to be negligible, despite the fact that y/x, the real criterion, may rapidly be increasing to a large value.

I would therefore suggest that the graphical representation be changed to $X = n$ and $Y = y/x$. If this be done Y will, in general, decrease when X is small, even though there be a real periodicity of small amplitude superimposed on observations with large accidental errors; then, when n has become large enough to damp out the major portion of these errors, increase rapidly, no matter how small the real periodicity, to an infinite limit. If, however, there are no real periodicity Y will approach one as a limit. Such cases as the annual cycle at Boston, where the amplitude is small but where n has become very large, and which look doubtful as plotted by Professor Marvin, despite our knowledge of their truth, will show clearly the differences between themselves and accidental combinations. In plate VIII I have replotted in this way the four curves of plate VII.

In conclusion, I wish to warn against a possible misunderstanding on the part of the reader concerning Professor Marvin's statement on page 118 of his article mentioned above, that "other sequences 15 months, 16 months, one-ninth the variable sun-spot period, like the circles, all fall in the class of perfect fortuity." In a letter to me of later date he says: "I would like to know what the testimony of the periodocrite principle would be in reference to the alleged cycles you have examined. I am sure it is easily possible for you to make the application, as you have all the tabulations and data most fully worked up, whereas for me to do the thing myself would mean practically the entire duplication of the work you have already done." It is evident from this statement that he means to refer only to the five towns in Iowa and not, as some might erroneously infer, to the great mass of data I have used.

TABLE 1.—Eastern group rainfall.

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	y	x	$\frac{y}{x}$
1	74	258	64	129	127	122	110	71	66	224	142	116	94	184	117	......	......	......
2	82	178	87	124	94	116	110	87	63	167	138	92	61	138	104	......	......	......
3	84	153	86	132	94	125	121	94	69	150	121	95	71	122	110	1.10	.58	1.90
4	92	133	89	124	96	108	127	92	73	134	130	89	76	111	102	.79	.50	1.58
5	91	125	90	114	92	109	117	100	79	128	122	97	73	114	106	.61	.45	1.35
6	91	117	97	118	99	113	119	97	85	118	111	93	73	112	109	.53	.41	1,29
7	98	110	93	118	96	121	111	100	93	120	111	98	76	107	111	.47	.38	1 24
8	104	116	89	114	99	125	114	97	88	117	110	101	74	102	114	.50	.35	1 43
9	103	117	88	112	100	125	116	98	90	114	102	104	74	99	117	.48	.33	1.45
10	103	119	89	107	100	122	117	98	89	111	104	100	77	98	113	.44	.32	1.38
11	100	119	91	104	100	123	111	96	90	109	103	99	75	95	113	42	.30	1 40
12	101	115	94	102	98	122	112	95	93	106	106	95	76	98	114	39	.29	1 34
13	100	113	95	101	94	118	113	96	93	105	105	95	77	99	116	.37	.28	1.32
14	100	117	96	100	96	119	110	95	92	104	104	94	78	97	114	.37	.27	1.37
15	103	116	97	99	99	118	108	94	94	107	102	93	80	100	115	.35	.26	1.35
16	103	114	100	100	96	115	111	93	95	106	100	94	81	98	117	.34	.25	1 36
17	104	114	103	99	100	115	110	92	96	106	100	94	80	97	115	.33	.24	1 37
18	102	114	102	98	99	115	110	92	97	103	100	93	81	96	114	.32	.23	1.39
19	103	114	102	99	99	115	107	94	98	101	101	92	82	97	115	.32	.22	1 45
20	104	114	104	99	100	115	106	93	98	103	101	92	82	100	114	.31	.22	1 41
21	106	115	103	101	100	115	107	92	98	103	100	91	81	98	112	.31	.22	1.41
22	108	114	104	102	100	113	106	91	97	102	100	92	79	98	112	.31	.21	1 48
23	108	114	103	101	101	112	105	91	95	101	101	90	79	98	113	.31	.21	1 48
24	108	115	105	103	101	110	107	94	96	100	101	90	81	97	112	31	20	1 50

TABLE 2.—Pacific group rainfall.

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	y	x	$\frac{y}{x}$
1	114	50	14	70	45	187	105	94	147	250	215	86	128	28	46			
2	142	56	34	88	82	157	106	90	88	140	113	104	128	48	86			
3	146	80	38	87	69	163	108	101	90	139	131	121	116	66	81	84	58	1 45
4	126	87	49	73	87	160	104	97	86	122	118	102	116	56	84	68	50	1 36
5	124	93	52	82	100	140	109	105	87	112	134	98	109	77	91	52	45	1 15
6	115	97	60	78	101	141	118	110	83	108	123	109	108	77	89	52	41	1 27
7	107	95	64	82	103	137	115	107	83	101	136	102	114	80	87	48	38	1 27
8	104	92	79	82	97	127	114	108	93	102	130	105	108	81	89	38	35	1 08
9	101	88	79	88	95	120	114	102	99	102	127	98	116	79	85	37	33	1 12
10	95	95	84	91	90	118	112	100	98	103	125	96	117	78	84	36	32	1 12
11	104	105	85	89	88	117	108	97	98	96	122	94	112	81	85	33	30	1 10
12	105	105	82	86	92	116	107	94	100	96	123	96	117	86	84	34	29	1 17
13	109	104	80	91	98	119	109	99	100	96	127	96	122	86	84	34	28	1 21
14	105	106	79	91	98	115	112	101	101	98	127	103	116	85	92	29	27	1 07
15	107	104	79	90	99	118	115	100	107	100	126	104	113	85	90	30	26	1 15
16	105	103	77	93	101	120	114	103	106	97	123	105	116	83	89	30	25	1 20
17	108	102	78	92	101	118	113	106	106	98	126	109	114	87	88	31	24	1 29

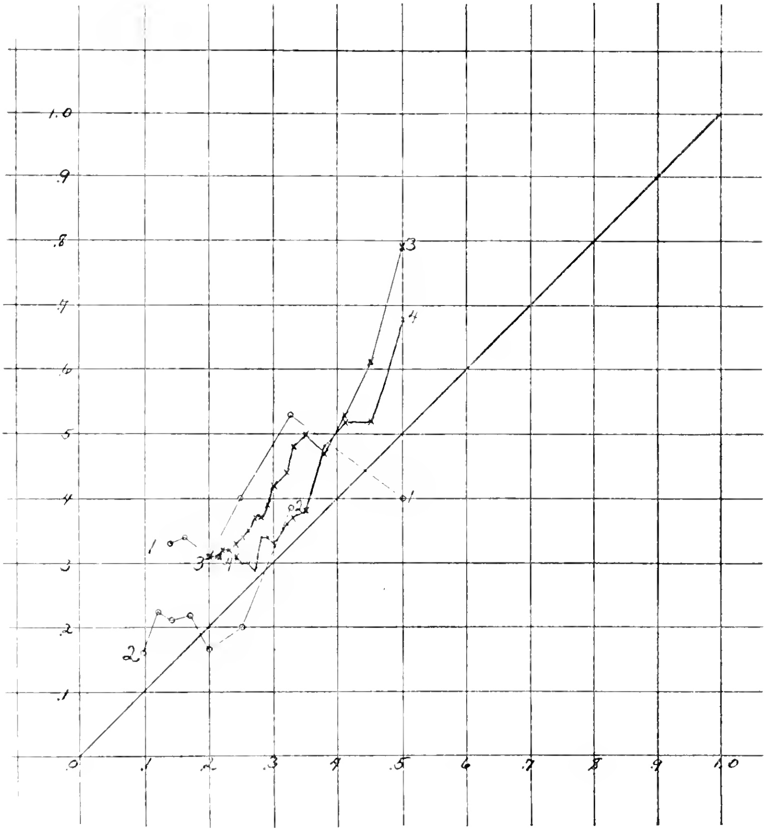

PLATE VII.—Application of Professor Marvin's periodocrites to various periodocrites.

1. Annual cycle, Washington, D. C., rainfall, fifty-year record.
2. Annual cycle, Boston rainfall, 103-year record.
3. Twenty-four cycles ninth harmonic of sun-spot period in Eastern group rainfall.
4. Seventeen cycles of same in Western group rainfall.

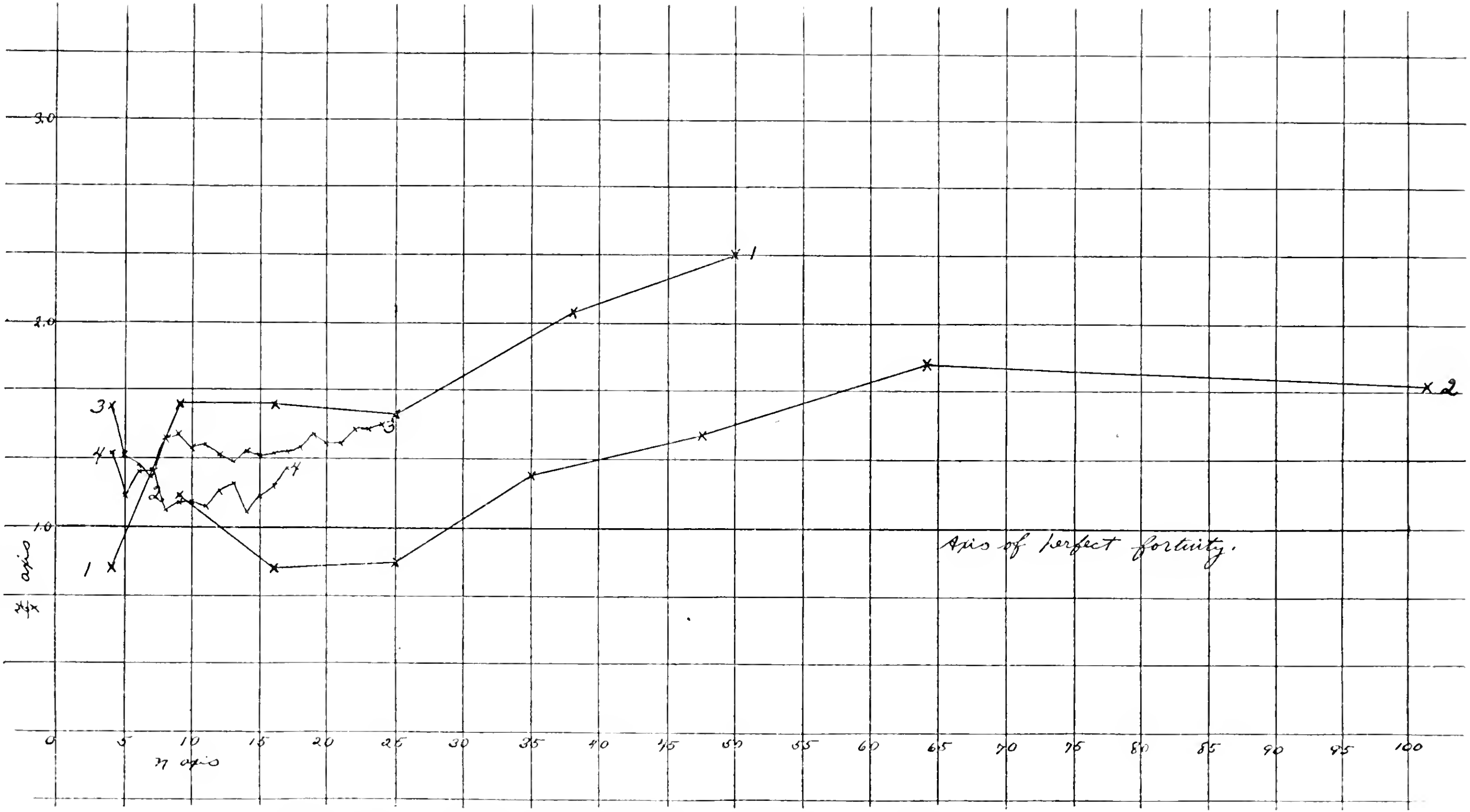

PLATE VIII.—Modification of Periodocrite. Periodocrites numbered same as in plate VII.

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III, 1898. Special Report on Coal; weight, 4 pounds.

IV, 1898. Upper Cretaceous Paleontology; exhausted.

V, 1899. Gypsum and Gypsum Cement Plasters; weight, 2 pounds.

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Report for 1899, 1903; postage, 4 cents each.

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BULLETIN OF THE UNIVERSITY OF KANSAS
VOL. XXI JULY, 1922 NO. 10, PART II

SCIENCE BULLETIN

Vol. XIII, Nos. 10, 11, 12, 13, 14, 15

(Continuation of Kansas University Quarterly.)

LAWRENCE, KANSAS

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NOTICE OF EXCHANGES.

The attention of learned societies and other institutions which exchange scientific publications with the University of Kansas is called to the list of publications of this University on the third and fourth pages of the cover of this issue.

Those marked "Supply exhausted" cannot be furnished at all, as far as the supply permits the remaining numbers will gladly be furnished to any of our exchanges who may need them to complete their files.

Back numbers of the *Kansas University Quarterly*, as far as possible, will be sent to those of our newer correspondents who are able and willing to reciprocate.

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THE KANSAS UNIVERSITY
SCIENCE BULLETIN.

Vol. XIII.] July, 1922. [No. 10.

On the Preparation of the Aryl Isothiocyanates.

BY F. B. DAINS, R. Q. BREWSTER, C. P. OLANDER.

THE aromatic mustard oils, RNCS, which have been the subject of many investigations on account of their reactivity, have been prepared by a number of different methods. The most common one involves the synthesis of the disubstituted thioureas from the amines and the subsequent splitting of the thioureas into aryl isothiocyanates and the amine or some derivative. Thus thiocarbanilide, when boiled with concentrated hydrochloric acid, 20 per cent sulphuric acid or concentrated phosphoric acid gave phenyl mustard oil and varying amounts of aniline and triphenyl guanidine.

The yield of mustard oil, based on the aniline used, in general is far from satisfactory on account of losses incurred in the preparation of the thiourea and the subsequent splitting with acid.[1]

An interesting modification in the preparation of these compounds depends upon the action of acetic anhydride or an acid chloride such as acetyl chloride upon the thiourea.[2] The acetyl derivative of the thiourea, which is first formed, readily breaks down into the mustard oil and an acyl-aryl amide,

$$RNHCSNCOCH_3R = RNCS + RNHCOCH_3.$$

While the above methods are of general applicability, it is evident that only one-half of the original amine can be converted into the isothiocyanate, and that it necessitates the synthesis of the substituted thiourea.

Fortunately, however, H. S. Fry's[3] interesting method for the preparation of the diaryl thiocarbamides has made readily accessible various thioureas that were difficult to obtain by the older methods.

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[1] J. 1858, 394. Z. 1869, 359. Ber. 15, 986 (1882).

[2] J. Chem. Soc., 59, 400 (1891). J. Am. Chem. Soc., 22, 188 (1900).

[3] J. A. Chem. Soc., 35, 1539 (1903).

A second general method for the synthesis of the mustard oils is based upon the intermediate formation of the salt of a substituted dithiocarbamic acid, RNHCSSMe. This is illustrated by the Hofmann[4] syntheses of alkyl isothiocyanates, which involve the desulphurization of the salt $RNHCSSNH_3R$ with mercuric chloride, silver nitrate, etc.

In the aromatic series compounds of the type $RNHCSSNH_3R$ cannot, as a rule, be isolated, but instead lose hydrogen sulphide and go over to the ordinary thiourea, RNHCSNHR. On the other hand, the aryl amines react with carbon bisulphide and ammonia and give almost quantitatively the corresponding ammonium salts, $RNHCSSNH_4$. This should afford a convenient source of mustard oils, provided some simple means could be devised for removing a mole of NH_4SH.

METHODS FOR SUCH ELIMINATION.

Andreasch[5] and others have shown that the ammonium dithiocarbamates react with ethyl chloroformate with the formation of aryl isothiocyanates, RNCS. The yields, however, are varying and the products are apt to be contaminated with the corresponding oxygen ureas. The method involves, too, the use of the expensive ethyl chloroformate.

In a paper published in 1891, Losanitsch[6] described a number of salts of phenyl dithiocarbamic acid and obtained from the ammonium dithiocarbamate, in water solution, the corresponding colored salts of copper, nickel, cobalt, iron, mercury and manganese. The statement was made "that the best method for the preparation of phenyl mustard oil is to treat a solution of ammonium phenyl dithiocarbamate with copper sulphate and distill with steam. The yield of mustard oil is theoretical." No confirmatory data, however, were given for this statement. Later Heller and Bauer[7] found that lead carbonate reacted with the ammonium aryl dithiocarbamates, yielding mixtures of the aryl isothiocyanates and monoaryl thioureas.

Since considerable amounts of the aryl isothiocyanates were needed in another investigation in this laboratory, it seemed advisable to follow up this observation of Losanitsch and ascertain

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[4] Ber. 1, 170 (1868). Ber. 8, 108 (1875). Ann. 371, 201 (1909).

[5] Monat. 27, 1211 (1906). Monat. 30, 701 (1909). Monat. 33, 363 (1912). Am. Ch. J. 24, 432 (1902). Ber. 35, 3368 (1902). Ber. 36, 3520 (1903). Ber. 40, 2198 (1912).

[6] Ber. 24, 3021 (1891).

[7] J. Prak. Ch. (2) 65, 365 (1902).

whether the method was really a practical one and to determine if possible the optimum conditions.

The investigation has shown that the general method suggested by Losanitsch is capable of giving very satisfactory results in the synthesis of aryl isothiocyanates. Yields of mustard oil up to 77 per cent based upon the weight of the amine have been obtained—a result which is impossible by the usual method.

REACTIONS INVOLVED IN THE DESULPHURIZATION OF THE ARYL DITHIOCARBAMATES.

Using aniline as a typical aryl amine the synthesis is best illustrated by the following reactions:

I. $C_6H_5NH_2 + CS_2 + NH_4OH = C_6H_5NHCSSNH_4 + H_2O$.

II. $C_6H_5NHCSSNH_4 + Pb(NO_3)_2 = C_6H_5NCS + NH_4NO_3$
$+ HNO_3 + PbS$.

Equation II does not occur directly, since the addition of the lead nitrate causes the precipitation of the lead salt—

III. $2C_6H_5NHCSSNH_4 + Pb(NO_3)_2 = (C_6H_5NHCSS)_2Pb + 2NH_4NO_3$.

The lead phenyl dithiocarbamate on heating breaks down as follows:

IV. $(C_6H_5NHCSS)_2Pb = C_6H_5NCS + C_6H_5NHCSSH + PbS$.

The free phenyl dithiocarbamic acid tends to decompose with the formation of thiocarbanilide, aniline, etc. To prevent this a second mole of lead nitrate is used:

V. $(C_6H_5NHCSS)_2Pb + Pb(NO_3)_2 = 2C_6H_5NCS + 2PbS + 2HNO_3$.

Since the nitric acid diminishes the yield by freeing phenyl dithiocarbamic acid from its NH_4 salt, an excess of ammonium hydroxide is added. The ideal proportions would be:

VI. $2C_6H_5NHCSSNH_4 + 2Pb(NO_3)_2 + 2NH_4OH = 2C_6H_5NCS$
$+ 2PbS + 4NH_4NO_3$.

For the best results, the solution after the addition of the lead nitrate should be neutral or only slightly acid. An excess of ammonia converts the mustard oil into monophenyl thiourea.

EXPERIMENTAL.

PREPARATION AND ISOLATION OF THE AMMONIUM PHENYL DITHIOCARBAMATE.

The following procedure, which is a modification of the method described by Heller and Bauer,[8] was found to give the best results. Carbon bisulphide (54 gms.) and 28 per cent ammonium hydroxide

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[8] J. Prak. Chem. (2) 65, 369 (1902).

(80 gms.) were mixed in a wide-mouthed flask or tall beaker set in ice. To this was added through a dropping funnel, in the course of 15 minutes, aniline (54 gms.), the whole being kept in agitation with an automatic stirrer.

The milky heterogeneous mixture, which first resulted, became clear and homogeneous after the addition of the aniline. The ammonium salt soon began to separate, and the mixture may become so thick as to stop the stirrer. After standing an hour in the ice bath the white ammonium salt was filtered, the mass washed with a little alcohol and dried quickly on a porous plate or between filter paper. The best yield of this salt was 86 per cent of the theory, although this may vary decidedly, not only in the case of aniline but also with the other aryl amines. This is due to the incomplete separation of the ammonium salt rather than to its non-formation.

PROPERTIES OF THE AMMONIUM PHENYL DITHIOCARBAMATE.

On standing, the salt slowly decomposed with the formation of hydrogen sulphide, ammonia, carbon bisulphide, aniline and thiocarbanilide. The decomposition was hastened when the salt was boiled with water. The results here indicated that the two main reactions were as follows, the first predominating:

I. $C_6H_5NHCSSNH_4 = C_6H_5NH_2 + CS_2 + NH_3$.

II. $C_6H_5NHCSSNH_4 = C_6H_5NCS + H_2S + NH_3$.

The mustard oil and aniline reacted to give thiocarbanilide, but the yield is low, only about 20 per cent of the theoretical.

With the ammonium salts of the p-chloro and p-bromophenyl dithiocarbamates, where the amines and isothiocyanates are less volatile, 55 to 60 per cent yields of the substituted thiocarbanilides have been obtained by this method.

DECOMPOSITION WITH ACIDS.

When an aqueous solution of the salt is treated with hydrochloric acid the quantitative decomposition can be expressed as follows:

$$C_6H_5NHCSSNH_4 + 2HCl = C_6H_5NH_2HCl + CS_2 + NH_4Cl.$$

Only traces of hydrogen sulphide and phenyl isothiocyanate are formed.

PREPARATION OF THE ARYL ISOTHIOCYANATES FROM THE AMMONIUM SALTS.

It is evident, then, that in order to produce the mustard oil, RNCS, from the dithiocarbamate, $RNHCSSNH_4$, some metallic salt must be used which will form a stable sulphide and an ammonium salt. To determine the best conditions for such a decomposition the following experiments were undertaken, using the dry ammonium salt of the aryl dithiocarbamates.

FERROUS SULPHATE.

A solution of 60 gms. of the iron salt in the minimum volume of water was added to 40 gms. of the ammonium phenyl dithiocarbamate in 200 cc. of water. A yellowish-brown precipitate formed immediately. The mixture, which had a noticeable odor of the phenyl isothiocyanate, was allowed to stand for an hour and then distilled with steam, but with the result that only 3 cc. of an impure mustard oil was obtained.

ZINC SULPHATE.

On mixing 30 gms. of the ammonium salt in 300 cc. of water with 47 gms. of zinc sulphate in 150 cc. of water a thick, white precipitate of the zinc phenyl dithiocarbamate was formed. This changed on steam distillation to zinc sulphide and gave a 23 per cent yield of the phenyl isothiocyanate.

COPPER SULPHATE.

To a solution of 25 gms. of the ammonium salt in 150 cc. of water was added 34 gms. of copper sulphate in the same volume of water. The odor of mustard oil was very pronounced, and the yellowish-brown copper salt changed readily, on distilling the mixture with steam, to the black copper sulphide. The yield of oil in this case was 71.7 per cent—a very decided increase.

LEAD NITRATE.

Using the same concentrations as above, 25 gms. of the ammonium salt and 40 gms. of lead nitrate gave the brown lead salt with a subsequent yield of 77.2 per cent phenyl isothiocyanate—a maximum which has not been exceeded.

In general it has been found that while both the copper and lead salts are suitable desulphurizing agents, the use of lead nitrate gave the better result in about the above ratio.

PREPARATION OF PHENYL ISOTHIOCYANATE WITHOUT SEPARATION OF THE AMMONIUM SALT.

The data obtained from the preparation of the ammonium salts of the aryl dithiocarbamates showed that the isolation of this compound might be far from quantitative, with the result that the yield of mustard oil based on the amine used would be proportionately lowered. This was proved directly by many experiments, two of which will be described in detail.

In each case the following amounts of reagents were used and the same procedure followed as exactly as possible:

Aniline	26 gms.
Carbon bisulphide	27 gms.
Ammonium hydroxide (28%)	44 gms.
Alcohol	20 cc.
Lead nitrate	100 gms.

The addition of the aniline required one-half hour. The stirring was then continued for another one-half hour, and the mixture filtered after standing for an additional hour. The separated salt was dissolved in 200 cc. of water, treated with the lead nitrate (in 200 cc. water), and distilled with steam. The yield of pure mustard oil was 20 gms. (53 per cent).

In the second case the unfiltered solution and salt was made up to 200 cc. with water and desulphurized as before. The product weighed 28 gms.—a yield of 74.2 per cent, based on the aniline used. The best yield obtained under these conditions was 76.8 per cent pure phenyl isothiocyanate. The difference in yield in the above experiments between 53 per cent and 74 per cent is due without question to the solubility of the ammonium salt in the aqueous ammonia.

LABORATORY PREPARATION.

The following directions are given as suitable for a laboratory experiment in the preparation of the phenyl isothiocyanate:

Place 54 grams of carbon bisulphide and 80 grams of conc. NH_4OH (28 per cent) in a tall beaker, surrounded by ice, and stir the mixture with a turbine. Drop 56 gms. of aniline into this mixture from a separatory funnel during the course of 20 minutes. The separation of ammonium phenyl dithiocarbamate soon begins. Continue the stirring for 30 minutes after all of the aniline has been added. Then allow the mixture to stand for another period of 30 minutes without stirring.

Dissolve the salt by the addition of 800 cc. of water, and add to the solution (with constant stirring) 200 gms. of lead nitrate dissolved in 400 cc. of water. Steam-distill the product from a 5-liter flask.

Put in the receiver a little dilute sulphuric acid; this will combine with traces of ammonia or aniline that might be driven over, and thus prevent the formation of any mono- or diphenyl thiourea.

LARGER-SCALE PRODUCTION.

The preparation of the mustard oil was carried out in a number of experiments, using from five to ten times the amount of the reagents listed above, with corresponding dilution. The percentage yields, however, were not so great as with smaller amounts. For instance, 280 gms. of aniline gave 232 gms. of product, and 560 gms. of aniline yielded 435 gms. of pure redistilled phenyl isothiocyanate. The low results were due in part to difficulties in properly mixing the reagents. If much free nitric acid was formed it decomposed the ammonium phenyl dithiocarbamate, thus preventing the formation of the lead phenyl dithiocarbamate. Other by-products that occurred were ammonium thiocyanate, diphenyl thiourea, triphenyl guanidine, which appeared as the nitrate, and monophenyl thiourea, where any excess of ammonia was present. In addition a strong current of steam is needed to separate the oil from the mass of lead sulphide formed.

ACTION OF LEAD NITRATE ON OTHER SALTS OF THE PHENYL DITHIOCARBAMIC ACID.

It seemed worth while to try the desulphurization of other than the ammonium salts, since in the absence of that reagent certain side reactions might be prevented.

Sodium Salt. $C_6H_5NHCSSNa$.

Aniline	28.0 gms.
Carbon bisulphide	27.0 gms.
Sodium hydroxide	13.1 in 50 cc. water.
Lead nitrate	100.0 in 300 cc. water.

The sodium salt which formed on mixing the reagents was so thick that the stirrer was stopped. Alcohol, 22 cc., was therefore added, and the stirring continued for one-half hour. After standing for an hour the orange-colored mixture was dissolved in 300 cc. of water and treated with the lead nitrate solution. Only a 30.2 per cent yield of the mustard oil was obtained, the greater portion of the aniline having been converted into thiocarbanilide.

Barium Salt. $(C_6H_5NHCSS)_2Ba$.

Aniline	28 gms.
Carbon bisulphide	30 gms.
Crys. barium hydroxide	47.5 gms. in 110 cc. of water.
Zinc chloride	42.1 gms. in 42 cc. of water.
Sodium hydroxide	9.6 gms. in 18 cc. of water.

The aniline was slowly added to the mixture of barium hydroxide and carbon bisulphide and then stirred for an additional hour. The odor of hydrogen sulphide became noticeable, showing decomposition. The zinc hydroxide formed by the addition of the sodium hydroxide to the zinc chloride was now added and the mixture allowed to stand overnight. On distillation with steam, 15.2 gms. of mustard oil, or 37.4 per cent, was isolated.

CALCIUM SALT. $(C_6H_5NHCSS)_2Ca$.

Parallel experiments were now made, substituting calcium for barium hydroxide, the other conditions remaining the same. Very little phenyl isothiocyanate was obtained, the main product being thiocarbanilide.

In the report on "The Manufacture of War Gases in Germany,"[9] it is stated that Kalle & Co. made the phenyl mustard oil used in the preparation of phenyl iminophosgene from the calcium phenyl dithiocarbamate, which was then desulphurized with a mixture of zinc chloride and sodium hydroxide.

That calcium phenyl dithiocarbamate was formed from the carbon bisulphide and calcium hydroxide was shown in the following experiment:

Aniline	28.0 gms.
Carbon bisulphide	27.2 gms.
Calcium hydroxide	12.0 gms. in 26 cc. of water.
Lead nitrate	100.0 gms. in 300 cc. of water.

On the addition of the aniline there was a tendency for the mass to collect in a gummy paste. This was prevented by the addition of a little alcohol and stirring the mixture for 24 hours. After desulphurization with lead nitrate 15.6 gms. of oil were isolated, which corresponded to a yield of 38.4 per cent. The increase in mustard oil is doubtless due to longer stirring and the more efficient desulphurizing agent, lead nitrate.

PREPARATION OF OTHER ARYL ISOTHIOCYANATES.

The following experiments were carried out in order to ascertain whether the method was suitable for the preparation of other aryl isothiocyanates:

o-TOLYL ISOTHIOCYANATE. o-C_7H_7NCS.

o-Toluidine	32.2 gms.
Carbon bisulphide	27.0 gms.
Ammonia water	47.0 gms.
Alcohol	20.0 cc.
Lead nitrate	100.0 gms. in 200 cc. water.

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[9] J. F. Norris, J. Ind. Eng. Chem. 11, 827 (1919).

The ammonium salt crystallized out readily after addition of the amine. The mixture was then brought into solution by the addition of 400 cc. of water and treated as before. The weight of pure o-tolyl mustard oil was 32.8 gms., or 73.27 per cent.

m-TOLYL ISOTHIOCYANATE. m-C_7H_7NCS.

Using the same proportions as before, the solid ammonium salt, which is easily soluble in water, soon formed. From the reaction mixture was isolated 33.5 gms. of oil, or 74.7 per cent yield.

p-TOLYL ISOTHIOCYANATE. p-C_7H_7NCS.

Under the above conditions 32.3 gms. (72.1 per cent) of the p-tolyl mustard oil (b. p. 270) were obtained.

1, 3, 4,-XYLYL ISOTHIOCYANATE. $(CH_3)_2C_6H_3NCS$.

1, 3, 4-Xylidine	36.4 gms.
Carbon bisulphide	27.0 gms.
Ammonium hydroxide	47.0 gms.
Lead nitrate	100.0 gms. in 200 cc. of water.

After three hours' stirring the ammonium salt separated in coarse crystals, which were dissolved in 400 cc. of water before the addition of the lead nitrate. The mustard oil was very slowly volatile with steam, and was obtained partly by this method and partly by extraction of the oily lead sulphide with carbon bisulphide. The separation was not complete, and only 25.5 gms. (52 per cent) of the xylyl isothiocyanate (m. p. 31°) were obtained.

PSEUDOCUMYL ISOTHIOCYANATE. 1, 2, 4, 5, $(CH_3)_3C_6H_2NCS$.

Pseudocumidine	20.0 gms.
Carbon bisulphide	15.0 gms.
Ammonium hydroxide	23.0 gms.
Alcohol	22.0 cc.
Lead nitrate	49.0 gms.

The ammonium salt separated after two hours' stirring. It was dissolved in 1,000 cc. of water and treated with the lead nitrate in the same dilution. The isothiocyanate is difficultly volatile with steam, and the yield, 50.2 per cent, could probably have been increased by extracting the sulphide residue with some solvent.

ALPHA-NAPHTHYL ISOTHIOCYANATE. A-$C_{10}H_7NCS$.

Alpha-naphthylamine	20.0 gms.
Carbon bisulphide	15.0 gms.
Ammonium hydroxide	22.0 gms.
Alcohol	20 cc.
Lead nitrate	46.2 gms. in 200 cc. of water.

The reaction mixture was dark colored and required long stirring before the ammonium salt separated. It was then dissolved in 400 cc. of water and desulphurized.

The isothiocyanate, which melted at 35°, was isolated by extracting the sulphide precipitate with repeated portions of alcohol. The product weighed 17.6 gms. (68.2 per cent).

BETA-NAPHTHYL ISOTHIOCYANATE.

The procedure was the same as with the alpha-naphthylamine, and while the ammonium salt, which was readily formed, reacted with the lead nitrate, no isothiocyanate could be isolated from the residue using alcohol as a solvent. It is probable that some other solvent would have proved more suitable.

o-ANISYL ISOTHIOCYANATE. $o\text{-}CH_3OC_6H_4NCS$.

o-Anisidin	37.1 gms.
Carbon bisulphide	27.0 gms.
Ammonium hydroxide	47.0 gms.
Alcohol	20 cc.
Lead nitrate	100.0 gms. in 200 cc. of water.

The ammonium salt separated quickly as a mass of coarse crystals. The mixture was allowed to stand for one hour and then dissolved in 800 cc. of water and desulphurized. The mustard oil, which distilled slowly with steam, weighed 35.2 gms. (70.7 per cent).

p-ANISYL ISOTHIOCYANATE. $p\text{-}CH_3OC_6H_4NCS$.

p-Anisidine	10.0 gms.
Carbon bisulphide	10.0 gms.
Ammonium hydroxide	13.0 gms.
Alcohol	15.0 cc.
Lead nitrate	27.0 gms. in 500 cc. of water.

The salt formed readily in large white crystals. After standing two hours the mixture was dissolved in 500 cc. of water and treated as usual. The mustard oil was easily volatile with steam and gave a yield of 9.2 gms. (68.6 per cent).

p-PHENETIDYL ISOTHIOCYANATE. $p\text{-}C_2H_5OC_6H_4NCS$.

In this case the weight of p-phenetidine was 41.3 gms.; otherwise the amounts of reagents corresponded to those used in the preparation of the o-anisyl isothiocyanate. The mustard oil distilled slowly with steam and gave a yield of 72.7 per cent.

HALOGEN SUBSTITUTED PHENYL MUSTARD OILS.

m-BROMOPHENYL ISOTHIOCYANATE. m-BrC_6H_4NCS.

m-Bromoaniline	15 gms.
Carbon bisulphide	10 gms.
Ammonium hydroxide	13.6 gms.
Lead nitrate	29.0 gms. in 500 cc. of water.

The dithiocarbamate formed very slowly and coarse crystals of the ammonium salt began to appear only after an hour's stirring. These were dissolved in 500 cc. of water.

The oil which came over with the steam solidified on cooling. The yield, however, was only 7 gms. (37.4 per cent).

p-BROMOPHENYL ISOTHIOCYANATE. p-BrC_6H_4NCS.

The same quantity of reagents were used as in the preceding preparation except that 15 cc. of alcohol was added in order to decrease the solubility of the ammonium salt, which separated in the form of fine, needle-shaped crystals. After standing overnight the mixture was dissolved in 500 cc. of water and filtered from a little unchanged p-bromoaniline. The yield of mustard oil was 39.6 per cent.

p-CHLOROPHENYL ISOTHIOCYANATE. p-ClC_6H_4NCS.

p-Chloroaniline	20.0 gms.
Carbon bisulphide	15.0 gms.
Ammonium hydroxide	24.5 gms.
Alcohol	20 cc.
Lead nitrate	52.0 gms.

The mixture containing the ammonium dithiocarbamate was dissolved in 500 cc. of water and treated as usual. The yield was 15.8 gms. of the solid isothiocyanate (59.6%).

p-IODOPHENYL ISOTHIOCYANATE. p-IC_6H_4NCS.

p-Iodoaniline	20 gms.
Carbon bisulphide	12 gms.
Ammonium hydroxide	14.2 gms.
Alcohol	20 cc.
Lead nitrate	30.2 gms.

The crystals separated after 30 minutes' stirring. The mixture after standing for four hours was added to 500 cc. of water, and later filtered from a dark-colored insoluble residue. The mustard oil, which was obtained in a 53.4 per cent yield, was volatile with steam and melted at 79°.

p-NITROANILINE.

All efforts to prepare the ammonium p-nitrophenyl dithiocarbamate failed, the nitroaniline being recovered unchanged.

RÉSUMÉ OF RESULTS.

Aryl isothiocyanates.	Per cent yields based on amines used.
Phenyl	76.8
o-Tolyl	73.2
m-Tolyl	74.7
p-Tolyl	72.1
1, 3, 4,-Xylyl	52.0
Pseudocumyl	50.7
Alpha-naphthyl	68.0
Beta-naphthyl	00.0
o-Anisyl	70.7
p-Anisyl	68.6
p-Phenetidyl	72.7
m-Bromophenyl	37.4
p-Bromophenyl	39.6
p-Chlorophenyl	59.3
p-Iodophenyl	53.3
p-Nitrophenyl	00.0

From the consideration of the foregoing results, it is evident that the success of the method is dependent upon at least three factors: First, the completeness of the formation of the ammonium aryl dithiocarbamate, $RNHCSSNH_4$. Second, the ease and completeness of separation from the sulphide precipitate. Third, the avoidance of side reactions leading to the formation of free aryl dithiocarbamic acid, aniline, etc. The low yield in the case of the xylyl, cumyl and alpha-naphthyl derivatives would seem to be due to their slight volatility with steam and the difficulty of extracting the oils from the mass of lead sulphide.

The cause of the failure with beta-naphthylamine must be determined by further investigation.

With the halogen substituted anilines which are less basic than the aniline, toluidine, etc., there is probably incomplete salt formation, which would thus account for the lower yields.

SUMMARY.

The paper describes a method for the preparation of aryl isothiocyanates which is relatively simple and inexpensive and which gives yields greater than any which require the intermediate formation of the diaryl thioureas.

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THE KANSAS UNIVERSITY
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A Rainfall Period Equal to One-ninth the Sun-spot Period.

DINSMORE ALTER.

SYNOPSIS.

PRELIMINARY discussions based on the rainfall of the United States have been published in the *Monthly Weather Review* and the *University of Kansas Science Bulletin.* The present paper completes the investigation of this period, using much longer records and the data from the United States, Northern Europe, Central Siberia, the Punjab in India, Chile, South Australia, Jamaica and Madagascar. Numerous tables and curves are given. The conclusion reached is that the period does exist, and that the relationship to sun spots is not a direct one, but due to an unknown common cause. In purely continental areas, minimum rainfall is connected with a maximum of sun spots; in purely marine, with a minimum of sun spots. For areas with rainfall between these types the period is not plainly found.

INTRODUCTORY.

In August, 1915, Dr. A. E. Douglass read a very interesting paper before the Berkeley meeting of the American Astronomical Society regarding an investigation of the growth of trees in many parts of the world, indicating an eleven-year period in rainfall (1).

It seemed to me that the data collected by the Weather Bureau should definitely settle such a question of periods. Some preliminary reading showed, however, that a tremendous amount of time had been spent on the problem (2), and that if solvable it must be very complicated. Other work prevented starting any actual investigation; then the war intervened and the problem was untouched till the spring of 1919. The first data examined were those from

Lawrence, Kan., where records since 1868 are available. Several hundred hours of work showed nothing. Once a stretch of five years was found which resembled another five quite closely after eliminating the seasonal curve. Another time resemblances were found after about twenty-two years. All such were easily explainable as accidental. It seemed useless to carry the work further with the data at hand.

A paper by Professor Turner (3), however, gave me a new suggestion, although there was little if any logical reason for any connection. In this paper Professor Turner shows plainly the existence of a period in earthquakes with a length between 14.8421 and 14.8448 months. It occurred to me that this period might be commensurable with the sun-spot period. Upon multiplying it by 9, I obtained 11.13 years, which is the mean sun-spot period to the exact hundredth of a year. Such an exact coincidence is very probably not accidental (4*a*).

The next move was to examine all sun-spot data in order to find whether such a period also exists in sun spots. The results have been inconclusive, some evidence favoring the existence of the period, but not being definite enough to settle the question either way. The general conclusion seems to be that any relationship of sun spots to weather is not a direct one, and that periodicities which are commensurable may exist in each separately, as might happen if the variations were due to a common cause. This will be more fully developed in the general discussion of results.

In three preliminary papers (4*b*) I have investigated the rainfall of the United States, and in them arrived at the conclusion that they afford evidence toward the existence of the rainfall periodicity. When these papers were published it was recognized that they did not constitute proof, that data were needed from all parts of the world and, as Marvin (5) stated in a critical discussion, long records were needed. Since the publication of the first papers I have been gathering all available data, much of it in unpublished manuscripts sent me by meteorologists from many countries of the world. The reduction of these data has been a long job, even requiring hundreds of hours to prepare a single table. For example, the rainfall of many separate stations were given for Sweden; these had to be combined as one table. The same was true of the Punjab in India, where data from twenty-five stations were copied out of Eliot's book and averaged to give a district record to 1900. After that it was necessary to borrow seventeen large volumes and copy a little from each to complete the tables. To complicate the task, these data were given for fifty-five districts during the early years and for thirty-three during the later. From some countries averages made correctly were sent in form to use, but in the main the data, as secured, required much work to put it in a form to begin the investigation. Such tables are added to this paper in order that other investigators may be saved the preliminary computations. All long records have been studied, with the exception of Canada, which is so close to the United States that it was felt the results secured would not be worth the work of averaging many stations together to get district values in usable form. In the proper places comments will be made on the methods of securing district averages in the United States and other countries. It is believed that many of these should be remade.

MATERIAL SUITABLE FOR HARMONIC ANALYSIS.

A mass of observational material, when plotted with time as abscissæ and observed values as ordinates, may show no repetition of the same curve, even though such a curve might exist. There may be nothing definite about it to indicate a period. In such cases ordinary methods of harmonic analysis become useless. This failure to repeat values, when a period exists, may be due to any one or more of the four following causes:

(*a*) Incommensurable periods may coexist. In this case the curve will never repeat itself, although for short periods of time there may be a fairly close approximation to such repetition. If there are three or more incommensurable periods the curve obtained for the data is very complex. For example, the seasonal variation of the rainfall would be incommensurable with a possible one equaling the sun-spot period. Of course, if one of such periods is known, as in the case of the seasonal variation in the example above, it may be eliminated.

(*b*) There may be large accidental errors. Such errors mask a periodicity almost completely in any one cycle and disappear only when the data values in each of a number of well-distributed phases are added through many cycles. From the theory of errors, their influence will be inversely proportional to the square root of the number of cycles added.

(*c*) Long-period variations may exist. If there are periods longer than the interval of the data they will produce much the same effect as accidental errors or incommensurable periods.

(*d*) There may be periods which vary in length. An example of such a period is the sun-spot period, which, although averaging

11.13 years, has varied from 7.3 to 17.1 years during the last 115 years.

When any of these four difficulties exists it is almost impossible successfully to treat the problem unless the investigator stumbles upon the true period, either by a fortunate suggestion or by some reason extraneous to the problem, or by the patient trial-and-error method by which Kepler found his three laws of planetary motion. Schuster (6) has developed a method designated as the periodogram, which will avail in some cases.

METHOD USED BY TURNER IN EXAMINING THE EARTHQUAKE DATA.

The exact form of this method seems to be due to Schuster (6), and is a slight modification of the one astronomers have used for generations. Suppose that we have a mass of material—for example, the number of earthquakes recorded per month, or the rainfall per month—through many years. Plotting shows no periodicity, or at the most only a faint hint of such. Chance or Schuster's periodogram leads us to suspect a period of, for example, 15 months. We can write the first 15 months' data in a row as the heads of as many columns. The sixteenth month, the thirty-first, etc., will follow successively in the first column, the seventeenth, thirty-second, etc., in the second column, and so on, the thirtieth, forty-fifth, etc., in the fifteenth column. Each column will then contain only months which are in the same phase of the suspected period, if it actually exists.

We will refer to one such row as a cycle, and to the columns as phases. Suppose the period to exist. It may not show in a single cycle, probably will not, because of large accidental errors or incommensurable periods, either or both of which may be present. But the months of any phase of an incommensurable period will, in the long run, be almost evenly distributed through all the phases of our assumed period, and will, therefore, be subject to the same laws as accidental errors, namely, their influence will be inversely proportional to the square root of the number of cycles. In the course of four cycles (five years in our present example) their importance will be only half as great as for any one cycle; after sixteen cycles one-quarter as great, etc. However, the effect of our assumed fifteen-month period will be equal in each, and therefore as prominent in the average as in any one cycle. Thus, no matter how large the accidental errors, or the variation due to incommensurable periods, the true variation from phase to phase will begin to appear.

If the assumed period does not exist, the mean values of the phases will approach each other as we increase the number of cycles.

This last point gives us two very powerful criteria for the verity of our assumed period:

(*a*) Having given *a large number of cycles*, we may compare the phase values of the first half of the cycles with those of the latter half. If the variation be real the curves from the two halves of the data should agree fairly well. If the variation be accidental there can be only chance resemblance. Unless the assumed period exists, the two halves of the data are entirely independent, when there are enough cycles to eliminate residuals of other periods that might exist. A very simple test for a real relationship between the two curves may be made as follows: There is an even chance that if the results are purely accidental, any pair of values from the same phase in the two curves will lie on the same side of the normal. If there are three curves, one-fourth of them should show all three curves on the same side. Much departure from this accidental grouping indicates strongly a correlation.

(*b*) Having obtained the phase values, as above, for each half of the data, we may consider half the difference of identical phases in the first and last halves of our data as a measure of the deviation of the two curves from each other and of the amount of chance error left in each phase. Call this half difference d. We will have in this example $d_1, d_2, \dots d_{15}$. The probable error of any point on the curve which is formed from the whole of the data will be given by the formula,

$$\epsilon = 0.6745 \sqrt{\frac{\Sigma(d^2)}{n-1}}.$$

If this probable error is as large as half the variation from maximum to minimum phase there is approximately an even chance that the variation is accidental. If the ratio of ϵ to the variation is smaller than about one-eighth, the chances are less than one in a thousand that it is accidental. These ratios are tabulated in the general discussion of results for each set of data. Both these criteria must be applied in any case under discussion.

Let us suppose that the assumed period is not an exact number of months; for example, $14\frac{6}{7}$ months. In this case 7 cycles will equal 104 instead of 105 months. We must spread our 104 months over 7 cycles of 15 phases each; that is, over 105 phases. To do this we will fill each of the first 6 cycles and the first 14 phases of the seventh cycle just as formerly, using all the data that we have for 7 cycles. We will then use the month's data which we used for the fourteenth phase of the seventh cycle again in the fifteenth phase. Doing this, no month will fall more than a half phase from the proper one as determined by the mean of all positions. If we assume a period of $15\frac{1}{7}$ months we will merely skip one of the month's data, or better still, average it with the next following one. In this manner any period may be plotted with any number of phases desired, and no month's data more than a half phase from its proper place.

FIRST APPLICATION OF THIS METHOD TO RAINFALL.

One-ninth of the mean sun-spot period is very nearly $14\frac{6}{7}$ months. I tabulated all the rainfall data from Lawrence, Kan., beginning with 1868, according to the method outlined above. The result showed a variation of about 12 per cent each side of the normal. Next I divided the data into halves and found the two to agree fairly well. Following this I examined data from all of Kansas, from Nebraska, New England and Ohio. The data from Ohio checked fairly well; those from New England and Nebraska gave results which were discordant with themselves. The variation of the sun-spot period now came to mind. If there were any real variations due to sun-spots or to a common cause they would certainly have to keep a constant relationship with the phases of the sun-spot period.

Table 1 shows the dates of maxima and minima of sun-spots as determined by Wolf and Wolfer (7). It also shows the number of years intervening between successive maxima or minima; in other words, the actual sun-spot periods during those years. As a first approximation to keeping the phases in step with the sun spots, I plotted the rainfall between the dates of each pair of consecutive minima on a period one-ninth that interval. Minima occurred in 1889, August, and in 1901, September. The interval is 145 months. I therefore used a period of $16\frac{1}{9}$ months between those dates. The next minimum occurred in 1913, May. This interval is 141 months, and I used a period of $15\frac{6}{9}$ between these dates. When this was done I secured very much better results than before, so much better that I could not believe them due to accident. I obtained similar curves for each state the whole length of the Atlantic and Gulf coasts as far as Texas. When the data of New England and Pennsylvania were divided in halves, curves of similar shape were obtained for each, differing only in phase. This improvement over the results from a constant period indicated that a more rigid method of keeping constant relationship with the sun-spot phases should be devised before definite conclusions were drawn.

RIGID FOLLOWING OF THE SUN-SPOT PHASES.

It is evident that the sun-spot period between the minima named above had values of 145 and 141 months, respectively. Let us examine the two maxima occurring between these dates. One occurred in 1894, February, and the other in 1906, May, with an interval of 147 months. This must have been the average value of the sun-spot period between these dates. It is longer than the period obtained from either pair of minima named above, yet it occurs as part of each of them and contains no part that is not in one or the other of them. We are forced, therefore, to the conclusion that if continuous (8*a*)—

The length of the sun-spot period is continuously varying and a value of the period obtained between successive maxima or successive minima is merely an average of all values passed through in this interval.

If we had a curve with time plotted along the axis of abscissæ and the corresponding values of the sun-spot period as ordinates, the average value of the sun-spot period between two maxima or two minima occurring at t_1 and t_2 would be given by—

$$t_1 - t_2 = \text{average value} = \int_{t_1}^{t_2} \frac{\text{curve}}{t_1 - t_2} \, .$$

If we plotted abscissæ and ordinates on the same scale, these average values would form squares bounded by ordinates through the dates which limit them. The area between the axis of abscissæ and the unknown curve, described above, representing the actual value of the period at all times, would in the interval between two maxima or two minima have to equal the corresponding known square. Since these squares overlap, we know the value of a series of overlapping definite integrals of the unknown curve. From these data it is possible, assuming the simplest curve to be the true one, by the aid of a planimeter, to construct the curve without knowledge of its mathematical form. In doing this it is easier to choose some convenient period as the axis of abscissæ and to measure departures from this period. Changing the axis in this way merely changes all the integrals by a known constant amount and changes the known squares into known rectangles. It is also practical to magnify the scale of ordinates very much over the scale of abscissæ. Locating the curve consists first in measuring the area of each of the rectangles; then penciling in what appears to be the curve, measuring the definite integrals of the approximate curve with the planimeter; erasing for a new approximation, and repeating many times. In the curve of the sun-spot values reproduced as Figure 1, I have erased each part of the curve probably a hundred times. Although very laborious, the process, with enough patience, yields very good results. The accuracy of the period curve depends upon the accuracy with which the epochs of maxima and minima are obtained. A steep but narrow peak, such as that of 1861, may be unreal for this reason. However, due to the short duration of such a peak and the fact that it must almost immediately be counterbalanced, there will usually be little effect in data extending over a long range.

In the preceding paragraph I have spoken of the sun-spot period at any date as a varying quantity, not even approximately constant through a single cycle. This may necessitate a definition of "period" somewhat different from what is ordinarily understood. I therefore give the following definition, which will be adhered to whether referring to sun spots or rainfall.

The length of the period at any date is the reciprocal of the rate of change of phase at that date and need not continue even approximately through a complete cycle.

From this curve I have taken the mean value of the sun-spot period for each year. These values are given as column 2 of table 2. Column 3 gives the departures from 15 months of one-ninth these values. Obviously, 15 months was chosen because it is the nearest integral number of months to one-ninth of a period. If, for example, the number given for any year in column 3 were + 9, it would mean that during that year one-ninth of the sun-spot period was 16 months. If it were — 9 it would mean that the period was 14 months. In the first case it would be necessary, working on a 15-phase basis, to skip a month every 16 months as long as that length of period persisted; in the second case to repeat one every 14 months. We can thus construct a table of months to be repeated in the analysis of our rainfall data when the ninth of the sun-spot period is less than 15 months, or to be skipped (or better still, averaged with the next adjacent one) when the ninth is more than 15, in order that Wolfer's sun-spot maxima may all fall in one phase and his sun-spot minima in one.

In this work I have in each case averaged the month to be skipped with the next following one instead of actually skipping. Thus three months' data give two phases, the result desired through skipping, and all data are used. There is, however, such a slight gain in accuracy that I scarcely believe it worth the slight extra work involved. If this averaging and repeating is done correctly the epoch of maximum of each of the cycles of the sun spots will always fall in one phase of the suspected rainfall variation and also each minimum in one. Wolfer's values of maxima and minima are uncertain by a month or so, and therefore in the first paper the placing of them within one phase from the mean was considered as a perfect check in determining the months to be averaged or repeated. When there was a greater error than this in determining the position of a maximum or a minimum it meant that there was a slight error in the curve and that it was necessary to apply a slight adjustment factor to the values of the period taken from it. In no case did I have a large factor to apply, thereby showing that the curve as constructed was approximately correct. Indications from the work explained above were that the period taken from it could be relied upon to within three or four months, and that such errors as did occur were canceled in most cases by ones of opposite sign before adjustment had become serious.

I did not realize at the time that readers might think this discrepancy purposely made by me in order to better my results. To avoid this objection I have, in this paper, made the Wolf-Wolfer epochs fall exactly in the same phase each cycle. The phase in which the sun-spot maximum falls has been numbered 1 and that in which minimum falls 8. For 1913 Wolfer has published two dates of sun-spot minimum, first May, and later August. I used the former in the first paper before seeing his later work. The sun-spot curve seems to me to indicate May, or even an earlier epoch, correct. Wolfer's later epoch may, therefore, be a typographical error, and I have continued to use May. Since a short period locates its epochs of maxima and minima more exactly than a long one, it will be possible later, if the existence of the short rainfall period be admitted, to revise the Wolf-Wolfer epochs from the rainfall data. Such a gain in accuracy would mean much in an investigation of the sun-spot periodicity.

Table 3 shows which months I have averaged and repeated in the analysis of the rainfall data of each country investigated. It is probably useless to emphasize that there was no change in this table for any of the countries under consideration. At first thought the results of table 3 and of figure 1 are startling. However, an inspection of the much greater changes in the period which have persisted through entire cycles during the last 115 years, namely, from 88 to 205 months, shows that these variations through short periods of time are to be expected. Moreover, there is no way to draw a curve satisfying the necessary conditions and having smaller variations, unless possibly by introducing more points of maxima and minima upon it. Such a complication would be much less probable than the variations shown by the present one, all of which are less than the variations from the mean value of complete cycles of approximately 11 years have been in the rather recent past, as shown by table 1.

THE RAINFALL DATA EXAMINED.

I have examined the rainfall averages of each of the forty-two sections in which the United States has been divided by the Weather Bureau, of a number of stations in Central Siberia, of the Punjab in India, of a few towns in Chile, of complete records of Denmark and Sweden and stations in Holland and England, of South Australia, of Jamaica, and of Tananarive, Madagascar. I had a small amount of data from the Soudan and Abyssinia and scattered small amounts from other countries, but none of these enough to examine with any weight. There were also data such as received from Canada, where the proximity of countries for which I had data made it seem unwise to take the great amount of time necessary to average the individual stations, and where, unlike Madagascar, thousands of miles from the nearest data used, it seemed useless to obtain results with the little weight that would be attached to one station.

The results from each of the sections named above are discussed here, the tables are given from which these results are deduced, the values are given for each individual cycle, and the means of the halves or thirds are given and plotted, as also the curves from the whole data. The sections are grouped in three main divisions:

(A) Interiors and eastern coasts of large continents. There are three such sections: Eastern United States, Central Siberia, and the Punjab.

(B) Western coasts of continents. This group includes the Pacific coast of the United States, the group of countries from the northwest European coast, and a very small amount of data from Chile.

(C) Other sections. This includes South Australia, Jamaica and Tananarive, Madagascar.

The last sun-spot maximum occurred in 1917, and all data since then are thus unavailable for use in examining the existence of the period. This would not be a serious handicap for predicting, if the period should be proved to exist, since the course of the maxima and minima could be followed from cycle to cycle by using means from a large number of sections and an extrapolation made for a cycle in advance without serious error. Indeed, in such a case it might be possible to predict the time of the next sun-spot maximum or minimum quite accurately from the rainfall data.

Effect of Annual Cycle. In many cases the residual left from the seasonal variation is large enough to distort the curves materially. I have, therefore, always carefully eliminated it, no matter how large or how small. To do this I have, wherever it is very pronounced, prepared two tables for each section according to the plan previously outlined, repeating and averaging in each one the months determined by table 3. In the first of these tables I have used the actual values of the rainfall. In the second I have used instead of each January the mean of all the Januaries, and so on for each month of the year. In this second table the mean monthly values were repeated or averaged exactly as in the first one, to give a table entirely similar to the first table. The variation from phase to phase in this second table is, therefore, entirely the seasonal residual and contains all of it. For the average state in the United States it is approximately four per cent each side of the normal, the rest of the seasonal variation having been damped out by the process of tabulating the incommensurable period which is being investigated. The quotients of the sums of each phase of the first table by the second give us the percentage of normal rainfall of that phase for the section concerned throughout all the years of the data. Each month is in this way weighted in accordance with its normal rainfall. In no case has there been any smoothing of results other than that marked in the tables where the *mean* has sometimes been smoothed by averaging each phase with the ones immediately adjoining for better examination.

In the eastern United States and northern Europe the yearly variation of rainfall is small enough that each month may be weighted the same without serious error. I have, therefore, in these two cases divided the actual rainfall of each month by its normal and thus obtained the percentage of normal to plot. This has the advantage for the reader that he need look at but one table instead of two to see how the period has been followed from cycle to cycle.

It may occur to some that possibly there is in some manner a residual of the seasonal effect left in this period, despite the elimination explained above. There are three answers that may be givn to this objection, all of which are merely the same one in different forms.

(*a*) In Professor Schuster's discussion of the periodogram (6) method of searching for periods we find the following: "There is a limit beyond which it is useless to go. This limit is reached when the values of A and B for two closely adjoining values n_1 and n_2 are no longer independent of each other. The theory of vibration shows that independence begins when there is an ultimate disagreement of phase amounting to about one-quarter of a period."

(*b*) Professor Turner has worked out the effects of any period on adjoining periods (8*b*). He divides the data into integral parts and calls any one of these submultiples q; p is a period near q, such that $q+x=p.x<1$. From the Fourier sequence the periods q and $q+1$ are independent. Let us consider the seasonal period as q and the ninth harmonic of the sun-spot period as p. In order that x may be as small as 1, we must have $q=3$. That x be less, requires $q=2$. But, quoting Professor Turner, "q is a fairly large integer for any periodicity worth serious consideration."

(*c*) The work involved in computing the periods near 12 months for each state is much greater than the value of the results. I have, however, taken Pennsylvania as typical of the United States and computed periods of 12, 13, 14, 15 and 16 months.

For 12 months, which is the seasonal period, the amplitude of the variation is 34 per cent; for 13 months it is 11 per cent; for 14 months it is 12 per cent; for 15 months it is 10 per cent; and for 16 months it is 17 per cent; the amplitude of the ninth harmonic of the sun-spot period is 26 per cent. The mean value of the ninth harmonic during this interval of years was 15.8 months, showing the increase in amplitude at the nearest of the other periods as demanded by the theory or the periodogram (6) or by the Fourier sequence (8*c*).

A serious source of weakness in the state averages published by the United States Weather Bureau and by almost every other meteorological service developed during this investigation. This may well be illustrated by the state of Washington as a fair sample. Within one year the number of stations used in the state average varied between 105 and 130. Over a number of years the range is larger. The eastern part of the state is very much drier than the western. If one is comparing two months' rainfall it becomes imperative that he know what stations were omitted each month. The month showing the greater fall may be below normal and that showing less may be above because of omission of eastern stations in the first and western in the latter. I realize that it is impossible to obtain a perfectly homogeneous record, since volunteer observers must sometimes fail, often through no fault of their own, but I would venture to suggest a method by which the records may be reduced to a near homogeneity. The sum of the actual rainfall for all the stations used may be divided by the sum of the normals of the several stations and the quotient published as the percentage of normal which fell that month. The means of the normals of stations chosen for accuracy of records and geographical distribution may then well be taken as the normal of the state, and when multiplied by this quotient will give a weighted mean of the state that will be practically homogeneous from year to year. This lack of homogeneity in state records is much more serious in investigation of long periodicities such as the Brückner and eleven-year cycles, and might easily show entirely negative results where the period actually exists. An example of the reduction of scattered material to homogeneity is given in this paper in the treatment of Chile, where long records are available from five towns with widely differing normals. These records begin in different years and omit certain years irregularly. The sums of the actual rainfall given were tabulated for the fifteen-month periodicity, as were also the sums of the normals for each month that a station was used. These sums were then added through each half of the data for each phase, and the quotient of actual by normal was taken. These tables are Nos. 19 and 20. In the eastern part of the United States the normals from one part of a state to another vary by small enough amounts that the records are not seriously impaired. For the western part I felt it best to take instead the stations on the coast having perfect records extending as far back as 1880. All such were used except where stations in California happened to be very close together, in which cases one was always omitted in order not to give that small section of the coast undue weight. Nineteen such stations in California and western Oregon were available. No station in Washington had such a long record without break. This procedure also has the advantage of almost doubling the length of record over the published state averages. The results from these stations are shown as tables 10 to 12. The names of the stations will be found at the heads of these tables. The Adelaide Observatory in South Australia seems to have kept the most ideal record from 1861 to 1907. They averaged the same fifty towns, apparently, from the beginning to the end of that period. Unfortunately, this method was discontinued and the present one of averaging all available stations, as in the United

States, instituted. The great shift in normal made it impossible to compare the early and the later records. This investigation of Australian rainfall ends, therefore, with 1907, although the later results kindly sent by the meteorological director of the commonwealth are published here for information:

GROUP A.

	Eastern United States.	Siberia.	The Punjab, India (smoothed).
ϵ	2.7	2.4	3.6
Range of curve from whole data	23	17	29
Ratio	0.117	0.141	0.138
Number phases on one side of normal	12	10	*9 8

The ratios in each of these cases are approximately one-eighth, showing, as previously developed, a very small chance of such accidental agreement. In the case of India the same ϵ was derived from the relationship of both the first and last of its three curves to the middle one. Since the ratio given measures the possibility of chance agreement of either of these curves with the middle one, the chance that both agree in this manner by accident is only the square of the chance that one does.

GROUP B.

	Pacific coast (smoothed).	Northern Europe.	Chile.
ϵ	3.8	2.5	3.9
Range	43	22	25
Ratio	0.088	0.114	0.156
Number of phases on one side of normal	*11 12	12	10

As would be expected from an examination of the curves, the chance of mere accidental agreement between the two halves of the Pacific coast and northern European curves is negligible. In the case of Chile, just as one would judge from the appearance of the curves, it is much larger than for the other two, but is still small.

GROUP C.

	South Australia.	Jamaica.	Madagascar (smoothed).
ϵ	4.6	3.5	5.1
Range	24	19	28
Ratio	0.193	0.184	0.182
Number of phases on one side of normal	8	10	8

The results of group C, while favoring the true existence of the periodicity to some extent, do not show the certainty of groups A and B. This is to be expected in the case of Jamaica, which is a

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* Unsmoothed.

small, mountainous island, where, as Professor Pickering says, "The rainfall is very unequal in different portions of the island." It varies from 33 inches west of the mountains to 248 on the eastern end of the island. For Madagascar there is but one station, with a record over only 21 cycles, so that the correlation is all that one could expect. In the case of South Australia, however, we have a long, homogeneous record from fifty stations. The effect of the period is evidently much less certain there than in the region of groups A and B. In this it reminds one of the results obtained from the central third of the United States, a region located between the two types represented by groups A and B. Data are not at hand to show whether such a reversal, as in the United States, would be found between the northern and southern parts of South Australia. An investigation of this character would, I venture to predict, show the reversal. I hope to secure data to examine this region more thoroughly.

GENERAL DISCUSSION.

In group A, which consists of interiors or eastern coasts of large continents, we find *the minimum of our curves coming exactly at phase 1 in each case. This is the phase, as told above, which every ninth cycle contains the sun-spot maximum.* Each of these curves shows also the effect of a second harmonic of this period with one minimum at this same phase, the other neutralizing the maximum, which would normally fall at phase 8. This much can safely be accepted as true features of purely continental curves.

In group B we find more variation in curves from one section to another. For the Pacific coast we find the minimum at phase 7 and the maximum at phase 13; for northern Europe the minimum at 7, if we smooth our curve, and the maximum at 14. The small amount of data from Chile does not give any very definite results, almost equal minima at 2 and 12, with maxima at 10 and 14. The marine type seems, then, with considerable uncertainty, to give a minimum of rainfall at time of sun-spot minimum and a maximum shortly before the sun-spot maximum.

The halves or thirds of the curves at any one place will differ from each other for one or more, probably all, of the following reasons:

(*a*) Accidental errors and other periodicities are not entirely damped out.

(*b*) The epochs of sun-spot maxima and minima are uncertain, and consequently some data are incorrectly placed by one or more phases. If this periodicity is generally accepted, the recent sun-spot epochs can be revised to give the best rainfall results, since the short period and the great amount of data will locate them more accurately than the sun-spot counts themselves.

(*c*) The curve probably actually undergoes changes, similar in shape and magnitude to those of the sun spots, one maximum of which will be several times higher than another. This is indicated directly by the persistency with which a phase for quite a number of consecutive cycles will often differ from its mean by fairly large amounts.

(*d*) If the rainfall is not a *pure continental* or *pure marine* type, we will have one type often prevailing, although in the long run the other dominates.

Although I have examined this period as though it varied in length, I do not desire to stand in the least committed to an actual variation. This period, the eleven-year period and the Brückner are all harmonics. When examined by itself each is found to be variable. However, it is quite possible that their variations and that of the sun-spot period are only apparent, being caused by the superposition of a number of constant periodicities. Regardless of this constancy, I believe these three periods not to be separate, but merely terms in an irregular, long-period rainfall variation. It is very important that a search be made very carefully to determine what other terms there may be of such large magnitude as these.

If the relationship between sun spots and rainfall were a direct one, the eleven-year period would certainly far overshadow both this and the Brückner. Instead, its magnitude seems usually to be less than either. The search for a thirty-three-year period in sun spots has been inconclusive, although analysis shows a very strong sun-spot variation of twice this length. The relationship of the Brückner cycle to the sun-spot period stands out vividly, however, if we look for its epochs in long, homogeneous records from which the eleven-year period has been eliminated by averaging between consecutive sun-spot maxima or minima. In concluding, I desire to quote from Pickering's statement, at the close of his article mentioned above, as most nearly expressing my own opinion on this relationship:

> "I do not believe that the sun spots themselves, or their absence, cause the droughts. The spots are merely a surface indication of an overturn of material and temperature occurring beneath the solar surface in connection with magnetic storms. . . . I have only to derive statistics from observed rainfall data to show the coincidence."

I wish to acknowledge the assistance of the research committee

of the Graduate School, whose grants for computers have been a very important factor in the prosecution of the work. Mr. Anthony Oates was engaged as computer for the earlier stages of the work and Miss Nellie Lynn for the later. Prof. F. E. Kester has devoted a great deal of time to discussing each phase of the problem, and to his suggestions is due much of the success. Prof. C. F. Talman has loaned me many books from the library of the United States Weather Bureau. Mr. S. D. Flora has thrown open to me all the records in the state meteorological office at Topeka. Prof. Carl Ryder has sent me a great deal of manuscript matter, which has been extremely valuable. The Governor General of Madagascar sent manuscript tables of rainfall and temperature at Tananarive. The Egyptian government sent valuable manuscript records of Soudan and Abyssinia, which unfortunately do not extend back far enough for present uses. Supplemented by the next ten years' records, they will be very valuable. Meteorologists of several other countries have sent all available printed records. To all these I owe my most sincere thanks.

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TABLE 1.—Wolf's & Wolfer's table of sunspot maxima and minima.
(Copied from *Monthly Weather Review*, August, 1920.)

Minima.			Maxima.		
Epochs.	Weights.	Periods.	Epochs.	Weights.	Periods.
1610.8	5	....	1615.5	2	....
1619.0	1	8.2	1626.0	5	10.5
1634.0	2	15.0	1639.5	2	13.5
1645.0	5	11.0	1649.0	1	9.5
1655.0	1	10.0	1660.0	1	11.0
1666.0	2	11.0	1675.0	2	15.0
1679.5	2	13.5	1685.0	2	10.0
1689.5	2	10.0	1693.0	1	8.0
1698.0	1	8.5	1705.5	4	12.5
1712.0	3	14.0	1718.2	6	12.7
1723.5	2	11.5	1727.5	4	9.3
1734.0	2	10.5	1738.7	2	11.2
1745.0	2	11.0	1750.3	7	11.6
1755.2	9	10.2	1761.5	7	11.2
1766.5	5	11.3	1769.7	8	8.2
1775.5	7	9.0	1778.4	5	8.7
1784.7	4	9.2	1788.1	4	9.7
1798.3	9	13.6	1805.2	5	17.1
1810.6	8	12.3	1816.4	8	11.2
1823.3	10	12.7	1829.9	10	13.5
1833.9	10	10.6	1837.2	10	7.3
1843.5	10	9.6	1848.1	10	10.9
1856.0	10	12.5	1860.1	10	12.0
1867.2	10	11.2	1870.6	10	10.5
1878.9	10	11.7	1883.9	10	13.3
1889.6	10	10.7	1894.1	10	10.2
1901.7	10	12.1	1906.4	10	12.3
1913.4*	10	11.7	1917.6	10	11.2

* See text.

TABLE 2.

Year.	Period.	Departure.	Year.	Period.	Departure.	Year.	Period.	Departure.
	Months.			*Months.*			*Months.*	
1850	180	+45	1871	106	—29	1892	144	+ 9
51	176	+41	72	135	0	93	145	+10
52	165	+30	73	156	+21	94	146	+11
53	146	+11	74	170	+35	95	147	+12
54	125	—10	75	180	+45	96	148	+13
55	100	—35	76	184	+49	97	149	+14
56	90	—45	77	184	+49	98	149	+14
57	93	—42	78	184	+49	99	149	+14
58	125	—10	79	181	+46	1900	149	+14
59	174	+39	1880	173	+38	01	149	+14
1860	196	+61	81	161	+26	02	148	+13
61	196	+61	82	144	+ 9	03	147	+12
62	173	+38	83	113	—22	04	146	+11
63	143	+ 8	84	102	—33	05	144	+ 9
64	104	—31	85	100	—35	06	142	+ 7
65	97	—38	86	100	—35	07	140	+ 5
66	94	—41	87	101	—34	08	138	+ 3
67	93	—42	88	108	—27	09	137	+ 2
68	93	—42	89	128	— 7	1910	136	+ 1
69	94	—41	1890	138	+ 3	11	136	+ 1
1870	96	—39	91	142	+ 7	12	135	0

TABLE 3.—Data repeated or averaged in keeping rainfall periodicity in step with sun spots.

Skipped or averaged.	Repeated.	Skipped or averaged.
1861......Mar., Sept.	1865......July.	1872......April.
1862......June.	1866......July.	1873......Sept.
1863......June.	1867......Mar., June, Sept., Dec.	1874......April, Sept.
	1868......Jan., Apr., Jun., Aug., Nov.	1875......Mar., June, Nov.
	1869......Feb., June, Oct.	1876......Feb., May, Aug., Nov.
	1870......April, Oct.	1877......Jan., Apr., Jul., Sept., Dec.
	1871......April.	1878......Mar., June, Aug., Nov.
		1879......Mar., July, Nov.
		1880......April, Oct.
		1881......July.
		1883......Mar.
Repeated.	**Skipped or averaged.**	**Repeated.**
1884......Jan., Sept.	1891......Jan.	1915......Jan.
1885......April, Oct.	1894......May.	1917......July.
1886......Jan., May, Sept.	1895......Jan. Sept.	
1887......Jan., May, Sept.	1896......April.	
1888......Jan., May, Sept.	1897......Mar.	
1889......Feb.	1898......Jan., Dec.	
	1899......Dec.	
	1901......Jan., Nov.	
	1902......June.	
	1903......Sept.	
	1909......July.	
	1913......Jan.	

TABLE 4.—Eastern United States. Table of observed per cent of normal of 26 states, comprising 20 meteorological districts.

YEARS.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1878	57	103	89	128	132	82	82	125	64	162	67	117
79	63	73	75	62	59	102	100	123	45	83	171	133
1880	131	120	92	117	131	98	85	113	100	98	93	73
81	58	208	129	77	58	172	73	31	118	277	180	147
82	94	214	148	115	165	200	98	115	57	162	105	108
83	74	258	64	129	127	122	110	71	36	218	149	116
84	94	184	117	89	99	121	117	60	109	103	60	170
85	127	68	28	93	89	102	84	138	96	145	108	80
86	115	87	102	90	120	89	73	96	102	56	146	86
87	91	158	69	91	79	82	93	93	73	113	80	131
88	110	89	131	64	124	87	77	134	135	132	130	85
89	114	71	61	73	103	123	138	68	117	76	163	64
1890	121	138	130	97	132	99	84	124	144	152	62	86
91	129	149	71	129	59	98	106	119	56	66	136	96
92	127	78	90	113	124	132	104	97	90	36	117	77
93	99	137	76	131	134	98	69	99	104	119	101	88
94	83	116	71	80	113	69	78	85	126	101	71	95
95	135	50	81	112	87	83	95	90	54	65	116	113
96	66	121	101	62	88	114	134	76	123	75	139	49
97	90	125	135	110	87	86	122	82	63	68	129	112
98	128	69	110	96	92	87	108	142	102	168	136	81
99	112	125	131	63	80	80	96	83	94	74	70	93
1900	86	114	100	107	84	104	99	77	83	116	139	82
01	79	74	105	131	120	93	88	149	106	59	59	156
02	71	103	117	77	75	120	92	74	137	120	112	140
03	95	162	130	97	86	126	97	111	65	103	69	77
04	95	73	109	83	82	88	101	111	89	54	62	97
05	90	94	86	101	115	107	116	117	98	116	73	129
06	106	60	126	63	92	114	126	121	126	124	92	110
07	102	66	79	113	134	107	98	88	145	85	145	127
08	90	136	99	116	134	79	97	105	65	70	61	90
09	78	141	97	137	117	125	90	81	93	71	67	100
1910	105	105	45	104	102	121	99	80	83	125	72	77
11	89	68	69	130	56	94	79	138	111	142	133	136
12	93	88	146	148	116	93	105	103	125	79	79	106
13	145	83	159	95	94	70	89	78	123	140	87	76
14	79	97	82	108	56	73	85	67	74	104	91	130
15	145	102	53	43	130	94	114	145	101	122	96	112
16	113	81	76	78	112	125	138	80	90	87	74	100
17	108	72	126	100	86	110	102	100	96	120	31	55
18	118	60	72	146	95	87	77	88	115	150	99	125
19	93	89	115	91	145	100	114	109	66	186	128	86

TABLE 5.—Eastern United States, beginning January, 1887. Observed percentages of normal.

CYCLES.	Phase numbers.														
	(15)	(1)	(2)	(3)	(4)	(5)	(6)	7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
1	91	91	158	69	91	79	79	82	93	93	73	73	113	80	131
2	110	110	89	131	64	124	124	87	77	134	135	135	132	130	85
3	114	71	71	61	73	103	123	138	(68)	117	76	163	64	121	138
4	130	97	132	99	81	124	144	152	62	108	149	71	129	59	98
5	106	119	56	66	136	96	127	78	90	113	124	132	104	97	90
6	36	117	77	99	137	76	131	134	98	69	99	104	119	101	88
7	83	(116)	71	96	69	78	85	126	101	71	115	50	81	112	87
8	83	95	72	65	116	113	66	121	82	88	114	134	76	123	75
9	139	49	90	130	110	87	86	122	82	63	68	129	120	69	110
10	96	92	87	108	142	102	168	108	112	125	131	63	80	80	96
11	83	94	74	82	86	114	100	107	81	104	99	77	83	116	139
12	80	74	105	131	120	93	88	149	(106)	59	156	71	103	117	75
13	98	92	74	137	120	112	140	95	162	130	97	86	126	97	88
14	103	69	77	95	73	103	83	82	88	101	101	89	54	62	97
15	90	94	86	101	115	107	116	117	98	116	73	129	106	60	126
16	63	(92)	114	126	121	126	124	92	110	102	66	79	113	134	107
17	98	88	145	85	145	127	90	136	99	116	134	79	97	105	65
18	70	61	90	78	141	97	137	117	125	90	84	93	71	67	100
19	105	105	45	104	102	121	99	80	83	125	72	77	89	68	69
20	130	56	94	79	138	111	142	133	114	88	146	148	116	93	105
21	103	125	79	79	126	83	159	95	(94)	70	89	73	123	140	87
22	76	79	97	82	108	56	73	85	67	74	104	91	130	145	145
23	102	53	43	130	94	114	145	101	122	96	112	113	81	76	78
24	112	125	138	80	90	87	74	100	108	72	126	100	86	110	102
Mean, 1-12,	96	94	90	95	102	99	110	117	88	95	112	100	100	100	101
Mean, 13-24,	96	87	90	98	114	104	115	103	106	98	100	97	99	96	97
Mean of all	96	90	90	96	108	102	113	110	97	97	106	98	100	98	99

TABLE 6.—Central Siberia. Table of observed percentages of normal.

YEARS.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1838	13	50	21	82	54	87	95	118	101	62	79	18
39	8	41	57	128	150	118	55	129	117	203	162	119
40	3	42	127	126	160	103	146	63	120	79	46	17
41	41	4	47	76	185	150	106	43	134	201	40	28
42	21	31	4	31	80	92	155	129	188	50	50	27
43	36	16	26	35	73	234	99	129	46	90	89	22
44	19	83	123	74	60	114	110	201	130	40	118	73
45	68	2	65	81	103	89	147	79	97	17	10	45
46	0	63	84	220	108	146	118	151	5	104	140	222
47	33	43	106	43	35	230	183	119	156	19	49	36
48	133	6	66	39	62	76	96	106	168	144	23	39
49	72	15	43	44	73	73	108	164	165	82	34	7
1850	43	31	52	85	24	108	57	90	48	56	16	97
51	106	58	91	138	104	22	81	117	111	132	139	28
52	33	151	162	32	145	98	64	56	91	95	112	35
53	21	27	95	145	61	74	59	72	58	111	91	62
54	162	18	84	37	118	75	58	197	121	42	47	64
55	16	60	132	49	99	37	43	36	5	36	91	77
56	38	51	69	111	195	148	115	71	177	94	75	134
57	5	72	61	97	58	70	96	33	71	98	122	71
58	60	115	11	96	69	68	40	79	52	53	79	54
59	15	134	55	60	72	120	95	43	137	26	82	32
1860	27	29	54	72	27	51	39	52	50	45	38	33
61	29	36	41	34	86	89	49	94	101	65	126	24
62	20	39	18	74	64	98	56	31	70	26	11	18
63	48	12	79	2	18	91	111	40	121	40	30	11
64	48	38	61	46	59	57	52	121	91	29	50	36
65	56	36	20	66	43	22	95	50	53	58	87	72
66	44	43	94	12	87	26	31	170	182	57	12	28
67	121	45	165	42	10	54	35	106	90	65	13	69
68	88	23	55	43	31	127	114	102	113	19	61	86
69	39	40	51	42	25	112	140	70	53	25	53	38
1870	55	34	61	63	98	25	120	162	61	43	99	91
71	52	56	29	76	66	93	86	106	70	38	72	89
72	24	85	67	68	102	69	142	123	91	85	100	95
73	43	70	86	74	118	38	52	81	121	96	10	133
74	125	65	122	171	43	57	45	110	75	115	108	81
75	112	85	141	93	99	86	63	101	90	91	63	132
76	70	116	101	145	87	119	105	119	63	96	78	140
77	86	112	90	124	49	66	120	66	86	58	57	41
78	48	57	16	58	106	148	72	68	122	120	153	79
79	77	126	24	89	127	92	92	163	129	86	96	113
1880	47	88	138	41	70	128	79	147	110	148	54	35
81	111	83	33	42	128	115	127	80	135	84	101	39
82	129	63	104	66	117	132	139	61	109	83	61	69
83	90	205	46	21	103	116	124	72	72	74	47	98
84	98	91	83	43	46	112	68	118	81	34	31	91
85	86	121	54	76	107	95	114	85	125	183	64	123
86	125	99	105	78	105	64	107	93	85	64	78	99
87	69	108	119	89	125	70	61	112	125	94	121	125
88	63	90	128	117	69	69	74	72	58	84	109	96
89	71	56	123	88	103	93	123	109	61	105	92	77
1890	95	157	105	145	121	105	102	91	109	101	124	109
91	116	69	105	99	132	134	78	68	117	150	120	118
92	97	107	86	92	93	128	82	93	58	77	80	105
93	66	113	115	86	77	134	125	91	74	135	127	116
94	133	123	96	136	145	89	115	136	116	46	117	90
95	129	125	116	167	81	129	77	81	67	132	101	80
96	100	86	47	117	89	98	109	113	106	107	129	86
97	113	84	87	117	128	118	94	116	98	125	83	97
98	123	71	36	117	115	51	61	73	85	104	145	99
99	153	92	107	98	116	109	131	60	60	65	82	67
1900	70	148	84	82	87	45	92	99	108	98	92	78
01	91	81	140	153	75	58	88	123	81	135	138	93
02	222	94	252	90	117	123	93	80	74	140	115	133
03	144	104	100	138	99	89	109	110	145	83	100	139
04	110	286	87	103	100	108	96	131	104	101	95	125
05	116	71	89	93	124	84	83	122	130	154	127	112
06	154	73	134	80	134	160	153	104	101	107	114	144
07	143	89	77	86	110	110	120	130	99	144	111	155
08	105	103	155	72	105	137	115	108	172	54	124	119
09	109	130	134	125	87	51	112	64	147	80	172	98

Three or more stations available beginning April, 1873.

TABLE 7.—Central Siberia. Observed percentages of normal is tabulated beginning April, 1873.

Cycles	Phase numbers.														
	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(1)	(2)	(3)
1	74	118	38	52	101	96	110	133	125	65	146	43	57	45	92
2	115	108	81	112	113	93	92	63	101	90	77	132	93	101	116
3	119	112	63	87	113	112	107	49	93	76	58	49	48	62	58
4	127	70	122	136	(79)	77	75	89	127	92	163	129	91	113	47
5	88	90	70	128	79	147	129	54	35	111	83	33	42	128	121
6	80	135	84	101	39	129	63	104	66	117	132	139	61	109	83
7	61	69	90	126	21	103	116	124	72	72	74	47	(98)	98	98
8	91	83	43	46	112	68	118	81	81	34	31	91	86	121	54
9	76	76	107	95	114	85	125	183	183	64	123	125	125	99	105
10	78	105	105	64	107	93	85	85	64	78	99	69	69	108	119
11	89	125	125	70	61	112	125	125	94	121	125	63	63	90	128
12	117	69	69	69	74	72	58	58	84	109	96	71	56	56	123
13	88	103	93	123	(109)	61	105	92	77	95	157	105	145	121	105
14	102	91	109	101	124	112	69	105	99	132	134	78	68	117	150
15	120	118	97	107	86	92	93	128	82	93	58	77	80	105	66
16	113	115	86	77	134	125	91	74	135	127	116	133	(123)	96	140
17	89	115	136	116	46	117	110	125	116	167	81	129	77	74	132
18	101	80	100	86	82	89	98	109	113	106	107	129	86	113	86
19	117	128	118	94	116	98	125	83	110	71	36	117	115	51	61
20	73	85	104	122	153	92	107	98	116	109	131	60	60	65	74
21	70	148	84	82	87	45	92	99	108	98	97	84	81	140	153
22	75	58	88	123	(81)	136	93	222	94	252	90	120	93	80	74
23	140	115	133	144	104	100	138	99	89	109	128	83	100	139	110
24	286	87	103	100	108	96	131	104	101	95	125	116	71	89	93
25	124	84	83	122	130	154	127	112	154	73	134	80	(134)	160	153
26	104	101	107	114	144	143	89	77	86	110	116	120	130	99	144
27	111	155	105	103	155	72	105	137	115	108	172	54	124	119	109
28	130	134	125	87	82	64	147	80	172	98	..	.	.		.....
1=14	102	106	93	102	96	104	105	106	99	97	112	85	85	106	105
15=28	108	99	97	96	100	100	103	100	106	107	102	94	91	94	102
1=28	105	103	95	99	98	102	104	103	102	102	107	90	88	100	104

The means above are adjusted to make their mean values 100.

TABLE 8.—The Punjab, India. Means of 25 towns, 1863 to 1900, and of Punjab meteorological districts, 1901 to 1918. Data in inches and hundredths.

YEARS.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1863	209	13	116	36	26	415	1413	658	70	179	13	59
64	64	108	48	175	152	97	553	658	190	2	0	57
65	128	322	263	83	49	74	344	782	518	0	7	203
66	178	83	32	72	26	233	765	695	55	20	0	0
67	34	34	87	122	170	79	536	854	162	3	0	52
68	89	188	130	143	48	149	503	253	65	44	0	30
69	139	31	447	13	1	135	766	188	541	56	0	8
1870	6	18	154	39	11	303	322	639	178	16	0	38
71	20	206	5	16	87	499	548	208	115	0	0	93
72	140	70	113	59	93	226	893	671	296	6	0	56
73	44	13	48	2	174	29	855	548	380	69	2	64
74	127	86	129	30	26	342	700	353	240	1	0	3
75	6	151	9	1	90	59	626	943	1080	65	14	46
76	38	44	149	103	85	114	1050	354	201	140	22	1
77	263	312	104	189	112	182	226	67	342	113	138	407
78	75	220	17	202	213	73	624	1011	122	13	0	24
79	4	16	140	3	69	432	344	653	116	60	0	73
1880	21	133	0	7	32	330	828	153	176	0	14	75
81	7	92	204	78	53	256	860	670	73	9	0	3
82	190	107	8	66	19	106	868	374	503	0	0	2
83	236	14	71	18	108	119	447	162	544	4	99	12
84	30	68	91	24	22	296	633	507	573	63	2	1
85	292	33	28	108	268	215	394	701	95	2	0	158
86	224	21	243	14	89	444	924	394	77	102	11	44
87	99	0	11	7	2	138	568	1062	274	15	0	18
88	113	102	52	21	43	99	620	710	260	31	39	6
89	228	305	22	36	83	113	679	693	49	0	0	0
1890	396	21	79	60	40	294	905	777	68	30	43	176
91	291	98	146	41	71	35	357	601	221	74	3	0
92	49	44	10	2	71	102	775	1091	373	5	0	95
93	303	261	72	72	203	387	972	222	728	2	3	34
94	372	96	149	39	34	606	986	574	341	0	33	193
95	228	89	93	63	10	484	286	760	17	2	2	6
96	44	115	46	40	31	197	374	494	48	14	15	29
97	100	47	67	76	36	128	506	677	176	6	0	53
98	29	340	4	1	89	174	728	258	271	0	4	83
99	1	61	15	29	33	281	282	148	27	11	1	0
1900	131	37	38	113	61	56	526	790	746	10	1	127
Mean	1.20	1.03	0.92	0.58	0.73	2.24	6.60	5.63	2.60	0.35	0.14	0.57
1901	151	100	72	19	133	56	500	398	74	6	0	8
02	0	4	38	34	77	224	430	348	212	30	4	0
03	64	2	128	16	68	28	626	451	314	18	0	24
04	135	4	331	4	60	72	252	429	196	14	44	46
05	194	98	90	11	22	64	390	100	450	6	2	60
06	15	340	141	11	11	152	334	506	532	2	0	40
07	63	219	130	182	30	127	218	570	12	1	0	0
08	126	38	2	137	48	48	645	1116	338	2	4	12
09	46	82	12	185	6	242	676	362	409	6	0	138
1910	88	18	10	55	10	254	385	666	174	96	0	12
11	264	26	374	26	10	193	80	215	222	48	84	2
12	188	20	30	101	28	50	448	479	160	2	23	8
13	4	168	104	10	134	256	406	558	68	6	8	42
14	62	136	61	166	69	162	994	302	374	120	40	42
15	50	142	170	66	20	98	158	220	192	44	0	10
16	6	56	22	24	57	156	601	743	207	89	0	1
17	21	6	42	1 6	125	237	476	938	934	202	0	30
18	15	6	201	142	3	79	139	302	66	6	......	......
Mean*	0.91	0.91	1.07	0.65	0.49	1.36	4.46	4.66	2.46	0.31	0.13	0.28

* 1917 not included in these means because received after manuscript was sent to printer.

TABLE 9.—The Punjab, India. Means of twenty-five towns, 1863 to 1900. Mean of Punjab meteorological districts, 1901 to 1917.

ACTUAL OBSERVED VALUES IN INCHES.

CYCLES.	Phase numbers.														
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
1	209	13	116	36	220	1413	658	70	179	13	59	64	108	48	175
2	152	97	553	658	190	2	0	57	128	322	263	83	49	74	344
3	344	782	518	0	7	203	178	83	32	72	26	233	765	765	695
4	55	20	0	0	34	34	87	(87)	122	170	79	79	536	834	162
5	162	3	0	52	52	89	89	188	130	143	143	48	149	149	502
6	253	253	65	44	0	0	30	139	31	31	447	13	1	135	135
7	766	188	541	56	56	0	8	6	18	154	39	39	11	303	322
8	(639)	178	16	16	0	38	20	206	5	16	16	87	499	548	208
9	115	0	0	93	140	70	86	93	226	893	671	296	6	0	56
10	44	13	48	2	174	29	855	548	224	2	64	127	86	80	26
11	342	700	353	120	0	3	6	80	1	74	626	943	1080	40	46
12	41	149	94	114	702	201	81	132	312	146	112	204	204	113	272
13	75	118	202	143	818	122	6	(24)	4	78	3	69	388	653	116
14	30	73	21	133	4	32	330	828	153	88	14	75	7	92	204
15	78	53	558	670	73	9	0	3	190	107	8	66	19	106	868
16	374	503	0	0	2	236	42	18	108	119	447	162	544	4	99
17	(12)	30	30	68	91	24	22	296	633	507	573	573	63	2	1
18	292	33	28	108	108	268	215	394	701	95	2	2	0	158	224
19	224	21	243	14	89	89	444	924	394	77	77	102	11	44	99
20	99	0	11	7	2	2	138	568	1062	274	274	15	0	18	113
21	113	102	52	21	43	43	99	620	710	260	260	31	39	6	228
22	305	305	20	36	83	113	679	(693)	49	0	0	0	36	21	79
23	60	40	294	905	777	68	30	43	234	98	146	41	71	35	357
24	601	221	74	3	0	49	44	10	2	71	102	775	1091	373	5
25	0	95	303	261	72	72	203	387	972	222	728	2	3	34	372
26	(96)	149	39	606	786	574	341	0	33	210	89	93	63	10	484
27	286	388	2	2	6	44	115	43	31	197	374	494	48	14	15
28	29	100	57	76	36	128	506	677	176	6	0	41	340	4	1
29	89	174	728	258	271	0	44	1	61	15	29	33	281	282	148
30	27	11	1	131	37	38	113	61	56	526	790	746	10	1	127
The 1901-1917 Data Begin Here.															
31	100	72	19	133	56	500	398	(74)	3	8	0	4	38	34	150
32	430	348	212	30	4	0	64	2	128	16	68	28	626	382	18
33	0	24	135	4	331	4	60	72	252	429	196	14	44	46	194
34	98	90	11	22	64	390	100	450	6	2	60	15	340	141	11
35	(11)	152	334	506	532	2	0	40	63	219	130	182	30	127	218

36	570	12	1	0	0	126	38	2	137	48	48	645	1116	338	2
37	4	12	46	82	12	185	6	459	362	409	6	0	138	88	18
38	10	55	10	254	385	666	174	96	0	12	264	26	374	26	10
39	193	80	215	222	48	84	2	188	20	30	101	28	50	448	479
40	160	2	23	6	168	104	10	(134)	256	406	558	68	6	8	40
41	62	136	61	166	69	162	994	302	374	120	40	42	50	50	142
42	170	66	20	98	158	220	192	44	0	10	6	56	22	24	57
43	156	601	743	207	89	0	1								

Normal Values in Inches.

1	120	103	92	58	148	660	563	260	35	14	57	120	103	92	58
2	73	224	660	563	260	35	14	57	120	103	92	58	73	224	224
3	660	563	260	35	14	57	120	103	92	58	73	224	660	660	563
4	260	35	14	57	120	103	92	(92)	58	73	224	224	660	563	260
5	260	35	14	57	57	120	120	103	92	58	58	73	224	224	660
6	563	563	260	35	14	14	57	120	103	103	92	58	73	224	224
7	660	563	260	35	35	14	57	120	103	92	58	58	73	224	660
8	(563)	260	35	35	14	57	120	103	92	58	58	73	224	660	563
9	260	35	14	57	120	103	75	73	224	660	563	260	35	14	57
10	120	103	92	58	73	224	660	563	260	24	57	120	103	75	73
11	224	660	563	260	24	57	120	98	58	124	660	563	260	24	57
12	112	92	66	224	612	260	24	88	103	75	73	442	412	35	36
13	120	98	58	148	612	260	24	(57)	120	98	58	73	442	563	260
14	24	57	120	103	75	73	224	660	563	148	14	57	120	103	92
15	56	73	442	563	260	35	4	57	120	103	92	58	73	224	660
16	563	260	35	14	57	120	98	58	73	224	660	563	260	35	14
17	(57)	120	120	103	92	58	73	224	660	563	260	260	35	14	57
18	120	103	92	58	58	73	224	660	563	260	35	35	14	57	120
19	120	103	92	58	73	73	224	660	563	260	260	35	14	57	120
20	120	103	92	58	73	73	224	660	563	260	260	35	14	57	120
21	120	103	92	58	73	73	224	660	563	260	260	35	14	57	120
22	103	103	92	58	73	224	660	(563)	260	35	14	57	120	103	92
23	58	73	224	660	563	260	35	14	88	103	92	58	73	224	660
24	563	260	35	14	57	120	103	92	58	73	224	660	563	260	35
25	14	57	120	103	92	58	73	224	660	563	260	35	14	57	120
26	(103)	92	58	148	660	563	260	35	14	88	103	92	58	73	224
27	660	412	35	14	57	120	103	75	73	224	660	563	260	35	14
28	57	120	98	58	73	224	660	563	260	35	14	88	103	92	58
29	73	224	660	563	260	35	36	120	103	92	58	73	224	660	563
30	260	35	14	120	103	92	58	73	224	660	563	260	35	14	57
31	91	107	65	49	136	446	466	(246)	22	28	91	91	107	65	92
32	446	466	246	31	13	28	91	91	107	65	49	136	446	356	31
33	13	28	91	91	107	65	49	136	446	466	246	31	13	28	91
34	91	107	65	49	136	446	466	246	31	13	28	91	91	107	65
35	(49)	136	446	466	246	31	13	28	91	91	107	65	49	136	446
36	466	246	31	13	28	91	91	107	65	49	136	446	466	246	31
37	13	28	91	91	107	65	49	291	466	246	31	13	28	91	91

TABLE No. 9—Concluded.

Normal Values in Inches—Concluded.

Cycles.	Phase numbers. (1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
38	107	65	49	136	446	466	246	31	13	28	91	91	107	65	49
39	136	446	466	246	31	13	28	91	91	107	65	49	136	446	466
40	246	31	13	60	91	107	65	(49)	136	446	466	246	31	13	28
41	91	91	107	65	49	136	446	466	246	31	13	28	91	91	91
42	107	65	49	136	446	466	246	31	13	28	91	91	107	65	49
43	136	446	466	246	31	13	28								
Sum actual, 1-15	3305	2640	3035	2137	2470	2245	1776	2544	1755	2309	2570	2426	3908	3834	4131
Sum normal, 1-15	4077	3414	2508	1725	2178	2037	2270	2554	2143	1791	2229	2461	3535	3909	4447
Quotient	81	77	122	124	113	110	86	100	82	129	115	98	111	98	90
Smoothed	83	93	108	120	116	103	99	89	104	109	114	108	102	100	90
Sum actual, 16-30	2607	2172	1881	2496	2403	1748	3035	4735	5222	2677	3891	3095	2600	1006	2352
Sum normal, 16-30	2991	2168	1859	2087	2364	2166	3055	4681	4745	3700	3723	2849	1801	1795	2374
Quotient	87	100	101	120	102	81	99	101	110	72	105	109	144	56	99
Smoothed	95	96	107	108	101	94	94	103	94	96	95	119	103	100	81
Sum actual, 31-43	1964	1650	1830	1730	1916	2443	2039	1863	1601	1709	1477	1108	2834	1712	1341
Sum normal, 31-43	1992	2262	2185	1679	1867	2373	2284	1813	1727	1598	1414	1378	1672	1709	1530
Quotient	99	73	84	103	103	103	89	103	93	107	104	80	170	100	88
Smoothed	87	85	87	97	103	98	98	95	101	101	97	118	117	119	96
Total actual	7876	6462	6746	6363	6789	6436	6850	9142	8578	6695	7938	6629	9342	6552	7824
Total normal	9060	7844	6552	5491	6409	6576	7609	9048	8615	7089	7366	6688	7008	7413	8351
Quotient	87	82	103	116	106	98	90	101	100	95	108	99	133	88	94
Smoothed	88	91	100	108	107	98	96	97	99	103	101	113	107	105	90

TABLE 10.—Mean rainfall in inches of Ashland, Albany, Cascade Locks, Portland, Roseburg and The Dalles, in Oregon.

YEARS.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1879	....	....	845	281	501	83	131	107	198	302	538	779
1889	960	421	355	291	256	116	36	88	79	145	246	944
81	1080	1152	278	281	108	272	92	102	170	609	446	540
82	419	754	247	399	111	91	85	23	71	716	342	1087
83	878	157	340	519	175	2	0	12	65	344	556	(560)
84	387	540	261	337	105	164	92	15	342	352	198	883
85	346	698	50	105	345	170	9	0	242	180	784	656
86	787	275	400	305	149	38	96	2	246	278	168	996
87	1207	354	588	423	289	104	7	23	171	135	370	1024
88	732	189	284	123	102	486	104	8	67	376	427	427
89	294	98	212	266	280	62	22	60	145	399	381	549
1890	917	1038	496	133	88	209	32	29	36	233	49	383
91	387	701	320	259	211	265	58	76	174	396	539	1127
92	450	202	263	410	159	75	61	8	124	233	551	650
93	186	592	353	541	255	110	19	4	337	529	799	522
94	1040	(536)	826	266	171	236	32	2	188	434	257	473
95	770	140	336	217	343	35	44	13	204	5	360	984
96	714	393	357	446	396	94	6	71	76	208	1244	679
97	270	654	578	170	88	188	45	41	193	201	927	833
98	412	537	216	157	161	145	54	76	260	155	715	368
99	622	562	445	379	248	80	10	237	118	366	746	626
1900	472	432	372	158	273	195	16	81	176	545	427	498
01	689	652	367	249	193	99	8	30	(326)	115	482	546
02	324	781	481	600	242	69	124	50	123	134	944	927
03	801	145	289	164	116	194	48	43	132	220	993	278
04	492	1013	813	236	58	64	72	13	56	544	451	763
05	344	160	440	83	236	128	7	17	201	408	256	619
06	538	538	250	160	279	238	0	8	198	262	777	607
07	674	492	424	371	135	130	53	141	148	100	569	1064
08	402	290	419	192	276	97	14	80	32	451	295	378
09	850	632	204	92	184	44	106	18	112	289	1185	376
1910	552	590	248	245	215	116	1	4	79	322	961	401
11	680	275	98	206	300	71	16	10	378	98	406	457
12	873	492	253	272	243	254	44	231	172	302	550	629
13	663	136	409	250	190	321	86	40	201	319	541	287
14	994	376	262	305	143	172	6	0	296	414	370	217
15	461	390	230	186	326	72	103	6	50	198	981	728
16	504	588	775	277	254	135	239	38	70	98	558	432
17	340	383	444	904	200	70	10	6	114	6	506	1123
18	606	559	289	116	164	17	74	60	131	379	440	354
19	760	762	520	334	164	71	14	4	256	217	656	514
1920	375	21	415	358	90	166	62	106	409	344	592	810
21	652	645	433	262	149	115	3	22	223	279	1011	296
Mean	6 12	4 88	3 83	2 87	2 09	1 36	0 50	0 46	1 72	2 94	5 84	6 37

TABLE 11.—Mean rainfall in inches of Folsom, Hollister, Los Angeles, Marysville, Merced, Sacramento, San Francisco, San Jose, San Luis Obispo, Santa Barbara, San Bernardino, San Diego and Stockton, in California.

YEARS.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1878	635	769	272	174	30	3	1	0	16	47	44	(174)
79	289	246	278	184	86	7	1	1	0	79	233	383
1880	139	271	138	668	64	0	1	2	0	9	37	832
81	370	239	122	107	4	20	0	0	22	80	79	175
82	166	229	354	161	20	14	0	0	31	132	184	56
83	165	123	306	90	169	4	1	0	42	104	42	(148)
84	343	697	778	194	74	154	0	1	15	131	20	572
85	154	17	45	174	20	9	3	1	3	17	774	168
86	573	82	227	370	11	2	4	2	0	19	63	118
87	68	664	91	191	15	6	2	0	39	14	97	272
88	484	109	300	21	39	11	1	1	33	7	365	405
89	59	95	559	64	136	10	1	7	3	512	260	970
1890	574	318	247	76	86	2	1	17	71	5	24	306
91	59	594	157	160	58	10	2	7	23	5	30	363
92	147	251	309	87	209	6	0	0	6	69	375	434
93	314	287	560	86	33	0	2	0	10	34	152	208
94	284	(256)	69	35	131	35	1	2	88	113	39	672
95	681	160	208	93	61	0	1	0	49	44	118	101
96	619	12	250	280	58	0	5	31	18	117	280	210
97	304	435	187	41	19	4	0	1	7	149	40	97
98	113	60	189	25	116	6	1	0	60	43	44	109
99	333	16	421	51	38	53	0	5	0	291	269	222
1900	271	28	143	156	146	2	3	0	10	108	479	81
01	407	485	59	178	72	1	0	6	46	140	177	60
02	120	506	275	121	48	2	7	0	0	100	226	209
03	290	164	570	134	6	0	0	1	7	8	197	68
04	68	416	468	145	17	0	0	11	252	160	97	173
05	308	422	404	87	184	4	3	1	7	5	181	76
06	457	341	729	128	205	38	1	2	18	1	107	691
07	579	264	648	40	10	48	0	0	2	180	5	296
08	398	312	77	28	67	1	1	6	43	47	117	164
09	957	510	274	2	0	5	0	10	23	72	186	578
1910	280	99	274	26	2	0	1	1	41	65	39	98
11	1109	298	530	76	15	3	1	0	27	27	28	176
12	189	17	415	211	98	24	1	2	49	56	88	38
13	263	220	115	54	56	20	15	10	3	4	382	357
14	881	395	73	110	24	31	1	0	4	75	46	413
15	514	623	131	115	225	0	0	4	1	0	67	414
16	1173	253	159	18	12	0	3	8	72	135	69	410
17	217	431	82	66	26	0	2	1	14	2	46	32
18	75	482	531	51	6	9	3	6	230	34	265	182
19	136	470	230	27	20	0	0	2	74	31	32	226
1920	44	213	420	115	12	8	0	1	4	139	218	353
21	447	113	209	39	171	1	0	0	36	44	92	654
Mean	3.65	2.95	2.93	1.20	0.66	0.13	0.02	0.03	0.34	0.79	1.48	2.90

TABLE 12.—Nineteen California and Oregon stations, March 1879 to 1917. Given in inches.

SUMS OF ACTUAL VALUES OF ALL STATIONS.

CYCLES.	Phase numbers.														
	(11)	(12)	(13)	(14)	(15)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1	4085	4127	696	647	1191	4545	9656	7571	6041	7184	2362	700	225	563	728
2	1965	16480	11282	10024	3252	3074	707	1218	612	1302	4689	3707	5518	4668	7498
3	6084	4492	928	728	510	138	830	6014	4446	7245	7406	4280	4282	4543	109
4	20	74	936	3413	3881	(5288)	6779	6779	12309	11688	7144	1584	2982	551	100
5	2253	2253	3813	1444	12730	4083	4422	881	2897	2897	2329	1140	91	16	1494
6	1297	1297	14765	7424	12170	12170	2715	5349	6644	1041	1041	251	626	32	1480
7	1480	2304	1825	7518	8122	8122	10755	4706	5019	1937	1937	710	66	142	1540
8	1540	1001	3486	9681	10680	10680	2547	5607	1007	1121	1121	3057	629	60	835
9	835	2331	7305	7829	2523	1824	1824	8542	2436	3454	506	152	(458)	914	9043
10	5674	15902	12963	10359	6181	1784	1647	1280	204	392	1186	1471	604	4686	11934
11	3959	3628	2025	1717	370	546	1339	2445	3623	11484	4608	4468	5535	3592	3611
12	530	368	57	819	2290	8178	9541	5193	7275	9399	4362	1959	668	134	22
13	2148	3617	6774	5838	9936	(6544)	5844	2390	1878	213	34	2275	4070	2042	12521
14	2920	4672	2509	2856	217	269	970	598	3700	7224	12326	2509	5852	3135	567
15	109	825	674	2772	11112	6806	5574	8390	1550	776	1180	272	258	1244	3147
16	6084	5104	4007	3745	1265	2498	946	333	456	2332	1493	4242	8066	3583	8142
17	2942	1979	1174	58	1483	.712	6024	7304	6351	2953	4087	2976	3536	1192	121
18	484	1184	4677	8789	6730	10216	2974	3810	2090	609	51	254	(2546)	3850	4056
19	3495	11285	6466	3975	1254	835	301	739	2104	8607	8287	8581	3006	9140	2725
20	770	1170	290	579	1433	8524	2546	3830	11489	10965	3297	565	385	436	215
21	3615	3543	3969	6824	6016	6445	7892	1634	3811	816	79	112	1295	2498	3877
22	4100	9175	7665	10978	2628	(4336)	1915	10	77	1422	1582	6057	12630	11570	6389
23	10959	2747	945	1405	322	851	916	2934	3480	10232	7589	5784	3509	1459	2531
24	604	93	556	760	3315	3294	4391	17675	10425	4793	571	1108	482	234	972
25	2676	9526	9747	6958	4831	5042	1804	1310	699	26	35	1033	2771	6280	3774
26	18498	5517	7471	2228	2002	468	109	63	2626	938	2804	5038	7690	3177	6929
27	4380	2734	1842	277	1416	1676	2541	4385	5832	3683	3952	2198	(1867)	2189	714
28	366	1255	1963	8215	6362	17459	7381	2522	3256	1176	1440	41	1	1822	3459
29	2818	6674	9398	9398	10143	3092	2606	4883	431	618	91	309	1186	6752	9749
30	18270	6822	6717	1897	1677	813	1478	332	1562	2334	4238	7917	4861	7895	3737

SUMS OF NORMAL VALUES OF ALL STATIONS.

CYCLES.	(11)	(12)	(13)	(14)	(15)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1	4711	2161	991	323	1455	2747	6463	8516	6739	6114	2734	991	325	321	1455
2	4064	7546	8516	6739	6114	3308	2161	991	323	1455	2747	5380	7546	8516	6739
3	6114	3308	2161	991	325	321	1455	2747	5380	7546	8516	6739	4711	2161	991
4	325	321	1455	2747	5380	(7546)	8516	8516	6739	6114	3308	2161	991	325	321
5	1455	1455	2747	5380	7546	8516	6739	6114	3308	3308	2161	991	325	321	1455

6	2747	2747	5380	7546	8516	8516	6739	6114	3308	2161	2161	991	325	321	1455
7	1455	2747	5380	7546	8516	8516	6739	6114	3308	2161	2161	991	325	321	1455
8	1455	2747	5380	7546	8516	8516	6739	6114	3308	2161	2161	991	325	321	1455
9	1155	2747	5380	7546	8516	6739	6739	6114	3308	2161	991	325	(321)	1455	2747
10	5380	7546	8516	6739	6114	3308	2161	991	325	321	1455	2747	5380	7546	7628
11	6114	3308	2161	991	325	321	1455	2717	5380	7546	8516	6739	6114	3308	2161
12	991	325	321	1455	2747	5380	7546	8516	6739	6114	3308	2161	991	325	321
13	1455	2747	5380	7546	8516	(6739)	6114	3308	1576	325	321	1455	2747	5380	7546
14	7628	6114	3308	2161	991	325	321	2101	5380	7546	8516	6739	6114	2734	991
15	325	321	1455	2747	5380	7546	8516	6739	4711	2161	991	325	321	1455	2747
16	5380	7546	7628	6114	3308	2161	991	325	321	1455	2747	5380	8031	6739	6114
17	3308	2161	991	325	321	1455	2747	5380	8031	6739	6114	3308	2161	991	325
18	321	1455	2747	5380	7546	7628	6114	3308	2161	991	325	321	(1455)	2747	6463
19	8516	6739	6114	3308	2161	658	321	1455	2747	5380	7546	8516	6739	6114	3308
20	2161	991	325	321	2101	5380	7546	8516	6739	6114	3308	2161	991	325	321
21	1455	2747	5380	7546	8516	6739	6114	3308	2161	991	325	321	1455	2747	5380
22	7546	8516	6739	6114	3308	(2161)	991	325	321	1455	2747	5380	7546	8516	6739
23	6114	3308	2161	991	325	321	1455	2747	5380	7546	8516	6739	6114	3308	2161
24	991	325	321	1455	2747	5380	7546	8516	6739	6114	3308	2161	991	323	1455
25	2747	5380	7546	8516	6739	6114	3308	2161	991	325	321	1455	2747	5380	7546
26	8516	6739	6114	3308	2161	991	325	321	1455	2747	5380	7546	8516	6739	6114
27	3308	2161	991	325	321	1455	2747	5380	7546	7628	6114	3308	(2161)	991	325
28	321	1455	2747	5380	7546	8516	6739	6114	3308	2161	991	325	321	1455	2747
29	5380	7546	8516	8516	6739	6114	3308	2161	991	325	321	1455	2747	5380	7546
30	8516	6739	6114	3308	2161	991	325	321	1455	2,47	5380	7546	8516	6739	6114
Sum actual, 1-15	34899	63371	70038	85879	85165	74051	65150	66963	59645	67357	52231	28535	31864	26322	54629
Sum normal, 1-15	45674	46140	57531	68003	78957	78344	78103	75712	59832	57194	50047	39726	36861	34810	39467
Quotient	76	137	122	126	108	95	88	88	100	118	104	72	86	76	139
Smoothed	117	112	128	119	110	97	90	92	102	107	98	87	78	100	97
Sum actual, 16-30	80061	68808	68887	66086	51177	66261	43824	51991	54689	51504	39596	46215	53831	62077	57390
Sum normal, 16-30	64580	39808	64434	60907	56000	56065	50577	50338	50346	52718	53443	55922	60491	58494	62658
Quotient	124	173	104	119	91	118	87	103	109	98	74	83	89	106	92
Smoothed	130	134	132	105	109	99	103	100	103	94	85	82	93	96	107
Total sum, actual	114960	132179	136925	151965	136342	140312	108974	108954	114334	118861	91827	74750	85695	88399	112019
Total sum, normal	110254	85948	121965	128910	134957	134409	128980	126050	110178	109912	103490	95648	97352	93304	102125
Quotient	104	154	112	118	101	104	85	94	104	108	89	78	88	95	110
Smoothed	123	123	128	110	108	97	94	94	102	100	92	85	87	98	103

TABLE 13.—Per cent of normal rainfall at Chilgrove, West Sussex, England. Compiled from table of actual rainfall in "British Rainfall, 1919."

YEARS.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1834	107	135	73	55	57	129	322	78	24	41	107	57
35	38	169	121	39	76	91	11	26	195	135	146	12
36	96	90	226	262	19	62	99	91	127	139	186	54
37	144	160	24	73	34	45	47	77	78	84	58	90
38	17	71	122	51	84	167	49	64	91	53	191	123
39	38	143	83	92	34	54	226	89	218	83	111	210
1840	114	100	0	21	85	78	128	71	151	45	173	19
41	128	121	96	77	143	108	79	146	157	167	156	92
42	62	126	65	44	75	22	46	73	192	37	201	67
43	81	97	66	149	298	113	87	128	22	118	104	26
44	122	125	138	26	21	57	78	99	31	120	117	19
45	105	76	48	95	113	90	92	86	94	64	113	99
46	168	88	93	80	117	45	89	173	56	156	66	48
47	47	88	46	71	82	87	40	57	58	68	77	173
48	75	232	209	185	22	191	161	182	94	96	73	124
49	94	86	57	174	145	39	90	32	168	110	63	107
1850	67	82	19	218	132	108	157	100	94	56	96	68
51	153	38	190	93	73	92	90	50	0	106	27	28
52	159	106	23	26	106	286	62	172	192	154	244	156
53	156	45	89	177	109	108	244	115	117	141	45	19
54	99	33	18	8	189	82	32	45	39	95	52	62
55	22	61	127	23	143	56	170	44	88	171	48	48
56	126	55	54	198	185	96	30	142	136	76	29	82
57	93	18	95	108	65	100	57	80	153	196	59	37
58	52	42	72	137	116	43	111	85	83	52	50	98
59	76	90	81	168	59	56	106	58	141	98	143	102
1860	136	61	94	90	186	291	109	167	125	68	102	97
61	24	85	128	39	75	101	182	24	128	43	142	55
62	100	31	172	58	172	113	103	79	73	122	41	89
63	123	38	52	29	114	195	34	66	136	103	63	93
64	64	60	146	76	77	58	14	34	138	45	123	40
65	136	106	54	22	140	98	92	182	10	236	99	85
66	150	183	77	81	69	127	75	107	262	36	59	78
67	114	109	88	106	68	80	100	113	73	67	29	44
68	136	62	89	134	58	26	35	159	111	95	46	256
69	110	119	78	56	212	84	43	51	195	55	70	120
1870	75	138	90	11	70	19	61	121	65	114	56	102
71	110	79	63	246	29	166	200	58	165	42	24	64
72	242	116	119	49	136	88	114	53	83	142	153	168
73	153	131	105	38	71	109	98	67	103	107	82	21
74	80	95	26	144	19	134	54	83	89	117	80	80
75	149	98	65	71	59	140	166	55	85	133	150	38
76	36	151	132	110	27	69	34	103	167	54	122	212
77	259	84	121	155	162	26	133	160	63	88	226	86
78	66	120	72	156	109	86	43	184	66	88	142	54
79	78	175	29	191	133	201	174	211	152	31	20	22
1880	10	128	46	100	101	101	210	34	163	208	109	122
81	48	136	91	27	74	101	133	184	100	53	135	99
82	58	82	40	197	68	153	131	76	78	222	51	81
83	94	202	35	66	101	105	130	384	133	67	153	38
84	96	106	124	80	44	61	97	44	108	33	38	116
85	62	175	99	61	234	110	22	374	171	99	101	41
86	136	42	96	91	225	28	156	75	57	133	110	171
87	93	33	49	78	50	47	38	83	136	33	148	71
88	47	34	183	86	91	158	292	95	37	48	157	65
89	30	60	92	109	232	33	92	81	27	185	43	68
1890	121	47	73	145	87	151	155	119	55	27	95	18
91	106	2	180	52	114	87	117	251	43	170	134	134
92	39	35	42	47	46	95	100	109	109	108	112	76
93	61	146	10	2	42	72	155	27	65	123	80	103
94	214	108	82	132	64	96	212	61	92	128	190	93
95	98	6	121	162	12	32	201	135	214	99	196	109
96	61	24	202	34	27	184	42	45	308	92	32	182
97	103	173	260	146	67	116	28	200	105	12	47	138
98	30	71	38	67	207	123	143	65	71	98	139	86
99	110	110	35	152	43	82	69	25	112	68	165	68

TABLE 13—CONTINUED.

YEARS.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1900	153	302	44	97	55	165	47	126	44	66	128	144
01	44	76	121	158	60	157	108	62	82	73	17	165
02	46	111	101	57	112	165	51	233	38	73	137	72
03	108	81	183	141	174	119	134	197	154	250	75	96
04	213	199	64	104	218	55	59	85	99	67	41	125
05	45	34	254	100	24	190	13	124	79	58	157	40
06	305	185	65	51	175	57	17	37	54	137	163	79
07	45	78	51	267	143	140	68	75	21	174	97	134
08	51	77	150	123	123	32	140	148	64	77	42	124
09	35	19	222	80	86	145	131	77	130	221	21	158
1910	107	187	71	136	56	84	85	117	4	123	126	147
11	50	96	93	80	143	103	30	18	42	147	159	256
12	126	130	213	0	57	161	80	266	108	84	58	136
13	185	64	150	183	158	23	75	66	56	140	104	55
14	31	203	222	91	75	60	126	61	58	75	108	275
15	138	222	40	75	186	84	166	52	83	96	105	297
16	50	155	148	60	93	100	39	123	89	136	140	113
17	53	53	100	107	104	170	98	200	59	108	51	52
18	138	74	69	108	85	41	168	67	224	34	98	99
19	237	133	286	129	11	25	72	133	50	8	198	199
Normal in inches.	3.20	2.45	2.32	1.95	2.07	2.31	2.65	3.02	3.08	4.22	3.53	3.51

TABLE 14.—Per cent of normal rainfall at Utrecht, Holland.

YEAR.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1849	73	164	64	153	91	60	136	56	47	157	85	145	103
50	115	230	84	228	117	39	64	149	43	108	118	124	118
51	57	73	138	141	102	40	116	82	42	45	187	27	90
52	162	187	94	22	160	155	45	178	135	296	147	110	141
53	145	103	52	239	80	149	105	87	132	120	7	36	105
54	122	164	26	54	132	120	63	81	87	160	123	221	113
55	80	51	64	50	76	90	182	68	34	165	44	84	82
56	113	143	33	155	218	110	66	105	112	20	192	77	112
57	120	14	77	125	13	35	96	48	104	46	51	20	62
58	85	40	41	48	71	109	142	177	39	85	32	105	144
59	47	75	209	160	34	64	79	81	130	93	88	68	94
1860	127	93	167	103	143	82	73	88	113	71	93	42	100
61	19	48	127	98	114	183	121	84	152	4	126	34	92
62	107	44	43	63	60	102	125	75	61	128	42	85	78
63	75	72	63	50	61	97	36	79	128	40	65	99	72
64	38	65	93	23	62	107	26	101	123	43	59	14	63
65	99	117	93	19	86	18	256	218	14	105	39	13	90
66	120	129	111	87	73	70	141	102	190	14	194	122	113
67	137	104	58	119	53	112	142	41	120	90	57	108	95
68	95	87	133	94	61	26	25	116	34	83	47	138	78
69	74	157	79	50	267	79	53	102	118	133	112	96	112
1870	83	20	110	39	57	40	82	210	71	149	84	161	92
71	59	50	34	161	33	133	172	28	136	101	61	75	87
72	114	92	81	65	101	90	117	86	172	176	159	158	118
73	65	72	42	89	141	95	52	84	162	95	41	22	80
74	94	55	133	39	163	71	53	61	181	76	156	83	97
75	110	77	68	37	71	85	182	185	121	56	182	42	101
76	33	156	172	109	108	79	42	66	213	61	95	85	102
77	187	208	136	68	87	43	108	152	59	92	142	92	114
78	118	54	177	80	196	49	38	120	93	91	163	72	104
79	89	120	27	194	63	118	162	118	66	83	68	28	95
1880	59	80	75	67	24	178	94	62	137	172	141	173	105
81	56	182	147	53	175	124	48	155	103	66	48	150	109
82	76	74	163	121	106	248	129	130	131	104	155	127	130
83	71	67	81	7	75	52	140	65	93	104	142	83	82
84	150	63	59	43	70	28	138	64	88	94	79	141	85
85	94	127	57	45	151	56	9	55	124	212	83	54	89
86	189	64	103	43	158	130	106	54	29	82	79	139	98
87	33	20	59	96	109	18	22	39	74	133	83	101	66
88	46	64	179	81	51	170	168	75	46	99	66	53	92
89	33	138	103	89	152	130	167	160	163	87	82	115	118
1890	160	9	100	157	68	69	172	120	41	163	200	7	106
91	141	21	113	68	154	207	120	81	67	57	77	176	107
92	142	77	64	38	47	142	51	66	187	202	87	108	101
93	81	285	51	1	42	24	122	75	147	113	131	110	98
94	98	249	106	132	67	122	188	153	112	95	115	131	131
95	108	35	162	96	72	92	104	103	34	110	138	155	101
96	91	13	116	74	14	61	75	99	219	123	96	97	90
97	35	90	144	174	86	119	42	129	144	70	68	132	103
98	80	212	97	109	162	128	109	62	174	70	118	101	119
99	146	102	49	201	174	11	73	182	207	91	55	83	115
1900	120	127	46	101	100	140	78	150	23	134	48	117	99
01	86	64	141	197	66	81	117	83	169	108	102	145	113
02	80	79	93	84	154	40	105	132	66	59	54	92	86
03	77	79	135	292	115	152	105	112	161	165	143	40	131
04	108	136	74	48	135	120	31	71	63	59	100	79	86
05	59	87	155	120	73	110	102	140	75	200	99	42	105
06	206	118	105	62	185	81	79	73	52	77	101	105	104
07	69	111	107	93	132	162	43	60	56	101	71	124	94
08	97	129	83	75	118	113	97	126	56	36	98	54	90
09	40	85	126	215	77	66	116	163	93	136	70	166	113
1910	110	173	67	162	91	132	133	82	107	27	187	126	115
11	53	101	108	67	49	183	28	196	52	157	156	110	105
12	114	126	162	90	125	208	56	265	152	89	140	140	136
13	135	73	132	45	176	189	129	21	28	65	117	115	102
14	114	72	278	93	88	90	113	45	124	52	100	166	111
15	196	201	116	99	158	91	126	115	70	28	163	160	127
16	138	182	170	186	135	190	42	119	59	129	86	119	130
17	89	15	54	120	36	161	84	230	57	215	83	54	100
18	193	111	51	74	37	87	178	62	291	103	79	154	118
19	92	92	132	150	44	77	170	58	62	87	97	167	102
1920	155	92	38	203	124	45	130	137	39	14	21	88	91
21	156	25	62	67	41	75	150	35	32	34	56	......	....
Normals,	5.44	4.30	4.98	4.33	4.93	5.89	7.58	8.36	6.51	7.27	5.96	6.89	....

TABLE 15.—Number of rainfall stations in the different counties in Denmark.

COUNTIES.	Year.											
	1865.	1870.	1875.	1880.	1885.	1890.	1895.	1900.	1905.	1910.	1915.	1920.
Hjorring	1	1	4	5	7	8	9	9	9	11	7	8
Thisted	0	0	6	6	7	7	6	6	7	6	7	6
Ringkjobing	2	2	7	9	9	9	33	30	29	28	25	26
Ribe	0	1	4	6	8	10	18	18	18	17	15	12
Viborg	3	3	6	5	5	9	11	10	10	8	7	8
Aalborg	0	1	5	5	6	7	8	7	8	9	10	13
Randers	1	1	9	7	8	9	9	7	7	8	9	11
Aarhus	4	3	7	7	8	15	17	17	20	22	21	20
Vejle	0	1	7	7	8	9	11	10	11	9	9	10
Sonderjylland										..	..	25
Odense	1	1	11	12	12	17	17	18	20	20	20	20
Svendborg	1	1	9	11	10	17	16	17	17	18	16	16
Holbæk	0	0	7	10	11	11	12	10	10	11	11	11
Soro	1	2	4	5	6	9	8	11	10	9	13	14
Frederiksborg	0	1	5	8	5	5	4	5	8	6	10	11
Kjobenhavns	4	4	12	12	14	14	15	13	13	13	15	14
Præsto	0	0	13	14	14	17	14	14	13	17	22	21
Maribo	1	2	9	15	18	14	14	14	14	15	16	16
Total number	19	24	125	144	156	187	222	216	224	227	233	262

TABLE 15*a*.—Denmark. Observed per cent of normal rainfall of stations shown above made from manuscript copy of actual rainfall sent by Prof. Carl Ryder.

YEARS.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1860	......	......	......	......	......	......	......	......	......	......	......	58
61	40	113	150	77	77	163	133	92	155	12	189	37
62	87	45	79	80	97	178	117	63	108	132	71	130
63	113	83	103	114	77	151	68	76	160	62	71	104
64	54	86	126	54	82	190	57	125	149	61	88	23
65	80	86	39	17	72	43	99	126	31	112	101	29
66	150	240	55	125	118	116	101	126	144	30	150	114
67	157	166	82	193	113	99	170	31	147	110	65	70
68	115	143	158	111	31	33	49	79	123	114	80	236
69	82	139	45	37	153	81	46	75	110	114	123	116
1870	96	30	61	54	64	78	63	98	93	145	123	66
71	33	131	45	97	46	161	131	46	157	39	47	70
72	115	68	182	131	166	99	73	87	196	101	150	118
73	127	45	42	82	189	58	104	111	155	176	97	77
74	120	39	110	88	64	66	95	106	139	82	67	103
75	185	18	71	63	84	110	80	71	51	145	155	411
76	26	157	218	128	49	93	52	51	159	51	71	147
77	183	157	87	85	87	87	140	170	108	123	121	79
78	136	45	137	71	161	83	82	123	98	91	144	97
79	35	154	47	82	148	169	148	173	88	80	62	37
1880	23	166	63	114	49	116	164	43	139	171	176	116
81	42	71	87	20	87	60	121	157	118	139	105	77
82	89	74	124	131	110	178	151	114	72	121	168	79
83	75	68	34	56	46	66	145	110	113	124	170	103
84	172	134	92	45	105	52	117	44	79	130	64	137
85	92	116	39	99	130	83	41	107	149	145	54	60
86	124	50	79	94	94	75	90	44	77	88	86	139
87	21	27	66	102	133	31	82	46	129	119	101	97
88	54	135	163	122	84	153	180	84	52	82	101	87
89	28	92	79	82	46	52	117	149	96	170	54	43
1890	127	15	108	139	135	103	150	129	34	129	82	15
91	96	36	134	94	153	62	137	210	92	95	75	132
92	129	77	39	74	115	194	43	92	110	135	41	58
93	82	175	63	9	66	60	120	78	146	150	95	85
94	96	143	121	114	89	95	117	118	61	97	75	77
95	66	74	121	65	84	93	156	114	34	127	140	112
96	49	27	168	102	64	66	66	109	177	145	47	87
97	49	50	229	105	187	50	128	141	124	39	54	120
98	99	151	132	94	217	202	71	102	72	38	97	170
99	157	116	82	142	82	25	69	36	138	91	82	83
1900	148	181	50	134	79	109	115	95	78	160	69	128
01	77	53	116	162	89	190	54	58	39	53	121	130
02	(136)	30	132	63	199	66	84	146	59	83	17	77
03	103	160	84	148	84	76	128	139	92	233	93	41
04	96	160	79	160	120	78	28	75	38	82	129	110
05	80	68	150	151	87	91	85	147	125	132	75	29
06	167	(113)	108	74	115	83	57	112	51	76	146	74
07	92	80	76	57	118	194	79	103	28	82	82	132
08	99	151	121	125	146	91	85	107	88	17	84	48
09	82	45	100	139	110	107	107	79	116	110	107	163
1910	153	211	45	139	84	132	115	143	61	35	136	116
11	75	181	137	80	67	161	58	47	46	141	193	120
12	54	107	124	108	113	132	110	155	70	124	123	196
13	70	83	158	74	69	87	58	71	80	77	133	141
14	54	101	192	125	84	70	139	54	90	70	120	137
15	131	80	105	63	95	29	155	74	65	33	107	215
16	190	101	66	122	148	153	91	129	62	129	120	164
17	101	21	134	97	28	87	71	135	98	148	144	58
18	94	140	16	136	38	81	110	99	208	70	41	141
19	108	104	103	134	28	91	112	87	77	70	92	153
1920	162	143	66	256	156	58	129	88	97	21	34	104
21	218	65	82	65	77	56	49	108	64	91	......	......
Normals in mm	42.6	33.7	38.0	35.2	39.1	48.4	63.4	74.7	61.2	66.2	53.6	51.7

TABLE 16.—Sweden. Observed per cent of normal. Prepared from material from "Observations Meteorologiques Suedoises L'Academie Royale des Sciences de Suede," for 1910.

YEARS.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1860	180	90	111	138	113	167	72	165	109	131	86	97
61	72	104	119	50	116	57	128	118	107	27	190	42
62	65	58	72	129	81	175	132	68	59	137	105	104
63	107	77	89	137	64	88	69	100	157	76	73	94
64	44	112	136	61	58	134	65	102	127	73	95	46
65	113	84	47	24	110	59	94	114	36	101	98	34
66	119	238	91	91	139	118	122	15	155	23	152	127
67	186	115	64	173	56	145	136	53	99	109	90	128
68	101	155	144	122	58	42	53	85	132	126	74	127
69	45	132	46	58	173	124	46	110	102	121	112	97
1870	140	60	48	83	102	90	92	68	108	111	189	91
71	46	52	263	58	169	58	59	24	168	41	34	45
72	108	99	120	140	162	142	70	94	181	163	157	131
73	191	72	52	49	136	107	79	105	155	152	133	76
74	84	33	93	96	48	43	76	95	106	97	77	121
75	146	34	89	65	76	97	78	78	35	57	102	77
76	72	133	134	123	55	110	70	71	216	105	82	101
77	144	149	154	78	91	82	52	123	78	93	158	93
78	84	27	122	49	156	127	63	110	100	97	151	133
79	58	131	48	132	121	121	124	94	124	98	63	44
1880	281	133	34	76	65	72	126	39	77	93	131	135
81	49	257	86	53	103	98	117	131	120	98	105	90
82	83	91	117	162	114	118	148	130	65	94	147	120
83	73	54	59	50	80	101	172	123	148	97	178	91
84	126	83	90	44	125	146	133	38	75	122	51	170
85	42	50	36	30	51	32	25	57	45	73	21	25
86	53	13	39	58	27	29	21	13	22	22	41	64
87	83	39	50	120	92	53	115	87	132	83	11	140
88	61	92	108	81	101	67	158	83	99	121	77	124
89	69	133	72	81	71	59	146	124	115	106	69	52
1890	136	256	117	242	136	122	149	137	41	152	153	81
91	103	50	100	58	125	53	113	149	99	115	110	126
92	80	84	67	108	72	172	78	127	107	110	24	80
93	88	102	83	43	90	80	103	107	153	182	78	111
94	119	108	117	102	148	96	133	125	77	91	71	119
95	70	92	152	83	70	109	178	135	66	132	117	80
96	79	48	200	115	76	124	88	126	108	164	68	99
97	92	90	173	123	119	75	106	125	135	53	83	142
98	78	160	177	88	167	158	155	115	75	50	122	188
99	151	100	87	186	78	72	84	46	185	104	90	97
1900	116	178	67	107	78	71	99	116	72	161	131	147
01	64	63	101	106	50	160	32	70	37	116	79	135
02	108	50	118	37	111	82	132	153	79	114	30	77
03	113	99	102	195	78	92	114	188	84	145	60	79
04	96	152	84	149	131	101	30	127	70	95	104	120
05	68	53	98	122	63	87	112	139	109	85	101	29
06	122	116	121	109	155	88	78	91	35	70	161	86
07	106	104	77	127	105	158	144	113	40	90	63	123
08	78	126	115	102	104	120	84	95	97	20	86	86
09	88	40	205	130	102	102	116	109	92	156	64	179
1910	125	155	52	164	130	87	131	93	95	53	252	98
Normals	3.54	3.03	3.12	2.74	3.92	4.58	6.12	6.91	5.43	5.13	4.06	3.71

TABLE 17.—Per cent of normal rainfall of Chilgrove, England; Denmark; Sweden, and Utrecht, Holland—weighted equally because of geographical distribution. The record of Sweden is not included after December, 1910.

YEARS.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1861	39	88	131	66	96	126	141	80	136	22	162	42
62	90	44	92	82	102	142	119	71	75	130	65	102
63	104	68	77	82	79	133	53	80	145	70	68	98
64	50	81	125	54	70	122	40	90	134	56	91	31
65	107	98	58	20	102	54	135	160	23	138	84	40
66	135	198	84	96	100	108	110	88	188	26	139	110
67	148	124	73	148	72	109	157	59	110	94	60	88
68	112	112	131	115	52	32	40	110	100	104	62	189
69	78	137	62	50	201	92	47	84	131	106	112	107
1870	98	62	77	47	73	57	74	124	84	130	113	106
71	62	78	101	140	69	130	140	39	156	56	42	64
72	145	91	126	96	141	105	94	80	158	146	155	144
73	134	80	60	64	134	92	83	92	144	132	88	49
74	91	56	90	92	165	78	70	156	129	93	95	97
75	148	57	73	59	72	108	126	97	73	98	147	50
76	42	149	164	118	60	88	50	73	189	68	92	136
77	193	150	125	96	107	60	108	151	77	99	162	88
78	101	62	127	89	156	86	56	134	89	92	150	89
79	65	145	38	150	116	152	152	149	108	73	53	33
1880	93	127	54	89	60	117	148	44	130	161	139	136
81	49	162	103	38	110	96	105	157	110	89	98	104
82	76	80	111	153	100	174	140	112	86	135	130	102
83	78	98	53	45	76	81	147	170	122	98	161	79
84	136	96	91	53	86	72	121	48	88	95	58	141
85	72	117	58	59	142	70	24	148	122	132	65	45
86	170	42	79	72	126	66	91	46	46	81	79	172
87	230	30	56	99	96	37	64	64	118	92	86	102
88	52	81	158	92	82	137	200	84	56	88	100	82
89	40	106	86	90	125	68	130	128	100	137	62	70
1890	136	82	127	171	106	111	156	126	43	118	132	30
91	112	27	132	68	136	102	122	173	75	109	99	142
92	98	68	53	67	70	151	68	98	128	139	66	80
93	78	177	52	14	60	59	125	72	128	142	96	102
94	132	152	106	120	92	102	162	114	86	103	113	105
95	86	52	139	102	60	82	160	122	87	117	148	114
96	70	28	172	81	45	109	68	95	203	131	61	116
97	70	101	202	137	115	90	76	149	127	44	63	133
98	72	148	111	90	188	153	120	86	98	64	119	137
99	141	107	63	170	94	48	74	72	160	89	98	83
1900	134	197	52	110	78	121	85	122	54	130	94	134
01	68	64	120	156	66	147	78	68	82	88	80	144
02	92	68	111	60	144	88	93	166	60	82	60	80
03	100	105	126	194	113	110	120	159	123	198	93	64
04	128	162	75	116	151	88	37	93	68	76	93	108
05	63	60	164	123	62	120	78	138	97	119	108	35
06	200	133	100	74	158	77	58	78	48	90	143	86
07	78	93	78	136	124	164	84	88	36	112	78	123
08	81	121	117	106	123	89	102	119	76	38	78	78
09	61	47	163	141	94	105	118	107	108	156	66	166
1910	124	182	59	150	90	109	118	109	67	60	176	122
11	59	126	113	76	86	149	39	87	47	148	169	162
12	98	121	166	66	98	167	82	229	77	99	107	157
13	130	73	147	101	134	100	87	53	55	94	118	104
14	66	125	231	103	83	73	126	52	91	66	109	193
15	155	167	87	79	146	68	149	80	73	52	125	224
16	123	147	128	123	125	148	57	124	70	131	115	132
17	81	30	96	108	56	139	84	188	71	157	93	55
18	142	108	45	106	53	70	152	76	241	69	73	131
19	146	110	174	138	28	64	118	93	63	55	129	173

TABLE 18.—Per cent of normal rainfall of Chilgrove, England; Denmark; Sweden and Utrecht, Holland. Begins January, 1861.

Cycles.	Phase numbers.														
	(10)	(11)	(12)	(13)	(14)	(15)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1	39	88	98	96	126	141	80	79	162	42	90	44	92	82	102
2	130	71	75	130	65	102	104	68	77	82	79	92	80	145	70
3	68	98	50	81	125	54	70	122	40	90	134	56	91	31	107
4	98	58	20	102	54	135	135	160	23	138	84	40	135	198	84
5	96	100	108	110	110	88	188	26	139	110	148	124	73	(73)	148
6	72	109	109	157	59	110	110	94	60	88	88	112	112	112	131
7	115	115	52	32	32	40	110	110	100	104	62	62	189	78	137
8	137	62	50	201	92	92	47	84	131	106	106	112	107	98	62
9	77	47	47	73	57	74	(124)	84	130	130	113	106	62	78	101
10	140	140	69	130	140	39	156	56	42	64	145	91	126	118	105
11	94	80	158	146	155	144	134	80	60	64	134	92	83	92	138
12	88	49	94	56	90	128	78	70	156	111	95	97	148	57	66
13	72	117	97	73	98	98	42	156	118	74	50	131	68	114	172
14	125	102	60	130	88	162	94	62	108	156	71	112	92	(120)	65
15	145	94	116	152	150	108	73	43	93	127	54	74	117	148	44
16	130	150	136	49	162	103	38	110	96	131	110	89	98	104	76
17	80	111	153	100	174	140	112	86	135	130	102	78	98	49	76
18	81	147	170	122	98	161	(79)	136	136	96	91	53	86	72	121
19	48	88	88	95	58	141	72	117	58	59	59	142	70	24	148
20	122	132	132	65	45	170	170	42	79	72	126	126	66	91	46
21	46	46	81	79	172	230	230	30	56	99	96	96	37	64	64
22	118	118	92	86	102	52	52	81	158	92	82	82	137	200	84
23	56	56	88	100	82	40	106	106	86	90	125	68	130	(128)	100
24	137	62	70	136	82	127	171	106	111	156	126	43	118	132	30
25	70	132	68	136	102	122	173	75	109	99	142	98	68	53	67
26	70	151	68	98	128	139	66	80	78	177	52	14	60	59	125
27	72	128	142	96	102	132	(152)	106	120	97	162	114	86	103	113
28	105	69	139	102	60	82	160	122	102	148	114	70	28	172	63
29	109	68	95	203	131	61	116	70	101	170	115	90	76	149	127
30	44	63	133	110	111	90	188	153	120	86	98	64	119	139	107
31	63	170	94	48	74	72	160	89	98	108	197	52	110	78	121
32	85	122	54	130	94	134	66	120	156	66	147	78	68	(82)	88
33	112	92	68	111	60	144	90	166	60	82	60	80	100	105	126
34	194	113	110	120	159	160	93	64	128	162	75	116	151	88	37
35	93	68	76	93	108	63	60	164	123	62	120	78	138	97	119
36	108	35	200	133	100	74	(158)	77	58	78	48	90	143	86	78
37	93	78	136	124	164	84	88	36	112	78	123	81	121	117	106
38	123	89	102	119	76	38	78	78	61	47	163	141	94	105	112
39	108	156	66	166	124	182	59	150	90	109	118	109	67	60	176

40	122	59	126	113	76	86	149	39	87	47	148	169	162	98	121
41	166	66	98	167	82	229	77	99	107	157	102	147	101	(134)	100
42	87	53	55	94	118	104	66	125	231	103	82	73	126	52	91
43	66	109	193	155	155	167	87	79	146	68	149	80	73	52	125
44	224	123	147	128	123	125	148	57	124	70	131	115	132	81	30
Mean, 1–22	98	98	95	105	104	116	107	88	100	100	98	94	100	100	100
Mean, 23–44	100	89	101	117	100	107	109	93	104	98	113	85	98	94	93
Mean, 1–44	99	94	98	111	102	112	108	90	102	99	106	90	99	97	96

Means are adjusted to make their average 100.

TABLE 19.—Chile. Sums of rainfall in the following towns for years indicated: Concepcion, 1876-1887 and 1892-1915. Puerto Montt, 1862- April, 1873; 1888- July, 1895, and January, 1896-1915. Santiago, 1873-1915. Serena, 1869-1915. Valdivia, 1852-1879 and 1900-1915.

SUMS OF ACTUAL RAINFALL.

YEARS.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1852								5150	2580	620	2330	970
53	110	1420	1300	1970	5550	7500	2770	1760	2490	1260	1520	120
54	250	540	1410	2500	5490	7650	5270	2690	1310	1920	750	630
55	970	90	2080	3550	1780	4600	4610	4650	1390	990	400	2310
56	1100	500	3050	1930	1410	8340	2640	2640	1320	430	1550	1250
57	2320	1270	1650	2570	4730	6350	4220	1320	1760	1510	3220	1240
58	370	2260	560	3830	3990	2910	2240	5110	1950	580	2170	120
59	120	360	1630	2900	4750	6480	4220	1730	1650	740	660	140
1860	170	1680	890	1130	3830	2840	8630	6330	3150	910	940	280
61	120	190	1560	5310	3600	4250	4340	2570	1270	1480	640	170
62	2120	340	2770	4490	8150	13030	7170	5790	2460	4820	5520	2630
63	1490	1050	3010	6080	3960	8690	4470	4670	2210	1460	2490	3880
64	1500	800	2060	2770	8670	7630	6280	6740	3880	3040	2590	4270
65	1150	190	1560	2940	9050	6480	7320	7740	4580	6170	2170	2780
66	960	980	7900	4500	8970	2320	7610	10060	3820	2210	3500	560
67	650	1680	2820	5420	10820	6020	5390	4590	3260	1670	2470	4350
68	4220	5170	2750	3910	8880	10070	8130	4560	6640	4120	2100	6830
69	2580	1550	3210	1620	4780	4400	8720	11280	3370	3170	3260	5220
1870	2920	2130	6130	4130	8400	4380	8650	3600	1520	1600	1520	4880
71	3280	600	6860	3960	4985	4075	5470	8140	2610	4170	1190	1830
72	2060	1510	2920	3290	3680	5140	4875	8125	4850	4480	4060	3840
73	1440	566	3610	4228	3726	5890	5340	3187	3312	900	130	2210
74	250	210	1094	570	2744	6827	3598	4288	2897	2060	2068	160
75	1656	1186	2710	1204	7176	1893	3658	1250	590	960	934	2340
76	408	1466	3712	2264	5432	4155	8848	5881	3380	4726	1054	80
77	118	1279	2472	6640	3601	4109	12422	4894	5872	3888	1698	742
78	228	424	2716	5502	8897	10554	6432	2431	5051	3418	2695	474
79	446	582	1020	2138	5275	9160	11081	9804	718	938	1058	3032
1880	496	182	235	548	1436	8676	9018	4423	582	1002	126	616
81	186	304	50	2195	3773	2554	3380	2142	2969	1317	688	40
82	222	332	733	536	2248	1796	4385	3698	1031	376	877	0
83	176	38	1392	407	3349	6316	1382	836	1354	884	758	0
84	42	24	797	2920	614	2247	1722	3673	1591	1012	237	832
85	844	428	302	734	3955	757	4295	2425	1491	897	166	510
86	60	190	852	470	1512	2808	1731	1368	813	371	381	590
87	50	185	80	253	910	6643	1855	6958	2280	933	738	291
88	170	1240	750	2392	3694	4130	4111	7073	3368	3289	1522	1610
89	655	510	1520	1590	3210	1733	3870	2870	1496	740	1163	1909
1890	2162	730	805	486	1783	2841	4592	1703	1796	1133	520	2262
91	2200	1290	1930	1520	2910	6227	4654	2859	2310	3405	987	320
92	1233	2641	1535	1047	3360	2822	4080	4087	2549	2069	733	1157
93	4035	590	2270	1555	5414	3405	6648	3792	978	963	1419	1615
94	1534	1230	2326	1098	4668	3182	5181	4161	2715	3462	3574	1553
95	987	989	3222	1605	2412	4219	6826	5739	1510	1204	533	918
96	1373	410	1471	781	1942	3484	8203	4561	7270	2919	2153	603
97	313	990	2847	4587	6666	4819	3713	3491	1511	2338	2235	1894
98	1175	4251	2108	5081	5616	10006	6377	2783	3051	1733	2441	3323
99	2321	1296	2981	4380	8812	7430	13519	13047	1293	1240	2450	1150
1900	2220	3532	8567	3451	10757	10533	22182	9368	6177	6168	4155	576
01	1166	3439	1657	3639	10459	16351	13035	11198	4860	2200	5324	1578
02	1383	3495	4529	6093	15927	15389	13753	5536	5657	2392	3450	1529
03	510	501	738	2154	2864	13472	3779	3697	3019	1355	909	1445
04	679	285	1094	4784	9731	10565	17881	5736	7179	3029	1557	2132
05	369	71	3581	4011	6925	12188	9646	8120	4234	3906	450	1460
06	1421	1137	1578	4438	9484	8181	6869	5618	3916	1346	223	955
07	916	1271	558	364	5215	9114	6817	6337	5171	2866	449	2171
08	102	609	3202	6184	8909	6913	2958	6908	3144	1968	1864	879
09	484	854	265	2737	2948	5655	2865	6751	1723	2055	1967	811
1910	2756	1951	564	3678	5324	13591	9993	12160	1934	1248	3094	120
11	1092	851	644	7038	10577	5191	6221	6948	3814	917	4497	2912
12	903	3579	1443	7136	9364	8967	5405	7820	1904	3716	3192	2242
13	129	1379	2177	8693	12355	5986	15961	6161	5289	2048	349	1526
14	3242	390	1740	2024	9691	17961	13405	6552	10493	3150	5615	1564
15	192	1772	1250	9038	17618	10368	11040	8119	3291	2923	2553	1991

TABLE 19—CONTINUED.

SUMS OF NORMAL RAINFALL FOR EACH MONTH WHERE ACTUAL RAINFALL HAS BEEN USED.

YEARS.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1852	...	...		...	...		...	3365	2101	1417	1233	1047
53	634	738	1418	2376	3910	4457	4310	3365	2101	1417	1233	1047
54	634	738	1418	2376	3910	4457	4310	3365	2101	1417	1233	1047
55	634	738	1418	2276	3910	4457	1310	3365	2101	1417	1233	1047
56	634	738	1418	2376	3910	4457	4310	3365	2101	1417	1233	1047
57	634	738	1418	2376	3910	4457	4310	3365	2101	1417	1233	1047
58	634	738	1418	2376	3910	4457	4310	3365	2101	1417	1233	1047
59	634	738	1418	2376	3910	4457	4310	3365	2101	1417	1233	1047
1860	634	738	1418	2376	3910	4457	4310	3365	2101	1417	1233	1047
61	634	738	1418	2376	3910	4457	4310	3365	2101	1417	1233	1047
62	1846	1815	3005	4286	6788	6925	7213	5747	3748	2840	2686	2479
63	1846	1815	3005	4286	6788	6925	7213	5747	3748	2840	2686	2479
64	1846	1815	3005	4286	6788	6925	7213	5747	3748	2840	2686	2479
65	1846	1815	3005	4286	6788	6925	7213	5747	3748	2840	2686	2479
66	1846	1815	3005	4286	6788	6925	7213	5747	3748	2840	2686	2479
67	1846	1815	3005	4286	6788	6925	7213	5747	3748	2840	2686	2479
68	1846	1815	3005	4286	6788	6925	7213	5747	3748	2840	2686	2479
69	1847	1815	3013	4311	7001	7403	7554	6000	3815	2877	2693	2479
1870	1847	1815	3013	4311	7001	7403	7554	6000	3815	2877	2693	2479
71	1847	1815	3013	4311	7001	7403	7554	6000	3815	2877	2693	2479
72	1847	1815	3013	4311	7001	7403	7554	6000	3815	2877	2693	2479
73	1854	1831	3058	4466	4745	5770	5555	4239	2435	1608	1312	1105
74	642	754	1471	2556	4745	5770	5555	4239	2435	1608	1312	1105
75	642	754	1471	2556	4745	5770	5555	4239	2435	1608	1312	1105
76	819	981	2060	3436	6751	8318	8185	6131	3423	2220	1734	1368
77	819	981	2060	3436	6751	8318	8185	6131	3423	2220	1734	1368
78	819	981	2060	3436	6751	8318	8185	6131	3423	2220	1734	1368
79	819	981	2060	3436	6751	8318	8185	6131	3423	2220	1734	1368
1880	185	243	642	1060	2841	3861	3875	2766	1322	803	501	321
81	185	243	642	1060	2841	3861	3875	2766	1322	803	501	321
82	185	243	642	1060	2841	3861	3875	2766	1322	803	501	321
83	185	243	642	1060	2841	3861	3875	2766	1322	803	501	321
84	185	243	642	1060	2841	3861	3875	2766	1322	803	501	321
85	185	243	642	1060	2841	3861	3875	2766	1322	803	501	321
86	185	243	642	1060	2841	3861	3875	2766	1322	803	501	321
87	185	243	642	1060	2841	3861	3875	2766	1322	803	501	321
88	1220	1093	1640	2090	3713	3781	4148	3256	1981	1614	1532	1490
89	1220	1093	1640	2090	3713	3781	4148	3256	1981	1614	1532	1490
1890	1220	1093	1640	2090	3713	3781	4148	3256	1981	1614	1532	1490
91	1220	1093	1640	2090	3713	3781	4148	3256	1981	1614	1532	1490
92	1397	1320	2229	2970	5719	6329	6778	5149	2969	2226	1954	1753
93	1397	1320	2229	2970	5719	6329	6778	5149	2969	2226	1954	1753
94	1397	1320	2229	2970	5719	6329	6778	5149	2969	2226	1954	1753
95	1397	1320	2229	2970	5719	6329	6778	5149	2969	2226	1954	1753
96	1397	1320	2229	2970	5719	6329	6778	5149	2969	2226	1954	1753
97	1397	1320	2229	2970	5719	6329	6778	5149	2969	2226	1954	1753
98	1397	1320	2229	2970	5719	6329	6778	5149	2969	2226	1954	1753
99	1397	1320	2229	2970	5719	6329	6778	5149	2969	2226	1954	1753
1900	2031	2058	3647	5346	9629	10786	11088	8514	5070	3643	3187	2800
01	2031	2058	3647	5346	9629	10786	11088	8514	5070	3643	3187	2800
02	2031	2058	3647	5346	9629	10786	11088	8514	5070	3643	3187	2800
03	819	981	2060	3436	6751	8318	8185	6132	3423	2220	1734	1368
04	819	981	2060	3436	6751	8318	8185	6132	3423	2220	1734	1368
05	819	981	2060	3436	6751	8318	8185	6132	3423	2220	1734	1368
06	819	981	2060	3436	6751	8318	8185	6132	3423	2220	1734	1368
07	819	981	2060	3436	6751	8318	8185	6132	3423	2220	1734	1368
08	819	981	2060	3436	6751	8318	8185	6132	3423	2220	1734	1368
09	819	981	2060	3436	6751	8318	8185	6132	3423	2220	1734	1368
1910	2031	2058	3647	5346	9629	10786	11088	8514	5070	3643	3187	2800
11	2031	2058	3647	5346	9629	10786	11088	8514	5070	3643	3187	2800
12	2031	2058	3647	5346	9629	10786	11088	8514	5070	3643	3187	2800
13	2031	2058	3647	5346	9629	10786	11088	8514	5070	3643	3187	2800
14	2031	2058	3647	5346	9629	10786	11088	8514	5070	3643	3187	2800
15	819	2058	3647	5346	9629	10786	11088	8514	5070	3643	3187	2800

TABLE 20.—Chile. Table made from sums given in Table 19, beginning January, 1862.

SUMS OF ACTUAL RAINFALL.

Cycles.	Phase numbers.														
	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(1)	(2)	(3)	(4)
1	2120	3460	2770	4490	8450	10100	5790	2460	4820	5520	2630	1490	1050	3010	6080
2	3960	6580	4670	2210	1460	2490	3880	1500	800	2060	2770	8670	7630	6280	6740
3	3880	3040	2590	4270	1150	190	1560	2940	9050	6480	7320	7320	7740	4580	6170
4	2170	2780	960	980	7900	4500	8970	2320	7640	7640	10060	3820	2210	3500	560
5	650	1680	2820	(2820)	5420	10820	6020	6020	5390	4590	3260	3260	1670	2470	4350
6	4350	4220	4220	5170	2750	3910	3910	8880	10070	10070	8430	4560	4560	6640	4120
7	2100	2100	6830	2580	1550	1550	3210	1620	4780	4100	4400	8720	11280	3370	3170
8	3170	3260	5220	2920	2130	6130	4130	4130	8400	4380	8650	(3600)	1520	1600	1600
9	1520	4880	3280	600	6860	3960	3960	4985	4075	5470	8140	2610	4170	1190	1830
10	2060	1510	2920	3485	5140	4875	8125	4850	4480	4060	3840	1440	566	3610	4228
11	3726	5890	5340	3187	2106	130	2210	250	210	1094	1657	6827	3598	4288	2478
12	2068	160	1656	1186	1957	7176	2776	1250	590	960	1687	408	2589	2264	4794
13	8848	4630	4726	567	714	2472	5120	4109	8658	4880	1698	485	424	4109	8897
14	8493	3741	3418	(1581)	446	582	1579	5275	9160	10444	718	938	2045	496	182
15	235	992	8676	9018	4423	582	564	616	186	304	50	2195	3773	2554	2761
16	2969	1317	688	40	222	332	733	536	2248	1796	4385	3698	1031	376	877
17	0	176	38.	900	3349	6316	1382	836	1354	884	758	(0)	42	42	24
18	797	2920	614	2247	1722	3673	1591	1591	1012	237	832	844	428	302	734
19	734	3955	757	4295	2425	1491	897	897	166	510	60	60	190	852	470
20	1512	1512	2808	1731	1368	813	813	371	381	590	50	50	185	80	253
21	910	910	6643	1855	6958	2280	2280	933	738	291	170	170	1240	750	2392
22	3694	3694	4130	4111	7073	3368	3368	3289	1522	1610	655	510	510	1520	1590
23	3210	1733	3870	(2870)	1496	740	1163	1909	2162	730	805	486	1783	2841	4592
24	1703	1796	1133	520	2262	1745	1930	1520	2910	6227	4654	2859	2310	3405	987
25	320	1233	2641	1535	1047	3360	2822	4080	4087	2549	2069	733	1157	4036	590
26	2270	1555	5414	3405	6648	3792	978	963	1419	1615	1534	(1230)	2326	1098	3925
27	5181	4141	2715	3462	3574	1553	988	3222	1605	2412	4219	6826	5739	1357	533
28	918	1373	410	1471	1362	3484	8203	4561	7270	2919	2153	603	313	990	3717
29	6666	4819	3713	3491	1511	2338	2235	1894	2713	2108	5081	5616	10006	6377	2783
30	3051	1733	2441	2822	1296	2981	4380	8812	7430	13519	13047	1293	1240	2450	1685
31	3532	8567	3451	10757	10533	22182	9368	6177	6168	4155	576	2302	1657	3639	10457
32	16351	13035	11198	(4860)	2200	3451	1383	3495	4529	6093	15927	14571	5536	5657	2392
33	3450	1529	510	501	738	2154	2864	13472	3779	3697	2187	909	1445	679	285
34	1094	4784	9731	10565	17881	5736	7179	3029	1557	2132	369	71	3581	4011	6925
35	12188	9646	8120	4234	3906	450	1460	1421	1137	1578	4438	(9484)	8481	6869	5618
36	3916	1346	223	955	916	1271	558	364	5215	9114	6817	6337	5171	2866	449
37	2171	102	609	3202	6184	8909	6913	2958	6908	3144	1968	1864	879	484	854
38	265	2737	2948	5655	4808	1723	2055	1967	811	2756	1951	564	3673	6234	13591

39	9993	12160	1934	1248	3094	120	1092	851	641	7038	10577	5191	6221	6948	3814
40	917	4497	2912	903	3579	1443	7136	9364	8967	5405	7820	1904	3716	3192	2242
41	754	2177	8693	(12355)	5986	15961	6161	5289	2048	349	1526	3242	390	1740	2024
42	9691	17961	13105	6552	10493	3150	5615	1564	192	192	1772	1250	9038	17618	10368
43	11040	8119	3291	2923	2553	1991									

Sums of Normal Values of All Stations.

1	1846	1815	3005	4286	6788	7069	5747	3748	2840	2686	2479	1846	1815	3005	4286
2	6788	7069	5747	3748	2840	2686	2479	1846	1815	3005	4286	6788	6925	7213	5747
3	3748	2840	2686	2479	1846	1815	3005	4286	6788	6925	7213	7213	5747	3748	2840
4	2686	2479	1846	1815	3005	4286	6788	6925	7213	7213	5747	3748	2840	2686	2479
5	1846	1815	3005	(3005)	4286	6788	6925	6925	7213	5747	3748	3748	2840	2686	2479
6	2479	1846	1846	1815	3005	4286	4286	6788	6925	6925	7213	5747	5747	3748	2840
7	2686	2686	2479	1847	1815	1815	3013	4311	7001	7001	7403	7554	6000	3815	2877
8	2877	2693	2479	1847	1815	3013	4311	4311	7001	7403	7554	(6000)	3815	2877	2877
9	2693	2479	1847	1815	3013	4311	4311	7001	7403	7554	6000	3815	2877	2693	2479
10	1847	1815	3013	5665	7403	7554	6000	3815	2877	2693	2479	1854	1831	3058	4466
11	4745	5770	5555	4239	2022	1312	1105	642	754	1471	3650	5770	5555	4239	2022
12	1312	1105	642	754	2014	4745	5668	4239	2435	1608	1208	819	1520	3436	7534
13	8185	4777	2220	1551	900	2060	5094	8318	7158	2822	1734	1094	981	2748	6751
14	8252	4777	2220	(1551)	819	981	2748	6751	8318	7158	3423	2220	1551	185	243
15	642	1950	3861	3875	2766	1322	652	321	185	243	642	1060	2841	3861	3320
16	1322	803	501	321	185	243	602	1060	2841	3861	3875	2766	1322	803	501
17	321	185	243	851	2841	3861	3875	766	1322	803	501	(321	185	185	243
18	642	1060	2841	3861	3875	2766	1332	1332	803	501	321	185	243	642	1060
19	1060	2841	3861	3875	2766	1382	803	803	501	321	185	185	243	642	1060
20	2811	2811	3861	3878	2766	1322	1322	803	501	321	185	185	243	642	1060
21	2841	2811	3861	3878	2766	1322	1322	803	501	321	1220	1220	1093	1640	2090
22	3713	3713	3781	4148	3256	1981	1981	1614	1532	1490	1220	1093	1093	1640	2090
23	3713	3781	4148	(3256)	1981	1614	1532	1490	1220	1093	1640	2090	3713	3781	4148
24	3256	1981	1614	1532	1490	1156	1640	2090	3713	3781	4148	3256	1981	1614	1532
25	1490	1397	1320	2229	2970	5719	6329	6778	5149	2969	2226	1954	1753	1397	1320
26	2229	2970	5719	6329	6778	5149	2969	2226	1954	1753	1397	(1320)	2229	2970	6024
27	6778	5149	2969	2226	1954	1753	1358	2229	2970	5719	6329	6778	5149	2598	1959
28	1753	1397	1320	2229	4344	6329	6778	5149	2969	2226	1954	1753	1397	1320	2600
29	5719	6329	6778	5149	2969	2226	1954	1753	1358	2229	2970	5719	6329	6778	5149
30	2969	2226	1954	1575	1320	2229	2970	5719	6229	6778	5149	2969	2226	1954	1892
31	2058	3647	5346	9629	10786	11088	8514	5070	3643	3187	2800	2044	3647	5346	9629
32	10786	11088	8514	(5070)	3643	2994	2031	2058	3647	5346	9629	10937	8514	5070	3643
33	3187	2800	819	981	2060	3436	6751	8318	8185	6132	2822	1734	1368	819	981
34	2060	3436	6751	8318	8185	6132	3423	2220	1734	1368	819	981	2060	3436	6751
35	8318	8185	6132	3423	2220	1734	1368	819	981	2060	3436	(6751)	8318	8185	6132
36	3423	2220	1734	1368	819	981	2060	3436	6751	8318	8185	6132	3423	2220	1734
37	1368	819	981	2060	3436	6751	8318	8185	6132	3423	2220	1734	1368	819	981
38	2060	3436	6751	8318	7158	3423	2220	1734	1368	2031	2058	3647	5346	9629	10786
39	11088	8514	5070	3643	3187	2800	2031	2058	3647	5346	9629	10786	11088	8514	5070

TABLE 20—CONCLUDED.

SUMS OF NORMAL VALUES OF ALL STATIONS—Concluded.

CYCLES.	Phase numbers.														
	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(1)	(2)	(3)	(4)
40	3643	3187	2800	2031	2058	3647	5346	9629	10786	11088	8514	5070	3643	3187	2800
41	2044	3647	5346	(9629)	10786	11088	8514	5070	3643	3187	2800	2031	2058	3647	5346
42	9629	10786	11088	8514	5070	3643	3187	2800	819	819	2058	3647	5346	9629	10786
43	11088	8514	5070	3643	3187	2800	......	......	......	......	......	......	......	......	......
Sum actual, 1–23	63176	65140	79627	63116	77135	78480	74031	61667	87892	79000	73025	63161	60231	56724	68892
Sum normal, 1–23	69085	63981	65648	64351	64753	68482	74903	80899	85216	79167	73926	67321	61019	59974	65492
Quotient	90	101	120	97	118	114	98	75	102	99	99	91	98	93	104
Sum actual, 24–43	95471	103310	85492	81114	90571	87814	73320	75003	69389	77013	88686	66849	72879	78740	73227
Sum normal, 24–43	94966	91730	88076	87896	84420	85178	77761	77361	75677	77760	79143	79243	77242	79132	85125
Quotient	104	116	100	96	110	106	97	100	95	102	115	86	97	102	89
Sum actual, 1–43	158647	168450	165119	144630	167706	166294	147351	136670	157281	156013	161711	130010	133110	135464	142119
Sum normal, 1–43	164051	155711	153724	152247	149173	153660	152664	158260	160893	156927	153069	146564	138261	139106	150617
Quotient	98	107	106	96	113	109	98	87	99	100	107	90	97	98	95

Quotients are adjusted to make their mean 100.

TABLE 21.—South Australia. Table made from data of 50 stations in South Australia—given in "Meteorological Observations of the Adelaide Observatory, 1907." Table made from January, 1861, to December, 1907, inclusive.

MEAN ACTUAL RAINFALL IN HUNDREDTHS OF AN INCH.

CYCLES.	Phase numbers.														
	(10)	(11)	(12)	(13)	(14)	(15)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1	70	73	183	463	330	417	197	199	63	405	33	51	44	167	440
2	347	327	200	122	68	30	92	48	138	60	530	340	402	237	400
3	101	110	100	44	6	155	227	282	260	399	142	199	25	44	2
4	27	86	86	318	174	407	407	188	210	54	26	61	64	54	68
5	80	426	214	357	357	283	220	289	120	11	28	136	60	(60)	210
6	205	228	228	447	147	460	460	314	50	44	44	146	146	7	109
7	191	191	112	456	456	316	218	218	264	128	88	88	35	67	107
8	107	141	90	222	256	256	119	161	138	162	162	177	46	296	2
9	7	190	190	202	420	254	(493)	290	396	396	87	137	113	148	83
10	72	72	290	329	311	222	184	130	315	161	207	42	100	192	333
11	503	229	130	192	252	68	107	150	97	287	272	196	207	247	191
12	99	43	151	15	151	215	226	257	338	214	46	52	50	138	140
13	374	348	361	117	199	222	23	67	206	178	252	148	159	74	106
14	406	298	146	130	238	48	16	80	220	109	346	168	136	(64)	7
15	22	116	374	160	266	228	143	178	41	73	248	244	228	191	290
16	254	129	42	201	22	34	114	240	450	182	149	126	65	49	27
17	3	35	175	227	185	295	284	91	183	121	42	21	89	132	521
18	342	306	287	211	144	139	(82)	180	150	13	157	142	399	400	88
19	189	302	302	142	53	134	59	139	69	133	133	171	330	190	232
20	176	116	116	23	127	93	93	38	11	128	109	109	69	288	434
21	174	174	215	103	73	52	52	51	44	160	236	236	496	298	195
22	255	255	218	230	102	56	56	17	48	42	222	222	311	370	178
23	114	141	35	41	47	199	54	54	58	687	331	466	141	(393)	236
24	270	160	32	198	102	67	127	176	430	450	394	200	248	234	38
25	36	68	140	64	178	275	186	150	240	101	138	96	39	64	142
26	172	226	238	304	254	349	90	141	26	2	38	275	571	369	220
27	272	346	151	146	52	52	(8)	174	198	206	367	318	180	340	20
28	269	53	140	349	82	281	389	277	108	40	92	178	50	92	213
29	267	207	164	98	39	31	138	49	81	66	216	193	241	345	210
30	74	46	4	54	44	252	223	426	469	234	110	159	97	70	115
31	89	137	226	342	84	124	199	98	150	67	14	207	281	206	331
32	146	412	184	84	56	61	46	50	198	121	401	246	155	(212)	221
33	64	39	73	132	26	88	249	151	157	188	50	283	78	131	146
34	276	162	329	260	248	184	264	120	209	95	49	140	216	300	280
35	198	78	204	66	11	118	34	21	307	395	343	382	182	205	218
36	25	7	7	28	232	70	(177)	432	371	300	320	166	247	87	9
37	22	44	298	175	238	300	263	118	145	182	85				

MEAN NORMAL VALUES OF ALL STATIONS.

1	84	60	139	257	304	284	257	192	106	90	84	60	98	180	257
2	294	257	206	179	106	90	84	60	98	180	257	294	257	206	179
3	106	90	84	60	98	180	257	304	284	257	206	179	106	90	84
4	60	98	180	257	304	284	284	257	206	179	106	90	84	60	98
5	180	257	304	284	284	257	206	179	106	90	84	60	98	(98)	180
6	257	304	304	284	257	206	206	179	106	90	90	84	84	60	98
7	180	180	257	304	304	284	257	257	206	179	106	106	90	84	60
8	60	98	180	257	304	304	284	257	206	179	179	106	90	84	60
9	98	180	180	257	304	284	(257)	206	179	179	106	90	84	60	98
10	180	180	257	304	284	257	206	179	106	90	84	60	98	218	304
11	284	257	206	179	106	90	84	60	98	180	257	304	284	257	192
12	106	90	84	60	98	218	304	284	257	192	106	90	84	60	98
13	218	294	257	206	179	98	84	79	180	280	284	232	179	98	72
14	98	218	294	257	192	106	87	60	139	257	294	232	179	(98)	84
15	60	139	257	304	270	206	179	98	84	60	98	218	304	284	257
16	206	142	90	84	60	98	180	257	304	270	206	179	106	90	84
17	60	98	180	257	304	284	257	206	179	106	90	84	60	139	257
18	304	284	257	206	179	106	(90)	84	84	60	98	180	257	304	284
19	257	206	206	179	106	90	84	60	98	180	180	257	304	284	257
20	206	179	179	106	90	84	84	60	98	180	257	257	304	284	257
21	206	206	179	106	90	84	84	60	98	180	257	257	304	284	257
22	206	206	179	106	90	84	84	60	98	180	257	257	304	284	257
23	206	206	179	106	90	84	60	60	98	180	257	304	284	(257)	206
24	179	106	90	84	60	98	180	257	304	284	257	206	179	106	90
25	72	98	180	257	304	284	257	206	179	106	90	84	60	98	180
26	257	304	284	257	206	179	106	90	84	60	98	180	257	304	284
27	257	206	179	106	90	84	(60)	98	180	280	284	257	206	179	106
28	90	72	98	180	257	304	284	257	192	106	90	84	60	98	218
29	304	284	257	206	179	106	90	84	60	139	257	304	284	257	206
30	179	106	90	72	98	180	257	304	284	257	206	179	106	87	60
31	98	180	257	304	284	257	206	179	106	87	60	98	180	257	304
32	284	257	206	179	106	90	72	98	180	257	304	284	257	(206)	179
33	98	84	60	98	180	257	294	257	206	179	106	90	84	60	98
34	180	257	304	284	257	192	106	90	84	60	98	180	257	304	284
35	257	206	179	106	90	84	60	98	180	257	304	284	257	206	179
36	106	90	84	60	98	180	(257)	304	284	257	206	179	106	90	84
37	60	98	180	257	304	284	257	206	179	106	90	.....	.....	.....	.....
Sum actual, 1–18	3210	3348	3359	4243	3984	4049	3612	3332	3639	2997	2859	2474	2368	2567	3124
Sum normal, 1–18	2835	3226	3716	3996	3937	3636	3563	3198	2928	2918	2735	2648	2542	2470	2746
Quotient	109	100	86	102	97	107	97	100	119	99	100	89	89	100	109
Sum actual, 19–37	3118	2976	3078	2842	2048	2786	2707	2687	3316	3497	3648	3997	3932	4194	3538
Sum normal, 19–37	3502	3351	3370	3053	2979	3005	2882	2828	2992	3335	3658	3741	3793	3645	3506
Quotient	92	92	94	96	72	96	97	98	114	106	103	110	107	118	104
Actual total	6328	6324	6437	7085	6032	6835	6319	6019	6955	6494	6507	6471	6300	6761	6662
Normal total	6337	6576	7086	7049	6916	6641	6445	6026	5920	6253	6393	6389	6335	6115	6252
Quotient	99	95	90	99	86	102	97	99	116	103	101	100	99	110	106

Quotients are adjusted to make their means 100.

TABLE 22.—Jamaica. Observed per cent of normal rainfall. Prepared from table given by W. H. Pickering in "The Relation of Prolonged Tropical Droughts to Sun Spots," in the *Monthly Weather Review* for October, 1920.

YEARS.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1870	102	158	96	61	190	55	92	84	109	165	163	136
71	59	58	71	76	71	30	80	51	77	88	77	83
72	77	103	95	45	57	37	61	77	62	60	41	93
73	207	71	170	25	55	40	54	111	145	85	46	115
74	88	80	19	96	116	61	54	141	93	115	136	49
75	66	24	80	67	94	57	82	75	103	55	30	133
76	154	29	51	102	88	83	172	74	70	112	117	113
77	152	43	167	64	165	99	99	26	68	44	100	155
78	162	102	87	15	53	101	123	158	101	111	96	190
79	72	193	202	159	100	162	94	180	100	158	69	35
1880	111	29	34	61	127	47	81	140	54	39	29	157
81	31	146	40	101	112	85	100	91	104	120	99	66
82	74	70	110	73	90	36	79	70	119	89	70	78
83	140	127	127	73	58	76	66	79	106	80	67	58
84	121	125	80	40	74	105	53	74	84	94	65	48
85	44	54	46	103	54	51	64	91	84	63	62	307
86	136	166	83	139	58	355	131	198	80	79	48	111
87	154	84	74	98	102	129	151	101	78	84	106	15
88	35	69	53	79	232	103	56	80	110	43	60	203
89	122	33	130	147	86	191	128	75	111	104	57	59
1890	133	106	182	74	61	63	105	101	89	70	85	106
91	88	82	26	186	135	151	117	109	86	152	100	101
92	102	50	70	62	94	112	93	112	121	120	130	71
93	88	118	60	119	119	110	192	99	108	102	132	212
94	52	92	103	128	183	59	125	61	95	123	66	129
95	34	182	68	134	108	56	105	119	93	118	101	75
96	134	177	133	80	109	74	106	69	112	75	60	111
97	23	28	57	155	119	75	125	96	137	190	75	72
98	45	143	139	89	183	116	137	101	96	102	62	54
99	101	103	117	105	46	71	82	62	101	235	196	145
1900	133	151	76	124	85	94	151	79	110	64	68	116
01	100	43	103	56	67	214	159	95	144	96	131	106
02	145	111	132	118	98	157	72	79	80	71	73	163
03	49	51	99	107	116	91	91	186	73	72	75	95
04	87	169	213	130	83	232	90	80	88	163	102	78
05	200	108	232	113	90	154	58	90	112	122	88	141
06	86	187	172	176	145	175	88	102	145	83	99	41
07	66	136	10	27	56	91	90	68	73	104	56	90
08	111	184	106	76	54	178	88	102	82	109	86	138
09	111	59	89	80	75	98	116	119	216	117	276	34
1910	135	80	138	78	57	88	117	110	118	145	100	238
11	111	52	63	88	113	57	68	64	78	82	64	167
12	112	85	152	48	50	37	90	93	85	81	350	69
13	93	41	118	174	88	58	94	80	94	69	113	68
14	68	75	127	104	73	80	62	62	51	63	127	98
15	162	105	100	192	70	182	122	206	225	106	144	119
16	91	191	83	178	170	97	159	202	104	160	233	32
17	81	119	78	155	80	127	110	110	209	68	123	97
18	23	123	182	139	137	77	76	106	74	89	66	91
19	160	91	60	163	159	53	91	52	84	76	67	127
1920	72	87	106	6	90	......	......	......	......	......	......	......
Normals in inches,	3.92	2.75	3.21	4.56	9.13	6.53	4.75	6.82	7.38	10.16	7.64	5.07

TABLE 23.—Jamaica. Observed per cent of normal is tabulated, beginning January, 1870.

Cycles.	Phase numbers.														
	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(1)	(2)	(3)	(4)	(5)	(6)	(7)
1	102	158	96	61	61	190	55	92	(81)	109	165	165	163	136	59
2	58	71	76	76	71	30	80	51	77	88	77	83	77	103	95
3	51	37	61	77	62	60	41	93	207	71	170	25	55	40	54
4	111	115	46	115	88	80	19	106	61	54	141	104	136	49	66
5	24	74	94	70	75	103	55	82	154	40	102	86	176	72	112
6	115	98	167	114	99	62	56	100	158	102	51	53	112	130	111
7	(143)	72	193	180	100	162	137	100	158	52	100	29	34	94	47
8	81	140	54	34	157	31	146	40	101	112	85	96	101	120	99
9	66	74	70	110	73	90	36	79	70	119	89	70	78	140	127
10	100	58	76	66	79	106	80	67	(58)	121	121	125	80	40	74
11	105	53	74	84	84	94	65	48	44	54	46	103	103	54	51
12	64	91	84	63	63	62	307	136	136	166	83	139	58	58	355
13	131	198	80	80	79	48	111	154	154	84	74	98	102	102	129
14	151	101	78	28	84	106	15	35	35	69	53	79	232	232	103
15	56	80	110	110	43	60	203	122	33	33	130	147	86	191	128
16	(75)	111	104	57	59	133	106	182	74	61	63	105	101	89	70
17	85	106	85	26	186	135	151	117	109	86	152	100	101	102	50
18	70	62	94	112	93	112	121	120	130	71	88	118	60	119	119
19	110	192	99	108	102	132	212	52	(92)	103	128	121	125	61	95
20	123	66	129	108	68	134	108	56	105	119	106	101	75	134	177
21	133	94	74	106	69	112	75	60	111	23	28	106	119	75	125
22	96	137	190	75	72	94	39	89	183	116	137	101	96	102	62
23	78	103	117	105	46	71	82	62	101	235	196	139	151	76	124
24	85	94	151	79	110	64	68	116	72	103	56	67	214	159	95
25	(144)	96	118	145	111	132	118	98	114	79	80	71	73	163	49
26	51	99	107	116	91	91	186	72	75	95	87	169	213	130	83
27	232	90	80	88	163	102	78	200	108	232	113	90	154	58	90
28	112	122	88	141	86	187	172	176	(145)	175	88	102	145	83	99
29	41	66	136	10	27	56	91	90	68	73	104	56	90	111	184
30	106	76	54	178	88	102	82	109	86	138	111	59	89	80	75
31	98	118	216	117	276	34	135	80	138	78	57	88	117	110	118
32	145	100	238	111	52	63	88	113	57	68	64	78	82	64	167
33	112	85	152	48	50	37	90	93	85	81	350	69	67	118	174
34	(88)	58	94	80	94	69	117	68	68	75	127	104	73	80	62
35	62	51	63	127	98	162	162	105	100	192	70	182	122	206	225
36	106	144	119	91	191	83	178	170	97	159	202	104	160	233	32
Mean, 1-18	93	99	96	88	91	97	104	101	107	87	104	101	108	109	108
Smoothed	100	96	94	92	92	97	101	104	98	99	97	104	106	108	103
Mean, 19-36	99	91	114	94	92	88	107	93	92	110	108	92	111	104	104
Smoothed	98	101	100	100	91	96	96	97	98	103	103	103	104	106	106
Mean, 1-36	96	95	105	91	92	92	106	97	100	98	106	96	110	106	106
Smoothed	99	99	97	96	92	97	98	101	98	101	100	104	104	107	103

TABLE 24.—Tananarive, Madagascar. Rainfall in mm.

YEARS.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
1890	18880	15270	12380	13100	0	1302	240	58	58	15403	23901	29955	129747
91	11700	23843	35133	4528	469	224	557	534	1982	28173	3635	18389	129167
92	36374	33996	3007	5064	574	665	442	1175	424	5611	7517	28113	122962
93	25853	24182	18607	10001	4131	1412	1460	887	237	8219	1616	50343	146948
94	47306	21811	22957	1844	3496	597	849	3307	6244	1902	10327	40132	160772
95	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
96	16820	41155	6490	12505	630	1040	100	933	393	7320	15605	15455	118446
97	46065	15095	27500	4480	1108	100	170	55	690	7770	7960	44647	155640
98	41699	11800	13820	2785	472	1009	535	1650	380	3263	7385	36816	121614
99	23470	30281	37733	12616	2783	232	802	1056	91	14746	14009	10116	147936
1900	41449	33277	14280	2060	310	82	439	1112	4128	2709	3249	15104	118199
01	41200	23627	22918	894	294	1213	162	799	386	991	4068	37217	133769
02	12200	30358	21516	9423	1431	420	364	113	2096	5506	11549	18439	113415
03	44565	23810	25840	1852	700	631	756	836	1190	7226	19729	24218	151383
04	31777	24842	17356	697	905	2548	943	1717	1271	2680	3262	36547	124545
05	40502	53237	11665	8039	1140	215	756	1901	2381	6829	31347	35541	193553
06	4945	66995	24004	13270	320	225	670	70	3220	13825	10090	24760	166494
07	19105	16710	34655	3765	0	1685	1790	105	5155	7055	16425	54770	161220
08	20940	47040	18115	3740	3245	114	859	0	720	5310	8172	45237	153492
09	13099	20183	1675	6120	600	480	25	3135	4565	4663	6102	8565	69212
1910	21162	22798	26092	180	11	23	57	70	2	1950	14984	31284	120576
11	32681	27787	25301	3828	1322	1426	703	667	481	1617	16374	13227	125474
12	23301	15071	12141	7299	189	485	934	110	2325	2443	943	25459	90700
13	49075	44162	6064	1928	3770	273	463	419	4953	5238	16571	24286	157202
14	61814	46426	7412	5354	833	130	1579	328	80	5648	11917	7549	149070
15	27781	27075	22142	8352	3200	309	113	212	214	2464	15922	15098	122882
16	29355	24652	21576	5774	3132	593	613	571	661	5185	39063	44902	176077
17	20533	23850	8596	6541	263	154	1077	2391	864	1662	17139	52281	135351
18	19572	15787	11486	2159	2007	928	600	315	359	1963	13011	26605	94792
19	27480	28110	24442	1018	1261	2057	402	313	2538	3590	11537	33782	136530
1920	38211	51067	8087	4344	692	720	1069	312	247	605	14821	10635	130810
21	58273	24303	11229	513	4077	179	462	508	104	2624	20389	37662	160323
Mean.	305 28	293 10	178 80	53 45	14 02	6 99	6 45	8 27	15 34	61 03	128 58	289.40	1360 74

TABLE 25.—Tanañarive, Madagascar, beginning January, 1890.

Cycles.	Phase numbers.														
	(13)	(14)	(15)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
1	18080	15270	12380	13100	0	1302	240	58	58	15403	23901	20828	23843	35133	4528
2	469	224	557	534	1982	28173	3635	18389	6374	33996	3007	5064	574	665	442
3	1175	424	5611	7517	28113	25853	24182	18607	10004	4131	1412	1460	887	237	8219
4	1616	50343	47306	(21811)	22957	2670	597	849	3307	6244	1902	10327	40132		
5									16820	41155	9498	630	1040	100	933
6	393	7320	15605	15455	46065	21298	4480	1108	100	170	55	690	7770	7960	43173
7	11800	13820	2785	472	1009	535	1650	380	3263	22100	23470	30281	37733	12616	2783
8	233	802	1056	91	14746	12062	41449	33277	14280	2060	310	82	439	1112	4128
9	2709	3249	28151	23627	22918	894	294	1213	162	799	(386)	2580	37217	12200	30358
10	21516	9423	926	364	113	2096	5506	11549	18439	41565	23840	25840	1852	700	631
11	756	1013	7226	19729	24218	31777	24842	17356	697	905	2548	943	1717	1271	2680
12	3262	36547	40502	53237	11665	8039	1140	215	756	1901	2381	6829	31347	35541	4945
13	66995	24004	13270	(320)	225	670	70	3220	18825	10090	24760	19105	16710	34655	3765
14	0	1685	1790	105	5155	7055	16425	54770	20940	47040	18115	3740	3245	114	859
15	0	720	5310	8172	45237	13099	20183	1675	6120	600	252	3135	4565	4663	6102
16	8565	21162	22798	26092	1805	115	234	57	70	25	1950	14984	31284	32681	27787
17	25361	3828	1322	1426	703	667	481	1617	16374	13227	23301	15071	12141	7299	189
18	485	934	110	2325	2443	943	37367	44162	6064	1928	(3770)	273	463	419	4953
19	5238	16571	24286	61814	46426	7412	5354	833	130	1579	328	80	5648	11917	7549
20	27781	27781	27075	22142	8352	3200	309	113	212	214	26164	15922	15098	29355	24652
21	21576	5774	3132	593	613	571	661	5185	39063	44902	20533	23850	8596	8541	263
NORMAL VALUES IN HUNDREDTHS OF MM.															
1	30528	29310	17880	5345	1402	699	645	827	1534	6103	12858	29734	29310	17880	5345
2	1402	699	645	827	1534	6103	12858	28940	30528	29310	17880	5345	1402	699	645
3	827	1534	6103	12858	28940	30528	29310	17880	5345	1402	699	645	827	1534	6103
4	12858	28940	30528	(29310)	17880	3374	694	645	827	1534	6103	12858	28940		
5									30528	29310	11612	1402	699	645	827
6	1534	6103	12858	28940	30528	23645	5345	1402	699	645	827	1534	6103	12858	29734
7	29310	17880	5345	1402	699	645	827	1534	6103	20899	30528	29310	17880	5345	1402
8	699	645	827	1534	6103	20899	30528	29310	17880	5345	1402	699	645	827	1534
9	6103	12858	29734	29310	17880	5345	1402	699	645	827	(1534)	6924	28940	30528	29310
10	17880	5345	1050	645	827	1534	6103	12858	28940	30528	29310	17880	5345	1402	699
11	645	1180	6103	12858	28940	30528	29310	17880	5345	1402	699	645	827	1534	6103
12	12558	28940	30528	29310	17880	5345	1402	699	645	827	1534	6103	12858	28940	30528
13	29310	17880	5345	(1402)	699	645	827	1534	6103	12858	28940	30528	29310	17880	5345
14	1402	699	645	827	1534	6103	12858	28940	30528	29310	17880	5345	1402	699	645
15	827	1534	6103	12858	28940	30528	29310	17880	5345	1402	672	827	1594	6103	12858
16	28940	30528	29310	17880	5345	1402	699	645	827	1534	6103	12858	28940	30528	29310

17	17880	5345	1402	699	645	827	1534	6103	12858	28940	50328	29310	17880	5345	1402
18	699	645	827	1534	6103	12858	29734	29310	17880	5345	(1402)	699	645	827	1534
19	6103	12858	28940	30528	29310	17880	5345	1402	699	645	827	1534	6103	12858	28940
20	30528	30528	29310	17880	5345	1402	699	645	827	1534	6103	12858	28940	30528	29310
21	17880	5345	1402	699	645	827	1534	6103	12858	28940	30528	29310	17880	5345	1402
Sum actual, 1–11	88747	101888	121603	102700	162123	126660	106875	102786	103501	171528	90630	98675	153204	71904	70575
Sum normal, 1–11	101786	104494	111073	123029	134733	123300	117027	111975	128374	127305	113452	107076	120918	67907	81702
Quotient	87	99	111	85	121	104	93	93	82	136	81	93	128	107	87
Smoothed	91	99	98	106	103	106	97	89	104	100	103	101	109	107	94
Sum actual, 12–21	129283	139006	139595	176226	122622	41771	82754	111847	109154	121506	97553	102989	129097	165185	108361
Sum normal, 12–21	146427	134302	133800	113588	96446	77817	83942	93261	88571	111335	144287	129272	145492	144398	141274
Quotient	88	103	103	153	126	53	97	119	122	108	67	79	88	114	76
Smoothed	89	98	120	127	111	92	90	113	116	99	85	78	94	93	93
Total sum, actual	218030	240894	261198	278926	284745	168431	189629	214633	212655	293034	188183	201664	282301	237179	178939
Total sum, normal	248213	238796	244873	236617	231179	201117	200969	205236	216944	238640	257739	236348	266410	212305	222976
Quotient	88	101	107	118	123	84	94	105	98	123	73	85	106	112	80
Smoothed	90	99	109	116	108	100	94	99	109	98	94	88	101	99	93

SUPPLEMENTARY TABLES.

Data collected during the investigation, but not used, published to make available for other problems. All this information was obtained in manuscript form with the exception of that from India, which was collected from the large annual volumes of "India Rainfall," 1901-1918.

SUPPLEMENTARY TABLE No. 1.—Showing total monthly and annual rainfall recorded at Alexandria and the normal for 1891-1920 in mm.

YEARS.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
1891	9	9	7	0	0	0	0	0	6	4	2	76	113
92	51	11	13	2	2	0	0	0	0	11	85	23	198
93	89	27	53	2	3	drops	0	0	drops	6	11	107	298
94	52	17	40	drops	6	0	0	0	0	0	102	30	247
95	1	0	4	16	0	0	0	0	0	0	46	100	167
96	69	45	19	2	0	0	0	0	1	1	41	27	205
97	126	12	14	0	0	0	0	0	0	14	1	107	274
98	57	4	1	0	0	0	0	0	0	0	60	144	266
99	73	23	2	0	0	0	0	0	0	58	25	64	245
1900	14	33	16	0	2	0	0	0	0	0	10	125	200
01	83	0	4	0	0	0	0	0	14	0	30	57	188
02	104	8	4	6	1	0	0	0	drops	5	36	92	256
03	90	34	14	1	drops	drops	0	drops	0	drops	10	24	173
04	63	12	drops	2	drops	0	0	1	drops	3	65	50	196
05	46	16	14	drops	0	0	0	0	0	28	7	159	270
06	32	43	6	3	9	drops	0	drops	0	19	64	31	207
07	25	13	38	7	0	0	0	2	drops	0	50	25	160
08	80	47	14	3	0	1	0	0	drops	0	39	76	260
09	43	41	0	51	drops	0	0	0	0	21	22	31	209
1910	86	8	19	2	3	0	0	drops	4	0	30	28	180
11	28	42	12	2	drops	0	0	0	drops	8	17	79	188
12	21	24	9	0	2	0	0	0	0	drops	10	27	93
13	12	36	21	drops	drops	0	drops	0	drops	14	79	98	260
14	28	31	7	8	0	drops	0	drops	drops	drops	29	103	206
15	19	19	19	1	drops	0	0	0	drops	0	14	10	82
16	109	14	8	2	drops	0	0	drops	drops	0	21	45	199
17	66	39	13	1	drops	0	0	0	drops	8	8	65	200
18	39	31	6	drops	0	0	0	0	0	drops	53	50	179
19	36	4	1	drops	drops	0	0	0	0	3	54	126	224
1920	35	42	11	drops	drops	drops	drops	0	0	0	6	39	133
Normal	53	24	13	4	1	0	0	0	1	7	34	67	204

NOTE.—"Drops" indicate that rain was too small to measure.

SUPPLEMENTARY TABLE No. 2.—Showing total monthly and annual rainfall recorded at Khartoum (Gordon College) and the normal for 1899-1920 in mm.

YEARS.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
1899	0	0	0	0	0	1	13	12	......	6	0	0	[32]
1900	0	0	0	drops	0	23	80	47	23	8	drops	0	181
01	0	0	0	0	0	16	24	16	drops	8	0	0	64
02	0	0	0	0	0	0	116	5	2	drops	0	0	123
03	0	0	0	0	24	0	18	12	14	drops	0	0	68
04	0	0	drops	0	drops	0	34	76	20	drops	0	0	130
05	0	0	drops	0	6	16	8	75	4	50	0	0	159
06	0	0	0	0	0	4	90	96	24	13	0	0	227
07	0	0	0	0	0	drops	14	163	12	0	0	0	189
08	0	0	drops	0	0	1	64	44	31	12	0	0	152
09	0	0	drops	drops	1	drops	71	26	11	3	0	0	112
1910	0	0	0	0	0	35	38	15	22	drops	0	0	110
11	0	0	0	0	7	drops	55	12	2	1	0	0	77
12	drops	0	drops	0	drop	drops	drops	98	18	0	0	0	116
13	0	0	0	drops	drops	0	7	70	22	2	0	0	101
14	0	0	drops	0	drops	1	30	54	11	5	0	0	101
15	0	0	0	0	9	8	19	63	77	0	0	0	176
16	0	0	0	drops	14	22	33	57	20	0	0	0	146
17	0	0	0	0	drops	34	0	24	18	0	0	0	76
18	0	0	0	0	drops	14	30	50	drops	drops	0	0	94
19	drops	0	0	drops	7	drops	38	23	7	drops	0	0	75
1920	0	0	drops	drops	4	0	103	185	49	drops	0	0	341
Normal	0	0	0	0	3	8	40	56	18	5	0	0	130

NOTE.—"Drops" indicate that rain was too small to measure. Brackets [ ] are used to denote that the observations are incomplete.

SUPPLEMENTARY TABLE No. 3.—Showing total monthly and annual rainfall recorded at Adis Ababa and the normal for 1898-1920 in mm.

YEARS.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
1898	8	15	105	73	41	121	352	290	151	18	10	0	1184
99	2	11	......	......	......	......	......	......	......	......	......	......	......
1900	......	......	......	......	......	[108]	283	328	194	0	13	5	[931]
01	16	54	124	100	36	222	277	250	128	21	0	13	1241
02	1	76	49	89	42	172	236	291	184	0	11	1	1152
03	29	25	83	88	268	191	269	267	224	20	0	8	1472
04	0	37	136	57	58	124	350	196	176	40	0	0	1170
05	5	7	48	88	41	94	294	352	113	1	45	0	1000
06	9	156	189	103	60	132	380	358	119	16	28	0	1550
07	0	20	11	140	36	61	176	284	108	14	83	drops	933
08	38	7	10	70	5	91	284	365	220	28	8	0	1126
09	48	0	18	133	130	208	210	364	174	0	10	drops	1295
1910	0	1	25	48	66	147	268	334	226	20	0	14	1149
11	7	4	67	38	31	140	306	230	155	46	64	0	1088
12	53	139	51	43	20	182	286	319	111	0	0	0	1204
13	0	65	66	102	108	104	192	311	134	0	0	0	1082
14	10	94	77	125	18	68	288	323	308	100	0	32	1443
15	2	23	105	126	133	121	345	378	570	59	27	11	1900
16	64	57	91	74	148	294	248	418	321	5	drops	7	1727
17	28	39	10	115	194	279	281	287	270	53	0	34	1590
18	0	84	70	104	74	106	208	264	51	drops	drops	0	961
19	11	47	66	32	43	90	316	253	133	0	0	0	991
1920	2	10	61	74	26	151	280	300	165	5	3	0	1077
Normal	15	48	70	87	75	146	279	307	192	20	14	6	1259

NOTE.—"Drops" indicate that rain was too small to measure. Brackets [ ] are used to denote that the observations are incomplete.

SUPPLEMENTARY TABLE No. 4.—Copenhagen. Rainfall in mm.

From Meteorological Institute, Copenhagen. Sent by Prof. Carl Ryder.

YEARS.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
1820	.....	.....	.....	.....	.....	.....	.....	.....	55	50	60	23	.....
21	64	5	22	25	74	4	21	31	63	42	81	67	499
22	44	17	63	15	3	2	138	116	41	28	33	12	512
23	39	85	33	44	36	76	66	45	50	32	45	69	620
24	26	26	43	27	40	38	34	76	53	56	150	119	688
25	40	45	23	100	41	70	27	99	83	51	131	40	750
26	10	71	41	44	7	22	41	25	34	87	54	51	487
27	97	5	93	45	55	39	56	48	40	53	40	70	641
28	28	32	64	54	24	54	145	88	70	38	38	58	693
29	22	90	21	27	34	43	126	81	61	107	83	7	702
1830	35	70	38	103	60	107	56	100	72	28	9	27	705
31	45	61	49	19	40	130	18	52	27	34	61	21	557
32	18	1	36	2	40	47	71	73	50	28	35	34	435
33	19	58	67	29	19	61	30	87	43	73	50	204	740
34	79	29	40	14	39	29	3	43	68	49	78	32	503
35	23	56	24	55	82	15	2	40	56	45	43	29	470
36	103	53	67	31	15	27	91	30	70	32	62	70	651
37	15	50	33	36	38	28	20	57	54	38	51	31	451
38	38	12	59	93	20	30	44	133	33	53	25	16	533
39	48	22	13	43	43	56	55	36	73	10	43	27	469
1840	74	29	5	5	60	31	63	66	59	58	54	13	517
41	71	11	25	29	30	99	96	48	76	171	62	51	769
42	17	0	66	0	24	94	36	3	58	26	48	27	399
43	125	61	18	50	14	104	69	47	26	100	54	17	685
44	121	61	44	15	21	34	54	123	27	90	57	17	664
45	35	21	34	17	122	16	75	105	63	104	49	83	724
46	58	55	83	37	22	28	74	22	12	34	26	36	487
47	32	37	39	43	62	51	39	26	66	34	24	16	469
48	9	55	38	63	10	97	38	110	36	104	56	19	635
49	50	44	34	19	9	104	121	45	48	95	27	35	631
1850	17	53	12	54	38	37	117	61	57	54	79	21	600
51	32	30	63	86	48	68	46	28	27	45	85	14	572
52	55	62	11	22	52	80	5	68	69	74	101	81	680
53	56	42	22	51	36	37	75	64	46	34	17	7	487
54	45	30	20	21	47	46	27	134	67	39	36	70	582
55	30	8	35	41	60	55	74	76	30	80	6	35	530
56	44	41	3	66	49	57	63	40	57	23	67	64	574
57	40	18	32	57	10	15	32	43	28	38	27	19	359
58	29	9	19	17	93	27	51	55	14	31	23	35	403
59	29	57	38	52	13	51	34	52	107	45	61	65	604
1860	34	36	33	51	40	93	23	132	51	55	24	25	597
61	20	48	62	13	28	76	106	51	73	6	84	29	596
62	34	24	24	20	28	86	80	34	89	79	31	68	597
63	42	35	49	47	25	60	65	64	75	27	23	78	590
64	23	23	47	15	28	119	43	152	86	41	61	6	644
65	28	12	13	7	16	29	55	57	31	56	48	4	356
66	44	93	32	72	91	44	53	77	65	26	77	55	729
67	68	68	16	74	48	55	125	18	76	65	54	34	701
68	27	53	58	52	7	3	8	60	64	61	25	100	518
69	25	30	14	10	74	32	23	63	42	59	37	32	441
1870	32	6	9	16	19	33	12	60	65	99	47	33	431
71	84	21	19	21	16	75	80	26	84	16	25	20	487
72	35	18	57	45	86	51	61	30	89	90	56	64	682
73	36	11	9	28	73	56	114	84	69	99	55	33	667
74	40	7	45	31	15	25	87	68	67	33	60	43	521
75	66	2	31	10	24	68	50	46	38	62	72	18	482
76	12	51	69	29	40	54	45	34	76	34	21	50	515
77	79	54	24	19	44	39	100	123	43	70	40	38	673
78	48	15	36	21	57	58	35	46	49	41	93	29	528
79	17	42	8	49	39	57	108	111	29	40	17	5	522
1880	8	41	14	31	13	41	92	8	59	123	105	53	588
81	6	20	26	3	47	20	93	66	72	61	52	35	501
82	24	16	45	40	18	81	46	88	46	53	67	29	553
83	22	10	5	17	22	37	87	55	54	67	84	46	506
84	78	49	49	19	30	27	75	44	35	102	36	55	599
85	3	36	22	17	49	78	15	83	92	99	18	20	552
86	40	7	16	28	37	42	50	29	46	73	24	59	451
87	5	10	23	41	69	24	44	43	52	49	45	54	459
88	29	26	71	19	44	54	96	48	22	43	45	56	553
89	15	31	26	34	43	25	60	107	88	72	15	14	530

TABLE 4—CONCLUDED.

YEARS.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
1890 ...	42	3	31	47	23	45	91	93	15	74	33	2	499
91 ...	36	13	51	21	73	69	97	170	42	61	38	60	731
92	56	12	25	37	36	89	26	94	50	90	7	37	559
93	22	72	30	6	32	19	51	57	68	141	63	38	599
94	34	50	40	62	46	34	136	65	35	93	42	34	671
95	17	11	40	16	38	48	86	87	14	63	78	66	564
96	22	8	78	42	30	42	32	81	100	84	31	40	590
97	9	12	93	52	47	33	43	68	94	9	32	41	533
98	46	42	46	51	101	96	59	51	67	11	39	76	685
99	68	38	37	54	23	15	32	16	97	43	55	39	517
1900	54	45	27	29	27	34	93	69	63	132	36	71	680
01	29	13	49	56	44	150	27	52	36	23	74	62	615
02	48	11	56	18	86	36	51	69	39	43	5	52	514
03	47	48	18	74	10	60	54	90	61	133	61	20	676
04	37	44	38	53	66	42	23	36	12	51	78	50	530
05	32	40	47	64	14	47	56	170	64	78	30	7	649
06	62	41	34	21	30	52	43	85	44	32	80	26	550
07	32	25	25	35	45	90	65	63	10	20	40	86	536
08 ...	23	50	34	52	80	56	50	72	61	9	34	20	541
09	33	19	31	39	32	64	46	40	45	46	62	87	544
1910	54	93	12	54	61	40	89	64	46	14	76	57	660
11	22	64	31	35	58	70	57	38	21	85	78	58	617
12	28	34	41	39	27	49	46	135	28	67	73	93	660
13	26	21	44	20	13	28	50	56	51	62	76	76	523
14	31	34	80	60	30	15	77	39	57	35	57	67	582
15	66	35	23	32	42	10	72	43	36	16	38	109	522
16	87	38	25	38	37	86	43	128	45	77	61	92	737
17	45	9	34	41	10	19	40	88	50	111	95	22	564
18	29	41	3	28	18	47	88	76	67	32	25	77	531
19	38	32	29	53	7	40	60	57	48	31	40	90	525
1920	60	28	19	102	100	38	81	95	34	2	10	54	623
21	77	15	20	22	34	48	36	101	35	53	51		...
Means	40 6	34 2	35 8	37 4	39 7	51 1	60 0	67 7	54 3	58 4	51 1	46 2	576 5

SUPPLEMENTARY TABLE No. 5.—Rainfall of agricultural districts of the state of South Australia.
All stations used.

YEARS.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
1908	50	47	123	64	246	269	99	198	263	215	32	42	1648
09	47	34	51	168	247	266	258	379	108	145	100	27	1830
1910.........	43	18	276	18	330	231	328	154	268	158	119	73	2016
11	29	192	56	27	208	208	174	135	171	69	21	159	1449
12.........	03	68	122	46	41	268	206	172	210	105	163	79	1483
13	13	129	173	42	(90)	33	94	182	215	182	83	98	1334
14.........	31	28	98	132	106	61	105	26	49	51	147	98	932
1915	42	19	20	119	188	268	186	290	239	80	21	34	1506
16	50	12	25	75	115	414	343	277	202	176	195	88	1972
17	123	149	105	47	301	245	314	249	282	187	101	89	2192
18	34	22	53	90	200	186	160	240	40	157	19	38	1239
19.......	30	237	22	56	153	106	109	129	169	95	39	148	1293
1920	32	04	44	76	158	375	197	281	231	158	218	94	1868
Means	41	74	.90	.74	1 83	2 25	1 98	2 09	1 88	1 37	.97	82	......

CORRELATION OF OLD AND NEW METEOROLOGICAL DISTRICTS OF INDIA.

Old No.	OLD NAME.	New No.*	Old No.	OLD NAME.	New No.*
1	Tenasserim	2	31	N W Frontier Province	14
2	Lower Burma, Deltaic	2	32	West Punjab	12
3	Central Burma, Deltaic	2	33	Malabar	30
4	Upper Burma, Deltaic	3	33*a*	Travancore	30
5	Arakan	3	34	Madras, South Central	31
6	East Bengal	5	35	Coorg	29
7	Assam Surma	4	36	Mysore	29
8	Assam Hills	4	37	Konkan	25
9	Assam Brahmaputra	4	38	Bombay, Deccan	26
10	Deltaic Bengal	5	39	Hyderabad, North	28
11	Central Bengal	5	40	Kkandesh	26
12	North Bengal	5	41	Berar	22
13	Bengal Hills	5	42	Central Province, West	23
14	Orissa	6	43	Central Province, Central	23
15	Chota Nagpur	7	44	Central Province, East	24
16	South Bihar	8	45	Gujarat	19
17	North Bihar	8	46	Kathiawar and Cutch	19
18	United Provinces, East	9	47	Sind	16
19	South Oudh	9	48	Baluchistan Hills	15
20	North Oudh	9	49	Central India, East	20
21	United Provinces Central	10	49*a*	Central India, East	21
22	United Provinces, West	10	50	Rajputana, E. Central India W	18
23	United Provinces, East Sub	9	51	West Rajputana	17
24	United Provinces, West Sub	10	52	Madras, East Coast North	33
25	United Provinces, Hills	10	52*a*	Madras, East Coast North	33
26	Southeast Punjab	11	53	Hyderabad, South	28
27	South Punjab	11	54	Madras Central	32
28	Central Punjab	12	55	Madras East Coast Central	33
29	Punjab, Submontane	11	56	Madras, East Coast South	31
30	Punjab Hills	13	57	Madras, South	31
31	North Punjab	14			

*New number, as used in these tables and "India Rainfall." Names of each district will be found at head of its part of table.

SUPPLEMENTARY TABLE No. 6.—The rainfall of the thirty-three districts of India, in inches, 1901-1918.

No. 1. BAY ISLES.

YEARS.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1907	322	0	345	43	1329	970	1397	1457	546	1061	1885	1198
08	41	168	0	70	1504	2327	1525	2246	1260	625	475	5
09	5	211	137	395	1324	1794	1901	1027	1469	1453	852	733
1910	53	45	453	356	612	1267	1025	1007	2197	1064	677	361
11	14	17	0	318	859	1679	1125	713	2216	1023	193	513
12	1925	1	0	43	629	2206	1726	1167	1221	981	457	55
13	171	1	3	5	559	1724	1375	731	1489	1123	847	572
14	0	0	0	85	895	1576	2182	1619	1119	353	667	793
15	89	111	65	81	917	999	1077	917	1311	1266	826	1083
16	0	0	0	2	1919	1772	1249	1673	1629	1187	619	401
17	24	7	273	9	976	938	1208	1352	1373	665	671	792
18	125	9	17	33	1715	1519	592	1462	839	585	......	......

TABLE 6—Continued.

No. 2.—Lower Burma.

Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1901	0	196	22	46	859	2059	2400	3951	1438	1240	165	7
02	....	29	39	80	1809	1987	2938	2130	1925	419	47	67
03	0	......	6	41	931	2264	2691	2408	1884	998	196	28
04	0	16	50	349	1083	3055	3244	2612	3039	396	552	21
05	2	15	20	10	1234	2933	3148	2134	2049	710	73	66
06	22	0	3	38	1148	2063	2571	1494	2047	667	220	3
07	35	3	204	28	1785	2649	2541	3600	1677	1017	73	151
08	3	2	14	101	1013	2769	2795	3113	1399	840	705	1
09	4	42	44	100	1324	2512	3452	2364	1960	926	514	16
1910	12	35	338	299	1627	1719	1830	2701	2215	697	299	9
11	5	6	20	392	950	2765	2950	3258	1561	908	13	3
12	122	6	10	45	1439	2326	2866	2656	1437	749	322	5
13	8	14	47	2	952	2270	3271	2817	1657	654	778	6
14	2	9	6	153	1001	3237	4027	3186	1278	724	282	187
15	21	8	42	146	1771	2306	3066	2687	1400	1201	216	319
16	0	3	15	114	1114	3635	1768	2435	2135	795	500	47
17	10	11	100	92	771	2988	3110	2462	1953	1223	197	66
18	12	0	48	127	2700	2524	2766	3313	2349	620		

No. 3.—Upper Burma.

Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1901	6	80	4	50	718	2316	2504	2610	1724	978	248	20
02	....	4	4	170	685	2178	3750	1615	1606	434	20	8
03	4		36	16	608	2116	1850	2815	1594	933	331	2
04	0	10	9	358	706	3056	3358	2211	1392	338	514	26
05	9	30	256	76	1004	2267	3352	2656	1760	658	34	146
06	6	54	8	32	852	2674	2802	1524	1713	568	102	4
07	38	4	83	64	498	558	434	534	581	460	9	126
08	17	3	6	88	467	641	529	857	635	328	831	0
09	5	3	1	167	763	653	697	888	592*	601	281	67
1910	6	15	114	290	716	682	624	659	857	710	176	0
11	14	3	41	347	579	877	555	646	680	564	23	1
12	12	9	19	74	553	751	648	914	598	652	127	10
13	9	19	39	31	413	779	722	813	649	655	206	21
14	1	15	17	92	656	1200	691	698	656	593	135	200
15	1	11	63	139	1037	840	661	661	641	533	125	100
16	5	8	4	126	442	811	719	926	963	624	307	63
17	2	57	8	126	399	787	450	1023	1008	723	226	4
18	3	2	35	110	1033	624	583	827	680	528		

No. 4.—Assam.

Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1901	68	52	115	1039	726	2125	1779	2005	1335	819	413	3
02	32	36	377	1475	149	2397	2181	2130	1652	363	35	8
03	47	100	426	574	817	2564	1855	2525	1398	683	294	3
04	41	251	235	2020	1467	1785	2292	1916	1138	475	268	17
05	51	82	760	842	1070	3308	2090	2839	1279	1251	25	100
06	36	254	339	1235	1394	1743	2416	2710	1295	643	185	4
07	236	128	364	1028	799	1928	2155	1221	1585	170	17	50
08	70	144	106	776	1217	1472	1880	1396	1459	401	30	0
09	87	33	16	803	1196	2154	1351	1742	915	499	111	39
1910	47	110	541	789	985	2147	2374	1530	993	933	49	22
11	304	81	358	917	1714	1858	2293	1600	1530	943	103	13
12	40	241	481	1194	943	1685	2065	1664	952	643	188	32
13	53	338	476	1321	1443	1724	1767	1403	1019	822	48	175
14	26	322	309	854	1087	1175	1520	1826	1215	279	39	51
15	34	204	293	792	2309	1852	2468	1815	997	411	40	16
16	77	118	437	921	1117	1337	1816	1614	1197	899	120	23
17	47	381	128	723	715	2109	1838	138[illegible]	1313	715	138	6
18	16	65	563	622	1109	2200	2649	2108	1386	283	....	....

TABLE 6—Continued.

No. 5.—Bengal.

Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1901	91	94	48	260	646	1547	1646	1392	1169	285	252	10
02	4	4	242	642	913	1442	2060	1524	1914	275	24	10
03	44	82	162	97	512	1667	1076	1836	1226	656	54	0
04	18	97	76	433	1154	781	1882	1346	820	374	65	5
05	78	140	380	422	938	967	2137	2186	1540	546	2	51
06	88	320	180	68	657	1190	1866	2149	1000	538	67	0
07	6	83	322	348	612	1358	1549	927	979	124	4	58
08	80	58	32	160	662	1408	1546	882	938	152	36	0
09	22	21	3	558	596	1904	1052	2380	972	532	72	78
1910	60	44	112	241	687	1544	1908	1388	961	734	13	0
11	37	10	186	338	1052	1686	1410	1286	1138	608	45	0
12	6	64	306	624	784	1384	1688	1365	771	619	365	0
13	4	283	113	160	1017	2477	1473	1451	1147	618	80	73
14	1	212	101	534	1031	885	1655	1388	885	147	12	88
15	17	81	325	247	1115	1607	1427	1537	1023	527	100	0
16	5	44	18	587	388	1798	1478	1708	1441	1165	191	1
17	2	122	71	312	701	1572	1651	1192	1020	1357	52	0
18	3	1	160	411	1062	2045	1475	1970	963	108	......	......

No. 6.—Orissa.

1901	180	254	44	173	298	309	1258	1002	837	346	549	0
02	23	1	92	313	322	515	1952	1264	679	119	22	170
03	34	106	69	83	254	641	1410	1116	1124	1117	122	6
04	1	49	86	19	361	1192	1010	1216	917	434	2	16
05	123	61	300	195	429	375	1057	787	1087	292	2	3
06	113	389	132	12	241	801	1152	825	1041	501	40	25
07	1	95	224	456	208	941	689	2354	648	103	13	96
08	144	4	63	23	193	1139	1212	1974	799	191	0	0
09	24	64	16	520	247	1181	1570	962	980	173	2	228
1910	67	4	9	148	257	932	1318	1211	1042	940	0	0
11	0	38	135	128	234	1350	621	1110	988	356	24	1
12	4	229	109	198	150	480	1368	1384	812	319	354	0
13	7	249	65	28	427	1056	2010	1126	581	458	110	6
14	0	134	49	213	772	860	1569	1072	1418	66	0	27
15	54	95	173	98	289	624	934	1060	1066	645	843	0
16	0	19	2	77	180	1458	883	1193	718	975	261	0
17	1	385	123	83	457	1292	1226	1263	958	1517	67	0
18	19	1	85	126	514	1336	694	1102	722	20	......	......

No. 7.—Chota Nagpur.

1901	359	282	45	62	145	293	1018	1623	1050	129	39	0
02	19	40	51	95	231	308	1721	833	1185	54	31	14
03	87	66	38	129	229	533	874	1112	831	886	3	0
04	5	71	168	37	451	1263	1963	1502	405	106	6	1
05	171	217	200	147	230	158	1781	962	1360	83	0	11
06	188	533	141	5	107	644	1461	937	749	307	30	6
07	9	227	313	95	74	1289	742	1917	875	2	0	108
08	65	160	17	1	186	813	1316	1451	610	108	0	1
09	114	47	5	332	109	1067	1055	1415	1218	84	0	61
1910	85	29	15	136	177	954	977	1101	969	320	25	0
11	5	0	123	29	141	1482	602	1544	1028	336	163	0
12	11	97	82	95	135	466	1430	1396	450	92	227	0
13	11	527	187	4	286	1425	1289	1498	650	316	80	51
14	0	85	97	80	514	408	1129	1258	631	80	0	29
15	39	155	106	35	184	433	973	820	800	207	178	0
16	0	64	1	67	86	1006	841	1173	785	923	67	0
17	6	170	64	28	375	1155	1272	1645	900	1016	4	4
18	16	4	16	47	251	1253	500	1526	680	0	......	

TABLE 6—Continued.

No. 8.—Bihar.

Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1901	220	79	46	5	243	264	864	1230	562	32	28	0
02	12	2	96	64	224	433	1375	842	1331	106	4	9
03	18	21	8	15	78	678	364	1240	664	567	0	0
04	34	8	12	14	446	697	1599	1416	313	394	37	10
05	58	112	132	88	303	178	1566	1928	1398	42	0	2
06	59	224	34	4	165	730	1388	1602	462	132	1	0
07	5	236	152	83	134	894	966	929	871	12	0	7
08	60	161	23	7	133	337	737	644	591	85	0	1
09	24	26	0	270	91	1666	1049	1361	699	132	0	19
1910	10	18	21	41	190	971	1273	1368	982	317	100	0
11	31	0	86	52	167	1313	719	1683	1240	532	71	0
12	19	19	98	101	250	559	1382	1203	379	42	289	0
13	0	148	78	5	407	1542	992	1414	1028	274	15	140
14	0	84	33	127	396	375	1163	1812	398	38	0	4
15	31	195	106	23	378	575	1194	1492	737	276	154	3
16	1	63	0	90	71	1112	1554	1284	1088	602	10	0
17	11	75	37	27	432	928	1338	878	1078	561	0	1
18	25	0	8	106	356	957	885	1990	937	29	......	......

No. 9.—United Provinces, East.

Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1901	245	125	36	4	61	186	862	1064	2434	19	0	6
02	16	6	10	10	94	133	1676	626	1011	54	3	0
03	30	1	4	2	55	202	628	1690	1065	1323	0	10
04	32	6	24	1	104	587	1350	1236	343	248	67	101
05	57	90	82	19	70	63	1294	1342	687	18	0	6
06	22	226	23	0	58	534	1366	1171	437	23	0	0
07	7	292	60	72	35	162	707	1164	73	0	0	0
08	75	1	22	6	18	206	1022	1254	295	38	0	2
09	33	23	0	259	20	930	1588	719	524	23	0	85
1910	16	1	1	5	92	605	774	1295	860	377	123	0
11	168	0	117	8	12	380	321	1149	1555	334	148	1
12	57	20	23	17	57	188	1279	1046	540	4	110	3
13	1	138	122	2	242	627	783	703	328	47	0	46
14	5	54	76	38	179	140	1642	1262	389	13	3	1
15	46	167	90	23	56	418	1091	1628	1439	383	4	7
16	0	72	0	24	26	1043	1129	1467	711	216	29	0
17	28	105	26	13	163	628	1324	918	1190	221	0	19
18	1	1	19	13	60	493	380	1006	355	0	......	......

No. 10.—United Provinces, West.

Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1901	278	162	67	4	81	102	783	1800	414	42	0	49
02	11	24	31	64	105	254	1473	917	1364	56	3	0
03	104	8	63	10	62	194	658	1349	740	594	0	17
04	63	6	160	12	144	410	1515	1439	501	18	87	70
05	206	168	125	30	85	178	778	703	414	1	2	28
06	37	367	92	8	55	794	1130	1020	732	14	0	31
07	83	287	103	114	56	68	774	1083	9	0	0	0
08	102	87	5	11	60	223	1414	1685	138	1	4	8
09	80	35	0	275	14	702	1534	957	452	5	0	148
1910	62	18	0	8	58	379	755	1379	893	690	16	1
11	329	6	182	7	3	315	263	643	1306	62	193	2
12	144	35	48	21	28	132	991	1067	981	0	31	7
13	2	188	124	7	229	572	611	457	84	11	6	39
14	0	63	101	88	135	241	1369	860	1051	56	25	0
15	103	274	222	33	58	239	954	1184	589	49	0	11
16	2	77	0	13	49	621	1362	1414	981	240	14	0
17	37	117	62	96	204	466	1428	1017	1281	357	0	25
18	36	2	64	46	34	470	409	723	115	2	......	......

TABLE 6—Continued.

No. 11.—Punjab, East and North.

Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1901	194	142	76	2	66	52	628	612	77	10	0	15
02	0	3	37	39	91	245	593	415	254	34	9	0
03	91	3	120	6	52	29	744	548	426	27	0	29
04	92	6	296	6	93	94	395	624	351	21	47	53
05	205	99	97	8	29	81	443	163	429	3	0	38
06	25	320	170	9	12	207	478	607	755	2	0	27
07	109	330	191	200	27	120	319	819	21	2	0	0
08	162	54	2	130	52	60	869	1622	257	5	7	21
09	84	98	9	232	11	359	902	658	638	12	0	176
1910	125	32	9	28	12	363	567	944	346	189	0	16
11	396	29	425	19	7	237	124	351	403	44	127	2
12	209	35	43	80	30	61	671	790	250	1	46	9
13	8	213	142	7	226	386	511	624	80	7	8	59
14	57	140	65	179	95	205	1240	368	608	146	36	50
15	93	238	228	62	24	116	260	373	369	72	0	12
16	7	86	21	20	54	219	914	907	332	127	0	2
17	31	13	40	213	134	345	714	992	1259	402	0	44
18	26	4	224	157	5	131	151	518	55	3	......	......

No. 12.—Punjab, Southwest.

1901	108	58	68	36	200	59	372	184	72	2	0	0
02	0	4	39	30	63	202	268	262	171	27	0	0
03	36	2	135	26	85	27	509	354	202	10	1	18
04	188	2	366	2	26	49	108	234	42	6	40	38
05	182	98	82	14	16	48	338	37	471	8	3	82
06	5	360	112	13	10	98	190	404	309	1	0	52
07	17	108	69	163	32	134	117	320	2	0	0	0
08	90	21	2	144	45	35	421	609	418	0	0	3
09	9	66	14	138	1	126	449	67	180	1	0	100
1910	70	5	10	82	9	141	203	389	2	4	0	8
11	131	23	324	31	14	149	37	79	40	53	42	2
12	168	6	16	122	26	38	226	168	69	4	0	8
13	0	124	66	13	43	125	300	493	57	6	8	24
14	66	133	57	154	43	118	748	236	141	93	45	33
15	8	45	112	71	15	79	57	68	16	17	0	7
16	6	27	22	28	60	92	288	579	82	51	0	0
17	13	0	44	96	116	129	237	883	609	1	0	16
18	4	8	178	126	1	27	127	97	77	10	......	......

No. 13.—Kashmir.

1901	589	725	315	61	335	152	1335	2363	277	19	0	65
02	23	72	382	291	232	354	1138	917	563	92	17	0
03	344	85	656	73	227	171	959	1851	694	34	0	263
04	333	97	557	111	250	191	1712	1297	302	142	79	171
05	438	448	607	95	208	206	1308	1034	229	2	2	139
06	209	747	468	31	67	778	1261	3172	1069	6	0	103
07	294	441	339	372	213	308	213	435	54	52	8	2
08	236	156	61	617	167	56	328	652	255	58	4	291
09	274	407	155	102	100	127	543	411	481	105	5	225
1910	318	272	200	309	113	257	366	528	68	2	0	173
11	839	172	702	174	59	124	190	252	148	39	168	76
12	413	127	272	244	230	47	343	302	12	14	40	119
13	210	312	223	340	145	251	291	445	65	29	82	138
14	139	654	393	487	262	327	1174	615	347	512	165	287
15	151	592	371	546	54	185	365	718	253	67	1	45
16	145	402	200	148	169	319	1043	1030	214	109	13	24
17	171	72	256	391	204	632	768	1086	906	417	1	257
18	81	89	854	661	16	244	370	517	75	53	......	......

TABLE 6—CONTINUED.

No. 14.—NORTHWEST FRONTIER PROVINCE.

YEARS.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1901	316	179	268	128	633	92	209	356	286	67	0	0
02	15	8	169	189	112	230	411	383	257	139	25	2
03	110	6	364	117	186	32	215	338	224	15	6	74
04	313	6	621	43	48	18	290	437	117	93	48	46
05	271	197	397	56	88	20	246	194	198	15	3	250
06	32	543	223	82	57	113	286	459	221	22	0	172
07	159	299	262	381	49	123	159	358	49	12	0	0
08	320	111	33	584	28	32	434	638	447	40	0	94
09	29	211	65	112	23	99	541	493	93	12	1	186
1910	380	90	50	219	50	207	584	614	32	0	0	39
11	383	38	707	95	28	114	47	227	124	92	95	50
12	253	103	26	222	44	38	418	381	59	23	2	9
13	16	229	135	62	56	164	205	392	96	14	37	60
14	61	334	171	328	139	204	675	358	170	368	69	153
15	2	232	202	438	39	88	122	196	147	70	0	8
16	47	171	92	151	160	66	301	794	179	57	1	9
17	70	4	218	89	102	152	242	714	279	20	0	131
18	10	26	454	285	5	117	146	198	74	7	..	

No. 15.—BALUCHISTAN.

1901	174	15	89	16	162	0	106	22	6	0	0	0
02	2	2	26	20	10	47	28	63	60	17	22	28
03	70	72	282	160	73	11	81	36	11	0	11	13
04	269	49	335	7	0	2	6	9	9	0	20	7
05	388	191	172	20	10	4	43	0	9	2	3	263
06	39	391	291	16	3	26	30	99	30	0	10	12
07	1	330	108	113	2	118	42	191	0	0	0	6
08	123	11	104	93	3	3	177	108	1	0	0	67
09	71	172	83	72	4	21	98	12	41	0	0	142
1910	191	24	62	48	9	42	200	78	0	0	0	109
11	385	56	381	62	1	2	7	42	9	47	99	26
12	350	19	15	90	13	17	166	52	15	0	2	100
13	46	234	178	8	2	71	80	145	4	36	61	106
14	114	347	78	71	4	85	281	29	50	153	189	60
15	42	18	131	257	1	5	31	19	10	12	0	1
16	168	91	29	91	26	22	48	391	7	1	0	6
17	118	5	161	15	47	1	35	341	141	0	24	53
18	12	107	380	71	2	2	32	16	19	1		

No. 16.—SIND.

1901	0	11	14	2	35	0	112	21	0	0	0	4
02	0	0	1	1	98	231	24	241	319	0	0	0
03	11	5	17	7	7	1	301	11	27	0	0	0
04	47	29	112	0	1	2	49	4	7	0	4	10
05	27	71	3	15	0	0	138	0	10	0	0	9
06	6	201	51	0	0	96	48	170	65	4	0	0
07	1	131	21	16	1	228	16	374	2	0	0	0
08	77	0	1	20	1	7	834	278	0	0	0	0
09	18	7	0	15	0	9	441	65	53	0	0	20
1910	47	0	0	9	3	118	566	156	1	0	0	0
11	6	0	59	0	0	10	0	15	7	1	5	0
12	35	0	0	6	5	27	238	189	12	0	0	0
13	0	65	17	0	0	36	939	517	228	3	1	73
14	0	80	3	4	23	154	274	3	45	16	6	2
15	0	7	40	35	0	0	31	1	42	38	0	0
16	8	0	0	0	9	49	191	698	139	5	0	0
17	3	2	17	12	124	31	88	442	569	124	0	0
18	0	0	33	5	0	0	0	92	7	0		...

TABLE 6—Continued.

No. 17.—Rajputana, West.

Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1901	34	0	3	0	15	12	333	237	6	14	0	
02	0	0	0	3	16	177	152	312	196	6	0	0
03	5	7	29	0	20	4	689	379	205	0	0	0
04	9	12	50	3	61	58	200	215	60	6	11	24
05	12	20	4	6	1	19	145	3	273	0	0	2
06	0	128	27	0	1	67	253	280	351	3	0	7
07	4	130	26	12	26	34	212	1089	1	0	0	0
08	38	1	0	6	22	124	940	1190	306	1	4	0
09	13	8	0	104	11	106	727	344	449	2	0	65
1910	8	0	0	17	1	302	231	632	41	3	0	0
11	5	0	119	1	0	113	11	62	240	25	8	0
12	35	0	0	7	21	102	519	457	73	27	12	0
13	0	24	8	0	60	217	232	309	126	1	0	33
14	8	8	0	29	16	204	503	238	210	24	14	0
15	30	91	64	1	2	71	95	93	51	122	0	0
16	5	1	1	7	65	86	271	808	403	76	0	0
17	6	5	7	51	229	305	441	971	860	308	0	3
18	2	0	14	3	4	25	23	189	22	1	......	......

No. 18.—Rajputana, East.

1901	103	51	11	2	16	65	693	755	30	34	0	3
02	16	3	0	5	27	154	1102	428	496	46	0	7
03	11	2	6	0	45	82	738	917	537	114	0	0
04	14	18	92	1	104	168	1167	1079	223	3	30	76
05	27	45	14	7	6	53	398	114	300	0	0	4
06	1	98	40	0	9	259	853	291	763	5	0	13
07	37	176	42	61	45	68	451	1252	11	0	0	0
08	69	4	6	2	31	174	1679	1435	269	1	5	0
09	29	6	0	203	24	424	1133	665	319	4	0	105
1910	42	11	0	7	9	384	412	908	754	341	4	0
11	74	3	69	3	1	273	168	337	781	23	96	1
12	45	17	11	14	13	98	1202	996	317	5	14	7
13	0	62	7	2	195	347	465	307	97	6	2	75
14	0	3	4	15	39	334	1247	478	454	59	17	0
15	68	123	190	14	16	129	312	498	131	156	0	4
16	1	28	0	2	37	311	669	1701	497	99	11	0
17	16	37	21	46	290	461	1218	1556	1206	354	0	1
18	25	0	14	5	5	103	189	623	97	0	......	......

No. 19.—Gujarat.

1901	0	0	2	6	21	214	886	652	76	48	0	0
02	10	0	0	2	4	106	830	1130	1048	12	4	42
03	0	0	1	0	34	94	1740	692	605	20	0	0
04	2	48	78	0	10	157	685	194	382	16	1	3
05	2	3	2	2	0	70	2100	116	257	6	0	0
06	0	46	0	0	0	688	1200	874	400	40	0	1
07	1	38	1	8	3	284	1276	1721	43	0	0	0
08	17	0	0	0	0	246	1880	1268	85	4	0	0
09	0	6	0	26	9	638	1473	712	588	8	0	26
1910	3	0	0	1	1	1041	1088	1177	170	78	23	0
11	10	0	84	0	3	554	223	297	193	1	7	1
12	0	0	0	2	3	406	2401	1067	150	33	127	0
13	0	0	0	0	32	1493	1463	632	505	4	0	1
14	0	15	0	1	27	927	1493	414	1035	38	23	0
15	21	6	52	7	6	445	476	306	184	380	2	0
16	0	0	0	0	30	400	687	1318	617	146	6	0
17	3	20	0	20	387	526	1129	1207	1158	954	0	0
18	2	0	1	0	43	139	393	561	50	2	......	......

TABLE 6—CONTINUED.

No. 20.—CENTRAL INDIA, WEST.

YEARS.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1901	112	62	19	10	10	102	965	1724	349	17	0	9
02	80	37	1	6	19	109	1659	685	792	79	25	22
03	15	1	1	0	43	174	947	1178	1008	458	0	0
04	13	48	99	0	49	348	1573	1041	449	55	14	53
05	48	15	31	12	13	97	1081	594	574	0	0	4
06	1	67	31	0	5	592	1494	672	1525	14	0	0
07	15	67	4	33	8	164	836	1343	122	0	26	0
08	57	2	28	4	4	343	1485	1159	178	0	3	1
09	12	5	0	106	29	599	1109	1083	388	8	0	69
1910	8	0	0	2	2	763	735	980	1019	173	103	0
11	70	5	12	0	2	487	475	569	798	46	118	0
12	16	22	2	1	10	199	1376	1064	329	11	234	7
13	0	35	5	0	124	665	1127	779	237	0	2	48
14	0	5	17	7	62	514	1483	557	578	26	45	0
15	47	106	106	23	22	359	595	850	288	273	12	16
16	0	28	0	1	68	742	911	2177	482	204	78	0
17	51	84	5	9	278	690	1192	1319	1063	345	0	0
18	3	3	10	0	34	354	461	876	261	1		..

No. 21.—CENTRAL INDIA, EAST.

1907	19	469	20	79	23	158	763	1875	27	0	14	0
08	78	58	15	1	28	141	2068	2328	314	55	1	21
09	87	46	8	250	10	951	1518	544	478	0	0	82
1910	24	1	1	12	58	692	560	1421	970	188	214	0
11	125	9	79	0	22	500	396	1365	1552	283	153	0
12	10	33	5	11	17	107	1790	1074	540	0	142	4
13	2	312	77	0	166	818	792	635	273	3	0	38
14	1	23	114	58	68	271	2095	972	310	9	1	0
15	60	117	96	29	28	499	800	1547	457	222	1	4
16	0	40	0	2	12	1012	927	1819	569	359	95	0
17	15	78	78	4	249	660	1571	1624	920	234	5	10
18	1	11	5	2	35	275	332	978	301	0	......	......

No. 22.—BERAR.

1901	211	16	65	48	21	578	942	1235	280	206	0	0
02	13	0	0	31	5	154	1087	681	401	197	92	155
03	31	4	0	6	183	374	1469	859	532	303	0	0
04	22	7	39	0	29	486	553	387	849	213	0	7
05	13	32	10	9	23	256	879	499	899	27	1	0
06	52	4	10	0	10	1019	1163	1130	305	24	37	86
07	5	317	4	129	2	646	884	878	98	2	63	1
08	2	9	94	33	4	780	990	991	660	1	0	8
09	7	37	14	38	84	535	889	517	684	26	0	292
1910	0	0	0	0	29	931	725	937	971	249	217	0
11	98	0	4	0	8	545	548	645	287	25	218	0
12	0	91	1	10	9	309	938	895	258	30	48	4
13	0	49	5	6	84	710	1208	622	537	44	1	127
14	0	55	42	45	73	1137	804	700	1100	19	37	63
15	120	22	283	83	32	729	901	413	657	411	29	124
16	0	29	2	7	119	922	1246	821	1081	345	145	0
17	4	212	76	16	170	789	884	639	1008	358	8	0
18	4	11	7	0	304	527	462	361	104	26	......	......

TABLE 6—CONTINUED.

No. 23.—CENTRAL PROVINCES, WEST.

YEARS.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1901	170	122	104	64	28	368	1395	2052	523	32	0	0
02	30	8	0	16	12	138	1238	867	827	106	116	66
03	24	14	0	6	185	413	1508	1458	976	400	2	0
04	6	72	130	0	37	584	984	784	650	157	0	32
05	36	37	40	50	37	255	1389	1010	1384	14	0	2
06	32	60	108	0	26	1208	1619	1146	874	19	18	44
07	30	330	7	135	21	497	889	1738	139	0	76	5
08	47	36	77	21	3	634	1541	1599	572	35	4	28
09	34	59	17	182	67	640	1233	965	553	4	0	237
1910	21	0	0	2	23	916	940	1319	1103	208	227	0
11	70	0	40	0	5	777	643	1092	1056	149	238	0
12	21	194	0	11	7	165	1489	1412	550	7	227	7
13	4	155	59	1	90	790	1289	1192	315	14	3	86
14	0	33	192	78	53	537	1607	1047	783	37	17	31
15	45	100	234	47	45	746	1449	1339	634	432	26	19
16	0	85	0	6	74	1058	1080	1523	1057	720	137	0
17	18	213	76	17	242	914	1284	1518	1411	313	0	6
18	4	28	11	2	162	941	809	984	295	5	......	......

No. 24.—CENTRAL PROVINCES, EAST.

1901	167	418	112	42	50	269	1397	1755	762	110	8	0
02	2	3	3	113	48	143	1679	1183	691	39	10	26
03	20	53	3	25	156	382	1453	1519	924	524	1	0
04	0	57	119	2	260	1455	1121	1618	419	268	4	0
05	210	107	84	104	104	135	1513	1062	1329	53	0	0
06	96	357	270	0	18	587	1803	985	971	148	23	41
07	20	146	83	238	12	803	1069	1797	427	0	36	60
08	36	185	9	2	18	910	1812	2202	714	51	0	10
09	20	38	26	376	25	823	2018	860	517	25	0	281
1910	11	1	4	26	42	1048	1340	1539	1132	248	255	0
11	21	0	49	0	12	1191	1037	1873	907	341	65	0
12	16	346	0	73	29	201	1910	2067	754	22	55	0
13	4	248	78	5	76	952	1365	1338	554	67	14	71
14	0	40	58	219	134	634	2046	1360	928	17	2	17
15	118	100	127	58	65	535	1485	1525	940	525	61	2
16	0	101	5	12	61	1114	1155	1442	783	637	107	0
17	4	330	103	44	164	1132	1542	1461	1120	560	3	3
18	43	16	11	15	225	2015	948	1481	498	2	......	......

No. 25.—KONKAN.

1901	......	1	10	103	97	2687	4111	2820	426	211	37	9
02	1	0	3	9	50	1606	3789	2023	2422	378	128	250
03	0	0	1	5	767	1696	5135	2565	1125	514	64	9
04	0	1	25	25	65	3537	2955	1407	837	359	1	0
05	0	1	0	10	4	1156	3120	1341	770	366	70	0
06	35	4	6	1	10	2072	4171	1936	876	173	37	61
07	6	4	2	118	12	2336	4626	3301	678	93	38	5
08	3	4	1	44	25	1746	5560	2594	819	109	8	0
09	1	0	10	8	111	2911	5062	1418	1461	108	49	1
1910	0	0	6	1	35	3119	1729	2964	1418	562	148	0
11	1	0	8	4	62	2032	2289	2825	631	192	89	17
12	0	0	0	38	116	2321	5083	2253	559	330	390	0
13	0	1	1	10	65	3467	4207	1345	730	569	4	0
14	0	3	0	12	31	2610	5753	3064	2024	107	94	22
15	1	18	25	71	74	3092	2788	1414	1465	573	78	5
16	0	0	1	30	146	3067	2768	3270	2251	837	485	0
17	0	76	10	8	93	3113	2711	3463	2380	1628	123	0
18	3	0	15	12	1269	1284	1588	2207	424	59	......	......

TABLE 6—CONTINUED.

No. 26.—BOMBAY DECCAN.

YEARS.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1901	....	15	28	140	154	426	782	701	356	296	20	2
02	26	0	0	32	72	399	806	420	592	288	148	268
03	26	0	0	14	303	342	1036	596	548	316	44	18
04	1	20	12	22	104	456	522	258	706	343	0	1
05	0	6	1	18	118	266	953	338	223	199	32	0
06	40	3	16	3	54	668	765	758	375	126	55	84
07	3	11	8	233	15	423	919	914	503	37	32	9
08	1	0	16	47	49	321	938	576	642	74	14	0
09	5	0	15	10	168	620	886	430	517	165	30	19
1910	0	0	11	4	83	660	663	901	691	351	123	0
11	6	0	14	6	97	511	503	521	132	165	145	27
12	0	3	0	80	109	326	1185	559	255	400	219	1
13	0	1	0	52	199	878	761	310	349	230	5	17
14	0	2	2	32	95	593	1333	853	733	96	156	43
15	40	19	64	105	93	719	869	310	819	284	122	57
16	0	1	2	44	248	485	911	616	748	576	465	0
17	0	70	28	32	64	609	402	651	904	634	191	0
18	23	1	12	27	372	211	226	394	269	73		....

No. 27.—HYDERABAD, NORTH.

YEARS.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1901	38	....	....	....	....	....	....	....	....	281	2	....
02	....	....	....	....	....	....	....	650	....	....	....	....
03	....		0	....	....	376	....	1054	735	....		37
04	0				46	452	568	268	1166	327	0	0
05	2	28	23	72		352	28	929	795	.	.	0
06	130	1	34	0	14	1002	927	637	406	92	64	86
07	4	19	12	287	0	558	695	861	299	1	11	36
08	6	5	35	9	13	355	681	658	1523	1	0	1
09	16	10	18	81	65	669	872	590	586	46	1	48
1910	0	0	2	0	69	851	727	663	1593	270	149	0
11	15	0	10	1	9	415	789	765	383	23	90	3
12	0	93	0	47	36	201	902	640	262	78	80	0
13	0	38	0	64	106	550	1105	329	320	154	0	44
14	0	20	3	14	42	1117	1003	771	1132	54	43	71
15	103	6	259	62	35	775	509	574	1055	392	59	32
16	0	31	6	14	135	637	1261	544	1106	486	228	0
17	1	284	88	69	123	692	937	927	1313	356	134	0
18	34	1	14	17	405	324	457	423	465	11	....	....

No. 28.—HYDERABAD, SOUTH.

YEARS.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1901	26	167	14	168	291	430	625	347	289	248	71	....
02	....	....	....	....	....	....	....	576	....	....	....	....
03	....	....	0		....	234		1037	851			43
04	1	....	....		106	460	524	167	180	279	0	0
05	0	24	29	75		438	219	843	330	.	.	0
06	156	0	8	12	27	706	570	808	490	238	47	214
07	4	6	69	504	13	522	509	687	347	4	26	48
08	57	15	14	15	10	369	495	573	1849	18	0	0
09	3	0	4	151	58	553	702	624	676	31	0	0
1910	0	0	5	37	65	582	412	754	766	339	175	0
11	0	0	1	18	106	336	655	448	385	83	61	18
12	0	140	0	103	35	121	837	690	347	92	140	0
13	0	12	0	19	192	205	836	236	235	240	1	0
14	0	0	9	48	121	717	1068	850	945	54	35	24
15	59	33	250	56	101	575	600	749	886	746	94	1
16	0	10	0	115	111	682	1107	433	1105	1097	406	14
17	0	130	160	88	191	529	595	769	946	510	75	0
18	56	0	76	71	367	163	319	269	693	18	....	....

TABLE 6—CONTINUED.

No. 29.—MYSORE.

YEARS.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1901	29	116	30	212	392	1236	2136	839	634	840	456	76
02	0	24	77	308	458	758	2386	604	940	848	234	580
03	2	0	11	68	602	832	2839	1062	798	777	856	198
04	6	10	40	268	601	1650	1888	632	604	550	12	3
05	4	41	58	95	560	1078	1476	818	358	726	127	1
06	90	9	9	50	300	832	2165	1610	505	818	103	192
07	19	0	45	349	192	459	785	699	586	225	210	54
08	54	13	34	172	367	320	810	384	290	266	6	2
09	86	4	22	174	638	464	862	788	403	487	146	40
1910	0	3	30	95	359	433	972	818	416	901	328	0
11	2	1	22	109	519	574	821	298	213	668	142	28
12	3	18	12	160	276	476	1065	673	716	762	241	0
13	0	0	5	77	365	442	893	350	604	484	5	15
14	0	3	8	70	247	226	1092	539	391	456	261	95
15	40	9	134	169	264	829	655	263	687	409	348	37
16	0	0	0	87	572	623	747	783	544	660	613	27
17	1	144	60	73	227	603	369	660	1040	588	367	5
18	48	4	63	187	402	239	184	378	378	161	......	......

No. 30.—MALABAR.

1901	113	121	198	538	526	3146	2692	1346	660	880	1354	162
02	58	10	180	285	459	1574	4242	1147	1914	1296	620	483
03	12	54	20	312	858	2084	3703	1458	1168	1207	552	262
04	96	12	104	258	758	3941	2733	1130	806	1068	83	37
05	6	72	26	388	910	3111	2031	1178	702	1388	316	2
06	96	28	48	48	540	1614	3380	1588	526	966	640	316
07	28	1	83	509	256	3634	3940	4873	643	803	680	150
08	4	50	57	317	394	2931	5925	2296	452	621	57	20
09	165	13	35	188	2026	3775	4412	1142	899	590	467	88
1910	3	17	36	250	487	3753	2229	2305	1248	1103	747	0
11	4	8	22	98	562	4281	3284	1361	252	992	395	183
12	7	5	6	513	654	4141	4272	3055	561	1513	373	14
13	0	9	11	121	613	2800	3652	1206	814	1705	147	83
14	0	0	7	10	356	2696	4876	2476	979	1296	364	344
15	26	21	110	262	428	3128	3382	1487	1329	770	983	26
16	0	8	12	191	702	4493	2403	1996	1629	1135	516	29
17	0	194	119	84	401	3885	2089	1636	1914	1301	636	60
18	18	10	61	75	3109	2327	986	1674	481	622	......	......

No. 31.—MADRAS, SOUTHEAST.

1901	89	152	84	136	272	117	146	242	861	449	540	329
02	289	39	71	82	505	137	143	472	300	1139	740	429
03	82	32	6	69	473	205	212	408	792	547	783	768
04	135	0	2	68	457	95	294	133	281	613	102	16
05	24	26	69	253	310	158	123	367	234	941	587	16
06	202	50	59	31	139	154	247	714	234	657	753	505
07	31	5	80	297	188	1463	237	189	455	633	892	268
08	57	143	86	73	241	121	130	181	659	1091	174	108
09	457	38	19	243	447	93	118	853	469	511	281	86
1910	35	81	5	91	202	171	582	578	203	1072	615	2
11	16	3	17	111	251	204	160	128	496	490	777	569
12	29	10	10	42	215	139	107	280	435	987	1117	110
13	14	13	19	75	218	94	177	237	500	865	832	545
14	26	8	16	142	191	138	99	395	492	1200	529	557
15	152	90	173	133	193	206	447	311	515	334	997	269
16	0	13	13	70	204	89	634	450	368	786	633	143
17	70	135	117	35	278	245	172	622	584	499	707	209
18	405	28	86	31	286	138	145	198	189	257	......	......

TABLE 6—CONTINUED.

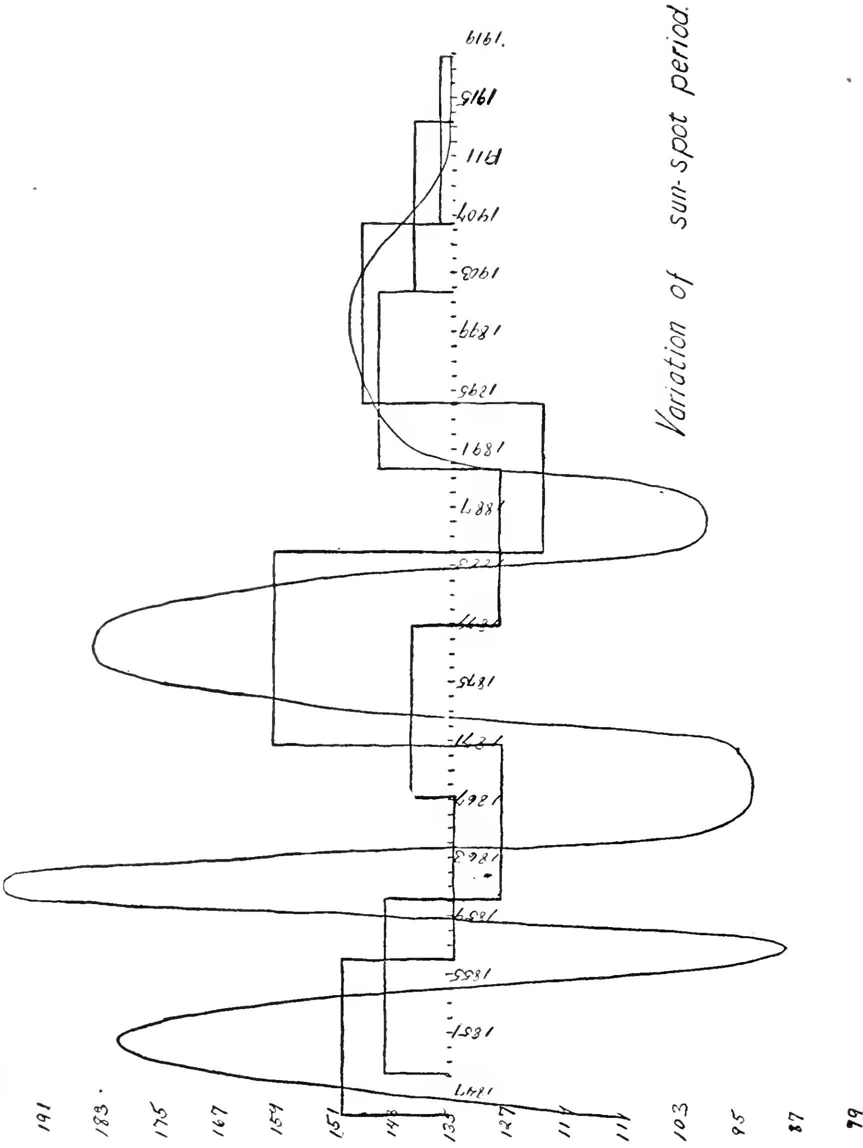
No. 32.—MADRAS, DECCAN.

YEARS.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1901	25	193	1	58	254	242	262	208	403	271	275	61
02	15	0	3	79	154	321	161	354	653	626	126	76
03	36	0	0	30	225	266	461	479	803	408	790	96
04	26	0	11	49	248	181	248	98	318	472	0	12
05	5	19	50	53	147	300	161	867	483	486	219	1
06	113	2	4	3	50	351	456	532	551	376	59	395
07	2	0	16	258	10	213	477	153	379	89	281	73
08	21	66	36	25	147	146	287	163	886	249	8	2
09	159	1	3	145	250	162	242	883	731	82	25	1
1910	0	0	5	36	153	173	600	668	865	516	339	0
11	0	0	3	53	202	234	309	239	382	285	124	35
12	0	20	2	56	72	139	299	453	659	419	468	0
13	0	0	0	30	249	191	401	94	474	531	1	78
14	0	0	2	59	175	190	338	517	621	132	133	25
15	109	14	212	52	185	227	502	213	774	277	529	6
16	0	2	0	31	218	228	828	623	716	1027	340	1
17	5	227	35	24	172	360	185	605	851	635	313	10
18	61	1	17	40	294	86	85	238	607	19	.....	.....

No. 33.—MADRAS, COAST NORTH.

1901	47	304	15	1	189	210	453	468	450	460	970	224
02	8	0	10	102	84	247	463	770	680	1208	610	400
03	48	23	3	20	368	410	762	731	722	558	1389	274
04	216	4	15	11	416	308	402	386	420	685	18	114
05	16	50	45	104	180	308	302	624	596	368	568	6
06	335	61	55	10	45	583	574	692	413	428	157	869
07	5	9	3	284	86	788	515	615	362	209	331	206
08	197	168	11	34	156	280	528	795	1073	465	85	8
09	113	13	6	438	156	460	828	739	690	96	26	263
1910	4	6	2	119	95	707	909	818	788	1149	336	0
11	0	1	35	55	109	579	571	480	719	522	427	127
12	5	62	16	79	127	219	872	993	774	473	388	3
13	0	47	4	31	251	448	787	529	507	904	79	104
14	4	21	22	273	367	688	728	778	1129	143	131	18
15	169	66	228	119	197	615	574	903	685	793	972	6
16	1	10	2	81	152	576	1027	886	641	1358	532	8
17	7	116	41	97	353	825	609	816	944	1080	491	51
18	151	17	40	53	331	475	462	599	595	88	.....	.....

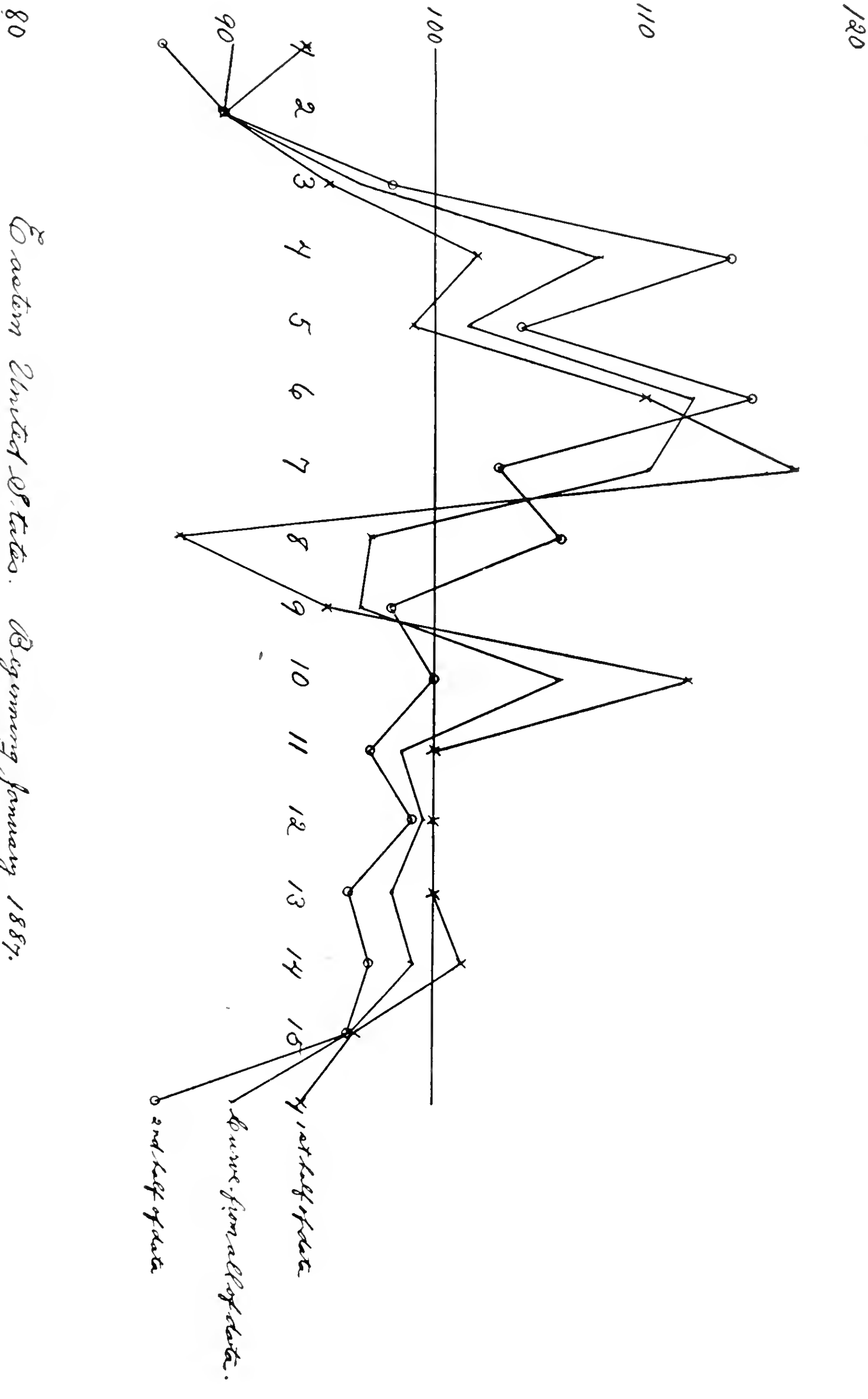
FIGURE 1.



RAINFALL PERIOD.
Dinsmore Alter.

FIGURE 2.

RAINFALL PERIOD.
Dinsmore Alter.



RAINFALL PERIOD.
Dinsmore Alter.

FIGURE 3.

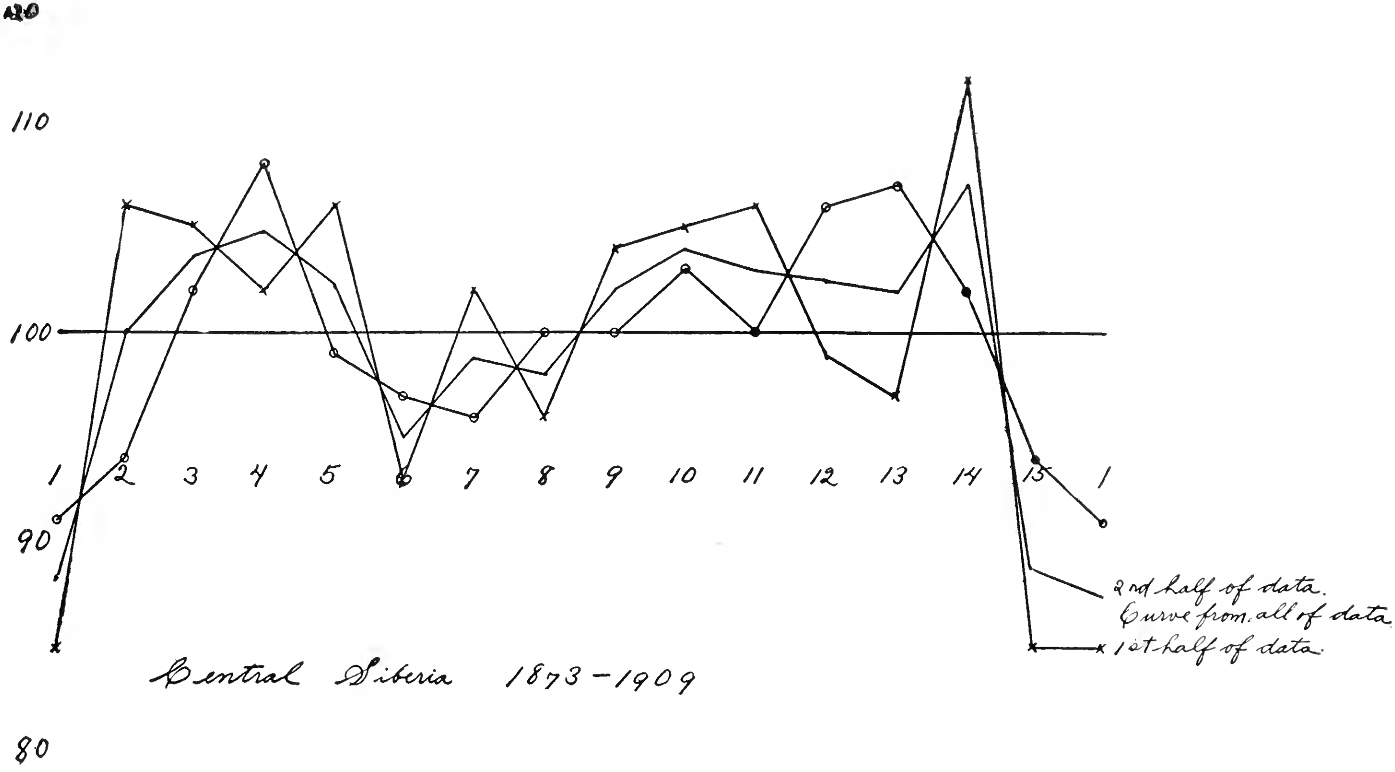
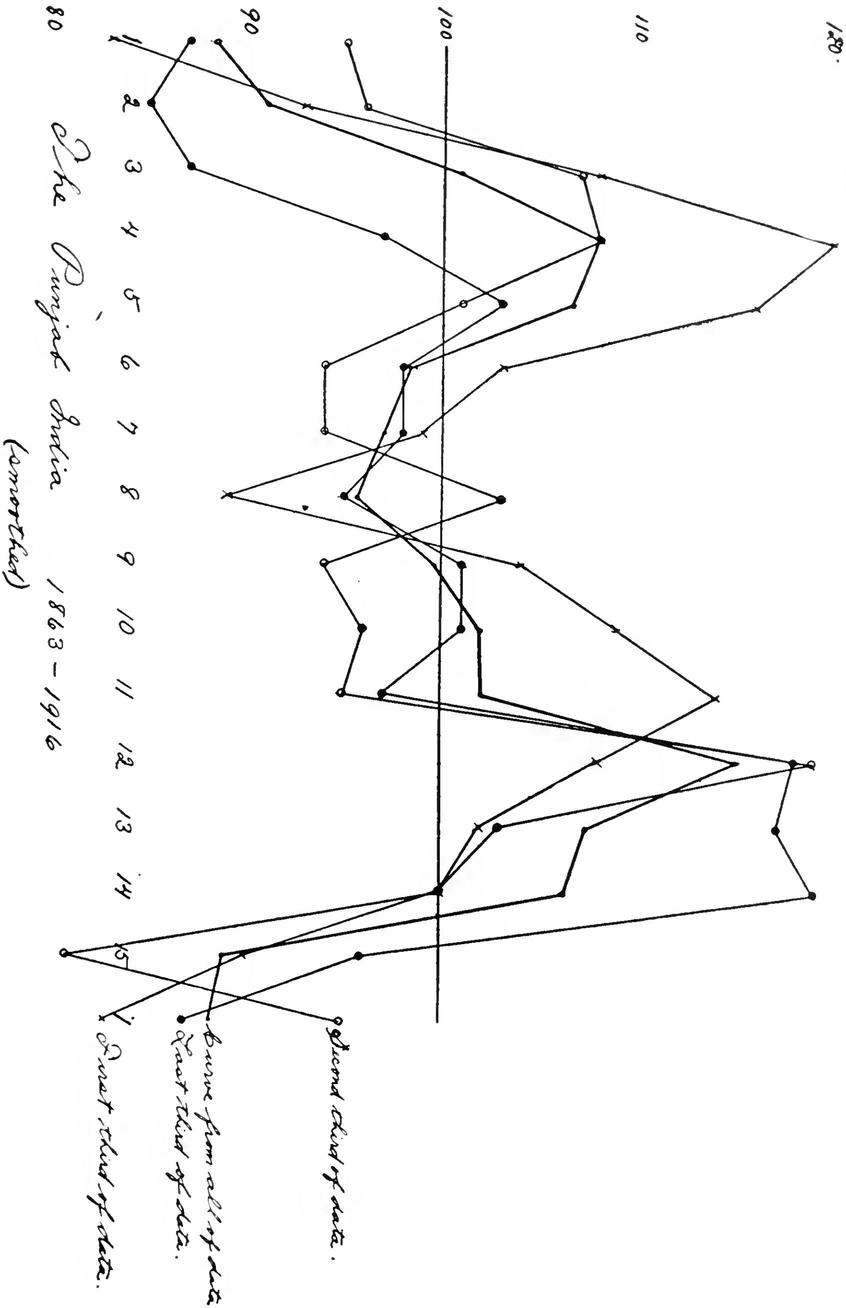


FIGURE 4.

RAINFALL PERIOD.
Dinsmore Alter.



RAINFALL PERIOD.
Dinsmore Alter.

FIGURE 5.

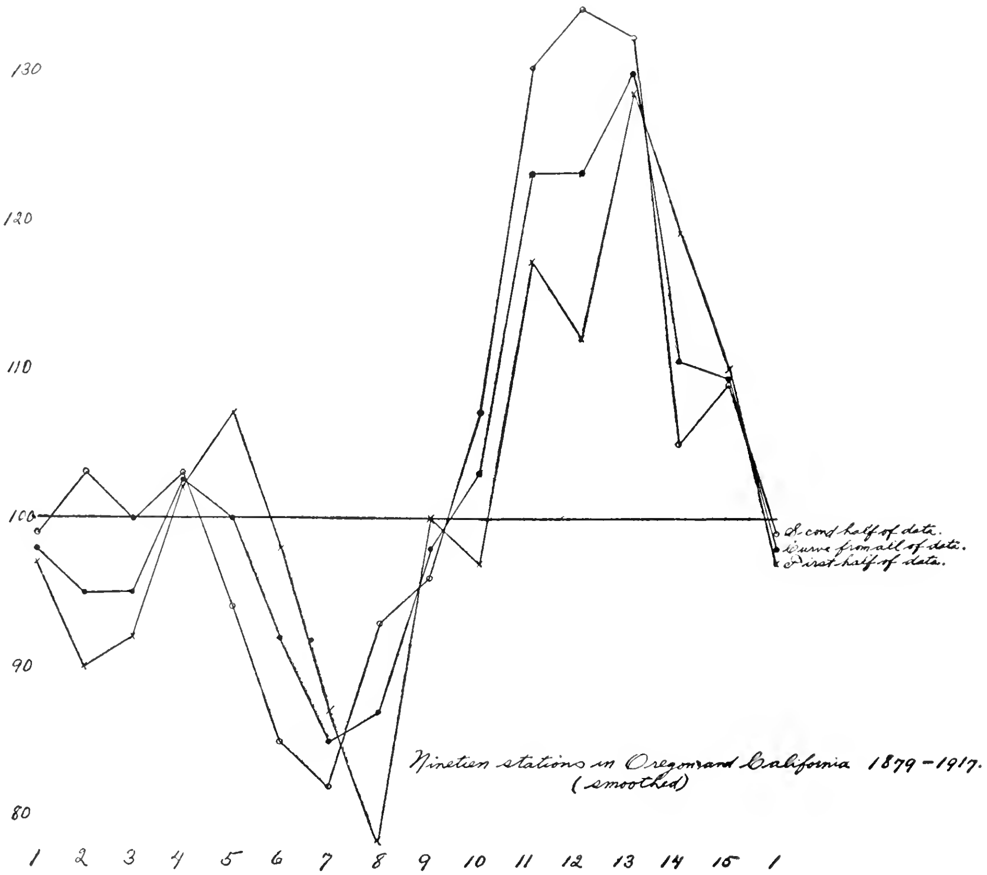
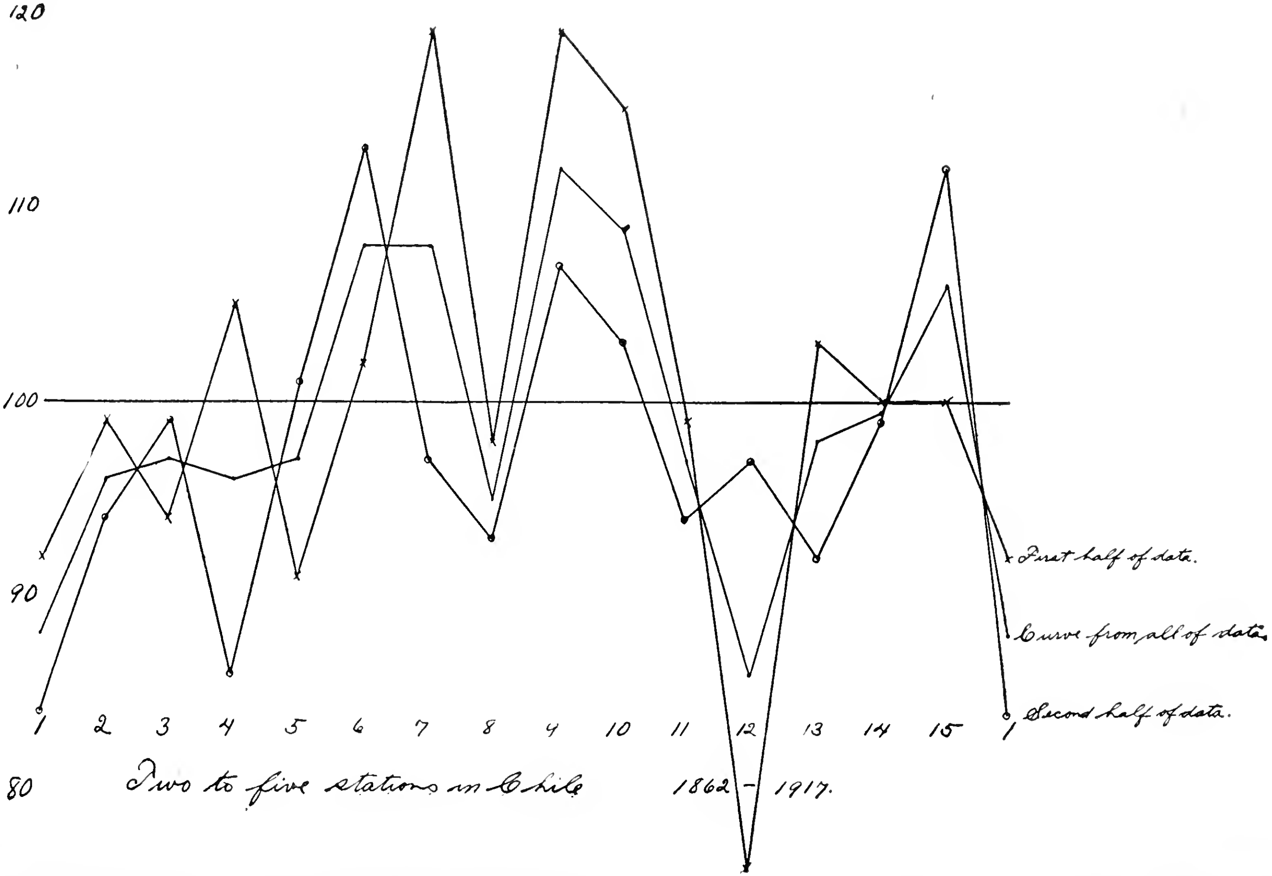


FIGURE 6.

RAINFALL PERIOD.
Dinsmore Alter.

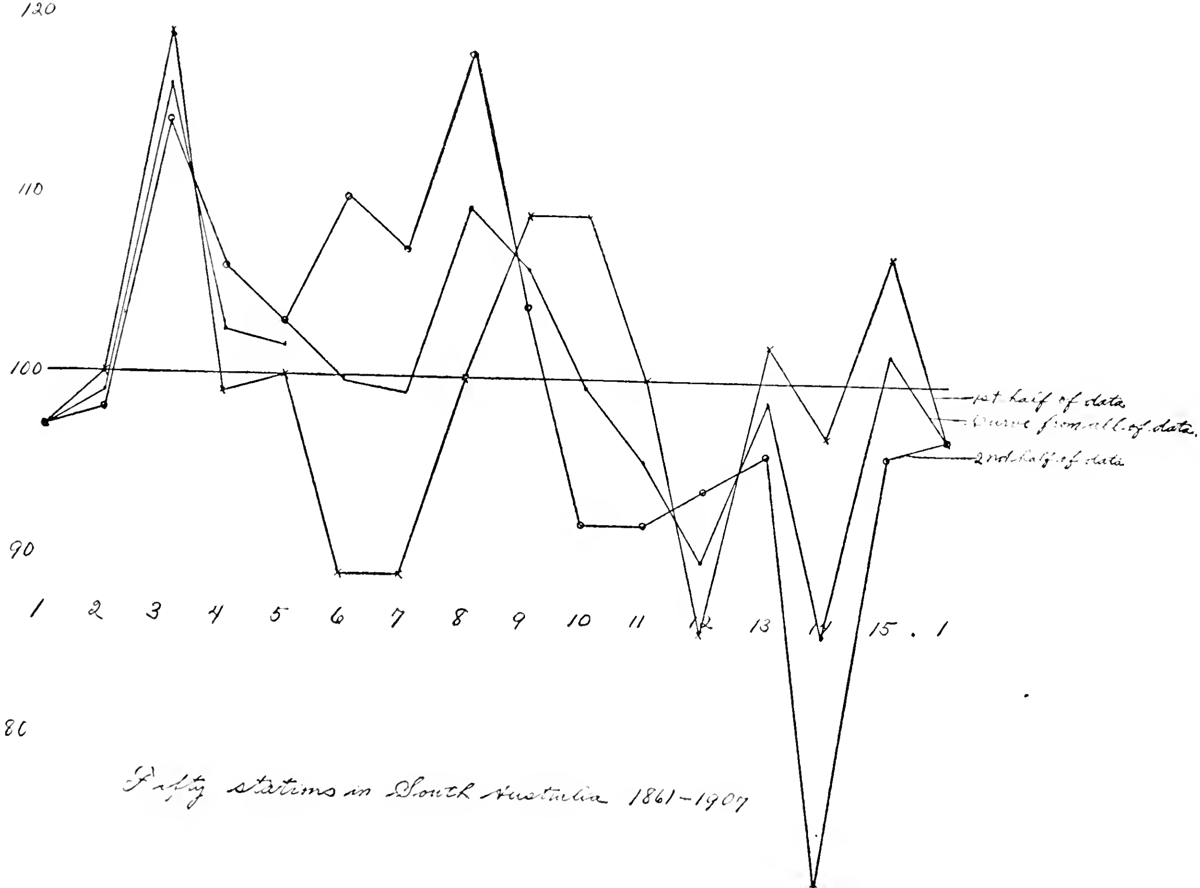
RAINFALL PERIOD.
Dinsmore Alter.

FIGURE 7.



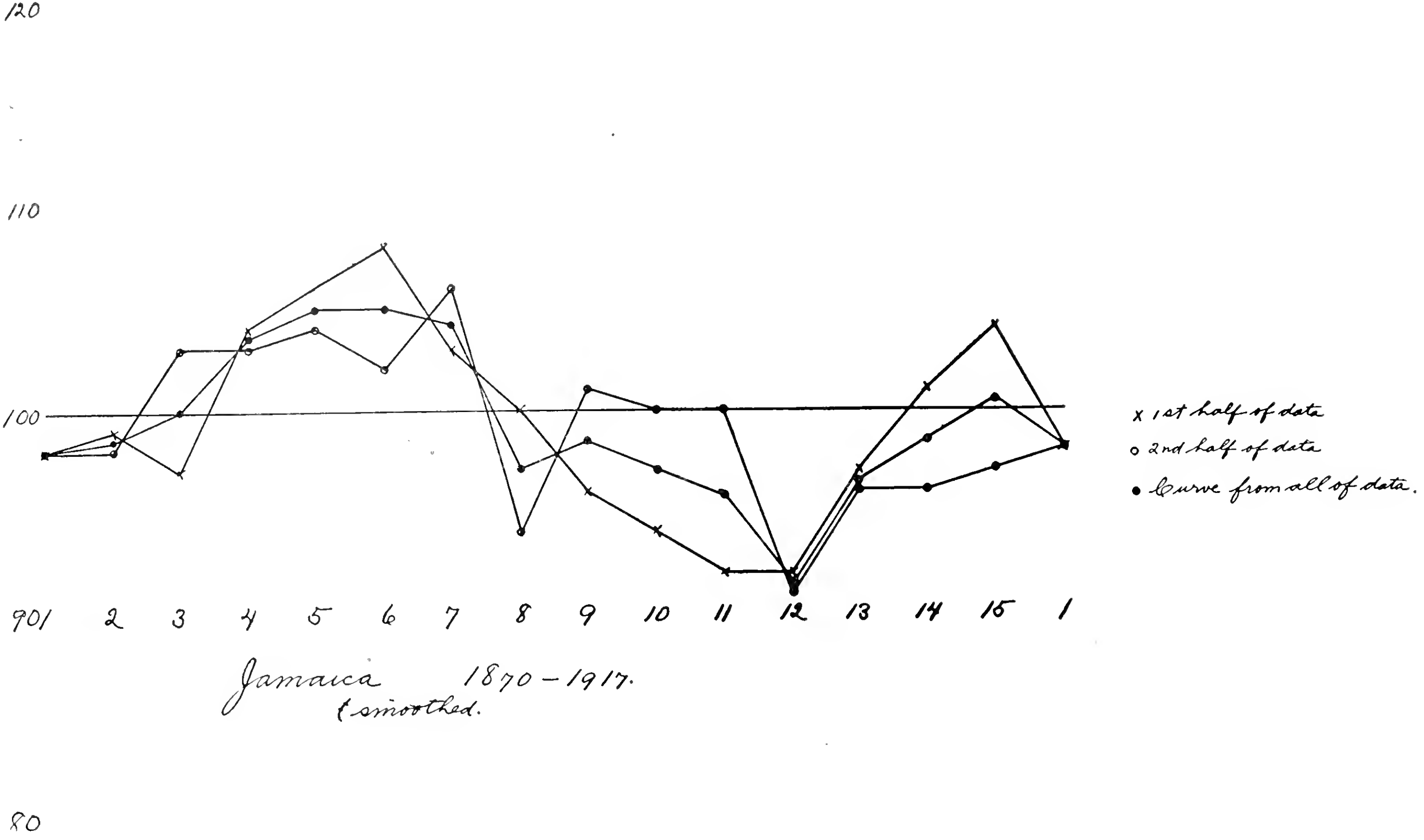
RAINFALL PERIOD.
Dinsmore Alter.

FIGURE 8.



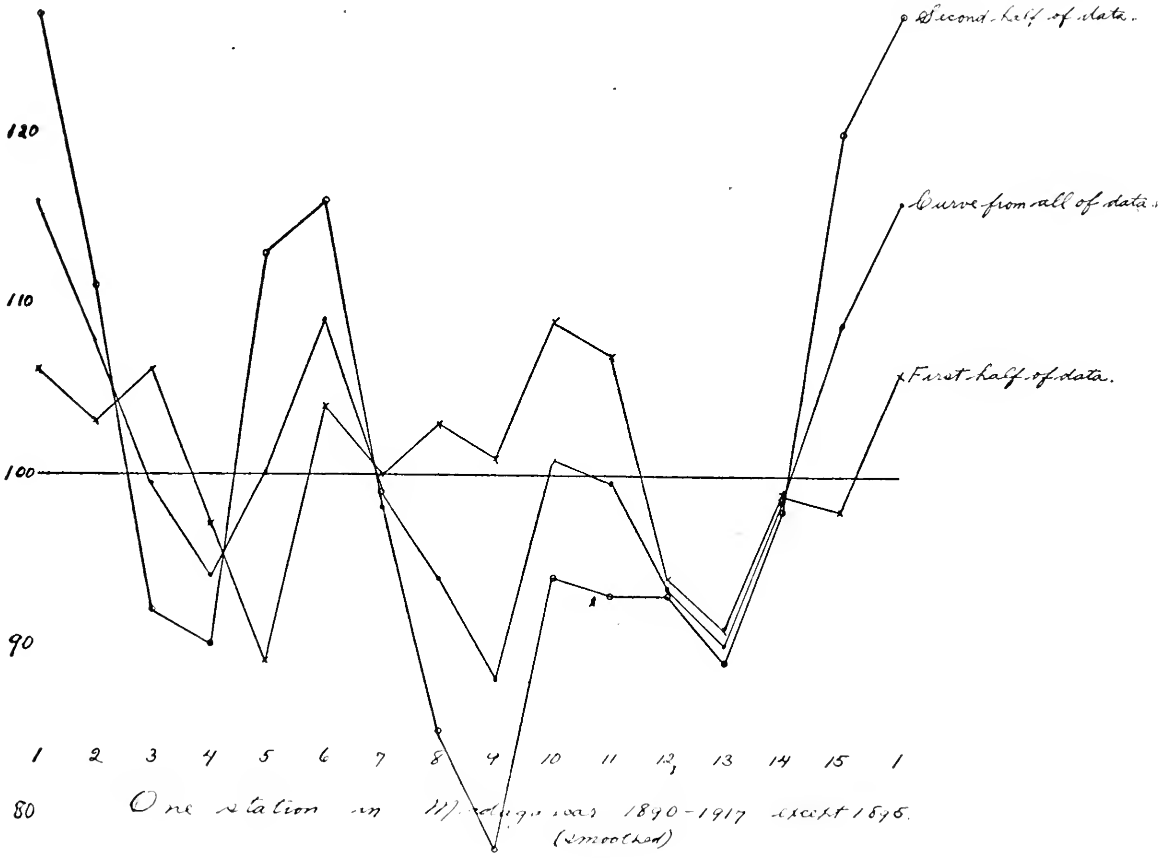
Fifty stations in South Australia 1861–1907

FIGURE 9.


120
110
100
90
80
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
1
x 1st half of data
o 2nd half of data
● Curve from all of data.
Jamaica 1870 – 1917.
(smoothed.

RAINFALL PERIOD.
Dinsmore Alter.

FIGURE 10.



One station in Madagascar 1890-1917 except 1896.
(smoothed)

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THE KANSAS UNIVERSITY SCIENCE BULLETIN.

VOL. XIII.] JULY, 1922. [No. 12.

Indications of a Gigantic Amphibian in the Coal Measures of Kansas.

By H. T. MARTIN,

Associate Curator, Paleontological Museum, University of Kansas.

INTRODUCTION.

IN the summer of 1919, Robert and James Coghill, students of the University of Kansas, discovered in the sandstone cliffs bordering the Wakarusa creek, five miles east of Lawrence, what to them appeared to be the footprints of some large animal impressed in the hard, sandy bottom of a small, narrow ravine that empties into Wakarusa creek from the east near Dightman bridge. The writer's attention was called to the find, and a visit to the locality revealed three or four tracks exposed to view. Unfavorable weather conditions prevented the removal of the tracks at the time, and the subsequent rains covered them with silty mud. It was not until the spring rains of 1921 had again washed them clear that work on their removal could be carried on. By this time additional tracks were exposed, and in a distance of thirty-nine feet, where the animal had traveled in a nearly direct line, nine very fine impressions of his huge feet were recorded.

The impressions, although in a nearly straight line, were not in consecutive order. As shown in the diagram (plate I, figs. 1 to 9), one space of twelve feet from the first track to the second was eroded and no impressions remained. Midway between the third and the fourth, a distance of eight feet, there is an indication of a track, but with no character. From track four to track five the bottom of the ravine is still covered with mud, and it is possible that more tracks will be found here. Eight of the tracks have been safely removed and placed in the museum. The first in the series yet remains *in situ*, but will be removed in the spring. The first impression in the series occurs at the mouth of the small ravine, where it empties over the edge of the deeply undercut, rocky, shelving bank into the Wakarusa. At this point the smooth, level bed of the creek is composed of the same sandy formation (plate II) as that in which the tracks appear. From the bed of the creek to the level of the first track there is an elevation of fourteen feet. This track, like several others in the set, shows the imprint of more than one foot. It also shows plainly that the animal must have been of great size and weight, for from the marks made by the claws (plate I, fig. 10) of the front foot, at the extreme upper edge of the basinlike cavity each impression has made, to the level of the superimposed impression of the hind foot there is a depth of over fifteen inches. It may be doubted if an animal of less than from 400 to 500 pounds weight could possibly have left as deep an imprint as is here shown. From the first track to the second, a distance of twelve feet, there is an elevation of three feet.

There is no doubt that the animal was well adapted for traveling on land, as well as for life in the wet and swampy marshes, and that its body was carried clear of the ground, requiring relatively long limbs. The imprints also indicate that an upright position was maintained, the toes of the feet being planted in a straight line parallel to the body and to the line of travel. The footprints suggest that the animal was of very robust build, possibly not unlike that of *Eryops* from the Permian of Texas, but probably of longer limb. It may well be that the form described herewith as *Onychopus gigas* is a Carboniferous representative of this well-known fossil amphibian, or some similar animal with a longer length of limb.

Onychopus gigas gen. et sp. nov.

An entirely new form of amphibian is indicated by the present series of footprints, for which the term *Onychopus gigas* is proposed. The generic term refers to the presence of claws, apparently for both fore and hind feet. Claws are known among previously described Paleozoic vertebrates, particularly among the Permian reptiles, but are here regarded as a generic character. Their presence is indicated in the long, sharply marked grooves on the edges of the footprints, where the sluggish animal lazily dragged his feet from the soft sand. Another new character is an apparent presence of heel pads (plate I, figs. 2-10), which are represented in the footprints as depressions at the base of the footprint. Further discoveries may locate the form in a genus of reptiles or amphibians already known, but for the present the footprints indicate an unknown animal.

Additional characters are indicated in the apparent presence of webs between the toes, extending a short distance on the phalanges. The body and the tail were carried clear of the ground, as there is no evidence of dragging. This is all the more unusual in view of the great depth of the impressions. The length of his sluggish stride was 450 mm.; the manus was 90 mm. in length and the pes 104 mm. Other detailed measurements are given in the description of the plate.

The most nearly related form is *Baropus lentus*, described by Marsh, from the Coal Measures of Osage county, Kansas (1). The present form differs from *Baropus* in being somewhat larger, and especially in the indications of the heel pads and claws. None of the other Coal Measures footprints from Kansas approach the present footprints in size save *Dromopus agilis* Marsh (2), from which it is clearly separated by a number of characters.

The present series of footprints have been compared with the descriptions of Coal Measures footprints given by King, Leidy, Lea, Butts, Marsh, Mudge, Dawson, Moore, Cox, Moodie and Woodsworth, a list of whose writings relating to this subject is to be found in Moodie's memoir (2) on "The Coal Measures Amphibia of North America." The present form is widely separated from the footprints recently described by Lull (3) as *Dromopus* (?) *woodworthi*, from the Coal Measures of Massachusetts.

It has been assumed, on account of the indications of four toes on the manus and five on the pes, that *Onychopus gigas* was an amphibian, though the discovery of skeleton material may make this assumption unwarranted. In view of the possibility of its being reptilian, the present footprints have been carefully compared with those described by Hitchcock (4), but none similar in form are found.

FORMATION.

The massive reddish-brown sandstone in which the tracks were found contains abundant flaky scales of mica. There are no perceptible lines of stratification and no lines of cleavage. The rocks are split up by horizontal, perpendicular and oblique cracks and fissures into sections of erratic shapes and sizes (plate II). A careful examination failed to reveal any invertebrates or other fossil forms in the sandstone bluffs, although remains of Coal Measures plants have been found elsewhere in this horizon.

The bottom of the ravine containing the tracks scales off more readily than the surrounding bluffs and is consequently rapidly eroding away. The banks of the ravine are very steep, the average width at the bottom being about 3 feet, with a width at the top of 25 feet, while the depth from the level of the banks above to the level of the tracks is 25 feet.

CORRELATION OF FORMATION.

The heavy sandstone rocks in which the impressions appear are exposed in a sharp escarpment on the south side of the Wakarusa creek for a distance of 1½ to 2 miles, in varying heights ranging from a thin feathering edge to 40 feet. The highest point is attained in close proximity to and just above the small ravine in which the tracks were discovered.

A short distance southwest, at the extreme eastern end of Blue Mound, and just above these exposures, an outcrop of the Iatan limestone occurs, thus definitely placing the sandy exposures in the division which composes the lowest member of the Douglas formation, and as it occurs immediately below the Iatan limestone constitutes a part of the uppermost strata of the Weston shales.

The inclusion of this heavy sandstone in the Weston shales will be better understood by referring to the description of the Douglas formation by Moore (5):

> "The shale members of the Douglas are variable in composition and texture, changing markedly from point to point. In the north there is a predominance of clay shales, which is sufficiently pure for use in brick manufacture, but towards the south the proportion of sand is notably increased. In places here the shale is replaced by thick, massive sandstones. Coal occurs at one or two horizons in the formation, but is not of great thickness and has been worked only locally."

DESCRIPTION OF TRACKS.

TRACK NO. 1, the first in the series, shows clearly where the front foot had pressed down in the soft, plastic mud to a depth of eight inches, leaving at this level a well-defined ledge. Immediately behind this narrow ledge the superimposed hind foot had pressed down to a depth of another seven inches, plainly indicating that the animal was of large size and great weight. This impression represents the tracks of the front and the hind foot of the left side.

TRACK NO. 2. (Plate I, fig. 2.) This track was located 12 feet from No. 1 and is one of the finest in the set, showing distinctly the impressions of five bluntly pointed toes. Between the toes the weight of the animal has caused the mud to ooze up, not in sharp ridges as one would expect if the animal had separate unwebbed phalanges, but in a smooth, rounding ridge, indicating that either a fleshy pad, or more likely a thick web, extended to the base of the short, blunt claws. The hinder part of the impression has unfortunately eroded away, so that no imprint of the heel is retained. Both the manus and the pes are represented here, and naturally that of the pes shows most distinctly. Towards the hinder part of the impression there is a small, round indentation, as if caused by a conical protuberance beneath the pad of the foot, as indicated in other tracks of the series. The elevation from the first track to the second is three feet.

TRACK No. 3. (Plate I, fig. 3.) This track was exactly two feet from its predecessor, measurements in each instance being made from the centers of the impressions. There are four distinct toe marks in this track, evidently a left manus. This track, like No. 2, was in a shelving, badly eroded place, leaving no imprint of the palm. From this track to No. 9, the last in the series, there is an elevation of 3 feet.

TRACK No. 4. (Plate I, fig. 4.) This impression was separated by eight feet of clear space from No. 3, and it has the least character of any in the set. There are four light toe marks, and two of the small, round depressions at the base of the palm. These were made, no doubt, by round, warty tubercles beneath the foot. The relative position of the toe imprints to each other indicates a right manus, but so indistinct are the surface toe marks that it is doubtful if they do not belong to the left instead of the right.

TRACK No. 5. (Plate I, fig. 5.) From the fourth to the fifth track there is a space of ten feet, covered to a depth of several inches with soft mud and yet unexplored. Future rains will doubtless disclose more impressions. Track No. 5 shows deep scoring on the edges of the depressions by the slipping of the claws. The four grooves thus made end with the same number of round pits, pressed a half inch or more below the level of the palm, while at the base of the palm one of the small circular pits occurs. These small pits appear at the base of each palm and sole wherever the conditions are favorable enough to retain the imprint of the hinder part of the foot. There is no doubt but that this track represents the impression of the left manus.

TRACK No. 6. (Plate 1, fig. 6.) Impression No. 6, two feet six inches from No. 5, is similar in all respects to others already described, and is the left pes.

TRACKS NOS. 7 AND 8. (Plate 1, figs. 7 and 8.) These two tracks were removed in one block. The distance of stride from No. 6 to No. 7 was two feet six inches. Here the animal changed its course and turned sharply to the left, making a short step of only twelve inches from track seven to track eight. Each of these tracks were pressed firmly into the sandy matrix, making a bowl-shaped depression, with sloping sides, twelve inches in diameter and six inches deep. Grooves in the sides of the depressions show distinctly where the toes and the pad of the front foot have pressed down to a depth of four inches. At this level there is a slight ledge left where the overlapping hind foot pressed still deeper down for another three inches, leaving a well-defined imprint of the short claws and the circular pits similar to those found at the base of the palm and sole of the other tracks collected.

TRACK NO. 9. (Plate 1, fig. 9.) This, the last track of the series, was situated two feet three inches from the preceding track, and six inches higher in elevation. This probably is of the left side, but whether of the manus or pes is rather doubtful. The imprint, being on higher and drier ground, was less distinct and showed less character than those made in more plastic material. The bank rises rapidly from the last track found, and although the overlying soil was cleared away for quite a space around, no other indications of tracks could be found.

The finding of these scarce footprints in the Coal Measures of Kansas will be welcomed because they may shed some light on the ancestors of the later Permo-Carboniferous amphibians, or possibly reptilian fauna of that age.

Thanks are here expressed to the finders of these rare tracks for their generosity in presenting them to the paleontological department of the University of Kansas.

I wish to express my thanks to Dr. Roy L. Moodie, College of Medicine of the University of Illinois, to whom I am under obligations for assistance in the preparation of this paper.

CONCLUSIONS.

The present series of footprints referred to under the new term of *Onychopus gigas* indicates one of the largest, if not actually the largest, pre-Triassic vertebrate thus far known from the geological horizons of the world. A short-bodied, long-limbed vertebrate with well-developed feet left these impressions, of whose bodily structure nothing whatever is known. So deeply marked are the footprints in the sandstone that it looks as if an elephant had recently waded through. A curious consistency of the sandy shale is indicated in the well-preserved indications of foot structure of *Onychopus gigas* as he trailed through the sandy mud many millions of years ago. It is extremely interesting to note the change in elevation between track one and track nine. While this may be due to the dip of the strata, it may also indicate the shelving bank of a Coal Measures stream which has again been exposed by the gradual erosion of the present Wakarusa creek.

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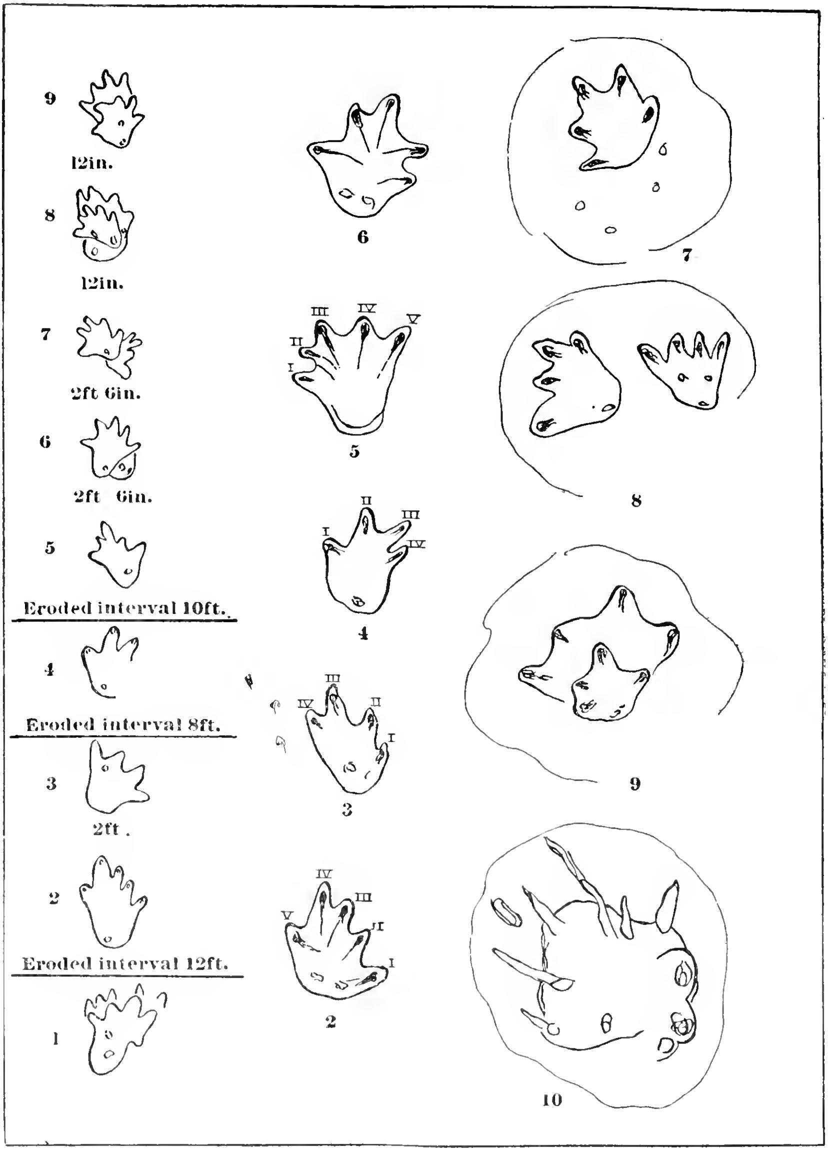
FOOTPRINTS OF A GIGANTIC AMPHIBIAN. PLATE I.
H. T. Martin.



EXPLANATION OF PLATE I.

The small figures on the left, from 1 to 9, indicate the series of amphibian footprints in the sandstone ledge of the Upper Coal Measures. After making the sixth impression the animal turned sharply to the left, so that the drawing does not represent exactly the manner of occurrence. It shows, however, the distance between impressions. No. 1 is possibly a fore-foot impression, with portions of another; No. 2, the left pes; No. 3, the left manus; No. 4, indefinite; No. 5, left pes; No. 6, left pes, part manus; No. 7, left pes, part left manus; No. 8, left pes, part manus; No. 9, undecided.

The figures 2 to 10 on the right of the plate are detailed studies of the best-preserved tracks.

No. 2, left pes with a distance of 130 mm. across the heel impressions at the level of digit I. The distance between the tips of digits I and II, II and III, III and IV is in each case 40 mm.; between IV and V is 80 mm. Small pits in the heel impression indicate heel pads.

No. 3, left manus. The small pits to the left indicate toe marks of another foot. The greatest width of this foot is 105 mm. The distance between the tips of digits I and II, II and III is in each case 50 mm.; between III and IV is 40 mm.

No. 4, right manus. The distance from the tip of digit III to the posterior edge of the heel pad is 95 mm.; between II and III, 45 mm.; between I and II, 48 mm.

No. 5, right pes. The greatest length is 110 mm.; the greatest width 120 mm.

No. 6, undoubtedly a pes, with well-marked heel pads. The greatest length is 140 mm., the greatest width 144 mm.

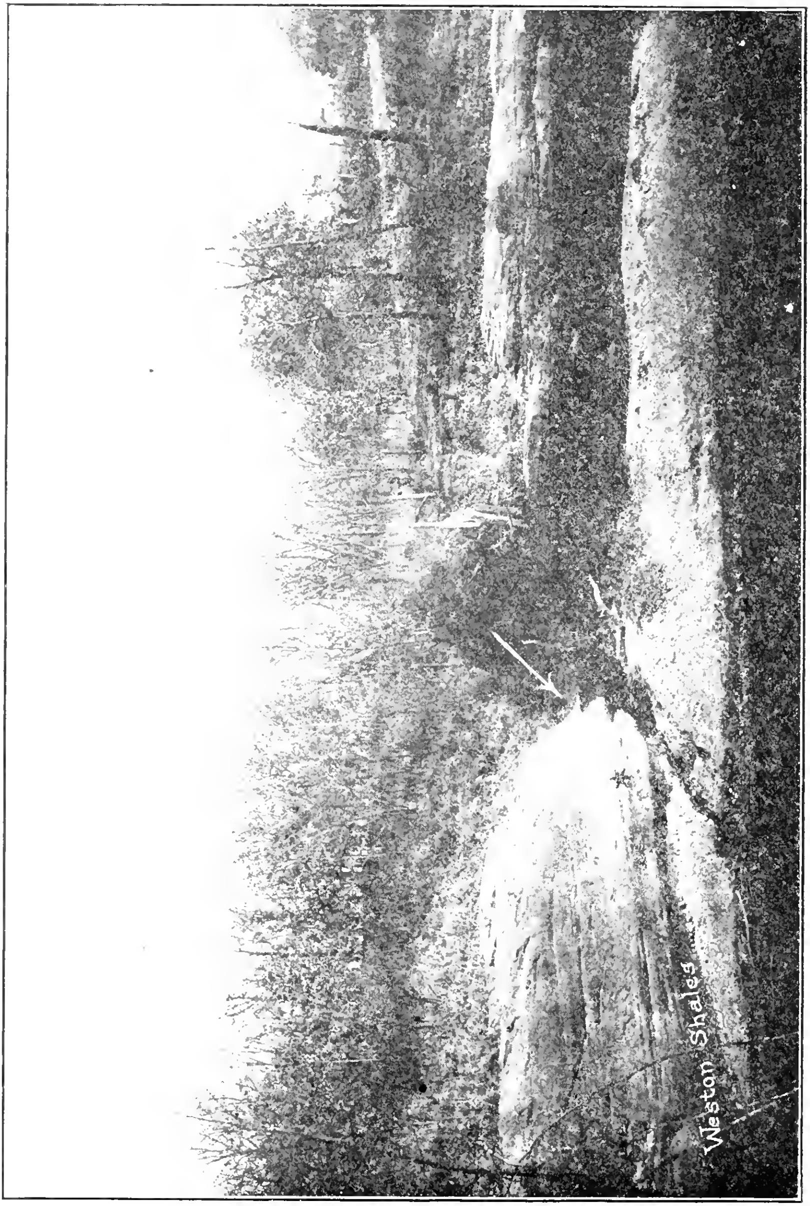
No. 7, a pes. The impressions below the pes represent a second impression, which was probably obliterated by the hind foot. The circle surrounding the footprints represents the edge of a three-inch depression in which the footprints occurred. This indicates both the great weight of the animal and the softness of the ground.

No. 8, a part of pes and manus, also occur in a depression three inches deep.

No. 9 shows two superimposed impressions of a fore and a hind foot. The greatest width of the hind foot is 135 mm.

No. 10 is a sketch of the appearance of the depression, showing the shape of the depression and the long furrows made by dragging blunt claws along a moist surface. Claws have been previously indicated in the remains of the larger Permian and Triassic amphibians, in the presence of blunt terminal rugose phalanges, but so far as I am aware no impressions of them have been so clearly recorded in the rocks of the Coal Measures.

PLATE II.



FOOTPRINTS OF A GIGANTIC AMPHIBIAN.
H. T. Martin.

EXPLANATION OF PLATE II.

Photograph of the east bank of the Wakarusa creek at Dightman's crossing, five miles southeast of Lawrence, Kan., showing the relation of the heavily bedded sandstone, in which the amphibian footprints were found, to the Weston shales which outcrop immediately at the edge of the water. The ravine in the center of the picture has a depth from the surface of twenty feet, and in this depression, on the ledge indicated at the point of the arrow, was found the series of footprints shown in the plate. This ledge at the position of the first track lies fourteen feet above the creek, but the stratum rises three feet between the first and the second impressions, between which there is an eroded interval of twelve feet. A further inclination of the stratum is indicated in the fact that there is a rise of four feet between the second and the last impressions, a distance of twenty-seven feet. The ledge on which the impressions were found is continued into the sandstone cliff immediately above the star (*).

FOOTPRINTS OF A GIGANTIC AMPHIBIAN.
H. T. Martin.

PLATE III.

Photographs of tracks Nos. 8 and 9, showing the imprint of both the front and the supraimposed hind foot on each impression.

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On Some Isothiourea Ethers.[1]

(Contribution from the Chemical Laboratory, University of Kansas.)

BY F. B. DAINS AND W. C. THOMPSON.

ONE of the characteristic reactions of the substituted thioureas is their ability to add directly alkyl halides, with the formation of halogen halide salts of bases, in which the alkyl group is joined to sulfur.[2]

$$\mathrm{RNHCSNHR + R'X = RNHC(SR')NR,HX.}$$

From these salts, the free thiourea ethers can be obtained by the action of alkalies. As part of an investigation now in progress, it was deemed advisable to synthesize the n-propyl and n-butyl ethers of certain thioureas and, owing to the departure of one of the authors from this laboratory, to record these preliminary results at this time.

EXPERIMENTAL.

γ-PROPYL-α, β-DIPHENYL THIOUREA. $C_6H_5NHC(SC_3H_7)NC_6H_5$.

(n-Propyl ester of phenylimino-phenyl thiocarbamic acid.)

A mixture of thiocarbanilide (15 gms.) and normal propyl iodide (10 gms.) was heated on the water bath for an hour. The light-brown viscous liquid solidified on cooling. After crystallization from alcohol the hydrogen iodide salt was obtained in the form of colorless rhombic crystals, which melted at 103°. The salt was slightly soluble in ether, cold water and cold alcohol, but readily soluble in hot water, hot alcohol and acetone. The yield was 80 per cent.

Calc. for $C_{16}H_{18}N_2S,HI$: N, 6.93. Found: 7.09, 6.79.

The free base, which was insoluble in water, was obtained by

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[1] The authors wish to express their thanks to the research committee of the University for a grant which was of assistance in the prosecution of this work.

[2] Ber. 14, 1490 (1881); 15, 1314 (1882); 21, 962, 1857 (1888).

neutralizing an aqueous solution of the salt with sodium hydroxide. The white needles, which separated from alcohol, melted at 61.5°.

Calc. for $C_{16}H_{18}N_2S$: N, 10.39. Found: 10.10, 10.16.

γ-n-BUTYL-α, β-DIPHENYL THIOUREA. $C_6H_5NHC(SC_4H_9)NC_6H_5$.

The mixture of normal butyl iodide and diphenyl thiourea was heated on the steam bath for an hour. The salt, which solidified on cooling, could not be purified by crystallization. It was therefore ground up and thoroughly washed with ether, in which it was insoluble. The yield of the hydroiodide, which melted at 122°, was 83 per cent.

Calc. for $C_{17}H_{20}N_2S,HI$: N, 6.78. Found: 6.66, 6.68.

An aqueous solution of the salt was treated with sodium carbonate. The free base was obtained a heavy, colorless, noncrystallizable oil, which was readily soluble in the ordinary organic solvents.

Calc. for $C_{17}H_{20}N_2S$: N, 9.85. Found: 9.92, 9.95.

γ-n-PROPYL-α, β-DI-p-TOLYL THIOUREA. $C_7H_7NHC(SC_3H_7)NC_7H_7$.

Di-p-tolyl thiourea and normal propyl iodide reacted readily on warming and the resulting hydrogen iodide salt was purified by washing with cold alcohol. It then melted at 165°. The yield was 88 per cent.

Calc. for $C_{18}H_{22}N_2S,HI$: N, 6.57. Found: 6.29, 6.51.

The salt was freely soluble in water and the thio ether, precipitated by the addition of alkali, crystallized from alcohol in fine, white needles which had a melting point of 99°.

Calc. for $C_{18}H_{22}N_2S$: N, 9.36. Found: 9.18, 9.35.

γ-n-BUTYL-α, β-DI-p-TOLYL THIOUREA. $C_7H_7NHC(SC_4H_9)NC_7H_7$.

The hydrogen iodide salt, which was obtained in a 95 per cent yield from the normal butyl iodide and the thiourea, melted at 145°.

Calc. for $C_{19}H_{24}N_2S,HI$: N, 6.36. Found: 6.35, 6.35.

The free base formed by neutralizing an alcoholic solution of the salt was a thick, colorless liquid, insoluble in water but soluble in organic solvents.

Calc. for $C_{19}H_{24}N_2S$: N, 8.97. Found: 9.12, 9.33.

γ-n-PROPYL-α, β-DI-2, 4-DIMETHYL-PHENYL THIOUREA.
$(CH_3)_2C_6H_3NHC(SC_3H_7)NC_6H_3(CH_3)_2$.

Di-m-xylyl thiourea and normal propyl iodide reacted easily on warming, but the product, which was obtained in 87 per cent yield, proved to be the free base and not its salt. This when purified from alcohol melted at 113.5°.

Calc. for $C_{22}H_{28}N_2S$: N, 8.58. Found: 8.46, 8.46.

THIOETHERS FROM UREAS CONTAINING TWO DIFFERENT GROUPS.

γ-METHYL-α-p-BROMOPHENYL-β-PHENYL THIOUREA.

$C_6H_5NHC(SCH_3)NC_6H_4Br$ or $C_6H_5NC(SCH_3)NHC_6H_4Br$.

The unsymmetrical nature of the mol did not prevent the addition of the alkyl iodide, since when methyl iodide and phenyl-p-bromophenyl thiourea were heated under the usual conditions a yield of 69 per cent of the hydrogen iodide salt was obtained. It melted at 152°.

Calc. for $C_{14}H_{13}N_2SBr,HI$; N, 6.24. Found: 6.04, 6.27.

The thioether was preciptated when an alcoholic solution of the salt was made alkaline with sodium carbonate and then diluted with water. When purified, the white needles melted at 79°.

Calc. for $C_{14}H_{13}N_2SBr$; N, 8.72. Found: 8.54, 8.77.

γ-n-PROPYL-α-p-BROMOPHENYL-β-PHENYL THIOUREA.

$C_6H_5NHC(SC_3H_7)NC_6H_4Br$.

Normal propyl iodide and the thiourea united to form a salt, which, however, failed to crystallize, but remained as a heavy, red oil.

Calc. for $C_{16}H_{17}N_2SBr,HI$; N, 5.88. Found: 5.46.

The thioether, which was isolated in a 70 per cent yield, melted at 84°, after purification from alcohol.

Calc. for $C_{16}H_{17}N_2SBr$; N, 8.02. Found: 8.09, 8.07.

γ-n-BUTYL-α-p-BROMOPHENYL-β-PHENYL THIOUREA.

$C_6H_5NHC(SC_4H_9)NC_6H_4Br$.

The hydrogen iodide salt from the thiourea and the normal butyl iodide separated in this case also as a thick noncrystallizable oil.

Calc. for $C_{17}H_{19}N_2SBr,HI$; N, 5.70. Found: 5.37, 5.62.

The free base obtained in the usual manner was a viscid oil, soluble in alcohol and ether.

Calc. for $C_{17}H_{19}N_2SBr$; N, 7.71. Found: 7.72, 7.52.

γ-n-BUTYL-MONOPHENYL THIOUREA. $C_6H_5NHC(SC_4H_9)NH$.

When monophenyl thiourea and normal butyl iodide were warmed on the water bath, a gummy mass was obtained. This was dissolved in hot alcohol and neutralized with sodium carbonate. On dilution with water the thiourea was precipitated as a heavy oil, which failed to crystallize.

Calc. for $C_{11}H_{16}N_2S$; N, 12.72. Found: 13.03, 13.05.

SUMMARY.

A number of new alkyl ethers of substituted thioureas have been prepared. While usually these ethers are solid crystalline compounds, the normal butyl derivatives thus far isolated are basic oils. The di-m-xylyl thiourea gave the free base and not the hydrogen iodide salt with normal propyl iodide.

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The Size of the Thymus Gland in Relation to the Size and Development of the Foetal Pig as Studied in a Varied Range of Stages.

BY DONALD N. MEDEARIS AND ALEXANDER MARBLE.

From the Laboratory of Comparative Anatomy, University of Kansas.

INTRODUCTION.

THE thymus gland has long been a favorite subject for study and for speculation as to its function and possible effect upon growth. Much work has been done in extirpation of the gland in postnatal animals in order to note the effect upon metabolism. Different results have been obtained as different species of animals were examined, depending largely upon the time of involution of the gland in that particular animal. H. Matti (1) found that extirpation of the thymus in pups (eighteen days to eight weeks in age) caused slowness of movement, muscular weakness, softness of bones, bone changes resembling those in rickets, and subsequent death. Almost similar results were reported by Basch (2). Such findings would seem to indicate a direct effect upon bone formation, and accordingly upon the size of the animal. That the size of thymus is correlated with size of animal (*i. e.*, in individuals below age of involution stage) is evidently accepted as probable by Badertscher (3), who states in a description of a sketch that "[above is an] outline drawing of the exposed left thymus of a 'runty' pig, one day old and only 240 mm. in length; the thymus in this specimen was a few millimeters shorter than that in the full-term embryo; this is perhaps due to the fact that the specimen was a 'runt.'" On the contrary, Hatai (4), in a study of postnatal rat thymi, states that "the weight of the thymus is correlated with the *age* of the rat rather than the body weight," thus showing a counter finding.

This problem, then, was deemed worthy of investigation, and for study the fœtal pig was chosen, largely because it shows the typical mammalian characteristics and because little work of any sort has been attempted with the fœtal pig; then, too, the material was fairly easily obtained and was found to be highly satisfactory. Since the pig had been selected, a further phase of the subject arose, and its importance became evident: as yet (as we believed after a search through literature) no one had studied the thymus in any great number of fœtal pigs and had tabulated measurements and thus secured normal averages and percentages. Such tables of averages, etc., we recognized to be of great value as a basis for further work in this direction or in any phase of thymus work in pigs. Extensive work of this sort has been done by Hatai (5) and by Jackson (6) in albino rats, and by others.

Therefore, it is with this twofold purpose that this paper is presented: (1) to give our findings as to the relation of the size of the thymus gland to the size of the fœtal pig, and (2) to furnish, as a possible basis for further research, tables of measurements and weights of many individual pig fœti of various sizes, with the measurements and weights of their thymi and individual and group averages. We hope to further continue the study to include postnatal pigs; in this study a further object of interest will be the determination of the time of the involution stage, since such time would be expected to lie in the postnatal period.

METHODS OF OBTAINING SPECIMENS AND LABORATORY TECHNIQUE USED.

Specimens were obtained from the plant of the Armour Packing Company in Kansas City, Kan. The collectors went on the killing floor of the plant, secured suitable uteri, removed the fœti, tied the umbilical cords, and put the pigs into a preservative solution (formaldehyde) ready for shipping. Litters were kept separate by means of cheesecloth bags for individual litters. Care was taken to get fœti of as wide a range of lengths as possible, varying from 9.5 to 28.5 centimeters.

In the laboratory each pig was weighed, its length recorded (head to rump measurement taken), and its sex determined; then each pig was given a litter letter and a serial number, and tagged so that future identification was possible. The remaining procedure in the actual bulk of the work was simple, and the dissection progressed rather rapidly once the technique was mastered, and an exact idea of the extent of the thymus was secured. The neck and upper thoracic region of the body were stripped of skin, and the thymus beneath (easily seen) dissected away from the surrounding tissue. The gland was then washed, dried superficially on filter paper, and weighed. This process was carried out on almost 150 pigs, and tables and curves were made and studied to determine tendencies.

RELIABILITY OF RESULTS.

Before going into the body of the report it may be well to consider just how reliable were the results obtained, and wherein lay sources of error. (1) In the weighing of the pigs, some of them may have absorbed more of the formaldehyde preservative than others; some may have lost more of their body fluids than others. This error seems to us, however, as negligible. (2) The chemical balances used were not of the best, and, too, the thymi may not have received exactly the same treatment after removal from the pig, although every effort was put forth to secure uniformity. To this end, all weighings (practically) were made by one operator. (3) Lengths of the pigs may not be entirely accurate, although here, too, the greatest care possible was taken to secure exactness. (4) Lastly, incomplete removal of the thymus, or removal of other tissue as thymus, may have occurred in some cases. The greatness of this error depends, of course, upon the skill of the workers, and it is their hope that this has been a negligible factor of error. Taking all in all, then, it is extremely probable that the material and data to be set forth are accurate to this degree, that they may be taken as the basis for conclusions of a definite nature. Such conclusions are, in our minds, accurate and reliable enough to merit consideration.

THE THYMUS: ITS GENERAL SHAPE AND EXTENT.

It was not our purpose to study the structure of the thymus in any detail, and this part of the report is merely made in passing, without any attempt at thoroughness. Our findings seem to be similar in many respects to those of Badertscher (3) as to the anatomy of the gland.[1] In the fœtal pig it is comparatively very long, extending usually from a point over the upper half or third of the heart, underneath the sternum (as viewed from the ventral side), and up to the base of the mandible. The portion covering the heart is strongly attached to the pericardium; it is roughly triangular in shape, with the apex pointing posteriorly, and lies mainly to the left of the median line. The anterior end of this, the thoracic

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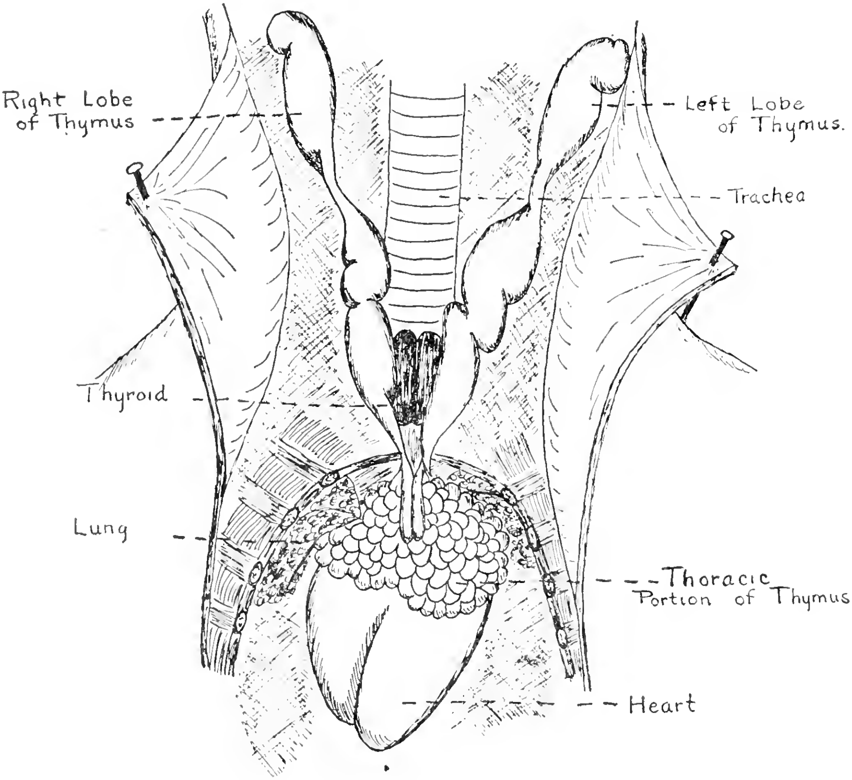
[1] In a further paper (7) Badertscher discusses the development of the thymus in the pig from the standpoint of histogenesis.

portion of the gland, narrows down, and the thymus appears beneath the sternum as two slender, parallel ribbons of glandular tissue. Once into the neck region, however, these two ribbons become very much larger and diverge, passing anteriorly to the base of the mandible, one on each side. In the thyroid region they parallel each other closely, lying on opposite sides of the thyroid, and thus fairly close to the median line. Then each passes from here into deeper tissue and obliquely away from the median line, ending behind the mandible. The thymus seems to be made up of many small lobules, combined into larger lobes. The accompanying sketch will give, perhaps, a clearer idea of the form of the gland.



SKETCH of the THYMUS in SITU

TABLE NO. 1.

Table No. 1 shows the original data as taken in the laboratory concerning each pig, together with individual averages, sex averages, and litter averages. From the table all the derivations and calculations of the report will be taken. Its value lies largely in reference, and will not be used much to point out conclusions. However, it is well to note from it the number of pigs dissected, namely, 147 from 18 different litters.

Relation of Sex to Thymus.

An examination of the averages listed beneath each litter in table No. 1 will readily show, in regard to sex, that males and females have practically the same percentage of thymus in the same stage of development. Consider particularly the percentage thymus by weight as balanced against the length of the pig, and this statement becomes evident. It is true that in several of the litters the females have the greater percentage of gland, but this tendency is practically balanced by the fact that many of the litters show approximately equal averages for males and females, and others show the balance in favor of the males. If our results be taken to show any positive tendency at all, it is that the females have the larger thymi (proportionally), but the writers believe that this is due to the small number of pigs dissected, and that such a positive tendency is too weak to merit much consideration. As such, special curves and tables have not been made for this part of the report. Notwithstanding, Hatai (4) in relevant material states that "so far as our present data are concerned, the thymus gland of the female of the albino rat appears to be slightly heavier than that of the male; nevertheless, the difference found is too slight to justify treating the sexes separately."

TABLE No. 1.

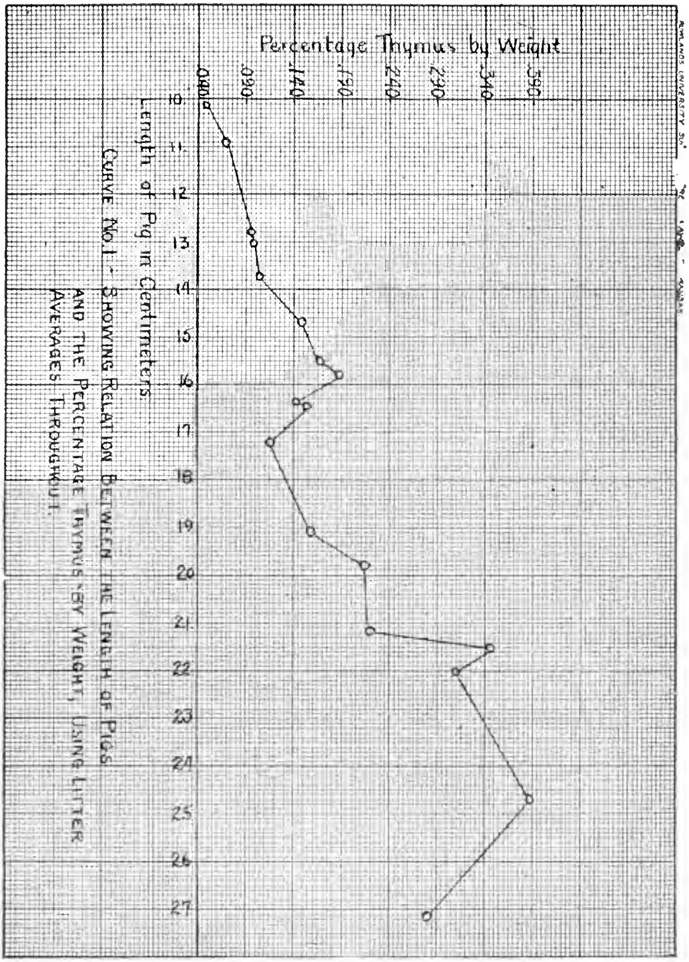
Pig.	Sex.	Pig length in cms.	Thymus length in cms.	Per cent by length.	Pig weight in grams.	Thymus weight in grams.	Per cent by weight.
1 A1	Male	15.5	4.0	25.8	235	.310	.132
2 A2	Male	15.0	3.75	25.0	192	.454	.236
3 A3	Male	15.5	3.8	24.5	233	.255	.109
4 A4	Male	15.5	3.8	24.5	202	.260	.129
5 A5	Male	16.0	4.0	25.0	212	.295	.134
6 A6	Female	17.5	4.5	25.7	265	.503	.189
7 A7	Female	16.0	3.5	21.9	237	.636	.268
8 A8	Male	16.0	3.7	23.1	228	.325	.143
9 A9	Male	16.5	3.7	22.4	243	.402	.165
10 A10	Male	15.5	3.8	24.5	228	.295	.129
11 A11	Male	14.0	3.5	25.0	174	.205	.118
12 A12	Male	16.0	3.8	23.8	234	.350	.150
13 A13	Male	11.5	2.3	20.0	102	.140	.137
14 A14	Male	17.0	4.5	26.5	265	.661	.287
Averages	Male, 86 per cent	15.3	3.72	24.2	212	.329	.156
	Female, 14 per cent	16.8	4.0	23.8	251	.569	.229
	Litter	15.5	3.8	24.1	218	.364	.166
15 B1	Male	11.0	2.5	22.7	100	.070	.070
16 B2	Female	11.0	2.75	25.0	102	.095	.093
17 B3	Female	10.0	2.5	25.0	76	.031	.041
18 B4	Male	10.5	....	....	89	....	....
19 B5	Female	11.0	2.75	25.0	90	.070	.078
Averages	Male, 40 per cent	11.0	2.5	22.7	100	.070	.070
	Female, 60 per cent	10.7	2.7	25.0	89	.065	.071
	Litter	10.9	2.6	24.4	92	.067	.071
20 C1	Female	11.5	2.5	21.7	107	.120	.112
21 C2	Male	13.0	2.5	19.2	145	.121	.083
22 C3	Female	13.5	2.7	20.0	136	.130	.096
23 C4	Female	13.0	2.5	19.2	123	.150	.122
24 C5	Male	13.0	2.5	19.2	122	.130	.107
25 C6	Male	14.0	3.5	25.0	164	.150	.091
26 C7	Female	14.0	4.0	28.6	143	.134	.094
27 C8	Male	11.5	2.5	21.7	102	.110	.108
28 C9	Male	13.5	3.25	24.1	164	.158	.096
Averages	Male, 56 per cent	13.0	2.85	21.8	139	.134	.097
	Female, 44 per cent	13.0	2.9	22.3	127	.134	.106
	Litter	13.0	2.9	22.1	134	.134	.101
29 D1	Male	25.0	6.5	26.0	752	2.986	.397
30 D2	Male	25.0	7.0	28.0	771	2.580	.334
31 D3	Male	25.0	7.5	30.0	815	2.860	.351
32 D4	Female	25.0	7.0	28.0	843	3.550	.421
33 D5	Male	23.5	7.0	29.8	669	2.788	.417
Averages	Male, 80 per cent	24.6	7.0	28.5	752	2.804	.375
	Female, 20 per cent	25.0	7.0	28.0	843	3.550	.421
	Litter	24.7	7.0	28.4	770	2.953	.384
34 E1	Female	14.5	3.4	23.5	184	.276	.150
35 E2	Female	15.0	3.5	23.3	196	.268	.137
36 E3	Male	15.0	3.5	23.3	211	.238	.113
37 E4	Male	15.0	3.5	23.3	208	.410	.197
38 E5	Male	16.0	3.5	21.9	195	.250	.128
39 E6	Male	12.5	3.0	24.0	126	.180	.143
Averages	Male, 67 per cent	14.6	3.4	23.1	185	.269	.145
	Female, 33 per cent	14.8	3.4	23.4	190	.272	.144
	Litter	14.7	3.4	23.2	187	.270	.145
40 F1	Female	13.5	3.0	22.2	122	.125	.102
41 F2	Female	13.5	3.0	22.2	130	.214	.165
42 F3	Male	13.0	3.0	23.1	115	.184	.160
43 F4	Male	13.0	3.2	24.6	115	.085	.074
44 F5	Female	13.0	3.2	24.6	120	.115	.096
45 F6	Male	13.0	2.5	19.2	102	.080	.078
46 F7	Male	12.0	2.75	22.9	95	.068	.072
47 F8	....	13.5	....	....	....	....	....
48 F9	Male	13.5	3.0	22.2	140	.082	.059
49 F10	Female	12.5	3.2	25.6	120	.108	.090
50 F11	Female	11.0	2.5	22.7	83	.072	.087
51 F12	Male	13.0	3.3	25.4	126	.117	.093
52 F13	Female	12.0	2.6	21.7	96	.085	.089
Averages	Male, 50 per cent	12.9	2.96	22.9	116	.103	.089
	Females, 50 per cent	12.6	2.9	23.2	112	.120	.105
	Litter	12.8	3.0	23.0	114	.111	.097

TABLE No. 1—CONTINUED.

Pig.	Sex.	Pig length in cms.	Thymus length in cms.	Per cent by length.	Pig weight in grams.	Thymus weight in grams.	Per cent by weight.
53 G1		22.0	6.0	27.3	635	3.241	.510
54 G2		22.0	5.5	25.0	549	1.280	.233
55 G3		22.0	6.2	28.2	665	1.900	.286
56 G4	Males, 5	22.0	6.0	27.3	658	2.914	.443
57 G5	Females, 3	21.5	5.8	27.0	610	1.999	.312
58 G6		21.5	5.5	25.6	581	2.379	.409
59 G7		22.0	6.0	27.3	635	2.205	.347
60 G8		19.0	5.2	27.4	346	.755	.218
Averages	Male, 63 per cent Female, 37 per cent	21.5	5.8	26.9	589	2.084	.315
61 H1	Male	17.0	4.5	26.5	251	.305	.122
62 H2	Male	16.0	4.3	26.9	257	.420	.163
63 H3	Female	16.5	4.0	24.2	271	.751	.277
64 H4	Male	12.5	3.3	26.4	118	.133	.112
65 H5	Male	13.5	4.0	29.6	154	.323	.209
66 H6	Female	16.0	4.0	25.0	235	.519	.221
67 H7	Male	17.5	4.5	25.7	318	.705	.222
68 H8	Male	14.0	3.2	22.9	159	.205	.129
69 H9	Male	18.0	4.5	25.0	316	.847	.268
70 H10	Male	16.5	3.8	23.0	245	.410	.168
Averages	Male, 80 per cent	15.6	4.0	25.8	227	.419	.174
	Female, 20 per cent	16.25	4.0	24.6	253	.635	.249
	Litter	15.8	4.0	25.5	232	.462	.189
71 I1	Male	14.0	3.7	26.4	137	.137	.100
72 I2	Female	13.5	2.9	21.5	135	.170	.126
73 I3	Female	14.0	3.5	25.0	125	.114	.091
74 I4	Male	14.0	3.5	25.0	150	.160	.107
75 I5	Male	13.5	3.2	23.7	145	.120	.083
76 I6	Female	13.5	3.1	23.0	137	.155	.113
77 I7	Female	13.5	3.2	23.7	145	.160	.110
78 I8	Male	13.5	3.3	24.4	143	.142	.099
Averages	Male, 50 per cent	13.8	3.4	24.9	144	.140	.097
	Female, 50 per cent	13.6	3.2	23.3	136	.150	.110
	Litter	13.7	3.3	24.1	140	.145	.104
79 J1	Male	17.0	4.3	25.3	267	.332	.124
80 J2	Male	18.5	4.3	23.2	295	.385	.131
81 J3	Male	17.0	4.5	26.5	285	.320	.112
82 J4	Male	17.5	4.0	22.9	255	.340	.113
83 J5	Female	17.5	4.0	22.9	245	.228	.094
84 J6	Female	17.0	4.0	23.5	250	.232	.093
85 J7	Male	17.0	4.0	23.5	228	.260	.114
86 J8	Male	16.0	4.0	25.0	205	.280	.137
Averages	Male, 75 per cent	17.17	4.2	24.4	256	.319	.122
	Female, 25 per cent	17.25	4.0	23.2	248	.230	.093
	Litter	17.2	4.1	24.1	254	.297	.115
87 K1	Male	19.5	5.5	28.2	440	.750	.170
88 K2	Male	20.0	4.5	22.5	460	.813	.177
89 K3	Female	20.0	5.0	25.0	430	1.055	.245
90 K4	Female	20.0	4.5	22.5	420	.820	.195
91 K5	Male	19.5	4.3	22.5	405	1.115	.275
Averages	Male, 60 per cent	19.7	4.7	24.4	435	.893	.207
	Female, 40 per cent	20.0	4.8	23.8	425	.938	.220
	Litter	19.8	4.76	24.1	431	.911	.212
92 L1	Male	16.5	4.4	26.7	270	.432	.160
93 L2	Male	16.5	4.4	26.7	245	.392	.160
94 L3	Female	17.0	4.2	24.7	270	.335	.124
95 L4	Male	16.5	3.5	21.2	250	.407	.163
96 L5	Male	16.5	4.3	26.0	250	.370	.148
97 L6	Female	16.5	4.2	25.5	240	.365	.152
98 L7	Male	16.5	4.5	27.3	250	.365	.146
99 L8	Male	15.5	3.6	23.2	125	.200	.160
Averages	Male, 75 per cent	16.3	4.1	25.2	232	.361	.156
	Female, 25 per cent	16.8	4.2	25.1	255	.350	.138
	Litter	16.4	4.1	25.1	238	.358	.152
100 M1	Male	21.5	6.0	27.9	515	1.220	.237
101 M2	Female	21.0	5.3	25.2	515	.920	.179
102 M3	Female	20.5	5.4	26.3	445	1.032	.232
103 M4	Female	21.0	5.3	25.2	475	1,183	.250
104 M5	Male	21.0	5.5	26.2	445	.887	.200
105 M6	Male	19.0	5.3	27.9	342	.685	.200
106 M7	Male	22.5	5.5	24.9	550	1.315	.239
107 M8	Male	22.0	5.5	25.0	500	1.255	.251
108 M9	Male	22.0	5.5	25.0	420	.772	.184
Averages	Male, 67 per cent	21.3	5.55	26.2	462	1.014	.218
	Female, 33 per cent	20.8	5.3	25.6	478	1.045	.220
	Litter	21.2	5.48	26.0	467	1.030	.219

TABLE No. 1—CONCLUDED.

Pig.	Sex.	Pig length in cms.	Thymus length in cms.	Per cent by length.	Pig weight in grams.	Thymus weight in grams.	Per cent By weight.
109 N1	Female	19.0	4.5	23.7	400	.710	.178
110 N2	Male	19.5	4.6	23.6	360	.517	.144
111 N3	Male	19.0	4.8	25.3	420	.580	.138
112 N4	Male	19.5	5.0	25.6	430	.550	.128
113 N5	Male	18.5	4.5	24.3	360	.466	.130
114 N6	Male	18.5	4.5	24.3	380	.635	.167
115 N7	Female	19.0	4.3	22.6	395	.805	.204
116 N8	Male	19.5	5.0	25.6	407	.672	.165
Averages	Male, 75 per cent	19.1	4.7	24.8	393	.570	.145
	Female, 25 per cent	19.0	4.4	23.1	398	.757	.172
	Litter	19.1	4.65	24.4	394	.617	.157
117 O1	Male	14.0	3.5	25.0	170	.180	.106
118 O2	Female	17.0	4.7	27.6	275	.602	.219
119 O3	Female	16.5	4.2	25.5	280	.405	.145
120 O4	Male	16.0	4.6	28.7	230	.255	.111
121 O5	Female	16.0	4.2	26.3	263	.426	.162
122 O6	Female	17.0	4.1	24.1	262	.425	.162
123 O7	Male	18.0	4.5	25.0	313	.370	.118
124 O8	Female	16.5	4.1	24.8	290	.351	.121
Averages	Male, 38 per cent	16.0	4.2	26.2	238	.268	.112
	Female, 62 per cent	16.6	4.3	25.7	274	.442	.162
	Litter	16.4	4.2	25.9	260	.377	.143
125 P1	Male	24.5	6.4	26.1	735	2.285	.311
126 P2	Female	24.0	6.0	25.0	700	2.135	.305
127 P3	Female	23.5	6.0	25.5	590	1.610	.273
128 P4	Female	23.5	6.0	25.5	665	1.940	.292
129 P5	Female	24.5	6.0	24.5	675	1.975	.293
130 P6	Female	21.5	5.0	23.3	495	1.540	.311
131 P7	Female	20.5	5.5	26.8	435	1.375	.316
132 P8	Female	23.5	6.3	26.8	740	2.002	.271
133 P9	Male	22.0	6.1	27.7	620	1.930	.311
Averages	Male, 22 per cent	23.3	6.3	26.9	678	2.108	.311
	Female, 78 per cent	23.0	5.8	25.3	614	1.797	.294
	Litter	23.1	5.9	25.7	628	1.866	.298
134 Q1	Male	9.5	2.3	24.2	55	.019	.035
135 Q2	Male	10.5	2.5	23.8	68	.040	.059
136 Q3	Male	10.0	2.3	23.0	66	.032	.048
137 Q4	Female	10.0	2.2	22.0	63	.029	.046
138 Q5	Female	10.5	2.3	21.9	63	.022	.035
139 Q6	Male	10.0	2.4	24.0	63	.025	.040
140 Q7	Female	10.0	2.5	25.0	61	.035	.057
111 Q8	Female	10.5	2.5	23.8	61	.032	.052
Averages	Male, 50 per cent	10.0	2.4	23.8	63	.029	.046
	Female, 50 per cent	10.3	2.4	23.2	62	.030	.048
	Litter	10.1	2.4	23.5	63	.029	.047
142 R1	Male	27.0	9.0	33.3	1,098	2.480	.226
143 R2	Male	25.5	7.0	27.5	693	1.549	.224
144 R3	Male	27.5	8.0	29.1	932	3.365	.361
145 R4	Male	27.5	7.5	27.3	999	3.010	.301
146 R5	Female	26.5	8.6	32.5	925	2.500	.270
147 R6	Male	28.5	9.0	31.6	1,035	2,972	.287
Averages	Male, 83 per cent	27.2	8.1	29.8	951	2,675	.280
	Female, 17 per cent	26.5	8.6	32.5	925	2.500	.270
	Litter	27.1	8.2	30.2	947	2.646	.278



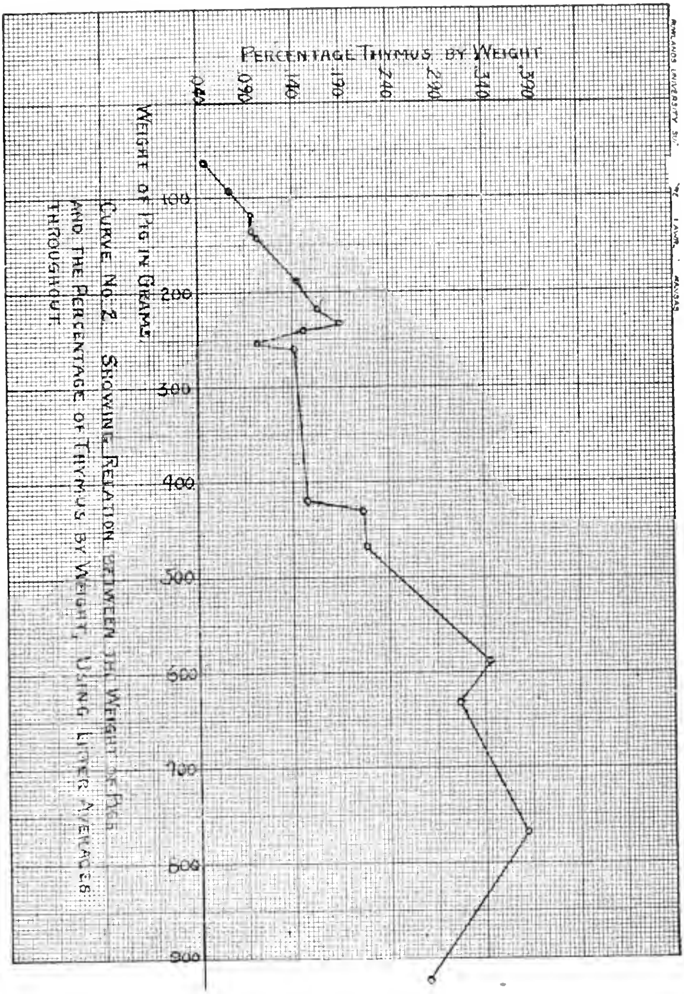
Curve No. I.—Showing Relation Between the Length of Pigs and the Percentage Thymus by Weight, Using Litter Averages Throughout.

RELATION BETWEEN THE LENGTH OF PIGS AND THE PERCENTAGE THYMUS BY WEIGHT, USING LITTER AVERAGES THROUGHOUT.

Table No. 2 and curve No. 1 are to be considered in this connection. Curve No. 1 shows that as litters made up of larger and larger fœti, as regards length, are examined, the percentage thymus by weight increases steadily. There is a marked drop near the center of the curve which cannot be explained, but it does not obscure the general tendency of an increase in percentage thymus by weight. It will be noted that the value for the litter of pigs of average length, 27.1 centimeters, has dropped quite appreciably. Whether or not this means that at 24 cm. or 25 cm. the gland reaches its greatest stage of development we do not know; not enough pigs longer than 25 cm. were examined. It would be an interesting problem to work out to see at just what stage the thymus development ceases, and when it commences to atrophy.

TABLE No. 2.

LITTER.	Pig length in cms.	Thymus length in cms.	Per cent by length.	Pig weight in gms.	Thymus weight in gms.	Per cent by weight.
Q	10.1	2.4	23.5	63	.029	.047
B	10.9	2.6	24.4	92	.067	.071
F	12.8	3.0	23.0	114	.111	.097
C	13.0	2.9	22.1	134	.134	.101
I	13.7	3.3	24.1	140	.145	.104
E	14.7	3.4	23.2	187	.270	.145
A	15.5	3.8	24.1	218	.364	.166
H	15.8	4.0	25.5	232	.462	.189
L	16.4	4.1	25.1	238	.358	.152
O	16.4	4.2	25.9	260	.377	.143
J	17.2	4.1	24.1	254	.297	.115
N	19.1	4.7	24.4	419	.617	.157
K	19.8	4.8	24.1	431	.911	.212
M	21.2	5.5	26.0	467	1.030	.219
G	21.5	5.8	26.9	589	2.084	.345
P	22.0	6.1	27.7	628	1.930	.311
D	24.7	7.0	28.4	770	2.953	.384
R	27.1	8.2	30.2	947	2.646	.278



Curve No. 2. Showing Relation between the Weight of Pigs and the Percentage of Thymus by Weight, Using Litter Averages Throughout

RELATION BETWEEN THE WEIGHT OF PIGS AND THE PERCENTAGE THYMUS BY WEIGHT, USING LITTER AVERAGES THROUGHOUT.

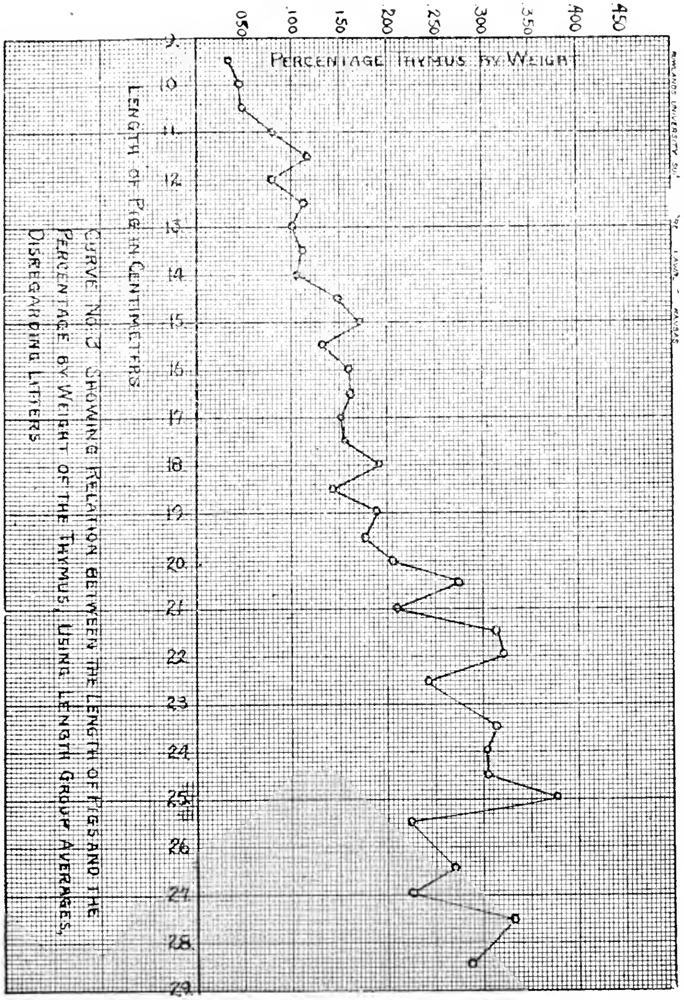
Table No. 3 and curve No. 2 show practically the same tendency as to table No. 2 and curve No. 1, *i. e.*, as heavier and heavier pigs are examined, the percentage of thymus by weight increases steadily. There is practically the same inexplicable deviation or drop near the center of the curve, and the possible maximum point centering about pigs of a weight of 770 grams.

TABLE No. 3.

LITTER.	Pig weight in gms	Thymus weight in gms.	Per cent by weight.	Pig length in cms.	Thymus length. in cms.	Per cent by length.
Q	63	.029	.047	10.1	2.4	23.5
B	92	.067	.071	10.9	2.6	24.4
F	114	.111	.097	12.8	3.0	23.0
C	134	.134	.101	13.0	2.9	22.1
I	140	.145	.104	13.7	3.3	24.1
E	187	.270	.145	14.7	3.4	23.2
A	218	.364	.166	15.5	3.8	24.1
H	232	.462	.189	15.8	4.0	25.5
L	238	.358	.152	16.4	4.1	25.1
J	254	.297	.115	17.2	4.1	24.1
O	260	.377	.143	16.4	4.2	25.9
N	419	.617	.157	19.1	4.7	24.4
K	431	.911	.212	19.8	4.8	24.1
M	467	1.030	.219	21.2	5.5	26.0
G	589	2.084	.345	21.5	5.8	26.9
P	628	1.930	.311	22.0	6.1	27.7
D	770	2.953	.384	24.7	7.0	28.4
R	947	2.646	.278	27.1	8.2	30.2

RELATION BETWEEN THE LENGTH OF PIGS AND THE PERCENTAGE BY WEIGHT OF THE THYMUS, USING LENGTH GROUP AVERAGES THROUGHOUT, DISREGARDING LITTERS.

Table No. 4 and curve No. 3 show that as larger and larger fœti (as regards length) are examined and classified regardless of litter, there is a steady increase in the percentage thymus by weight. The increase is not as uniform, however, as when the pigs are classified according to litter, as will be shown by a comparison of curve No. 1 with curve No. 3. The former is the smoother. Hence from these calculations on lengths, we may conclude that pigs tend to have the same size thymus, relatively, as that of other pigs of the same litter, regardless of individual pig lengths.



Curve No. 3 Showing Relation Between the Length of Pigs and the Percentage by Weight of the Thymus, Using Length Group Averages, Disregarding Litters

TABLE No. 4.

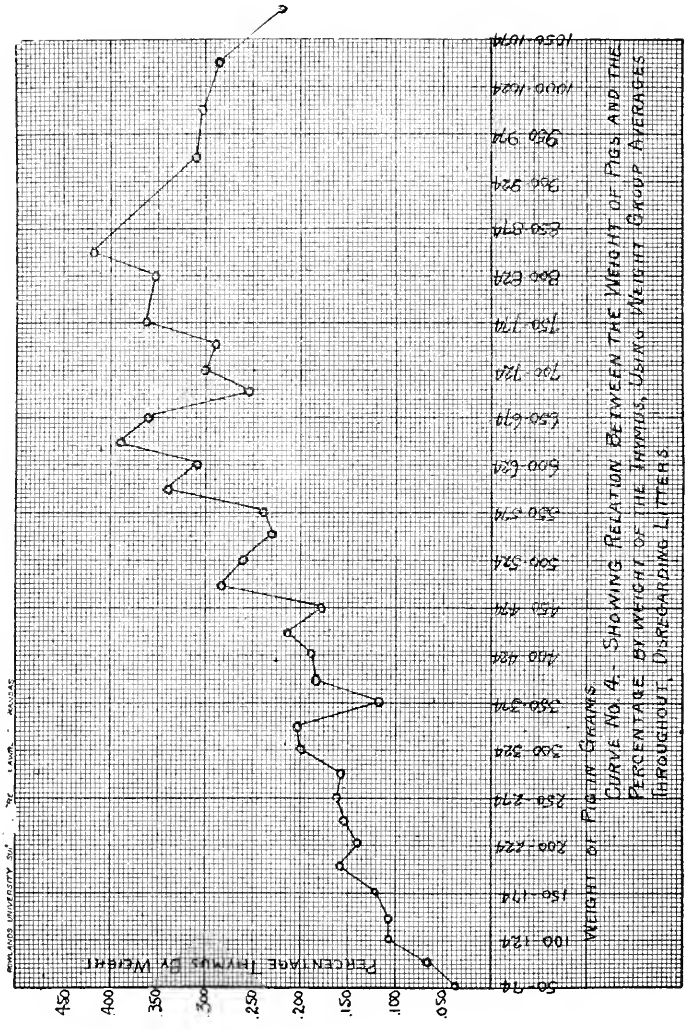
Class.	Pig.	Per cent thymus by weight.	Pig weight in gms.	Per cent thymus by length.
9.5 cm....	Q1	.035	55	24.2
	Avg.	.035	55	24.2
10.0 cm....	Q7	.057	61	25.0
	Q6	.040	63	21.0
	Q4	.046	63	22.0
	Q3	.048	66	23.0
	B3	.041	76	25.0
	Avg.	.046	66	24.0
10.5 cm....	Q8	.052	61	33.8
	Q5	.035	63	21.9
	Q2	.059	68	23.8
	Avg.	.049	64	26.5
11.0 cm....	F11	.087	83	22.7
	B5	.078	90	25.0
	B1	.070	100	22.7
	B2	.093	102	25.0
	Avg.	.082	94	23.9
11.5 cm....	C8	.108	102	21.7
	A13	.137	102	20.0
	C1	.112	107	21.7
	Avg.	.119	104	21.1
12.0 cm....	F7	.072	95	22.9
	F13	.089	96	21.7
	Avg.	.081	95.5	22.3
12.5 cm....	H4	.112	118	26.4
	F10	.090	120	25.6
	E6	.143	126	24.0
	Avg.	.115	121	25.3
13.0 cm....	F6	.078	102	19.2
	F4	.074	115	24.6
	F3	.160	115	23.1
	F5	.096	120	24.6
	C5	.107	122	19.2
	C4	.122	123	19.2
	F12	.093	126	25.4
	C2	.083	145	19.2
	Avg.	.102	121	21.8
13.5 cm....	F1	.102	122	22.2
	F2	.165	130	22.2
	I2	.126	135	21.5
	C3	.096	136	20.0
	I6	.113	137	23.0
	E9	.059	140	22.2
	I8	.099	143	24.4
	I5	.083	145	23.7
	I7	.110	145	23.7
	H5	.209	159	29.6
	C9	.096	164	24.1
	Avg.	.114	141	23.3
14.0 cm....	I3	.091	125	25.0
	I1	.100	137	26.4
	C7	.094	143	28.6
	J4	.107	150	25.0
	I18	.129	159	22.9
	C6	.091	164	25.0
	O1	.106	170	25.0
	A11	.118	174	25.0
	Avg.	.105	153	25.4
14.5 cm....	E1	.150	184	23.5
	Avg.	.150	184	23.5
15.0 cm....	A2	.236	192	25.0
	E1	.137	196	23.3
	E4	.197	208	23.3
	E3	.113	211	23.3
	Avg.	.171	202	23.7
15.5 cm....	L8	.160	175	23.2
	A4	.129	202	24.5
	A10	.129	228	24.5
	A3	.109	233	24.5
	A1	.132	235	25.8
	Avg.	.132	215	24.5
16.0 cm....	E5	.128	195	21.9
	J8	.137	205	25.0
	A5	.131	212	25.0
	A8	.143	228	23.1
	O4	.111	230	28.7
	A12	.150	234	23.8
	H6	.221	235	25.4
	A7	.268	237	21.9
	H2	.163	257	26.9
	O5	.162	263	26.3
	Avg.	.162	230	24.8
16.5 cm....	L6	.152	240	25.5
	A9	.165	243	22.4
	L2	.160	245	26.7
	H10	.168	245	23.0
	L7	.146	250	27.3
	L5	.148	250	26.0
	L4	.163	250	21.2
	L1	.160	270	26.7
	H3	.277	271	24.2
	O3	.145	280	25.5
	O8	.121	290	24.8
	Avg.	.164	258	24.8
17.0 cm....	J7	.114	228	23.5
	J6	.093	250	23.5
	H1	.123	251	26.5
	O6	.162	262	24.1
	A14	.287	265	26.5
	J1	.124	267	25.3
	L3	.124	270	24.7
	O2	.219	275	27.6
	J3	.112	285	26.5
	Avg.	.151	261	25.4
17.5 cm....	J5	.094	245	22.9
	J4	.113	255	22.9
	A6	.189	265	25.7
	H7	.222	318	25.0
	Avg.	.155	271	24.1
18.0 cm....	O7	.118	313	25.0
	H9	.269	316	25.0
	Avg.	.194	314.5	25.0
18.5 cm....	J2	.131	295	23.2
	N5	.130	360	24.3
	N6	.167	380	25.4
	Avg.	.143	345	24.3
19.0 cm....	M6	.200	342	27.9
	G8	.218	346	27.4
	N7	.204	395	22.6
	N1	.178	400	23.7
	N3	.138	420	25.3
	Avg.	.188	381	25.4

TABLE No. 4—CONCLUDED.

CLASS.	Pig.	Per cent thymus by weight.	Pig weight in gms.	Per cent thymus by length.
19.5 cm...	N2	.144	360	23.6
	K5	.275	405	22.5
	N8	.165	407	25.6
	N4	.128	430	25.6
	K1	.170	440	28.2
	Avg.	.176	408	25.1
20.0 cm. ..	K4	.195	420	22.5
	K3	.245	430	25.0
	K2	.177	460	22.5
	Avg.	.206	437	23.3
20.5 cm....	P7	.316	435	26.8
	M3	.232	445	26.3
	Avg.	.274	440	26.6
21.0 cm. ..	M5	.200	445	26.2
	M4	.250	475	25.2
	M2	.179	515	25.2
	Avg.	.210	478	25.5
21.5 cm. ..	P6	.311	495	23.3
	M1	.237	515	27.9
	G6	.409	581	25.6
	G5	.312	640	27.0
	Avg.	.317	558	26.0
22.0 cm....	M9	.184	420	25.0
	M8	.251	500	25.0
	G2	.233	549	25.0
	P9	.311	620	27.7
	G7	.347	635	27.3
	G1	.510	635	27.3
	G4	.443	658	27.3
	G3	.286	665	28.2
	Avg.	.321	585	26.6
22.5 cm.	M7	.239	550	24.9
	Avg.	.239	550	24.9
23.5 cm...	P3	.273	590	25.5
	P4	.292	665	25.5
	D5	.417	669	29.8
	P8	.271	740	26.8
	Avg.	.313	666	26.9
24.0 cm...	P2	.305	700	25.0
	Avg.	.305	700	25.0
24.5 cm. ..	P1	.311	735	26.1
	P5	.293	675	24.5
	Avg.	.302	705	25.8
25.0 cm. ..	D1	.397	752	26.0
	D2	.334	771	28.0
	D3	.351	815	30.0
	D4	.421	843	28.0
	Avg.	.376	795	28.0
25.5 cm....	P2	.224	693	27.5
	Avg.	.224	693	27.5
26.5 cm. ..	R5	.270	925	32.5
	Avg.	.270	925	32.5
27.0 cm....	R1	.226	1,098	33.3
	Avg.	.226	1,098	33.3
27.5 cm....	R3	.361	932	29.1
	R4	.301	999	27.3
	Avg.	.331	965.5	28.7
28.5 cm. .	R6	.287	1,035	31.6
	Avg.	.287	1,035	31.6

RELATION BETWEEN THE WEIGHT OF PIGS AND THE PERCENTAGE BY WEIGHT OF THE THYMUS, USING WEIGHT GROUP AVERAGES THROUGHOUT, DISREGARDING LITTERS.

Table No. 5 and curve No. 4 show that as larger and larger fœti (as regards weight) are examined and classified regardless of litter, there is a steady increase in the percentage of thymus by weight. As has already been noted in curve No. 3, the increase is not uniform. When we compare this curve No. 4 with curve No. 2 (where the pigs are classified according to litters), it is evident that the latter is smoother by far. Hence from these calculations on weights in addition to the calculations already noted on lengths, we may conclude that pigs tend to have the same size thymus as that of other pigs in the same litter, regardless of individual sizes.



Curve No. 4.- Showing Relation Between the Weight of Pigs and the Percentage by Weight of the Thymus, Using Weight Group Averages Throughout, Disregarding Litters.

TABLE No. 5.

Class.	Pig	Pig weight in gms.	Per cent weight.	Pig length in cms.	Per cent length.
50-74	Q1	55	.035	9.5	24.2
	Q8	61	.052	10.5	23.8
	Q7	61	.057	10.0	25.0
	Q5	63	.035	10.5	21.9
	Q6	63	.040	10.0	24.0
	Q4	63	.046	10.0	22.0
	Q3	66	.048	10.0	23.0
	Q2	68	.059	10.5	23.8
	Avg.	....	0465	....	23.47
75-99	B3	76	.041	10.0	25.0
	F11	83	.087	11.0	22.7
	B5	90	.078	11.0	25.0
	F7	95	.072	12.0	23.9
	F13	96	.089	12.0	21.7
	Avg.	....	.0734	....	23.66
100-124	B1	100	.070	11.0	22.7
	F6	102	.078	13.0	19.2
	B2	102	.093	11.0	25.0
	C8	102	.108	11.5	21.7
	A13	102	.137	11.5	20.0
	C1	107	.112	11.5	21.7
	F4	115	.074	13.0	24.6
	F3	115	.160	13.0	23.1
	H4	118	.112	12.5	26.4
	F10	120	.090	12.5	25.6
	F5	120	.096	13.0	24.6
	F1	122	.102	13.0	22.2
	C5	122	.107	13.0	19.2
	C4	123	122	13.0	19.2
	Avg.	....	.1115	....	22.51
125-149	I3	125	.091	14.0	25.0
	L8	125	.160	15.5	23.2
	F12	126	.093	13.0	25.4
	E6	126	.143	12.5	24.0
	F2	130	.165	13.0	22.2
	I2	135	.126	13.5	21.5
	C3	136	.096	13.0	20.0
	I1	137	.100	14.0	26.4
	I6	137	.113	13.5	23.0
	F9	140	.059	13.5	22.2
	C7	143	.094	14.0	28.6
	I8	143	.099	13.5	24.4
	C2	145	.085	13.0	19.0
	I5	145	.083	13.5	23.7
	I7	145	.110	13.5	23.7
	Avg.	....	.1078	....	23.49
150-174	I4	150	.107	14.0	25.0
	H5	154	.209	13.5	29.6
	H8	159	.129	14.0	22.9
	C6	164	.091	14.0	25.0
	C9	164	.096	13.5	24.1
	O1	170	.106	14.0	25.0
	A11	174	.118	14.0	25.0
	Avg.	....	.1223	....	25.23
175-199	E1	184	.150	14.5	23.5
	A2	192	.236	15.0	25.0
	E5	195	.128	16.0	21.9
	E2	196	.137	15.7	23.3
	Avg.	....	.1628	....	23.43
200-224	A4	202	.129	15.5	24.5
	J8	205	.137	16.0	25.0
	E4	208	.197	15.0	23.5
	E3	211	.113	15.0	23.3
	A5	212	.134	16.0	25.0
	Avg.	....	.1420	....	24.26
225-249	J7	228	.114	17.0	23.5
	A10	228	.129	15.5	24.5
	A8	228	.143	16.0	23.1
	O4	230	.111	16.0	28.7
	A3	233	.109	15.5	24.5
	A12	231	.150	16.0	23.8
	A1	235	.132	15.5	25.8
	H6	235	.221	16.0	25.4
	A7	237	.268	16.0	21.9
	L6	240	.152	16.5	25.5
	A9	243	.243	16.5	22.4
	J5	245	.094	17.5	22.9
	L2	245	.160	16.5	26.7
	H10	245	.168	16.5	23.0
	Avg.	....	.1567	....	24.41
250-274	J6	250	.093	17.0	23.5
	L7	250	.146	16.5	27.3
	L5	250	.148	16.5	26.0
	L4	250	.163	16.5	21.2
	H1	251	.122	17.0	26.5
	J4	255	.113	17.5	22.9
	H2	257	.163	16.0	26.9
	O6	262	.162	17.0	24.1
	O5	263	.162	16.0	26.3
	A6	265	.189	17.5	25.7
	A14	265	.287	17.0	26.5
	J1	267	.124	17.0	25.3
	L3	270	.124	17.0	24.7
	L1	270	.160	16.5	26.7
	H3	271	.277	16.5	24.2
	Avg.	....	.162	....	25.5
275-299	O2	275	.219	17.0	27.6
	O3	280	.145	16.5	25.5
	J3	285	.112	17.0	26.5
	O8	290	.121	16.5	24.8
	J2	295	.131	18.5	23.2
	Avg.	....	.146	....	25.5
300-324	O7	313	.118	18.0	25.0
	H9	316	.268	18.0	25.0
	H7	318	222	17.5	25.0
	Avg.	....	.203	....	25.0
325-349	M6	342	.200	19.0	27.9
	G8	346	.218	19.0	27.4
	Avg.	....	.209	....	27.3
350-374	N5	360	130	18.5	24.3
	N2	360	.144	19.5	23.6
	Avg.	....	.137	....	24.0
375-399	N6	380	.167	18.5	24.3
	N7	395	.204	19.0	22.6
	Avg.	....	.186	....	23.5
400-424	H1	400	.178	19.0	23.7
	K5	405	.275	19.5	22.5
	N8	407	.165	19.5	25.6
	N3	420	.138	19.0	25.3
	M9	420	.184	22.0	25.0
	K4	420	.195	20.0	22.5
	Avg.	....	.189	....	24.1
425-449	N4	430	.128	19.5	25.6
	K3	430	.245	20.0	25.0
	P7	435	.316	20.5	26.8
	K1	440	.170	19.5	28.2
	M5	445	.200	21.0	26.2
	M3	445	.232	20.5	26.3
	Avg.	....	.215	....	26.4

TABLE No. 5—CONCLUDED.

CLASS.	Pig.	Pig weight in gms.	Per cent weight.	Pig length. in cms.	Per cent length.
450–474	K2	460	177	20 0	22 5
	Avg.	....	.177	....	22.5
475–499	M4	475	.250	21 0	25 2
	P6	495	.311	21.5	23 3
	Avg.	....	.281	....	24.3
500–524	M8	500	.251	22 0	25 0
	M2	515	.179	21.0	25 2
	M1	515	.237	21 5	27.9
	Avg.	....	.222	....	26 0
525–544	G2	549	.233	22.0	25 0
	Avg.	....	.233	....	25 0
550–574	M7	550	.239	22.5	24 9
	Avg.	....	.239	....	24.9
575–599	G6	581	.409	21.5	25.6
	P3	590	.273	23 5	25.5
	Avg.	....	.341	....	25 6
600–624	P9	620	.311	22 0	27 7
	Avg.	....	.311	....	27.7
625–649	G7	635	.347	22.0	27.3
	G1	635	510	22.0	27 3
	G5	640	.312	21.5	27 0
	Avg.	....	.390	....	27.3
650–674	G4	658	.443	22 0	27.3
	G3	665	.286	22 0	28 2
	P4	665	.292	23 5	25 5
	D5	669	.417	23.5	29 8
	Avg.	....	.360	....	27 7
675–699	P5	675	.293	24.5	24.5
	R2	693	.224	25.5	27.5
	Avg.	....	.259	....	26.0
700–724	P2	700	.305	24.0	25.0
	Avg.	....	.305	....	25.0
725–749	P1	735	.311	24.5	26.1
	P8	740	.271	23.5	26.8
	Avg.	....	.291	....	26.5
750–774	D1	752	.397	25.0	26.0
	D2	771	.334	25.0	28.0
	Avg.	....	.366	....	27.0
800–824	D3	815	.351	25.0	30.0
	Avg.	....	.351	....	30.0
825–849	D4	843	.421	25.0	28.0
	Avg.	....	.421	....	28.0
925–949	R5	925	.270	26.5	32.5
	R3	932	.361	27.5	29.1
	Avg.	....	.316	....	31.3
974–999	R4	999	.301	27.5	27.3
	Avg.	....	.301	....	27.3
1025-1049	R6	1,035	.287	28.5	31.6
	Avg.	....	.287	....	31.6
1075-1099	R1	1,098	.226	27.0	33.3
	Avg.	....	.226	....	33.3

COMPARISONS MADE TO CORRELATE THE SIZE OF UNDERDEVELOPED AND OVERDEVELOPED PIGS WITH THE SIZE OF THE THYMUS, TAKING PERCENTAGE THYMUS BY WEIGHT AS A STANDARD, AND GRADING PIGS IN THE LITTERS BY LENGTH.

As the title above indicates, table No. 6 is the result of an attempt made to correlate the size of underdeveloped and overdeveloped pigs with the size of the thymus, taking percentage thymus by weight as a standard, and grading pigs in the litters by length. In each litter the two smallest fœti (by length) and the two largest were studied as to percentage thymus by weight as seen in column F in the table. The percentages of the two smallest and the two largest were individually averaged (column G), and the two averages compared; the correlation noted was recorded in column H. Positive or + correlation is taken to mean that the overdeveloped pigs in the litter had a greater percentage of thymus than the underdeveloped pigs. As seen from the table, there were nine positives and nine negatives, hence we must conclude, from the data at hand now, that no parallelism exists between the large and small size, respectively, of underdeveloped and overdeveloped fœti, and the percentage of thymus by weight.

TABLE No. 6.

Column A. Serial No.	Column B. Litter No.	Column C. Pig length in centimeters.	Column D. Per cent thymus by length.	Column E. Pig weight in grams.	Column F. Per cent thymus by weight.	Column G. Averages of column F.	Column H. Correlation.
13	A13	11.5	20.0	102	.137	.128	+
11	A11	14.0	25.0	174	.118		
6	A6	17.5	25.7	265	.189	.238	
14	A14	17.0	26.5	265	.287		
17	B3	10.0	25.0	76	.041	.065	+
19	B5	11.0	25.0	90	.078		
16	B2	11.0	25.0	102	.093	.082	
15	B1	11.0	22.7	100	.070		
27	C8	11.5	21.7	102	.108	.110	—
20	C1	11.5	21.7	107	.112		
26	C7	14.0	28.6	143	.094	.093	
25	C6	14.0	25.0	164	.091		
33	D5	23.5	29.8	669	.417	.407	—
29	D1	25.0	26.0	752	.397		
32	D4	25.0	28.0	843	.421	.386	
31	D3	25.0	30.0	815	.351		
39	E6	12.5	24.0	126	.143	.147	—
34	E1	14.5	23.5	184	.150		
38	E5	16.0	21.9	195	.128	.121	
36	E3	15.0	23.3	211	.113		
50	F11	11.0	22.7	83	.087	.079	+
46	F7	12.0	22.9	95	.072		
48	F9	13.5	22.2	140	.059	.112	
41	F2	13.5	22.2	130	.165		
60	G8	19.0	27.4	346	.218	.314	+
58	G6	21.5	25.6	581	.409		
53	G1	22.0	27.3	635	.510	.429	
59	G7	22.0	27.3	635	.347		
64	H4	12.5	26.4	118	.112	.162	+
65	H5	13.5	29.6	154	.209		
69	H9	18.0	25.0	316	.268	.245	
67	H7	17.5	25.7	318	.222		
72	I2	13.5	21.5	135	.126	.120	—
76	I6	13.5	23.0	137	.113		
74	I4	14.0	25.0	150	.107	.104	
71	I1	14.0	26.4	137	.100		
86	J8	16.0	25.0	205	.137	.126	—
85	J7	17.0	23.5	228	.114		
80	J2	18.5	23.2	295	.131	.122	
82	J4	17.5	22.9	255	.113		
91	K5	19.5	22.5	405	.275	.223	—
87	K1	19.5	28.2	440	.170		
88	K7	20.0	22.5	460	.177	.211	
89	K3	20.0	25.0	430	.245		
99	L8	15.5	23.2	125	.160	.156	—
97	L6	16.5	25.5	240	.152		
94	L3	17.0	24.7	270	.124	.142	
92	L1	16.5	26.7	270	.160		

TABLE No. 6—Concluded.

Column A. Serial No.	Column B. Litter No.	Column C. Pig length in centimeters.	Column D. Per cent thymus by length.	Column E. Pig weight in grams.	Column F. Per cent thymus by weight.	Column G. Averages of column F.	Column H. Correlation.
105	M6	19.0	27.9	342	.200	.216	+
102	M3	20.5	26.3	445	.232		
106	M7	22.5	24.9	550	.239	.245	
107	M8	22.0	25.0	500	.251		
113	N5	18.5	24.3	360	.130	.149	—
114	N6	18.5	24.3	380	.167		
112	N4	19.5	25.6	430	.128	.147	
116	N8	19.5	25.6	407	.165		
117	O1	14.0	25.0	170	.106	.109	+
120	O4	16.0	28.7	230	.111		
123	O7	18.0	25.0	313	.118	.169	
118	O2	17.0	27.6	275	.219		
131	P7	20.5	26.8	435	.316	.314	—
130	P6	21.5	23.3	495	.311		
125	P1	24.5	26.1	735	.311	.302	
129	P5	24.5	24.5	675	.293		
134	Q1	9.5	24.2	55	.035	.046	+
140	Q7	10.0	25.0	61	.057		
135	Q2	10.5	23.8	68	.059	.047	
138	Q5	10.5	21.9	63	.035		
143	R2	25.5	27.5	693	.224	.247	+
146	R5	26.5	32.5	925	.270		
147	R6	28.5	31.6	1,035	.287	.294	
145	R4	27.5	27.3	999	.301		

Total result, 9+, 9 —.

COMPARISONS MADE TO CORRELATE THE SIZE OF UNDERDEVELOPED AND OVERDEVELOPED PIGS WITH THE SIZE OF THE THYMUS, TAKING PERCENTAGE OF THYMUS BY WEIGHT AS A STANDARD, AND GRADING PIGS IN THE LITTERS BY WEIGHT.

As the title above indicates, table No. 7 is the result of an attempt made to correlate the size of underdeveloped and overdeveloped fœti with the size of the thymus, taking percentage thymus by weight as a standard, and grading pigs in the litters by weight. In each litter the two smallest fœti (by weight) and the two largest were studied as to percentage thymus by weight as seen in column F in the table. The percentages of the two smallest and the two largest were individually averaged (column G), and the two averages compared; the correlation noted was recorded in column H. Positive or + correlation is taken to mean that the overdeveloped pigs in the litter had a greater percentage of thymus than the underdeveloped pigs. As seen from the table, there were ten positives and eight negatives. This is indeed a very weak positive correlation; so slight, in fact, that we feel that it must be disregarded until more positive data can be secured. Hence, once more we must decide, on the basis of the data at hand now, that no parallelism exists between the large and small size, respectively, of underdeveloped and overdeveloped fœti and the percentage of thymus by weight.

TABLE No. 7.

Column A. Serial No.	Column B. Litter No.	Column C. Pig weight in grams.	Column D. Pig length in centimeters.	Column E. Per cent thymus by length.	Column F. Per cent thymus by weight.	Column G. Averages of column F.	Column H. Correlation.
13 11	A13 A11	102 174	11.5 14.0	20.0 25.0	.137 .118	.128	+
14 6	A14 A6	265 265	17.0 17.5	26.5 25.7	.287 .189	.238	
17 19	B3 B5	76 90	10.0 11.0	25.0 25.0	.041 .078	.060	+
15 16	B1 B7	100 102	11.0 11.0	22.7 25.0	.070 .073	.082	
27 24	C8 C5	102 122	11.5 13.0	21.7 19.2	.108 .107	.108	—
25 28	C6 C9	164 164	14.0 13.5	25.0 24.1	.091 .096	.094	
33 29	D5 D1	669 752	23.5 25.0	29.8 26.0	.417 .397	.407	—
32 31	D4 D3	843 815	25.0 25.0	28.0 30.0	.421 .351	.386	
39 34	E6 E1	126 184	12.5 14.5	24.0 23.5	.143 .150	.147	+
37 36	E4 E3	208 211	15.0 15.0	23.3 23.3	.197 .113	.155	
50 46	F11 F7	83 95	11.0 12.0	22.7 22.9	.087 .072	.080	+
41 48	F2 F9	130 140	13.5 13.5	22.2 22.2	.165 .059	.112	
60 54	G8 G2	346 549	19.0 22.0	27.4 25.0	.218 .233	.226	+
55 56	G3 G4	665 658	22.0 22.0	28.2 27.3	.286 .443	.365	
64 65	H4 H5	118 154	12.5 13.5	26.4 29.6	.112 .209	.162	+
67 69	H7 H9	318 316	17.5 18.0	25.7 25.0	.222 .268	.245	
73 72	I3 I2	125 135	14.0 13.5	25.0 21.5	.091 .126	.109	—
67 69	I4 I5	150 145	14.0 13.5	25.0 23.7	.107 .083	.095	
86 85	J8 J7	205 228	16.0 17.0	25.0 23.5	.137 .114	.126	—
80 81	J2 J3	295 285	18.5 17.0	23.2 26.5	.131 .112	.122	
91 90	K5 K4	405 420	19.5 20.0	22.5 22.5	.275 .195	.235	—
88 87	K2 K1	460 440	20.0 19.5	22.5 28.2	.177 .170	.174	
99 97	L8 L6	125 240	15.5 16.5	23.2 25.5	.160 .152	.156	—
94 92	L3 L1	270 270	17.0 16.5	24.7 26.7	.124 .160	.142	

TABLE No. 7—Concluded.

Column A. Serial No.	Column B. Litter No.	Column C. Pig weight in grams.	Column D. Pig length in centimeters.	Column E. Per cent thymus by length.	Column F. Per cent thymus by weight.	Column G. Averages of column F.	Column H. Correlation.
105 108	M6 M9	342 420	19.0 22.0	27.9 25.0	.200 .184	.192	+
106 100	M7 M1	550 515	22.5 21.5	24.9 27.9	.239 .237	.238	
110 113	N2 N5	360 360	19.5 18.5	23.6 24.3	.144 .130	.137	—
111 112	N3 N4	420 430	19.0 19.5	25.3 25.6	.138 .128	.133	
117 120	O1 O4	170 230	14.0 16.0	25.0 28.7	.106 .111	.108	+
124 123	O8 O7	290 313	16.5 18.0	24.8 25.0	.121 .118	.120	
131 130	P7 P6	435 495	20.5 21.5	26.8 23.3	.316 .311	.314	—
132 125	P8 P1	740 735	23.5 24.5	26.8 26.1	.271 .311	.291	
134 140	Q1 Q7	55 61	9.5 10.0	24.2 25.0	.035 .057	.046	+
135 136	Q2 Q3	68 66	10.5 10.0	23.8 23.0	.059 .048	.054	
143 146	R2 R5	693 925	25.5 26.5	27.5 32.5	.224 .270	.251	+
142 147	R1 R6	1,098 1,035	27.0 28.5	33.3 31.6	.226 .287	.257	

Total result, 10 +, 8 —.

Note No. 1.—It will have been noticed that in the foregoing report nothing has been said concerning the percentage of thymi by length. An examination of the tables will show that there is indeed an increase in this percentage as larger and larger pigs are examined, but that this increase is neither marked nor uniform, and we must consider that part of the increase in weight must come by this increase in length. We feel that the method by which we secured the thymus lengths was not accurate and uniform enough to allow much value to be attached to the figures recorded. They may be taken as rather approximate. In general, the length of the thymus will average about 25 per cent of the total length of the pig. Suffice it to say, however, that we believe that as the fœti grow older and older there is an increase in the percentage of thymus by length; just how regular and consistent this increase is, we cannot say.

Note No. 2.—It is interesting to note that the pigs used for dissection showed a preponderance of males. This was probably purely accidental, however, and if larger numbers of animals had been used a more balanced ratio would have been secured.

CONCLUSIONS.

1. The thymus gland in the fœtal pig is comparatively very large, extending from a point above the upper half or third of the heart to the base of the mandible. In the thorax it consists of a single triangular body, but in the neck region is made up of paired branches which approximately parallel each other.

2. Sex appears to have no connection with the percentage of thymus found, except that possibly the values for the females may average a trifle higher than those for the males.

3. As larger and larger fœti, as regards both weight and length, are examined, the percentage of thymus by weight increases fairly steadily and rather uniformly.

4. Fœti tend to have the same size thymus as the average of pigs in their litter, regardless of individual size. No parallelism apparently exists between the small and large size, respectively, of underdeveloped and overdeveloped pigs, and the percentage of thymus by weight. Perhaps further work on this one question might bring a reversal of opinion, but the data obtained so far point to the statement made above.

5. Figures of percentage of thymus by length, while not very reliable, show that this percentage increases as larger and larger fœti are examined. Such increase, however, does not seem to be as uniform as that of the percentage by weight.

It is a pleasure to express here our appreciation of the help kindly given by Prof. W. J. Baumgartner in the preparation of this bit of work. It was at his suggestion that it was undertaken and by his guidance that it was carried out. Whatever of merit it has is due in large measure to him.

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A Comparison of the Antigenic and Cultural Characteristics of a Number of Strains of *Bacillus Typhosus*.*

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ALTHOUGH it has seemed to be the general concensus of opinion that *Bacillus typhosus* is a very homogeneous organism, yet in view of the fact that some observers have reported cultural and serological variations, it was thought advisable to investigate the cultural and serological reactions of the strains of *typhosus* used in this laboratory.

The work done may be divided into three phases, namely: cultural reactions, agglutination and absorption tests, and the Widal reaction. The source, place of isolation, name and date of the organisms used are tabulated in table I.

CULTURAL REACTIONS.

TECHNIQUE: The carbohydrate medium used was semisolid, to which was added 1 per cent of the carbohydrate desired, and Andrade indicator to make a pale, flesh color when cold. As a check a second set of determinations was run, using meat infusion broth adjusted to Ph, 7.0, to which 1 per cent of the carbohydrate was added, litmus being used as an indicator. For the lead acetate agar 1 per cent lead acetate solution was added to semisolid medium. Two per cent peptone gelatine, made according to a formula devised by Treece (1), was used for liquefaction and to test for gas production in noncarbohydrate media.

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TABLE I.—Organisms used for cultural and antigenic reactions.

No.	Source.	Name.	Date.
1	Blood culture—Lawrence, Kan	57	1913
21	Blood culture—Kansas City, Mo		1919
223	Blood culture—University of California		1914
25	Blood culture—Johns Hopkins Hospital		
33	Blood culture—Youngstown Hospital	McCreary	1921
4	Feces—Lawrence, Kan	Smith	1919
6	Feces—Lawrence, Kan		1918
8	Feces—Lawrence, Kan		1919
16	Feces—Carrier, Beau Desert, France	Schopinsky	1918
20	Feces—Topeka, Kan		1919
24	Feces—Fatal case, John Hopkins		1919
27	Feces—Kansas City, Mo		1920
28	Feces—Carrier	Light	1920
29	Feces—Carrier	Blythe	1920
30	Feces—Carrier	Dardrich	1920
31	Feces—Carrier	Cattler	1920
32	Feces—Carrier	Doud	1920
34	Feces—Carrier	Stitt	1920
35	Feces—Case	Levi	1920
7	Spinal fluid—Halstead, Kan		1919
12	Spleen—Autopsy	Rawlings	
	Spleen—Autopsy	Rawlings	
15	Gall bladder—Autopsy, France	Wable	1918
2	No history—New York board of health		
3	No history—New York city board of health	Bender	
10		Mt. Sinai	
11	No history—New York city board of health	Pfeiffer	
13	No history—American Museum	Hopkins	
14	No history—American Museum	Miller	
17	No history—Institute of Berlin	Ebert	1888
19	No history—University of Chicago	Jordan	1889
26	No history—Johns Hopkins Hospital		

TABLE II.—Cultural characteristics.

NUMBER.	Motility	Gram	Gelatine	Indol	Lead acetate	Dextrose	Mannite	Maltose	Lactose	Saccharose	Dextrin	Rhamomitinose	Salacin	Dulcite	Arabinose	Xylose	Litmus milk.
1, 2, 3, 4, 6, 7, 8	—	—	—	—	+	+	+	+	—	—	+	—	—	—	—	+	1 Neutral after 1 week.
9	—	—	—	—	+	+	+	+	—	—	+	—	+	—	—	+	
10, 11, 13, 14, 15, 16, 17, 20	—	—	—	—	+	+	+	+	—	—	+	—	—	—	—	+	15, 17, 19, neutral after 3 weeks.
12	—	—	—	—	+	+	+	+	—	—	+	—	—	—	—	—	
21	—	—	—	—	+	+	+	+	—	—	+	—	—	—	—	+	10 days.
23-25	—	—	—	—	+	+	+	+	—	—	+	—	+	—	—	+	23, 24, 26, neutral after 3 weeks.
24, 28, 29, 30, 31, 32, 33, 34, 35	—	—	—	—	+	+	+	+	—	—	+	—	—	—	—	+	
26, 27	—	—	—	—	+	+	+	+	—	—	—	—	+	—	—	+	

The litmus milk was kept for six weeks before being discarded. The cultural reactions are tabulated in table II. It will be observed from the table that none of the strains exhibited any variation in the media commonly used in routine laboratory procedure. All strains gave acid in dextrose, mannite, maltose, negative in lactose and saccharose, no liquefaction of gelatine, no indol, and an initial acidity in litmus milk. Three strains gave slight acidity in salacin, one strain gave no acid in xylose, Rawlings' strain, and one gave acid only after ten days. Two strains were negative in dextrin. All strains except No. 7 gave a distinct greenish-black cloud around the stab in 2 per cent peptone gelatine, but no gas. In litmus milk all but six organisms remained a permanent lilac color, six turned back to neutral in three weeks and one became a deep blue after one week.

In addition to the above strains an organism isolated from the feces of a clinical case of mild typhoid was studied. This organism is designated as No. 5. The patient at no time gave a positive Widal. The organisms were abundant in the feces and culturally differed from *Bacillus typhosus* only in giving very slow blackening of lead acetate agar, negative in xylose, negative in dextrin, positive in rhamnose, and distinct alkaline reaction in litmus milk after 72 hours, but with no saponification.

DISCUSSION.

Weiss (2) has reported the cultural characteristics of thirty-one strains of *typhosus* and groups them according to xylose fermentation. Three of his strains produced acid slowly and four remained negative. One of the negative strains was the Rawlings' strain which we also found to be negative.

Teague (3) objects to such a classification on the basis of xylose fermentation on the ground that the so-called negative strains are not really incapable of fermenting xylose, but ferment it slowly. Four of his strains failed to give acid on the thirty-second day, but these strains could be trained to give acid by plating on xylose agar. No attempt was made by the author to discover mutants from negative strains on any of the carbohydrates used.

Our strains were uniformly negative on dulcite and arabinose. Teague (3) reports eleven out of forty-one strains fermenting these sugars slowly. Krumwiede (4) also reports the fermentation in dextrin as varying with the sample used. The two cultures giving negative in dextrin might, therefore, have shown typical acid production with another sample.

The salacin fermentation seemed variable and did not correlate with any other characteristics.

The danger of confusing nongas-producing paratyphoid strains with *typhosus* has been recently emphasized. Ten Broek (5) reports a nongas-producing hog-cholera bacillus which resembles in some respects *B. typhosus.* Krumwiede (4) also reports a similarity both culturally and serologically between *B. pullorum* and *B. sanguinorum* and *B. typhosus.* Myers (6) reports the isolation of a rhamnose positive *typhosus* from a clinical case of typhoid which was also atypical in its serological reaction. It was difficult to decide, therefore, whether No. 5 was a true but irregular typhoid or a nongas-producing paratyphoid. Krumwiede (7), using the fermentation of rhamnose as the deciding factor between typhoid and paratyphoid, would place it in the para group.

AGGLUTINATION AND ABSORPTION TESTS.

Antigenic irregularities had been observed in this laboratory in the course of routine agglutination tests on organisms isolated from clinical cases of typhoid and a number of Widals. Parke-Davis antityphoid serum, serum from the city laboratory of Wichita, Kan., and serum sent us from the University of Chicago were used in checking up the antigenic properties of the following organisms: Nos. 1, 2, 4, 5, 20, 50, 51 and 52.

Culturally they were all typhoid. Nos. 50, 51 and 52 were strains isolated from feces in cases resembling influenza. They are not included in the other tables because of accidental loss.

TABLE III.—Quantitative variations in agglutinations with commercial sera.

No.	Sera used.					
	Parke-Davis.		Wichita.		University of Chicago.	
	Titre.	Reaction.	Titre.	Reaction.	Titre.	Reaction.
1	1-50	—	1-50	....	1-8000	4+
2	1-10000	3+	1-50	1+	1-10000	4+
4	1-1000	4+	1-400	4+	1-2000	4+
6	1-2000	4+	1-400	....	1-4000	4+
50	1-50	—	1-50	....	1-50	....
51	1-50	—	1-50	....	1-50	....
52	1-50	....	1-50	....	1-50	....
20	1-4000	4+	....	....	1-8000	4+

Numerous observers have remarked on the antigenic differences in typhoid. Durham (8) observed such differences, but did not attempt to group his strains. Weiss (1) and Hooker (9), however, offered a tentative grouping on the basis of their agglutination and absorption tests.

The agglutination tests in this series were all done with suspensions in sterile saline made from twenty-four-hour cultures. The serum used came principally from rabbits immunized in this laboratory.

A high-titred bivalent horse serum from the New York city board of health* prepared from the Mt. Sinai strain, and a freshly isolated strain as well as a high-titred serum for which the Rawlings strain had been used for immunization from the Lederle laboratories, were also used. Table IV gives a summary of the results. In addition to the results given here, eight other immune sera were used for agglutination against all the organisms with similar results.

The following technique was used for the absorption tests: The serum to be tested was diluted to one-tenth of the titre. This dilution was then saturated with organisms, washed from a twenty-four-hour agar slant to make a heavy emulsion. This was incubated at 37° C. for four hours and for four days at ice-box temperature, more organisms being added as the supernatant fluid became clear. The control of diluted serum in every case gave a good agglutination in spite of the prolonged incubation. If the control gave agglutination after absorption with the homologous organism the test was repeated.

Since considerable prominence has been given to the mirror reaction in the recent literature, it might be well to establish some standard method for absorption tests in order to get comparable results. We found the following points must be carefully considered in any test:

1. Weight of suspension.
2. Dilution of serum.
3. Time of absorption.
4. Repeated saturation.
5. Temperature.
6. Controls.

Krumwiede (4) recommends a proportion of 1-4 or 3, or at most 1-2 of packed cells to supernatant fluid. Our proportion after the final centrifugation was about 1-3. It was found that a dilution of one-tenth the titre of the serum was perfectly satisfactory. Although higher dilutions could be used, a lower dilution did not give complete absorption. Three or four hours was not long enough

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* I am indebted to the kindness of Dr. Charles Krumwiede for the use of this serum.

to give complete absorption and frequently absorption was not complete in twenty-four or forty-eight hours. After a standard of four days was chosen no more trouble was experienced. It was always necessary to add more organisms as the supernatant fluid became clear; the greater the tendency to agglutinate, the larger the number of organisms necessary for complete absorption. It was necessary to keep the serum at ice-box temperature because of the well-known tendency of diluted serum to deteriorate at room or incubator temperatures. A control of diluted serum which had been incubated under the same conditions as the test sera was necessary to show that no drop in titre had occurred, and a control of the serum to be tested saturated with the homologous organisms indicated the completeness of the absorption. Table V gives a summary of the absorption tests.

From table IV it will be seen that the strains of typhoid differ perceptibly in their agglutinating properties. On this basis we have placed the organisms tentatively into three groups. Group I is made up of eleven organisms; group II of twelve organisms; group III of two organisms. Group I serum agglutinates all other organisms in this group in dilutions practically as high as that given for the homologous organisms. Group I serum also agglutinates group II organisms, but in lower dilutions; conversely, the group I organisms are agglutinated by group II serum, but in lower dilutions than are the group II organisms. These two groups are closely related and interagglutinate to the degree indicated in the table. Groups I and II serum give slight or no agglutination with group III organisms. Group III, consisting of two strains, Nos. 2 and 3, interagglutinate perfectly at 1–15000, but this high-titred serum agglutinates members of groups I and II in low dilutions or not at all.

The results of agglutination tests using horse serum indicated that the same antigenic differences were present, but that they appeared in higher dilutions because of the higher titre of the serum.

To illustrate: No. 12, the Rawlings strain, was completely agglutinated at 1–80000, and No. 1 at 1–5000.

Many of these agglutination tests were checked by using the microscopic method, care being used to rule out the personal equation. Where partial agglutination occurred, the macroscopic method seemed to give more definite results.

It will be seen that the absorption tests show an even closer relationship between groups I and II than do the agglutination tests, No. 1 being somewhat more irregular than the others. The ab-

TABLE IV.—Agglutination reactions with immune sera.

Strain.	Serum.													
	1		4		7		20		12—Lederle.		2		3	
	Titre.	Reaction.	Titre.	Reaction.	Titre.	Reaction.	Titre.	Reaction.	Titre.	Reaction.	Titre.	Reaction.	Titre.	Reaction.
1	1-2000		1-1000		1-500	3+	1-2000	4+	1-2000	3+	1-100	4+	1-100	+
4	1-2000		1-1000		1-500	4+	1-4000	3+	1-2000	4+	1-100	+	1-100	±
6	1-2000		1-500		1-500	5+	1-2000	3+	1-5000	3+	1-100	±	1-100	±
7	1-1000		1-1000		1-3000	4+	1-3000	3+	1-8000	3+	1-100	2+	1-100	3+
8	1-200		1-500		1-3000	4+	1-2000	3+	1-2000	3+				
20	1-1000		1-1000		1-500	3+	1-3000	4+	1-2000	3+				
21	1-1000		1-500		1-2000	3+	1-2000	3+	1-2000	3+				
23	1-200		1-500		1-1000	3+	1-1000	3+	1-8000	3+			1-200	3+
24	1-1000		1 500		1-3000	3+	1-3000	4+	1-8000	4+			1-100	2+
25	1-50		1-1000		1-1000	3+	1-3000	4+	1-5000	3+			1-200	3+
26	1-500		1-2000		1-3000	4+	1-3000	4+						
27					1-1000	4+			1-1000	4+				
28					1-1000	4+	1-1000	4+	1-5000	4+			1-50	3+
29					1-500	4+	1-1000	4+	1-5000				1-50	2+
11	1-200		1-500		1-1000	3+	1-500	3+	1-8000	4+	1-200	4+	1-100	4+
9	1-2000		1-2000		1-2000	3+	1-3000	3+	1-5000	3+	1-1000	3+	1-1000	3+
12	1-1000		1-2000		1-2000	4+	1-2000	4+	1-8000	3+				
10	1-1000		1-2000		1-500	3+	1-2000	3+	1-5000	3+	1-200	3+	1-1000	3+
13	1-1000		1-1000		1-200	3+	1-2000	3+	1-5000	4+	1-200	4+	1-200	3+
11	1-1000		1-2000		1-1000	3+	1-1000	3+	1-2000	3+	1-200	3+	1-1000	3+
15	1-1000		1-500		1-2000	3+	1-2000	3+	1-500	3+	1-100	3+		
16	1-1000		1-5000		1-5000	3+	1-3000	3+	1-5000	4+	1-100	2+	1-100	4+
17	1-1000		1-5000		1-1000	3+	1-300	3+	1-5000	3+	1-100	2+		
19	1-1000		1-1000		1-1000	3+	1-1000	3+	1-5000	4+	1-100	2+	1-100	±
30					1-1000	4+	1-1000	4+	1-8000	4+	1-50	3+	1-50	3+
31					1-100	4+	1-1000	4+	1-8000	4+	1-50	±	1-50	2+
32							1-100	4+	1-5000	3+			1-50	3+
2	1-200		1-500		±		±		1-50	3+	1-15000	4+	1-12000	3+
3	1-200				±		±		1-50	3+	1-15000	3+	1-12000	4+

TABLE V.—Absorption tests with Immune sera.

Absorbing antigen.	Sera used.									
	1	12	9	2	3	27	7	13	20	8
1	+	±	±	±	—	±	±	+	±	±
4	+	+	+	—	—	+	+	+	+	+
6	±	+	±	—	—	—	+	+		+
7	±	+	+	—	±	+	+	+	+	+
8	±	+	+	—	—	—	+	+	+	+
20	±	±	+		—	+	+	+	+	+
21	+	+	±	—	—	+	+	+	+	+
23	+	±	+	±	±	+	+	+	+	+
24	+	+	+	—	—	+	+	+	+	+
25	+	±	+	—	—	+	+	+	+	+
26	+	+	±	—	—	+	+	+	+	+
27	+	—	+	—	—	+		+	+	+
9	+	+	+	—	—	+	+	+	+	
10	+	+	+	—	—	+	—	±	+	±
11	±	+	+	—	—	+	—	+	—	—
12	±	+	+	±	—	±	—	+	+	+
13	+	+	+	—	—	±	±	+	±	+
14	+	+	±	+	+	±		+	+	+
15	±	—	+	—		±	+	+	+	+
16	+	+	+	—		+	+	+	+	+
17	+	±	+	±	—	+	+	+	—	+
19	+	+	+	—		+	+	+	+	+
2	—	±	—	+	+	—	—	—	—	—
3	—	±	—	+	+	—	—	—	—	—

+ Absorption complete.
± Absorption incomplete but reduction of titre.
— No absorption.

sorption tests show a more striking difference between the two organisms in group III and the other groups. The antigenic differences shown by these organisms could not be correlated with their age as with Hooker's (9) organisms, nor with cultural differences as with Weiss' (2).

No. 5 was found to be entirely inagglutinable by any of the sera used. Serum prepared from this organism agglutinated only the homologous organism. It did not absorb any of the agglutinins from the sera prepared from other organisms, nor were its agglutinins absorbed by other organisms. These facts, in connection with the somewhat irregular carbohydrate reactions and the atypical growth on agar slants, made it seem advisable to consider this organism one of those unclassified, irregular organisms which are not infrequently isolated from stools, although in many respects this does not differ any more radically than irregular strains reported by other observers.

In running Widals in this laboratory it was customary to set up each serum with *B. typhosus*, para A and para B. A member of the department suggested that it might be advisable to use several strains of *B. typhosus* in setting up routine Widals. Accordingly, a Widal giving negative with the strain used, No. 2, was again set up, using three other strains of typhoid. It again gave a negative with No. 2, but was strongly positive with the other two strains. It was recognized that apparent antigenic differences of this sort might constitute an important source of error in making routine laboratory tests.

The sera for the Widals were obtained from various sources. Sera A, C, D, F, G, J and I were from clinical cases of typhoid from which the organism was subsequently isolated. The others came as positive Widals from reputable laboratories, the majority of which use the Rawlings strain. Most of the specimens were drops of blood dried on a metal slide or on filter paper. A dilution of 1–25 and 1–50 was made and an equal amount of a living suspension of the organism was added, making an ultimate dilution of 1–50 and 1–100. All Widals were set up using Nos. 1, 2, 3, 10 and 12. No. 12 was selected because it is the Rawlings strain and is used for the army vaccine. Numbers 2 and 3 were used because of the irregularities exhibited in the absorption tests and No. 10 because it was an organism giving a clear adherent agglutination with most sera used. The results of these tests may be seen in table VI.

It was noticed that fresh serum drawn from the clot and used within twenty-four or forty-eight hours gave positive agglutination with a larger number of organisms than those made from dried blood. In those Widals run with dried blood precipitation was usually marked in the tubes giving a positive Widal. This might be due to the presence of hemoglobin, foreign substances on the metal slides or paper, some change in reaction, or some biochemical change. This phenomenon is being investigated. No precipitation was noted in the Widals using clear serum, nor in the agglutination tests with rabbit serum. Stober (14) mentions the occurrence of both precipitation and agglutination with his immune sera.

TABLE VI.—Widal reactions.

ORGANISMS.	Sera.																				Percentages.		
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	+	±	—
1	—	—	—	—	+	—	—	.....	+	+	±	—	—	+	+	+	+	+	—	±	42	10	47
2	—	±	+	—	—	±	±	—	+	—	—	±	—	+	—	+	±	—	—	—	20	25	55
3	—		+	±	±	±	+	—	+		—	—	+	+	±	+	±	—	—	—	33	27	38
10	+	.....	+	+	+	+	+	.....	+	.....	±	±	±	±	—	±	+	+	+	+	70	23	6
12	+	+	+	+	+	+	—	+	+	+	+	—	±	+	+	±	±	+	+	+	75	15	10

+ = Clear-cut complete agglutination.
± Partial agglutination.
— = Negative agglutination.

From table VI it is readily seen that different organisms with the same sera set up at the time showed marked differences in agglutinability. This may be due to the different agglutinabilities inherent in the organisms themselves and such marked differences probably would not be noted had absorption tests been possible. It is recognized that these twenty positive Widals are too few to provide a basis for accurate conclusions. It seems highly probable that the dried-blood method exaggerates the antigenic differences between the organisms, changing what is probably a quantitative into an apparently qualitative difference between the organisms. The low percentage of positives given with Nos. 2 and 3 might be expected from the results given in the absorption tests using immune sera. No. 10, on the other hand, gave a very low percentage of negatives. Those read as partial agglutination in clinical work would be called positive. The tubes read as positive gave complete clearing of the supernatant fluid; those read as partial agglutination showed unmistakable agglutination, but with some cloudiness of the supernatant fluid. No. 10, therefore, gave 93 per cent positive. No. 12, while giving the highest percentage of complete agglutinations, gave only 90 per cent positive when partial agglutinations are included. It seems probable in view of the results obtained that it might be worth while to use more than one strain of typhoid in running Widals and to select easily agglutinable strains, such as No. 10 Mt. Sinai strain, and No. 12 the Rawlings strain.

The serological reactions here recorded might have an important bearing on the following points:

1. The occurrence of typhoid fever in vaccinated persons.
2. The advisability of using a polyvalent vaccine.
3. The occurrence of negative Widals in clinical cases of typhoid fever.
4. Sources of error due to the dried-blood method.

A number of cases of typhoid fever occurring in vaccinated individuals may be found in the literature. Vaughn (10) says that "It is possible that in so far as vaccination has failed it is due to the disease being caused by other members of the typhoid group, . . . which in all probability is much larger than we now appreciate." Mock (11) reports the occurrence of forty-five cases of typhoid and paratyphoid in individuals who had been vaccinated about one year previous to the attack. Some of the strains isolated were atypical in regard to their cultural and serological reactions, but were identified positively as typhoid or paratyphoid organisms.

Trowbridge (12) reports the occurrence of a typhoid epidemic among vaccinated persons in an institution. Here the original source of infection came from the milk supply, which was infected by a vaccinated worker with a mild case of typhoid. It is realized that in such an epidemic the dosage may have been sufficient to overcome the immunity acquired from vaccination. Wade and McDaniel (13) report the occurrence of an epidemic in an institution among vaccinated individuals. Here there seemed to be an interesting correlation between the negative Widals given after vaccination and the susceptibility of these persons to typhoid. Myers and Nielson (6) report the isolation of an atypical strain of typhoid from the blood stream and stool, respectively, of two vaccinated persons.

Hooker (9) and Weiss (2) conclude from their experiments that a vaccine made from several strains of typhoid would be more efficient than one made from a single strain. The results of these observers and the others reported, together with our findings, would suggest that at least it might be well to consider the use of a vaccine made from several strains.

Stober (14) reports three negative Widals and seven positive Widals, using an organism isolated from urine. Mock (11) also reports negative agglutination with typical typhoid organisms isolated from clinical cases. Robinson (15), on the other hand, reports no variability in 100 Widals using the Worcester and Rawlings strains.

In summing up the work done the following conclusions may be drawn:

1. Culturally, the typhoid organisms studied differ very slightly from each other, the reaction being most variable in dextrine, xylose, salacin and litmus milk. These variations cannot be correlated with the age of the culture nor source.

2. Cross-agglutination and absorption tests establish the existence of at least quantitative antigenic differences between the strains used. It occurs to the author that the conflict as to whether there are antigenic differences in the typhoid group may be due to the fact that qualitative rather than quantitative differences have been emphasized.

3. There is a marked difference in the agglutination of organisms with the sera used in Widals, and it would be advisable to set up each Widal with more than one strain, selecting strains which were known to give a high percentage of positives.

4. The use of fresh serum drawn from the clot is much more satisfactory than the use of dried blood, changing what is probably a quantitative difference into an apparently qualitative difference.

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