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On the Fœtal Membranes of Chelonia.

(Contributions to the Embryology of Reptilia II*)

by

K. Mitsukuri, *Ph. D., Rigakuhakushi,*

Professor of Zoology, Imperial University.

With Plates I—X.

Our knowledge of the fœtal membranes of Reptilia is confessedly still very imperfect. It is generally assumed that they resemble more or less closely those of Birds. Kölliker is altogether silent. Balfour gives very meagre information, on the subject in their respective treatises on Embryology, while Hertwig in his Lehrbuch treats Reptilia throughout as presenting the same appearances as Birds on this point. Recently Strahl (No. 5), Hoffman (Nos. 6 & 7), Ravn (No. 9) and Perenyi (No. 16) have touched on the subject but their observations are confined mostly to the earlier stages.

Whilst collecting embryos of Chelonia, I became aware of the fact that there are some very notable features presented by the fœtal membranes of these animals which, so far as I am aware, have hitherto been entirely overlooked. These features appeared to me so remarkable and interesting that I thought it worth while to inves-

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* I shall consider the article on "the Formation of the Germinal Layers in Chelonia" by Mr. Ishikawa and myself, and published in this Journal Vol. I and also in Quart. Jour of Micro. Sci. Vol. 27 as the first of this series of contributions to the Embryology of Reptilia.

tigate the whole history of these membranes in this group. The following embodies the results of my study on this subject.

The species which I have investigated are Clemmys (or Emys) Japonica, Gray. and Trionyx Japonicus, Schlegel. In earlier stages, the fœtal membranes of these two species are very much alike but in later stages they present differences which, in my opinion, are highly significant. For convenience of treatment, I shall divide the present article into three parts, as follows :—

I. Earlier Stages of the Amnion.

II. Origin of the Allantois.

III. Later Stages of the Fœtal Membranes.

And in each part, I shall treat the two species separately, generally giving the description of Clemmys first, as that species seems to have more primitive relations in its fœtal membranes. At the conclusion, I have put together some suggestions on the theoretical bearings of the facts brought forth under the head of General Considerations.

I. Earlier Stages of the Amnion.

a. Clemmys Japonica.

The first stage of which I shall give a description is represented in surface view in Figs. 1. and 1 *a.* Pl. I. There is at this period a deep horse-shoe shaped groove bounding the anterior end of the embryonic region—the "Vordere Grenzfurche" of German authors. The posterior wall of this groove is the head of the embryo, while its anterior wall is the first rudiment of the anterior fold of the amnion. The structure and relations of these parts will become clear from the sections to be described directly. The medullary groove is still open thoughout its length, its posterior part being wider apart than its anterior portion. The dorsal opening of the blastopore is very distinct. At the posterior end of the embryonic region, there is, in the specimen figured, a low semilunar fold bounding the embryo from behind. It gives one the impression of its being the posterior fold of the amnion. Such folds are not, however, found by any means in all the embryos, and even when present, are not always of the same figure and distinctness as in the figure. As the subsequent history shows, these inconstant folds at the posterior end of the embryo take no share whatever in the formation of the permanent amniotic sac.

Round the head-end of the embryo, there is an irregularly semi-circular transparent area of the blastoderm. In this area, there is usually an opaque line also semicircular and concentric with the cephalic groove (Fig. 1). Round the posterior end of the embryo, and along its sides, there is a broad horse-shoe shaped opaque streak which is caused by the abundant accumulation of yolk-granules—the germinal wall. The mesoblast, at this stage, extends into the head of the embryo proper, but anteriorly, laterally, and posteriorly the opaque horse-shoe shaped streak marks the limit of its extent. Hence the transparent area in front of the embryo is as yet free from the mesoblast.

In Fig. 58, Pl. VII. (See also Diag. I. Pl. X.), a median longitudinal section of the head end of the embryo is represented. It is evident from this section that the deep horse-shoe shaped groove at the anterior end (*a. l. f.*) is bounded posteriorly by the head (H. F.) of the embryo, while its anterior wall forms the first rudiment of the anterior fold of the amnion (Amn). The amnion is thus laid in the region into which the mesoblast has not yet found its way, and therefore, of necessity, consists at first only of the epiblast and hypoblast. In Fig. 59 (Pl. VII.), a transverse section of the same region is represented. From this and Fig. 58 (Pl. VII.), the characters of the two layers in the amnion will be easily understood. Where the layers reach the level of the general surface of the blastoderm, the epiblast presents a thickened ridge along the whole upper edge of the groove. As it is by the growth backward of this edge that the amnion comes to cover the embryo, this ridge of the epiblast must be the seat of an active growth. There is also in the median line a thickened ridge (Fig. 59. e.) of the epiblast which starting from the bottom of the groove reaches as far as the level of the blastoderm, fitting in its upward course the still open medullary groove of the head of the embryo.

In the semicircular transparent area in front of the anterior horse-shoe shaped groove, the epiblast consists of two layers of pavement cells, of which the upper is especially flat and seems to be of stiff consistency. The hypoblast in the region directly in front of the groove consists of polygonal cells. The opaque semicircular line in the transparent area already spoken of seems to be due to a special accumulation of the hypoblastic (Fig. 58.) cells. A little in front of this line, the hypoblast becomes suddenly a mass of fine yolk granules with nuclei scattered among them. At the periphery of the transparent area this passes rather abruptly into a bed of large yolk spherules.

The fact that the amnion in Reptilia, consists, when first laid, only of the two primary layers was made known by Strahl (No. 5), Hoffman (No. 6), Perenyi (No. 16), and Ravn (No. 9). Hoffman pointed it out as a point of great difference between the amnion of Reptilia and that of Birds, but it is now well known that, in Birds also, the amnion consists at first only of the epiblast and hypoblast. Kölliker refers to the fact in his classical work (zweite Auf. p.188, and Fig. 85), and Ravn (No. 8) has worked out the point elaborately. Van Beneden and Ch. Julin (No. 11) also observed the same fact in the

Rabbit and Bats and named the two-layered amniotic cap the "Pro-amnion." Fleischmann has also found the same state of things in the cat. It seems therefore an established fact that the head-fold of the amnion, when first laid, consists throughout the Amniota only of the epiblast and hypoblast and is therefore of the nature of Proamnion. In Reptilia, this point is made perhaps more conspicuous by the subsequent history of the fœtal membranes than in other groups.

It will be seen from this stage that the head of the embryo sinks from the first below the level of the blastoderm. Apart from any phylogenetic significance, there is mechanical necessity for its sinking in this manner. As soon as the development begins, the white of the egg is rapidly absorbed from the part over the blastoderm which becomes adherent to the inner surface of the shell membrane. There is therefore no space into which the head can grow except towards below. In removing embryos from the eggs, I availed myself of the fact of the blastoderm becoming adherent to the shell membrane, for, with a stout pair of scissors, I could easily cut a watch-glass shaped piece of the shell with the shell membrane and the embryo adherent to it, and inverting it, I could pour the preservative fluid into it, thus using it like a veritable watch glass, only excelling it in this that it keeps the embryo and the blastoderm stretched in their natural positions.

I am inclined to think that the semilunar ridge at the posterior end (Fig. 1) is also caused by the posterior heavy end of the embryo sinking into the space below. Its section is almost exactly like that of the lateral fold of the permanent amnion (Figs. 30 and 30*a*, Pl. V.). Such adventitious ridges seem to be produced here and there without any regularity (cf. also Fig. 2). They are of a transient nature and take no part in the formation of the amnion.

As later stages will show, the whole amniotic sac is produced solely by the growth backward of the anterior fold in conjunction with the lateral folds which rise gradually from before backward.

In the stage with two or three mesoblastic somites, as shown in Figs. 2 and 2*a*, Pl. I. (see also Diag. II. and II'. Pl. X.), the amniotic fold has extended nearly half over the body of the embryo whose anterior part has sunk meanwhile more and more below the level of the blastoderm. The posterior edge of the amniotic hood presents a horse-shoe shaped outline, being caused by the lateral fold of each side extending more posteriorly than the median part. There are again some irregular folds (*a*) in the posterior parts of the embryonic region.

Figs. 30–33 (Pl. V.) show a series of transverse sections selected from different parts of this embryo, Fig. 30 being the most posterior and Fig. 33 the most anterior.

Fig. 30 is from the region covered only by the lateral limbs of the horse-shoe shaped posterior margin of the amniotic hood. From this and Fig. 30*a* (Pl. V.) (the latter representing the left half of Fig. 30 under a much higher power of magnification) it will be seen that the lateral fold of the amnion, when first laid, presents two peculiarities: (1) it is purely epiblastic, and the mesoblast has no share whatever in it; (2) the fold is solid and not composed of the inner and outer limbs as represented in ordinary diagrams.

Fig. 31 is just in front of the point where the two lateral amniotic folds have united. One half of it is shown under a higher power in Fig. 31*a* (Pl. V.) The whole amnion here is composed of a solid sheet of the epiblast, the mesoblast insinuating itself between the epiblast cells only later on. The cells of this part of the amnion are in several layers, and of these, the cells of the outermost layer have undergone some process of hardening and their nuclei are stained deepest.

Fig. 32 is from the point where the head-end of the embryo is just beginning to sink below the level of the blastoderm. The mesoblast of the body has separated from the extra-embryonic part. The amnion is mostly epiblastic, although lined by the hypoblast for a short distance on each side.

Fig. 33 is from the head region which is completely sunk below the level of the blastoderm. As emphasized by Hoffmann, the head appears in the cross section below, instead of above, the blastoderm. The amnion is composed of the epiblast and hypoblast, each being only one-cell layered.

These sections show that the amnion at this stage consists, in the region of the sunken head, of the epiblast and hypoblast, and in the dorsal region, of the epiblast only. The mesoblast as yet has no share in it.

In the stage with 6 or 7 mesoblastic somites (Figs. 3 and 3 *a* Pl. I. See also Diag. III. and III'. Pl. X.), the amniotic hood has extended to the posterior end of the embryo, leaving only the region round the neurenteric canal exposed. The mesoblast has also very much increased in its distribution and has become, thoughout, split into the somatic and splanchnic layers. The cœlom has thus appeared not only within the body of the embryo proper but has extended itself into the extra-embryonic portion of the blastoderm. Although the mesoblast has originally spread from behind forward, the cœlomic cavity appears first in the neck region of the enbryo and spreads gradually backward—as was pointed out by Strahl (No. 5). In the stage represented in Fig. 3, when seen through from above, the extra-embryonic cœlomic cavities of two sides, extending into the amniotic folds come close together (but are not fused) in the median dorsal line along a considerable distance in the anterior part of the dorsal region, but separate from each other before the posterior edge of the amnion is reached, and, gradually lessening in their height, are lost together with the gradually lowering lateral folds of the amnion. Thus the mesoblast now has a considerable share in the formation of the amnion.

Figs. 34–38 (Pl. V.) are a series of transverse sections selected from different regions of this embryo.

Fig. 34 is from the region where the lateral folds of the amnion are still low. When we compare this with Fig. 30, we see that in this stage the somatic layer of the mesoblast is folded and pushing itself into the hitherto solid epiblastic amniotic folds.

Fig. 35 is from the region where the mesoblastic folds or, what amounts to the same thing, the extra-embryonic cœlomic cavities are still some distance from the median line. Fig. 35 *a* represents the median dorsal portion of the amnion in the same section under a higher power. It is evident that here also, a somatic fold of the mesoblast insinuating itself, so to speak, on each side into the originally solid epiblastic amnion is separating the latter into two limbs of which the inner is the true amnion and the outer the false amnion* or serous envelope.

In Figs. 36 and 36 *a*, the mesoblastic folds have reached further dorsalward, but the amnion and the serous envelope are united in the median line. In Fig. 36 *b*, a few sections forward of Fig. 36, the mesoblastic folds have reached still further dorsalward—the most dorsalward at this stage—but still there is a distinct connection between the amnion and the serous envelope.

The mesoblastic folds maintain themselves at the level given in Fig. 36 *b* for many sections forward, and the connection between the

* In future, I shall avoid using the term "false amnion" to denote the structure here indicated and shall call it the serous envelope, as the term "false amnion" is applied to two very different structures by German and English authors.

amnion and the serous envelope is also invariably present. (Compare Fig. 3, Pl. I.).

In Figs. 37 and 37 *a*, which are from the region of the heart, where the head-end is beginning to sink below the surface of the blastoderm, the mesoblastic folds have again receded from each other and the connection between the amnion and the serous envelope is again broad.

Fig. 38 is from the region of the head sunk below the level of the blastoderm, which therefore appears above the head in this section. The amnion or proamnion consists only of the epiblast and hypoblast.

The relations of different parts will become clearer, when studied in a longitudinal section.

Fig. 41 (Pl. V.) is such a section slightly out of the median dorsal line so that the extra-embryonic cœlomic cavity (cœl') of one side appears in the amnion. This section shows that the epiblastic amniotic fold reaches nearly to the neurenteric canal, while the hypoblastic fold extends only to the neck region. The triangular space between these two folds as seen in this section is occupied, for the most part, by the mesoblast enclosing a portion of the extra-embryonic cœlomic cavity. A little earlier there would have been no mesoblast in the amnion which then consisted, in the dorsal region, of the epiblast only, and in the sunken head part, of the epiblast and hypoblast. The mesoblast is now pushing itself into the solid epiblastic sheet of the amnion, dividing it into an outer and an inner limb. In Fig. 41, the posterior part of the epiblastic fold is, however, still solid. Anteriorly the mesoblast is insinuating itself between the epiblast and hypoblast. The cœlomic cavity in the mesoblast is widest in the anterior part.

One of my most important results is in regard to the connection between the amnion and the serous envelope, seen in Figs. 35–37. Contrary to what is hitherto known, the extra-embryonic cœlomic cavities of two sides are never united across with each other over the dorsal region of the embryo. A connection—quite elongated and definite in later stages—between the amnion and the serous envelope separates them to the very end of the development. That this structure causes great peculiarities in the fœtal membranes is to be expected and will become clear as later stages are described. This connection, I shall call hereafter the sero-amniotic connection. It does not extend to the sunken head part where the amnion consists of the epiblast and hypoblast, and is confined to the region behind the neck representing the original solid epiblastic sheet of the amnion or its prolongation behind.

While Fig. 3 (Pl. I.) no doubt represents the commonest and normal form in which the amnion spreads backward, it seems by no means to be the exclusive one. Fig. 14 (Pl. II.) shows one in which the posterior fold is present but a part of the left lateral fold is absent, so that the horse-shoe shaped posterior margin of the amnion is open toward the left. I have also another embryo in which a part of the right lateral fold is absent.

Now comes the most remarkable point in the development of the amnion in Clemmys. According to what is hitherto known about the amnion, one would expect that when it has reached the stage shown in Fig. 3 (Pl. I.) the posterior fold will be produced or the lateral folds will converge toward each other and thus the amniotic sac will be completely closed. Such is not the case in Clemmys. The anterior and lateral folds which starting from the head have gradually extended backward over the whole embryo do not stop at the posterior end of the embryo but continue to grow backward, although diminished in their width, until finally there is produced a tube extending backward from the posterior end of the embryo, almost as long as the body of the embryo itself, connecting the amniotic sac with the exterior. A reference to Figs. 4–7 (Pl. I.), will make the growth of this posterior tube clear. In Fig. 4, the folds have extended slightly beyond the posterior end of the embryo. Beyond this point, they suddenly come near each other, and being diminished very much in width, their continued growth backward produces a tube (Figs. 5 and 6). It will be seen that the extreme posterior point always presents a horse-shoe shaped outline, as it did when growing over the body of the embryo itself. Fig. 7 shows the stage of the greatest development of this tube in my possession. In three embryos of this stage whose lengths are 8, 8, and 8 ½ millimeters, the length of the posterior tube of the amnion is respectively 6, 8, and 7 ½ millimeters. The posterior opening is some distance beyond the edge of the vascular area.

The sections of this tube show that the relations of the different layers are in all essential respects exactly as in that part of the amnion proper enclosing the embryo as shown in Figs. 39 and 40 (Pl. V., from the embryo given in Fig. 5) of which Fig. 39 is from the anterior part of the tube near the embryo and Fig. 40 from about the middle of the tube. In the surface view, there is often seen a streak along the median line of the tube, which is shown by the sections to be a thickening on the floor of the tube. The structure of the similar tube in Trionyx is given in a more enlarged scale in Figs. 53–55 (Pl. VI.).

What the function of this remarkable tube connecting the amniotic sac with the exterior is,—whether it has any active function at all or is only of the nature of a remnant organ, I am unable to tell. I think it probable that it serves for conducting into the amniotic sac the nutritive matter from the white, with whose gradual disappearance from over the embryo the backward growth of the posterior amniotic tube seems to keep pace.

The condition of the amniotic sac proper at this stage when the posterior tube has already been developed is shown in the series given in Figs. 42-47 (Pl. VI.) from an embryo with twenty mesoblastic somites. An inspection of these figures shows that, over the posterior part of the embryo (Figs. 42 and 43), the amnion and the serous envelope are still adherent to each other for a considerable space: hence the extra-embryonic cœlomic cavities (cœl') of the two sides are separated from each other by a wide interval over the dorsal region. As we proceed forward, the mesoblastic folds gradually push toward the median line separating the amnion from the serous envelope, until, over the middle region of the embryo, they are separated only by a thin partition (Figs. 44 and 44*a*). This partition—the sero-amniotic connection—has now become vertically somewhat elongated and unlike Figs. 36*a* and *b* (Pl. V.) presents a string of cells in a cross-section (Fig. 44*a*). This represents the greatest vertical elongation of the sero-amniotic connection at this stage. Further forward, the mesoblastic folds become again separated by a considerable interval (Fig. 45). Anteriorly to the point where the head-end begins to sink beneath the surface of the blastoderm, the cœlomic cavities of two sides which arose separately have become united across, there being no sero-amniotic connection from the beginning in this part (Fig. 46). In the head which is freely projecting into the cavity below the blastoderm, the amnion still consists only of the epiblast and hypoblast (Fig. 47).

From what has been given above, it follows that the extra-embryonic cœlomic cavities of two sides are separated from each other over the dorsal median line by the sero-amniotic connection from the neck region to the very tip of the posterior tube. In front of the neck region, i. e., in the sunken head region, the cavities become early united across. It is important to remember this fact in order to understand the relations of some parts in later stages.

In a slightly older embryo, the sero-amniotic connection has increased more in its vertical extension. Figs. 48 and 48*a* (Pl. VI.) are from the tail region, Figs. 49 and 49*a* (Pl. VI.) from the middle of the body. In the latter, the sero-amniotic connection is of a considerable length, becoming quite definite.

As to the fate of the posterior amniotic tube. At the stage (Fig. 7, Pl. I.) when it is in its highest development, the axis of the tube is the same as that of the embryo, i.e., the embryo and the tube are in the same straight line. Beyond this stage, the tube begins to become curved, at first slightly, then more and more. In Fig. 13*a* (Pl. II.) the curvature is very slight; in Figs. 13*b* and 8 (Pl. II.) it has increased greatly; in Fig. 9 the distal portion of the tube is bent at a right angle to the proximal basal part; in Figs. 10 and 15 (Pl. II.), the tube has become very irregularly curved. It will be seen that the tail end of the embryo which is at first far in front of the horse-shoe shaped distal end of the posterior amniotic tube (Fig. 7) gradually approaches the level of the latter (Fig. 9) until in Figs. 10 and 15 it has pushed itself far behind. It is now the distal end of the tube that is in front. This change of the relative positions is no doubt due to the fact that the embryo and the amniotic sac proper grows more rapidly than the posterior amniotic tube which they push aside, so to speak, in order to grow beyond it. As the curvature becomes greater, parts of the tube become fainter and fainter in appearance. For instance, in Fig. 10, a large part of the tube excepting the distal horse-shaped end and the proximal basal part, was very difficult to recognize (being represented too distinctly in the Figure). In Fig. 15 I could detect only faint traces of the tube, here and there excepting the proximal basal part which is always distinct. The oldest stage in which I detected any portion of the distal half of the posterior amniotic tube is that given in Fig. 67 (Pl. VIII.). I found there the horse-shoe shaped distal end of the tube and the portion contiguous to it, but after a most careful search. I could not connect it with the proximal part. From these facts, it appears that the largest part of the posterior amniotic tube disappears entirely, and that only the proximal part—the part nearest the amnion proper (prox pt. Figs. 9, 10, and 15, Pl. II.)—remains permanently. It will be remembered that the sero-amniotic connection extends from over the neck region of the embryo to the tip of the posterior tube. As the proximal part of the tube remains permanently this marks in all later stages the posterior end of the sero-amniotic connection. As further growth in size of the amnion proper (accommodating itself to the growth of the embryo within it) takes place mostly behind the remnant of the posterior tube, the latter and the sero-amniotic connection come to lie in the anterior part of the amnion in older embryos. The growth in size of the amnion after being closed once is therefore due mostly to the enlargement of that part which is placed behind the posterior tube enclosing the tail end in a stage like Fig. 11 (Pl. II.).

In all the stages hitherto described, the head of the embryo projected below the level of the blastoderm covered by the proamnion which consists only of the epiblast and hypoblast (Fig. 41, Pl. V.). On this account, in sections of this region, the head is found below the general level of the blastoderm (Figs. 33, 38, Pl. V., Fig. 47, Pl. VI.). The manner in which this anomalous state of things is brought to a close, and in which the head covered by the amnion consisting of the epiblast and the somatic mesoblast comes to lie above the hypoblast as in other parts of the body, has been described by Strahl (No. 5) and Hoffman (No. 6) and quite recently by Ravn (No. 9).

The last named author (No. 8) has also studied the process in the chick and found it to be alike. My own observations agree in all essential points with the account given by these authors. The process briefly stated is as follows: As stated before, the extra-embryonic cœlomic cavities of the two sides become early united across in the head region, there being no sero-amniotic connection here. This united cavity or its mesoblast wall, in spreading itself, insinuates itself between the epiblast and hyopoblast of the blastoderm and thus pushes the hypoblast forward and downward. A comparison of Figs. 41 and 41*a* (Pl. V.) and Diags. III., IV., V. (Pl. X.) will make this point clear. In Fig. 41, the head is still entirely covered by the proamnion; in Fig. 41*a*, the extra-embryonic cœlomic cavity (cœl′) in enlarging itself, has pushed the hypoblast forward and peeled it off, so to speak, from the greater part of the proamnion covering the head, so that now the proamnion is found only on the ventral part of the head. Meanwhile, the embryo turning on its longitudinal axis comes to lie on its left side. These movements bring about the state of things as shown in Figs. 11 and 11*a* (Pl. II.) In Fig. 11 the embryo lies entirely on its left side, and a small anterior part of the head is covered by the now much reduced proamnion. In the ventral view of the same (Fig. 11*a*) the proamnion is very conspicuous, because it is transparent and without blood-vessels. A section from the head of this embryo is shown in Fig. 85 (Pl. X.). It shows how the proamnion extends now only for a short extent.

The final disappearance of the proamnion is brought about by the continued extension of the mesoblast. Although the encroachment of the proamnion takes place to some extent from behind and before, it takes place most actively from the two sides. Fig. 86 (Pl. X.) is a section similar to Fig. 85 from a somewhat older embryo.

How the proamnion has been encroached upon from both sides and has all but disappeared is very clear. if we compare these two figures. These two figures show also that the left vitelline vein (*Vra*) becomes much larger than the right.

b. Trionyx Japonicus.

Earlier stages in the development of the Amnion in Trionyx are very much as in Clemmys. There is in fact no point of any importance which is different in the two species. As, however, the Trionyx embryos in my possession show very well in surface views how the extra-embryonic cœlomic cavities arise first in the neck region and gradually spread backward, I shall introduce here some figures which illustrate that point among others.

Fig. 16 (Pl. III.) is the stage closely resembling Fig. 1 of Clemmys (Pl. I.). The anterior horse-shoe shaped groove ("die vordere Grenzfruche"), the still open medullary canal, and the transparent area in front of the embryo are all very similar to the Clemmys embryo of the corresponding stage.

In Fig. 17 (Pl. III.) the amnion has extended over the anterior half of the embryo. When seen from the ventral side the whole anterior end of the embryo covered by the proamnion is projecting below the level of the blastoderm, as shown in Fig. 17*a*. In the neck region where the embryo gains the level of the blastoderm, one is able to recognize distinctly the extra-embryonic cœlomic cavity on each side of the embryo appearing as a vesicle which bulges out the dorsal and ventral surfaces of the blastoderm (Figs. 17 and 17*a*). The level of its posterior limit is the same as that of the posterior limit of the amnion, and the growth backward of the cœlomic cavities progresses hand in hand with the backward growth of the amnion. These two cavities, one on each side of the embryo, are of course the same as Strahl's " Mesoblastische

Schläuche" (Cf. Strahl No. 5). The sections of this embryo show that in the region where the lateral folds of the amnion have not yet united in the median line (Fig. 50 Pl. VI.), the fold is purely epiblastic and solid, and the mesoblast has no share in it at all. In the region where the extra-embryonic body cavity is present (Fig. 51), the mesoblastic folds have already pushed themselves considerably into the epiblastic amniotic sheet, dividing it into two limbs: the amnion proper and the serous envelope. In the embryo of Clemmys given in Fig. 2 (Pl. I.), the mesoblast has as yet no share whatever in the formation of the amnion. It follows therefore that the mesoblastic folds begin to push themselves into the epiblastic amniotic sheet somewhat earlier in Trionyx than in Clemmys. Fig. 52 is from the head region of the embryo given in Fig. 17. The head is surrounded by the proamnion composed for the most part of the epiblast and hypoblast, and appears beneath the blastoderm instead of above it.

Figs. 18 and 19 (Pl. III.) show that the amnion is gradually spreading backward, and with it the extra-embryonic cœlomic cavities are growing larger and larger. In Fig. 18, the cavities of the two sides are still wide apart over the dorsal region of the embryo: in Fig. 19 they almost touch each other along the median dorsal line in the anterior dorsal part of the embryo, but are considerably apart in the posterior region. A section from the anterior region (Fig. 57) shows that they are separated by the sero-amniotic connection which appears, however, still very short in a section.

In the embryo given in Fig. 23 (Pl. IV.) the amnion has covered the embryo entirely and has even extended a short distance behind it. The cœlomic cavites are correspondingly enlarged.

In the stage given in Fig. 24 (Pl. IV.), the posterior amniotic tube has become already quite elongated. Its posterior opening is now just at the edge of the vascular area. The extra-embryonic cœlomic cavities have now extended so much that they are no longer recognizable as vesicles in a surface view. Figs. 53–55 (Pl. VI.) are three sections from different parts of the posterior amniotic tube of this embryo. Figs. 53 being near the posterior opening and others being in front of it. Only the epiblast and somatic mesoblast are represented in these figures. the cœlom. the splanchnic mesoblast and yolk being left out. as a comparison with Figs. 39 and 40 (Pl. V.) will show. Fig. 56 is the median part of the amnion from over the middle region of the body of the embryo and shows the greatest encroachment at this stage of the extra-embryonic cœlomic cavities, reducing the sero-amniotic connection to a mere septum-like partition.

Figs. 21 *a*, *b*, *c*. and *d*. (Pl. III.) show the posterior amniotic tube of four embryos of the stage a little older than that given in Fig. 24. In *a* the tube is still straight. in *b* it is slightly curved, and in *c* and *d* more curved. In *a* the embryo is 6 mm. long, while the posterior amniotic tube is only 3 ½ mm. As this is no doubt the stage of the highest development of the tube. it follows that the posterior tube in Trionyx is not as long relatively to the body of the embryo as it is in Clemmys.

In Figs. 22 *a* and *b* (Pl. III.) the posterior amniotic tube is becoming very irregularly curved.

In Fig. 27 (Pl. IV.). most of the posterior amniotic tube has already disappeared or at least is unrecognizable. The proximal or basal part of it is, however. very distinct. At this stage, the sero-amniotic connection exists from the neck-region to the tip of the remnant of the posterior amniotic tube.

The manner in which the proamnion consisting only of the epiblast and hypoblast is gradually replaced by the amnion consisting of the epiblast and mesoblast is exactly as in Clemmys.

II. Origin of the Allantois.

Besides Kupffer who derives the allantois from the neurenteric canal, the one who has most carefully studied its origin in Reptilia is Strahl (Nos. 1 and 2). According to this author, the allantois is laid, in Lacerta, as a solid knob at the posterior end of the embryo, subsequently hollows itself out, and only then comes to communicate with the hind-gut by an independently formed allantoic stalk. It then turns round the tail end and comes to lie in front of, and below, the latter.

After Strahl, Hoffmann (Nos. 6 and 7) and Perenyi (No. 16) have studied the origin of the allantois in Reptilia. The views which Hoffmann expresses in his first paper (No. 6) mainly support Strahl's observations, while in his second paper (No. 7) he seems to have somewhat modified his idea. For the exact details in which his later ideas differ from those of Perenyi (No. 16), I must refer the reader to the original papers themselves, as I have to confess my inability to grasp them precisely. Notwithstanding Perenyi's statement that they differ, it appears to me that they are describing substantially the same process. Under the circumstances, I am unable to say whether my results agree with the view of either or both of these authors, although I think we have arrived at nearly the same results. Hoffmann says that the origin of the allantois in Reptilia is throughout the same as in Birds (No. 7, *p.* 189). Such is the conclusion I too have arrived at, after a careful study of Chelonia. In fact, this is so much so that Gasser's figures (Nos. 12 and 13) or Balfour's description (Comp. Embryol. Vol. II.) on the origin of the allantois in Birds might be bodily adopted to describe the same process in Chelonia.

As I have a more complete series of the Trionyx embryos illustrating this point than those of Clemmys, I shall begin with the former species.

Figs. 60–63 (Pl. VII.) and Figs. 87 and 87*a* (Pl. X.) give successive stages in the development of the allantois in Trionyx.

Fig. 60 is from an embryo very similar to the one represented in Fig. 23 with about seventeen mesoblastic somites. The splanchnopleure has not yet been folded under to form the hind-gut. The first trace of the allantois (All.) is, however, already visible as a shallow notch in the posterior part of the tail-lobe. In a surface-view, this notch appears as a shallow transverse slit as represented in Fig. 20. From the first, the posterior wall of the allantois is lined with a distinct epithelium of the hypoblast. Its anterior wall is no doubt also of the hypoblastic nature, but is here fused with the indifferent cell-mass above it.

Figs. 61–63 (Pl. VII.) and Figs. 87 and 87*a* (Pl. X.) speak sufficiently for themselves and need not be minutely explained to those who are already familiar with the corresponding stages in Birds. By the gradual folding of the splanchnopleure on the ventral face, the hind-gut is produced, and on its ventral floor the allantois becomes established as a vesicle at first wide open above (Figs. 62–63) but with its gradual growth constricted at the neck (Fig. 87). Fig. 87*a* represents a cross-section of the allantoic region from an embryo of the same stage as that represented in Fig. 87. It shows that the cavity of the allantois is at this stage two-lobed.

Figs. 64–66 (Pl. VII.) are three successive stages in the development of the allantois in Clemmys. Although these do not give as complete a series as in Trionyx, they are yet sufficient to show that the process in Clemmys is in all essential respects similar to that in Trionyx.

In none of my series of sections can I detect any trace of an independently formed vesicle which afterwards puts itself in communication with the hind-gut by an independently formed stalk. The figures given above sufficiently warrant us in concluding that in Chelonia at least, the allantois arises as a diverticulum of the hind-gut and is from the first continuous with it.

III. Later Stages of the Foetal Membranes.

In the preceding two sections we followed separately the growth of the amnion and of the allantois up to a certain stage. It will be more convenient to treat the later stages of these membranes together. As the development advances, they begin to differ in the two genera Clemmys and Trionyx, until, when completed, they present important differences in their structures. As those in Clemmys present in my opinion more primitive relations, I begin with that species.

a. Clemmys Japonica.

As the allantois pushes itself out as a vesicle into the extra-embryonic cœlomic cavity, the allantoic blood-vessels are soon found distributed in two groups (Compare Fig. 27 Pl. IV.). One (the right) set of arteries and veins is placed in that part of the vesicle facing anteriorly while the other (the left) set is placed on the posterior external aspect of the vesicle. The manner of distribution of the blood-vessels exerts a considerable influence on the future shape of the allantois.

As the allantois spreads itself over the embryo as well as over the yolk in the extra-embryonic cœlomic cavity, it assumes a peculiar shape represented in Fig. 67 (Pl. VIII.). The vesicle now flattened is divided by two peculiar constrictions into two parts of unequal sizes. The larger part is again subdivided into two lobes by the posterior set of blood-vessels. These two lobes of the larger part may be called respectively the right, and the left lobe, while the smaller half of the allantoic vesicle may be called the middle lobe.

The two constrictions that divide the middle lobe from the larger half of the allantoic vesicle are caused in two different ways. The anterior constriction is very easy to explain. It was mentioned above that one set of the allantoic vessels runs on the anterior side of the as yet small allantoic vesicle. Now, in the rapid growth of the vesicle, the lines along which blood-vessels run cannot, on account of their presence, keep up in their growth with the rest of the vesicle, and are necessarily left behind until along these lines there are produced grooves at the bottom of which the blood-vessels run. When the allantoic vesicle is flattened, these grooves necessarily produce notches or bays in the margin of the vesicle, more or less deep according to the size of the blood-vessels. In the case of the anterior set of the allantoic vessels, the groove has become so deep that the right lobe and the middle lobe on the two sides of it have met again and become firmly appressed with each other, so that practically these blood-vessels are supported in their course by a mesentery-like fold of the allantoic vesicle. This explains the origin of the anterior constriction of the allantois. In a similar way the notch that divides the larger part of the allantois into the right and left lobes is produced by the posterior or left set of blood-vessels, although the notch is not as deep as in the anterior constriction and consists of two or three minor indentations.

The posterior constriction of the allantoic vesicle given in Fig. 67 is also not very difficult to explain. There can be no doubt that it is due in the main to the fact that the vesicle finds itself unable to spread freely over the embryo on account of the sero-amniotic connection. The only thing it can do is to grow round the sero-amniotic connection, thus producing a deep incision in its outline. The posterior constriction owes its origin to this circumstance, and thus between the middle, and the left, lobe there is always interposed the sero-amniotic connection. There are some details of this posterior constriction which I am not able to understand. The allantois prepares to meet the sero-amniotic connection, sometime before it reaches in its growth the latter structure (*i. e.*, before there is, so far as I see, any mechanical necessity for a constriction) by folding itself and producing a constriction. Thus in Fig. 67 the apex of the posterior constriction is some distance from the remnant of the posterior tube of the amnion (which marks the posterior end of the sero-amniotic connection), and is marked by folds of the allantois showing themselves as white streaks. The result of this is that in later stages (Fig. 12) the posterior constriction is, near its head, divided into two limbs: one contains the sero-amniotic connection and its termination, the remnant of the posterior tube of the amnion, and the other is simply an incision in the margin of the allantoic vesicle. In still later stages, the latter is much the deeper of the two and becomes quite conspicuous (Figs. 68 and 71, Pl. VIII.). I am unable to see any necessity for the existence of this incision. I can not detect any one large blood-vessel or set of blood-vessels, which might cause it, as the anterior constriction of the allantois is caused by the right set of allantoic vessels. It appears to be a congenitally acquired character.

The nearly circular shape of the middle lobe is produced by the fact that it is necessarily limited in its growth by the sero-amniotic connection which obstructs its front. In fact it is the right and left allantoic lobes that grow to cover the larger part of the yolk-sac.

The right and middle lobes are supplied mostly by the right set of blood-vessels, while the left lobe is supplied by the left set.

The allantois has not yet in this stage entirely covered the amnion and the embryo from above so that the amnion with its sero-amniotic connection, and the anterior dorsal part of the embryo are visible beyond the margin of the middle allantoic lobe. The amnion at these stages does not fit itself tightly over the embryo but leaves a spacious amniotic cavity around the embryo. Especially there is a remarkable snout-like prolongation of the amnion extending in front of the head.

Fig. 68 represents an embryo about forty days old. The allantois has now spread over a large part of the upper half of the yolk, and this extension is due mostly to the right and left lobes and not to the middle lobe. A peculiarly sharp demarcation between the middle and left lobes of this stage is due to the fact that the sero-amniotic connection is placed between them. The remnant of the posterior tube of the amnion appears as a white triangular patch extending to the left at the head of the posterior incision. The long white streak extending from the same point obliquely backward over the back of the embryo is the simple incision of the allantois referred to above in Fig. 12 (Pl. II.). The allantoic vesicle being of some thickness, the walls of the incision which extend from the inner to the outer limb of the allantois are of some depth, and being pressed from above are bent down and show as a white conical streak of peculiar appearance. Note also the deep anterior constriction with the right set of allantoic vessels at its bottom.

It may be remarked in passing that the position of the embryo on the yolk is not necessarily as in Fig. 68. The embryo is formed at any place which happens to be uppermost when the egg is deposited. If an egg happens to stand on its end, the embryo will occupy the end of the oblong yolk.

Fig. 69 (Pl. VIII.) gives a side view of a somewhat older embryo. The allantois has spread over the larger part of the yolk so that, in the figure, the latter shows bare only at the posterior part of the ventral side. The figure shows the left lobe of the allantois, the sero-amniotic connection with peculiar structures at its posterior end, and the left set of allantoic vessels with the corresponding incision in the margin of the allantoic vesicle.

Fig. 70 gives a ventral view of an egg of about the same stage. The three lobes of the allantois have now spread themselves over a part of the lower half and are here very conspicuous. The lobe that appears to the observer's right is the left allantoic lobe. Next to it is the middle lobe and finally at the observer's left is the right allantoic lobe. The incision between the middle and the right lobes is the anterior constriction of Figs. 67 and 68, and at its dorsal end is found the right set of allantoic vessels. The incision between the middle and the left lobes passing over the head of the embryo corresponds to the posterior constriction of the earlier stages, and has the sero-amniotic connection placed in it. While in Figs. 67 and 68 the embryo is confined to the space below the middle lobe, in this figure the head of the embryo appears below the left lobe to the left of the sero-amniotic connection. This is brought about by the following circumstances. In Fig. 67, the embryo lies on its left side and, the sero-amniotic connection being approximately over its dorsal median line, we are viewing it, so to speak, from the side. As the embryo and with it the amnion grow, the embryo comes again to lie on its ventral surface, as in the earliest stages, and the sero-amniotic connection again accompanying the dorsal surface of the embryo is turned toward the observer. The amnion is thus free to grow to the left of it, under the left allantoic lobe. The amnion being spacious, the embryo is able to move within it, and the head may now be seen to the left, or to the right, or directly under, the sero-amniotic connection, although the position shown in Fig. 71 appears to be the most normal.

The blood-vessels that pass through the umbilicus at these later stages, are arranged as in Fig. 75 (Pl. IX.). The most anterior is the vitelline vein, then comes the vitelline artery, after it the allantoic artery and last of all the allantoic vein. The last three divide into two, the right and left branches, soon after their exit from the umbilicus. The vitelline artery is distributed over the surface of the yolk, but the vitelline vein is somewhat peculiar: it is much larger than the vitelline artery and while it receives branches from the surface of the yolk, the main bulk of it enters right into the substance of the yolk. This no doubt makes the acquisition of nutriment from the yolk much easier.

I may now proceed to describe the relations of the embryo, the fœtal membranes and the yolk shortly before hatching. (Figs. 71 and 71*a* Pl. VIII. and Diag. VI. Pl. X.).

The yolk sac (Fig. 71*a*) is now reduced considerably in size and the three lobes of the allantois have entirely enclosed it. These three lobes never fuse with one another, but are permanently separate. The seams that separate them are roughly speaking tri-radiate, the center being at the anterior end of the yolk-sac slightly to the left (to our right as we view it from the ventral surface) of the median ventral line. The seam that extends transversely from the center towards the right (to the left of the observer) separates the middle (placed in front of it) from the right allantoic lobe (placed behind it) and corresponds to the anterior constriction in Fig. 67. Hence, at its distal end, is found the right set of the allantoic arteries and veins. The seam that runs back from the center nearly parallel with the median ventral line separates the left lobe (placed to its left or to the observer's right) from the right lobe, and corresponds to the shallow notch produced by the posterior (the left) set of blood-vessels in Fig. 67, or to the incision in Fig. 69. Hence, at its distal end the posterior or left set of allantoic vessels is found. The seam that separates the middle from the left allantoic lobe is different from the other two, for here the two lobes of the allantois cannot come into contact, being separated by the sero-amniotic connection. It passes over to the dorsal side of the embryo (Fig. 71), and its dorsal end has the triangular remnant of the posterior tube of the amnion, and the peculiar conical white streak caused by the simple incision of the allantois. (Compare Figs. 68, Pl. VIII., and 12, Pl. II.).

There is one feature in an egg thus advanced which deserves special notice. The white of the egg which disappeared very early from over the embryo continues to grow smaller and smaller in quantity. But it persists up to a very late date, if it ever disappears entirely. There is always, even in very much advanced eggs, a small mass of the white just at the point where the three lobes of the allantois meet at the lower pole. This mass seems to have undergone some change in its chemical composition for it is now much denser, slightly yellowish in color and sticky. To receive this mass the membranes are often shallowly depressed. Into the center of this mass of the white a thick low process of the membranes penetrates (shown in Fig. 71*a* on the left allantoic lobe, just to the right of the sero-amniotic seam), so that when the membranes are removed, the mass of the white with the central part hollowed out appears like a bowl. The cells of the serous envelope on the surface of this process are peculiarly modified. They are more columnar than in other parts (Fig. 29, Pl. IV.). Their nuclei are larger, irregular in shape, and stained deeper. In these cells are found many large vacuoles which remain unstained. There can be no doubt that these cells are absorbing albuminous particles from the mass of the white. It seems to me that here we have in a very primitive condition the structure described by Duval (No. 10) as the placenta in Birds.

The amnion in these later stages seems to envelope the embryo tolerably closely, and its cavity is no longer spacious.

In hatching, the yolk-sac passes into the interior of the body where it lies for a long time—in fact for several months, for I found it in young tortoises late in the spring of the year following that in which they were hatched. The amnion is torn into shreds, but the allantois seems to be split open by the anterior limbs of the emerging embryo along the sero-amniotic seam—if not always, at least in some cases, for I have specimens in which the allantois has been cast away in this manner and is uninjured. The outer shell which has become very brittle is easily broken through and the young tortoise emerges into the world.

We may now examine the microscopic structures of these membranes. We left the sero-amniotic connection in the condition represented in Fig. 49 (Pl. VI.). After that stage, as the distance between the amnion and the serous envelope increases and the connection becomes accordingly elongated in its vertical extension, the epiblast cells in it become flattened in the direction perpendicular to the plane of the connection. Fig. 76 (Pl. IX.) represents a part of a section of the sero-amniotic connection from the same embryo as that from which Fig. 86 (Pl. X.) is taken. The cells show decidedly the flattening referred to above.

This flattening goes on more and more, but I omit the intermediate stages and proceed to the description of the sero-amniotic connection in the finished fœtal membranes (Fig. 71, Pl. VIII.) Figs. 78–80 (Pl. IX.) are selected sections from an embryo of the same stage as that represented in Figs. 71 and 71*a* (Pl. VIII.). All three are from the region of the remnant of the posterior tube of the amnion, Fig. 78 being the most anterior, and in order to facilitate the understanding of these sections, I have introduced a diagram of this region in Fig. 77. In this diagram, the serous envelope is represented as spread over all the structures; the amnion is below it and is indicated only by the line from which the sero-amniotic connection arises. The remnant of the posterior tube of the amnion has before this stage been modified into a solid compressed string of cells and is shown by the heaviest dark line which stretches from the amnion to the serous envelope. The sero-amniotic connection is represented shaded by parallel dotted lines. Throughout the largest part of its length (from its anterior end to near its posterior end) this structure lies in one plane and is simply a membrane stretching between the amnion and the serous envelope. But on coming to the region of the posterior tube of the amnion, it makes a sudden turn of over 90° to the left and goes to the serous termination of the posterior tube, which latter structure it connects on its way with the serous envelope. It will of course be understood that the sero-amniotic connection from its anterior to its posterior end was originally in one straight line and that its peculiar bent termination at this stage was brought about by its accompanying the posterior amniotic tube in all its changes of relative position. It is this peculiar bent part of the sero-amniotic connection which is seen as the triangular white patch at the dorsal end of the sero-amniotic seam. (Figs. 68, 69, 71, Pl. VIII.).

Fig. 78 is from the region of the simple sero-amniotic connection (the line 1–1 in Fig. 77). In such a section, the sero-amniotic connection is really a striking structure, forming a broad and conspicuous connection between the serous envelope and the amnion. The epiblast cells in it are now very flat and closely packed. The allantoic lobes become closely applied against the mesoblast of the connection but are permanently separate from each other. The epiblast of both the amnion and the serous envelope consists of two layers of cells. The inner layer of the former and the outer layer of the latter consist of very much flattened cells with large nuclei—which, in the case of the serous envelope at least, are much larger and stained deeper than those of the second layer. It is the cells of the outer layer which become specially large in the region of the placenta. The second or underlying layer consists of cubical cells which in some places may be present in more than one layer. It is this inner second layer alone that forms the sero-amniotic connection, the outer taking no part in it. As regards the allantois, the outer limb is generally much thicker than the inner limb and has many more blood-vessels distributed in it. The thickness of the allantoic walls is crossed in all directions by slender spindle-shaped cells.

Fig. 79 corresponds to the line 2–2 in Fig. 77 just through the angle of the bend which the sero-amniotic connection makes. The sero-amniotic connection goes here on one side to the amnion and on the other to the remnant of the posterior tube of the amnion, which, being now reduced to a thick compressed and somewhat convoluted string of cells, shows in section as lobated cell-masses.

Fig. 80 corresponds to the line 3–3 in Fig. 77. The sero-amniotic connection is no longer continuous with the serous envelope but goes to the remnant of the posterior tube of the amnion. To the right of the sero-amniotic connection, the two lobes of the allantois meet but are not fused. This is the section of the conical white streak that stretches over the dorsal region of the embryo and corresponds to the simple incision of the allantois given in Fig. 12 (Pl. II.).

In a few more sections, the sero-amniotic connection disappears. The two lobes of the allantois, however, keep separate and meet in a seam for many more sections, as the simple incision of the allantois extends considerably further posteriorly than the most posterior point of the sero-amniotic connection. Finally, however, the allantoic cavity is continued across. As the incision is deeper in the inner limb of the allantois than in the outer, the allantoic cavity first becomes continuous near the external surface and then gradually extends toward the inner surface.

b. Trionyx Japonicus.

As in Clemmys, the allantoic blood-vessels group themselves into two sets: the anterior (or the right) and the posterior (or the left), while the allantois is still a small vesicle (Fig. 27 Pl. IV.). When the allantois has advanced somewhat in its development, it presents the shape represented in Fig. 72 (Pl. VIII.). This corresponds to Fig. 67 of Clemmys but presents some important differences. The allantois consists here of two lobes marked off from each other by two constrictions. One of these is just behind the eye and the other is directly opposite the first on the opposite side of the vesicle. Unlike Clemmys, both these constrictions are produced in the same way. That is, the line along which each set of blood-vessels passes from the inner to the outer limb of the allantoic vesicle is left behind in its growth, and the parts on each side of the same line growing faster and meeting each other soon produce a mesentery-like fold slinging these blood-vessels. In other words, both the constrictions of Trionyx are of the same nature as the anterior constriction of Clemmys (Fig. 67). The posterior constriction of Trionyx is not well-marked in Clemmys: it corresponds to the shallow notch caused by the posterior or left set of blood-vessels. On the contrary, that corresponding to the posterior constriction of Clemmys—to that caused by the presence of the sero-amniotic connection—is never produced in Trionyx, although at the spot where it ought to be produced, viz., opposite the remnant of the posterior tube of the amnion, the allantois is drawn out to a peculiarly shaped point as if it were trying to go round the sero-amniotic connection. From these considerations, it follows that that part of the Trionyx allantois in front of the anterior constriction corresponds to the right lobe of Clemmys, the part from the anterior constriction to the point opposite the remnant of the posterior tube of the amnion to the middle lobe, and the part from the same point to the posterior constriction to the left lobe. The middle lobe faces, as in Clemmys, the sero-amniotic connection.

Unlike Clemmys, however, the growth of the middle lobe pushes, so to speak, the sero-amniotic connection before it, so that the amnion comes gradually to assume the shape of a bag of which the sero-amniotic connection forms the puckered mouth. Reference to Figs. 25 and 26 (Pl. IV.) will make these processes clear.

In Fig. 25, the sero-amniotic connection is still directly over the dorsal side of the embryo and it is still straight. The allantois is pressing on it.

In Fig. 26, the growth of the amnion has removed the main portion of it from the sero-amniotic connection. The whole amnion has now assumed the shape of a bag hanging pendant by the sero-amniotic connection. The allantois is still pressing on the sero-amniotic connection, and its pressure, so to speak, has bent the hitherto straight sero-amniotic connection like the letter V. Moreover the general axis of the sero-amniotic connection which has hitherto been parallel with the axis of the embryo is now at right angle with the latter. The general appearance of the egg at this stage as seen from the ventral side is given in Fig. 73 (Pl. VIII.). The allantois has covered a larger part of the yolk sac, leaving only an oval space at the lower pole uncovered. This oval space is bounded anteriorly by the sero-amniotic connection bent like the letter V, and from this is seen stretching forward the anterior prolongation of the amnion which unites the main portion of the latter with the sero-amniotic connection (Comp. Diag. VII., Pl. X.). The two constrictions or mesentery-like folds of the allantois caused by the two sets of blood-vessels are also seen distinctly in the figure.

The final shape of the fœtal membranes is seen in Fig. 74 (Pl. VIII. Comp. Diag. VII., Pl. X.), and that part of the ventral surface where the lobes of the allantois finally meet is represented in a more enlarged scale in Fig. 81 (Pl. IX.). The space left uncovered by the allantois in Fig. 73 is now mostly grown over by the growth from the posterior side. There is however a small space still left uncovered by the allantois. It is triangular in shape; the apex of this triangle is bounded anteriorly by the sero-amniotic connection, now compressed to an irregular horse-shoe shaped opaque streak. On two sides of the triangle is the anterior allantoic lobe (which equals the middle and left lobes): posteriorly, it is limited by the posterior allantoic lobe (which equals the right lobe). From the lateral angles of this triangle the mesentery-like fold of the allantois stretches on each side to each set of the allantoic vessels. These correspond to the two notches in Fig. 72. The view from inside of this region is given in Fig. 81*a*. In this there is a ridge across the middle of the triangular area. This is the line of junction of the yolk-sac and the amnion, as will become clear from the sections to be described directly. It appears in the external view as an opaque line across the horse-shoe shaped sero-amniotic connection (Fig. 81). The anterior prolongation of the amnion connecting the main body of the latter with the sero-amniotic connection is now so disproportionately small compared with the amnion itself that it appears as a small irregularly triangular white patch (Fig. 81*a*, Ant. Prolong. Amn., and Fig. 81). Its cavity, now almost obliterated by the appression of its two walls, is still continuous with the amniotic cavity through a narrow slit (see Fig. 81*a* and Diag. VII.). It leads to the sero-amniotic connection. Figs. 82–85 (Pl. IX.) are a series of sections of this region, the plane of sections being in the antero-posterior direction. Fig. 82 is from the left side of the triangular uncovered area in Fig. 81*a* (or from the right side in Fig. 81). The two allantoic lobes, the anterior and posterior, are only slightly apart from each other. Attention is called specially to the section of a part of the anterior prolongation. Figs. 83 and 84 are from the triangular area itself. Here the two allantoic lobes are wide apart. The interspace is filled up mostly by the growth of the somatic mesoblast of the serous envelope. The sero-amniotic connection in Fig. 83 is of a very complicated figure. This arises from two reasons. In the first place, the section being taken in the antero-posterior direction, it cuts one limb of the horse-shoe shaped sero-amniotic connection more or less longitudinally. In the second place, the sero-amniotic connection is not in a simple straight line as in Clemmys, but being compressed and ruffled, appears as of an irregular pattern in a section. In Fig. 84, the sero-amniotic connection is cut more directly across. To give an idea of the structure of this region, I have given a part of Fig. 84 on a more enlarged scale in Fig. 84*a*. In Fig. 85, which was broken by accident, the two allantoic lobes have again approached each other, the section being out of the triangular area. They are, however, distinct and continue distinct until the sections reach the allantoic vessels.

In Trionyx, the remnant of the posterior tube of the allantois is not to be clearly distinguished. The place where it should be present is drawn out to a point (Fig. 26. Pl. IV.): that seems to be all the indication remaining in later stages of the posterior tube of the amnion.

The white remains to the last in Trionyx as in Clemmys, and is found opposite the triangular area of the ventral pole left uncovered by the allantois. This part is generally more or less depressed to receive the mass which is sticky and yellowish. The outermost cells of the serous envelope in this area undergo modifications similar to those of the corresponding spot in Clemmys. They become taller and larger and contain large vacuoles, their nuclei become larger and irregular in shape and stained deeper (Fig. 84*a*., Comp. Fig. 29, Pl. IV.). In Trionyx however, there appears to be no process that penetrates into the white as in Clemmys.

The yolk passes inside the embryo in hatching.

Of the completed fœtal membranes of Clemmys and Trionyx above described, there can be no doubt that Clemmys has retained more primitive relations. The main ground for this conclusion is that, starting from the same point, different structures (above all, the sero-amniotic connection) retain in Clemmys their original position and arrangement, while in Trionyx various structures are disturbed from their first arrangement, the sero-amniotic connection being pushed forward, bent and compressed into a secondary shape. If the process begun in Trionyx were to go one step further, no spot would be left uncovered by the allantois, the sero-amniotic connection might be pressed out of existence, the two allantoic lobes might come in contact with each other, and then the condition hitherto accepted as occurring in Birds would be the result.

General Considerations.

The noteworthy features in the history of the fœtal membranes of Chelonia as given above are :—

1. The presence of the Proamnion and the manner in which it is replaced by the permanent Amnion.

2. The presence of a peculiar tube stretching posteriorly from the posterior end of the Amnion connecting the cavity of the latter with the exterior—the Posterior Tube of the Amnion.

3. The permanence of the Sero-Amniotic Connection.

4. The differences in the fate of the Sero-Amniotic Connection in Trionyx and Clemmys.

5. The presence of the rudimentary "Placenta."

Of these, the first point has been noticed in nearly all the amniota whose development has been carefully studied within recent years. The only new feature is the fact that the dorsal part of the proamnion consists at first solely of a solid sheet of epiblast cells. The second, third, and fourth points are, so far as I am aware, brought out for the first time in the course of the present investigation. They certainly are very remarkable features, and, so far as our present knowledge goes, might be looked on as distinctive of the Chelonian fœtal membranes. I think it, however, highly probable that if other groups of Reptilia and Birds are carefully gone over again, many structures which are highly significant in the light of the facts now obtained will be found to have hitherto escaped notice or been laid aside as unimportant. For instance, in the sections of Lacerta given by several authors, the sero-amniotic connection is distinctively figured even up to comparatively late stages. Being possessed with the idea obtained from the study of Birds that it is soon to disappear, different writers have not thought it worth their while to follow its history further. Nevertheless I can not but think that the sero-amniotic connection runs a similar course in other groups of Reptilia as described now for Chelonia. I also think that the posterior tube of the amnion is not such an unique structure as it appears to be at present.

The fifth point, the presence of the rudimentary placenta, is certainly very interesting. If the depression into which the white is received should become deeper, and the allantoic folds should be produced to enclose it, we shall have exactly the same structure as "the placenta" described by Duval in Birds.

The Reptilia, being the lowest group of the Amniota, are of great importance in the comparative study of the fœtal membranes. What light does the history of the Chelonian fœtal membranes as given above throw on the phylogeny of those membranes in the Vertebrata? Without going into a general discussion of this difficult problem, I think I might offer here a few suggestions which have presented themselves to me in the course of the present investigation. I strongly incline to the view that the amnion was originally developed by mechanical causes. In Chelonia, when the head fold is produced, there are two reasons why it should sink into the yolk below. In the first place, the yolk is very large and liquid, especially just beneath the blastoderm, so that a slight weight is enough to sink any structure into it. In the second place, the white rapidly disappears from over the blastoderm, which adheres then firmly to the shell-membrane: hence there is no space for the head-fold to grow except towards below. Without asserting that these are the very same causes that produced the anterior fold of the amnion, I think it reasonable to assume that it was produced by some such mechanical means. In this relation, I think, those inconstant adventitious folds as given in Figs. 1 and 2 (Pl. I.) are highly significant. These undoubtedly arise by the neighboring parts sinking below. We might suppose that in the earlier stages of development many such folds are produced, different in different embryos according to their individual idiosyncracies, and the anterior fold of the amnion may be looked upon merely as one of these. Only the cause that produces it being present in all the embryos and acting permanently and augmenting steadily, finally gave rise to the structure which we call the amnion, heredity of course helping a great deal.

The anterior fold of the amnion, when produced, consists only of the hypoblast and epiblast, and is called the Proamnion. We now know that this is found in all the groups of the Amniota, and I think we ought to add the stage of the proamnion as of normal occurrence n the development of the amnion. In Chelonia, the dorsal part of the proamnion is for some time entirely epiblastic. Should this be looked upon as a primitive feature or as a secondary one? I am inclined to adopt the former view for two reasons :—

(1). The inconstant adventitious folds are, as previously stated, always purely epiblastic and exactly like the lateral folds of the proamnion (Fig. 30*a*, Pl. V.): hence, it is reasonable to conclude that all such folds produced on the surface of the blastoderm are at first always purely epiblastic, and the solid epiblastic dorsal sheet of the Proamnion produced by the coalescence of the lateral folds of two sides have reason to be simply epiblastic.

(2). In Clemmys, whose development is certainly more primitive than that of Trionyx, the solid dorsal sheet persists for a longer time than in the latter genus, and there is a considerable interval of time before the mesoblastic folds insinuate themselves into the epiblastic sheet. I think, however, that although these folds are solid and without any cavity, they ought to be regarded as consisting of two limbs, the inner and outer, which are firmly appressed against each other: otherwise there is no reason why the sero-amniotic connection, which ought to be regarded as the seam along which the folds of the two sides have met, should remain permanently and separate the mesoblastic folds of the two sides to the end.

If the dorsal part of the proamnion consisted primarily of the epiblast alone, why should the mesoblastic folds afterward insinuate themselves between the two limbs of that part, thus extending the extra-embryonic cœlomic cavity into that region? For the explanation of that process, I adopt Balfour's view. To give efficacy to the allantois as a respiratory organ, it is desirable that it should be spread as extensively as possible close under the surface of the egg; hence the extra-embryonic cœlomic cavity must have spread *pari-passu* with the gradual growth of the allantois. The extension of the folds of the somatic mesoblast into the epiblastic folds of the proamnion is, I think, due primarily to this cause. That the mesoblast spreads itself at present long before the allantois, is to be explained as a case of precocious development.

The sero-amniotic connection is, in my opinion, decidedly a primitive structure. The manner in which the allantois spreads itself in Clemmys by rounding the sero-amniotic connection can also be explained only on phylogenetic grounds. The manner in which the allantoic blood-vessels are slung on mesentery-like folds of the allantois, is, I think, also a primitive feature. The manner in which the sero-amniotic connection in Trionyx is pushed forward, bent and compressed, points out, I think, the way in which that structure historically disappeared in higher forms. As I have stated above, if the process begun in *Trionyx* is carried just one step further, the sero-amniotic connection would cease to exist. What is the cause which brought about this disappearance? So far as I can see, the sero-amniotic connection serves no practical purpose in *Clemmys* and its presence is only to be accounted for phylogenetically. If such is the case, it would be undoubtedly economical to skip over the roundabout manner by which the allantois spreads itself in *Clemmys* round the sero-amniotic connection. Hence its disappearance at last in higher forms. Whether the immediate agent of its forward shifting is the force exerted solely by the growing edge of the allantois I cannot tell. It is no doubt partly due to that, but in addition I offer the following as a suggestion. In *Trionyx*. the allantoic vessels come out symmetrically on each side: in *Clemmys*. the symmetry is disturbed, the right set is found more anteriorly than the left. As I have often remarked, *Clemmys* presents on the whole more primitive relations. but I cannot regard this asymmetry of the allantoic blood-vessels as a primitive condition: something being present in *Clemmys* has disturbed the original symmetry and being absent in *Trionyx* no longer intereferes with it and this something I think is the presence of the sero-amniotic connection. May not the tendency of the blood-vessels to assume a symmetrical arrangement help to push the sero-amniotic connection forward in *Trionyx*?

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Explanation of Figures in Plates I—X.

List of Reference Letters.

a. (Fig. 2) inconstant adventitious folds. *a. l. f.* anterior limiting furrow= vordere Grenzfurche. *All.* Allantois. *Amn.* Amnion. *b.v.* blood-vessels. *Coel.* coelom within the embryo. *Coel'.* extraembryonic coelom. *ch.* notochord. *Epi.* Epiblast. *H. F.* head-fold. *Hyp.* hypoblast. *Lat. f. Amn.* Lateral fold of Amnion. *Mes.* mesoblast. *N. E. Can.* neurenteric canal. *Post. Tu. Amn.* Posterior tube of Amnion. *prox. pt.* proximal part of posterior tube of Amnion. *Proam.* Proamnion. *Remnant. Post. Tu. Amn.* Remnant of posterior tube of Amnion. *Ser. Env.* Serous envelope. *Sero-Amn-Conn.* Sero-Amniotic connection. *v. v. a.* anterior vitelline vein. *yk.* yolk.

In colored figures of sections, the epiblast is always colored red, the mesoblast blue, and the hypoblast yellow. In Pl. IX. blue stands for the somatic mesoblast, and green for the splanchnic mesoblast.

Plate. I.

Fig. *1.* Dorsal view of a Clemmys embryo 2 days old. Zeiss *aa* × 2. (LIV.)

Fig. *1a.* Ventral view of the same. *aa* × 2.

Fig. *2.* Dorsal view of a Clemmys embryo 4 ½ days old, with 2–3 mesoblastic somites. *aa* × 2. (XXXXIX.)

Fig. *2a.* Ventral view of the same.

Fig. *3.* Dorsal view of a Clemmys embryo 4 days old, with 6–7 mesoblastic somites. Extra-embryonic cœlomic cavities of two sides distinctly seen almost touching each other over the median dorsal line of the embryo. *aa* × 2. (LV.)

Fig. *3a.* Ventral view of the same. *aa* × 2.

Fig. *4.* Dorsal view of a Clemmys embryo 7 days old. *aa* × 2. (XXXXI.)

Fig. *5.* ,, ,, ,, 8 ,, ,, *aa* × 2. (XXXXIII.)

Fig. *6.* ,, ,, ,, 9 ,, ,, *aa* × 2. (XXXIX.)

Fig. *7.* ,, ,, ,, 4 ½ ,, ,, *aa* × 2. (LIII.)

Plate. II.

Fig. *8.* Clemmys embryo slightly older than Fig. 7. Enlarged. (L.)

Fig. *9.* Clemmys embryo 13 days old. *aa* × 2. (XXVIII.)

Fig. 10. Posterior tube of the Amnion highly convoluted, from a Clemmys embryo 14 days old. *aa* × 2. (LVIII.)

Fig. 11. Dorsal view of a Clemmys embryo, 10 days old, $6\frac{1}{2}$ mm. long. Enlarged about 17 times. (LVII.)

Fig. 11a. Ventral View of another embryo from the same deposit. Enlarged about 17 times.

Fig. 12. Semi-diagramatic view of the posterior constriction of the Allantois in a Clemmys embryo 31 days old, seen from outside the serous envelope. *ca* × 7. (LVI.)

Fig. 13. Two Clemmys embryos 18 days old. Slightly enlarged. (XXXXV.)

Fig. 14. Dorsal view of a Clemmys embryo whose amnion is open toward the left. (XXXVIII.)

Fig. 15. Posterior tube of the Amnion disappearing. From a Clemmys embryo 13 days old, 8 mm. long.

Plate. III.

Fig. 16. Dorsal view of a Trionyx embryo $3\frac{1}{2}$ days old. *aa* × 2. (126.)

Fig. 17. Dorsal view of a Trionyx embryo $5\frac{1}{2}$ days old, 3 mm. long, with 5–6 mesobl. somites. *aa* × 2. (128.)

Fig. 17a. Ventral view of the same.

Fig. 18. Dorsal view of a Trionyx embryo $7\frac{1}{2}$ days old, $3\frac{1}{2}$ mm. long, with 7–8 mesoblastic somites. *aa* × 2. (141.)

Fig. 19. Dorsal view of a Trionyx embryo $8\frac{1}{2}$ days old, 4 mm. long. *aa* × 2. (142.)

Fig. 19a. Ventral view of the same. *aa* × 2.

Fig. 20. Ventral view of the posterior part of a Trionyx embryo

8 days old, showing the beginning of the Allantois. *AA* × 2. (112.)

Fig. 21. Posterior tube of the Amnion in four Trionyx embryos 13 days old. Slightly enlarged. (162.)

Fig. 22. Posterior tube of the Amnion in two Trionyx embryos 16 days old. *aa* × 2. (167.)

Plate. IV.

Fig. 23. Dorsal view of a Trionyx embryo $10\frac{1}{2}$ days old. *aa* × 2. (157.)

Fig. 24. Dorsal view of a Trionyx embryo $11\frac{1}{2}$ days old, $5\frac{1}{2}$ mm. long. Posterior Tube 2 + mm. long. (161.)

Fig. 25. Trionyx embryo 38 days old, seen from the side of the yolk-sac which has however been removed. (175.)

Fig. 26. Trionyx embryo 53 days old. The yolk-sac removed and the embryo seen from the ventral or yolk-sac side. × 3. (179.)

Fig. 27. Trionyx embryo $10\frac{1}{2}$ days old. (176.)

Fig. 28. Same embryo seen from its dorsal aspect, with the serous envelope lifted up, showing the sero-amniotic connection and the remnant of the posterior tube of the Amnion.

Fig. 29. Cells of the serous envelope in the region of the "placenta" in the Clemmys embryo represented in Figs. 71 and 71*a*. *DD* × 4.

Plate. V.

Fig. 30–33. (5–8). Selected transverse sections from the Clemmys embryo represented in Figs. 2 and 2*a*. *CC* × 1.

Fig. 30. From the region of the lateral limbs of the Amnion.

Fig. 31. From the region where the two lateral limbs have just united.

Fig. 32. From the region where the head is partly sunk below the level of the blastoderm.

Fig. 33. From the region of the head which is wholly sunk below the level of the blastoderm.

Fig. 30a. Region of the left amniotic limb in Fig. 30. under a higher power. *DD* × 4.

Fig. 31a. Left half of the amnion in Fig. 31. *DD* × 4.

Figs. 34–38. Selected transverse sections from the Clemmys embryo represented in Fig. 3 and 3*a*. *CC* × 1.

Fig. 34. From the region of the lateral limbs of the Amnion.

Figs. 35–36. From the dorsal region.

Fig. 37. From the region of the heart.

Fig. 38. From the region of the head.

Fig. 35a. Median dorsal part of the Amnion in Fig. 35. under a higher power. *DD* × 4.

Fig. 36a. Median dorsal part of the Amnion in Fig. 36. under a higher power. *DD* × 4.

Fig. 36b. The same region a few sections in front of Fig. 36. *DD* × 4.

Fig. 37a. Median dorsal part of the Amnion in Fig. 37. under a higher power. *DD* × 4.

Fig. 39. Transverse section of the posterior tube of the Amnion from the embryo given in Fig. 5. near its proximal end. *CC* × 1.

Fig. 40. Do. from about its middle. *CC* × 1.

Fig. 41. Longitudinal Section, slightly out of the median line, of a Clemmys embryo from the same stage as that represented in Fig. 3. *BB* × 2.

Fig. 41a. Diagrammatic longitudinal section of a Clemmys embryo somewhat older than that given in Fig. 41.

Plate. VI.

Figs. 42–47. Selected transverse sections from a Clemmys embryo 6 days old with 20 mesoblastic somites. *CC* × 1. (XXXII.)

Figs. 44a. Median dorsal part of the Amnion in Fig. 44. under a higher power. *DD* × 4.

Figs. 48–49. Selected transverse sections from a Clemmys embryo 9 days old. *CC* × 1.

Fig. 48. From the tail-region.

Fig. 49. From the dorsal region.

Fig. 48a. Median dorsal part of the Amnion in Fig. 48. under a higher power. *DD* × 4.

Fig. 49a. Median dorsal part of the Amnion in Fig. 49. under a higher power. *DD* × 4.

Figs. 50–52. Selected transverse sections from the embryo represented in Fig. 17. *CC* × 1.

Fig. 50. From the region of the lateral limbs of the Amnion.

Fig. 51. From the dorsal region of the Amnion.

Fig. 52. From the region when the head is sunk almost entirely below the level of the blastodem.

Figs. 53–55. Selected transverse sections from the posterior tube of the Amnion in the embryo represented in Fig. 24. Only the epiblast and somatopleuric mesoblast are represented, the hypoblast and splanchnopleuric mesoblast being omitted. *DD* × 4.

Fig. 53. Near the posterior opening of the tube.

Figs. 54–55. At various distances in front of Fig. 53.

Fig. 56. Median dorsal part of the Amnion in a section from the middle dorsal region of the Trionyx embryo represented in Fig. 24. *DD* × 4.

Fig. 57. Median dorsal part of the Amnion in a section from the dorsal region of Trionyx embryo represented in Fig. 19. *DD* × 4.

Plate. VII.

Fig. 58. Longitudinal section of an embryo from the same stage as that represented in Fig. 1. *DD* × 2.

Fig. 59. Transverse section of the embryo represented in Fig. 1. *DD* × 2.

Fig. 60. Longitudinal section of the Trionyx embryo shown in Fig. 20. *CC* × 2.

Fig. 61. Longitudinal section of a Trionyx embryo 10½ days old. *CC* × 2. (157.)

Fig. 62. Longitudinal section of a Trionyx embryo 9 days old. *CC* × 2. (115.)

Fig. 63. Longitudinal section of a Trionyx embryo 11½ days old. *CC* × 2. (116.)

Fig. 64. Longitudinal section of a Clemmys embryo 4 days old with 16 mesoblastic somites. *BB* × 2. (XXX.)

Fig. 65. Longitudinal section of a Clemmys embryo 6 days old with about 20 mesoblastic somites. *BB* × 2. (XXXII.)

Fig. 66. Longitudinal section of a Clemmys embryo 9 days old. *BB* × 2. (XXIX.)

Plate. VIII.

Fig. 67. Surface view of a Clemmys embryo 28 days old. Seen from outside the serous envelope. × 4½. (LXXI.)

The upper transparent membrane is the *serous envelope*. The lower opaque membrane with blood-vessels is the *yolk-membrane*. Between these two membranes are placed the *embryo*, *the allantois* &c. Different divisions of the allantois are sufficiently explained in the text. The white line close to and parallel with the median dorsal line of the embryo is *the sero-amniotic connection*: traced posteriosly, it bends sharply to the left, this short limb being the *remnant* or *proximal part* of the posterior tube of the amnion. Over the posterior part of the embryo, is a delicate, irregularly curved white tube: this is the distal part of the posterior tube of the amnion with its horse-shoe shaped posterior opening. It has no connection with the *proximal part*.

Fig. 68. Dorsal view of a Clemmys egg, with the embryo, the fœtal membranes, and the yolk-sac. About 40 days old. × 2. (LXXII.)

Fig. 69. Side view of a Clemmys egg with the embryo, the fœtal membranes, and the yolk-sac. 51 days old. Nat. size. (LXXIII.)

Fig. 70. Ventral view of a Clemmys egg with the embryo, the fœtal membranes and the yolk-sac. 55 days old. Blood-vessels on the yolk-sac omitted. Nat. size. (LXXV.)

Fig. 71. Dorsal view of a Clemmys embryo, shortly before hatching with the fœtal membranes. 45 days old. (LXIV.)

Fig. 71a. Ventral view of the same.

A low lobate process of the membranes situated close to the left of the tri-radiate allantoic seams penetrates into the mass of the white.

Fig. 72. Surface view of a Trionyx embryo $15\frac{1}{2}$ days old. $\times 5\frac{1}{2}$. (177.)

This corresponds to Fig. 67. of Clemmys, and the explanation of the latter is applicable to this. The white line stretching from the neck of the embryo to its posterior end is the *sero-amniotic connection.* Its slight posterior expansion marks the *remnant of the posterior tube of the amnion.*

Fig. 73. Embryo represented in Fig. 26. with the yolk-sac and the fœtal membranes. Blood-vessels on the yolk-sac omitted. Slightly enlarged. (179.)

Fig. 74. Ventral view of a Trionyx embryo 42 days old with the yolk-sac and the fœtal membranes. Slightly enlarged. (181.)

Plate. IX.

Fig. 75. Blood-vessels that pass through the umbilicus.

Fig. 76. Part of a transverse section through the sero-amniotic connection of a Clemmys embryo 13 days old. *DD* × 4. (LIX.)

Fig. 77. Diagram of the region of the posterior tube of the Amnion.

Figs. 78–80. Selected transverse sections through the posterior part of the sero-amniotic connection and the remnant of the posterior tube of the Amnion in the Clemmys embryo represented in Fig. 71. *CC* × 2.

Fig. 78. Through the line 1–1 in Fig. 77.

Fig. 79. " " " 2–2 in Fig. 77.

Fig. 80. " " " 3–3 in Fig. 77.

Fig. 81. Region on the non-embryonic pole of the yolk-sac where the allantoic lobes meet. From a Trionyx embryo similar to Fig. 74. Seen from outside the serous envelope. × 3. (182.)

Fig. 81a. The same region seen from inside.

Figs. 82–85. Selected sagittal sections through the region represented in Figs. 81 and 81*a*. *aa* × 2.

Fig. 82. is to the extreme left of Fig. 81*a*. and the sections gradually proceed toward the right.

Fig. 84a. Region of the sero-amniotic connection in Fig. 84. more highly magnified. *DD* × 2.

Plate. X.

Fig. 85. Transverse section from the head-region of the Clemmys embryo represented in Fig. 11. *aa* × 2.

Fig. 86. Similar section from the head-region of a Clemmys embryo 13 days old. *aa* × 2. (LIX.)

Fig. 87. Longitudinal section of a Trionyx embryo 16 days old (the same embryo as that given in Fig. 22). *CC* × 1. (167.)

Fig. 87a. Transverse section through the allantoic vesicle of an embryo of the same stage. *CC* × 1.

Diags. I–VII. Give a summary of the development of the fœtal membranes in Chelonia.

Diags. I–V. Applicable to both Clemmys and Trionyx.

Diag. I. Corresponds to Fig. 1. (Pl. I.) and to Fig.

58 (Pl. VII.). The head-fold of the embryo is sunk below the level of the blastoderm and enveloping it is the proamnion as yet only slightly developed.

Diag. II and II'. Correspond to Fig. 2 (Pl. I.). The amniotic hood proceeding backward has covered the anterior half of the embryo. Its cephalic portion consists of the hypoblast and epiblast; its dorsal portion of the epiblast alone. II' represents a cross-section of the dorsal region. It shows clearly that the mesoblast has as yet no share whatever in any part of the amnion (or more properly proamnion).

Diag. III and III'. Correspond to Fig. 3. (Pl. I.). The amniotic hood has extended nearly to the posterior end of the embryo. The extra-embryonic cœlomic cavities of two sides are united across in the head-region. The mesoblastic folds have also insinuated themselves into the hitherto solid epiblastic dorsal part of the amnion (III'.) A partition—*the sero-amniotic connection*—in the median line, however keeps the cœlomic cavities of two sides separate in the dorsal region.

Diag. IV and IV'. Represent the stage when the posterior tube of the amnion is fully developed. The sero-amniotic connection in a cross-section (IV'.) is now closely invested on each side by the mesoblastic fold, and is longer than in III'. The mesoblastic fold is peeling the hypoblast off the proamnion covering the head. (IV.).

Diag. V. All but a small proximal part of the posterior tube has now disappeared. The sero-amniotic connection is more developed. The mesoblastic fold has now entirely peeled the hypoblast off the proamnion, and the head is now enclosed in the amniotic cap consisting of the *epiblast* and *mesoblast*. Although these diagrams (III, IV and V) show the encroachment of the mesoblast on the proamnion as taking place from before backward, it in reality takes place mostly from two sides. In Diags. IV and V, the gradual development of the allantois is shown.

Diag. VI. Shows the fœtal membranes of Clemmys as completed.

Diag. VII. Shows the fœtal membranes of Trionyx as completed.

Fig. 1

Fig 1 a

Fig 2

Fig. 2 a

Fig 7

Fig 3 a.

Fig 3.

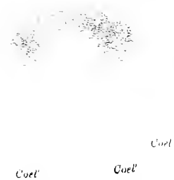

Fig 4.

Fig 5

Fig. 6.

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K. Nagahara & K. Matsumura del.

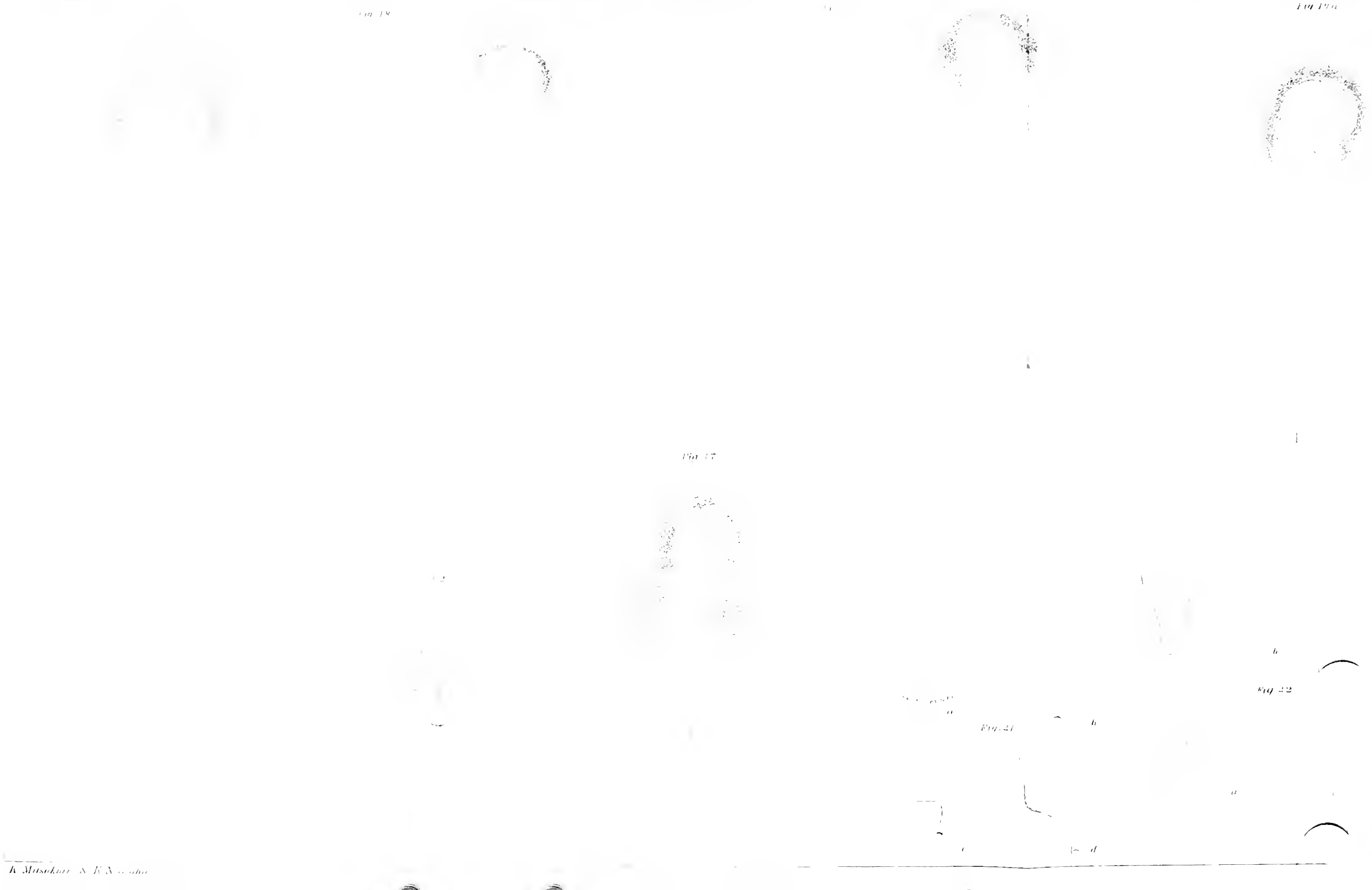
Fig. 17
Fig. 21
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Fig. 23.

Fig. 24.

Fig. 25.

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Fig. 27.

Fig. 29.

Fig. 28.

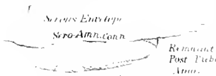



Fig 52
Fig 46
Fig 47
Fig 57
Sero-Amniotic Connection
Amniotic Cavity
Fig 44 a
Serous Envelope
Coel
Sero Amniotic Connection
Amniotic Cavity
Fig 49 a
Serous Envelope
Sero Amniotic Connection
Coel
Amniotic Cavity
Fig 56
Serous Envelope
Fig 53
Post tube Amn
Serous Envelope
Coel
Fig 55
Sero Amn Conn
Fig 54
Post Tube Amn

K. Mitsukuri del.

Fig. 67

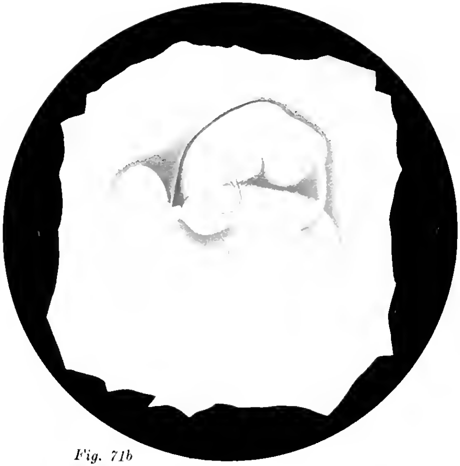


Fig. 72.

Fig. 71b

Fig. 70

Fig. 69

Fig. 73

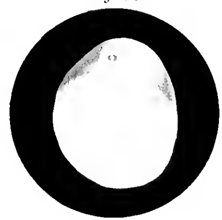


Fig. 71a

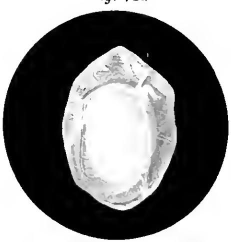
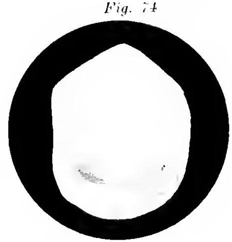


Fig. 68

Fig. 74



K. Nagahara del

Erratum.

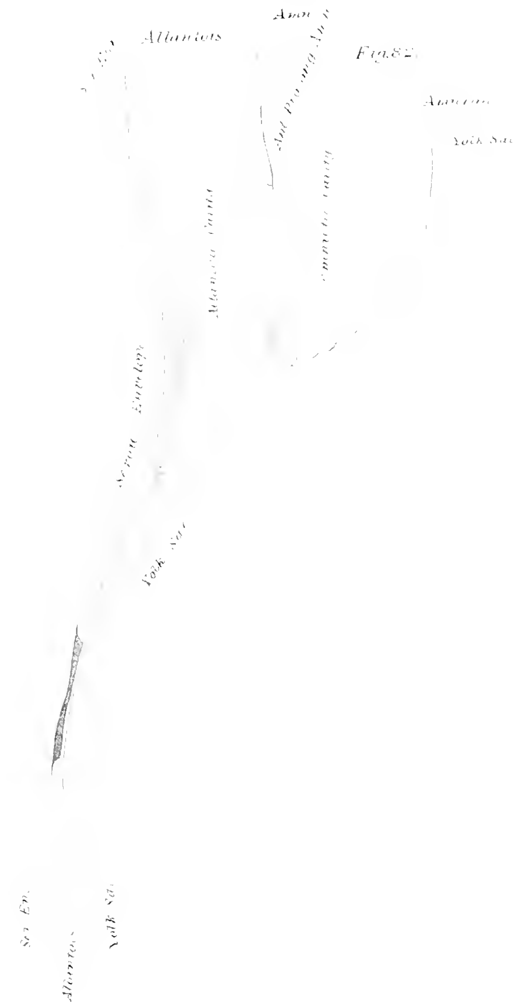
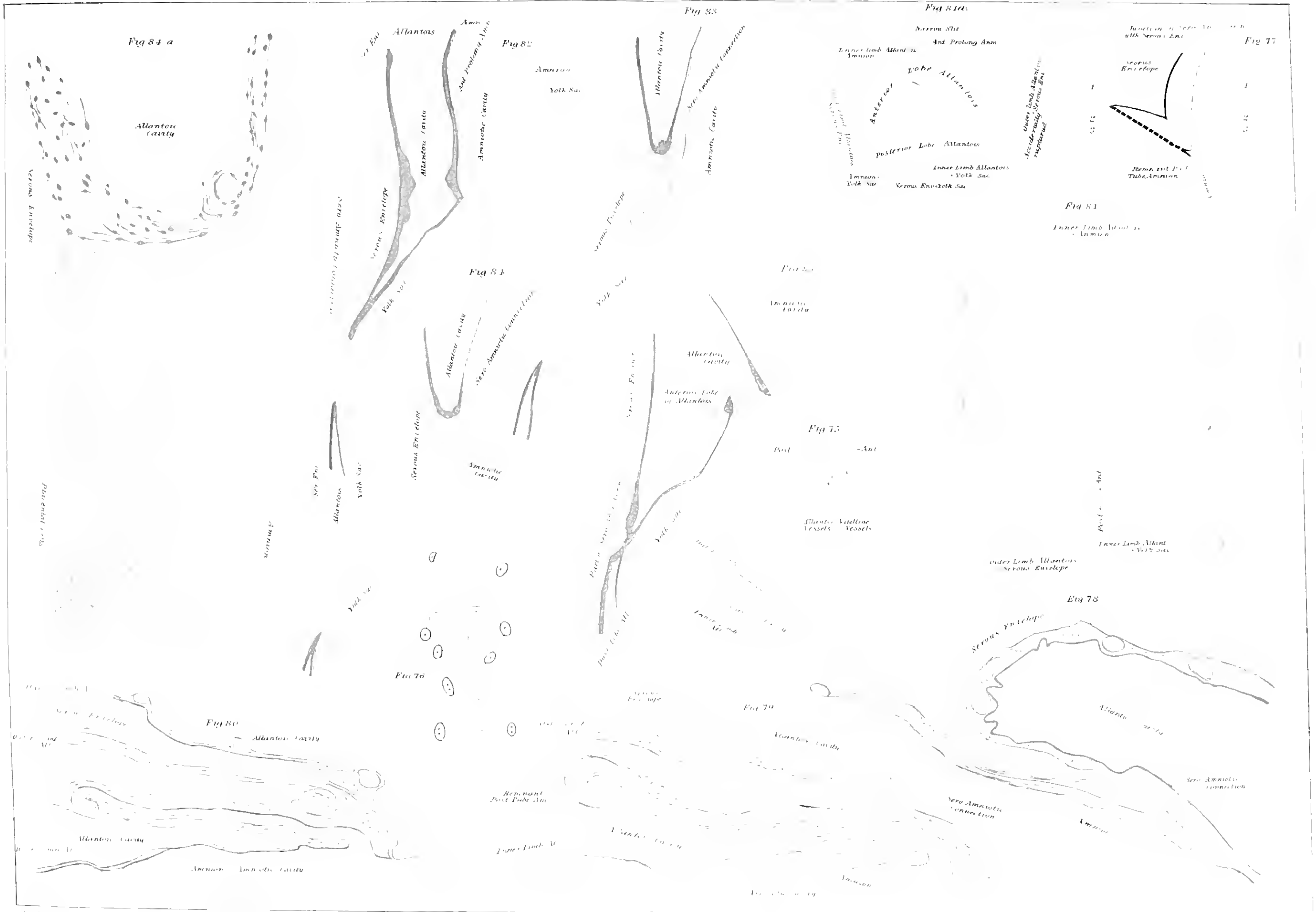


Fig.82.



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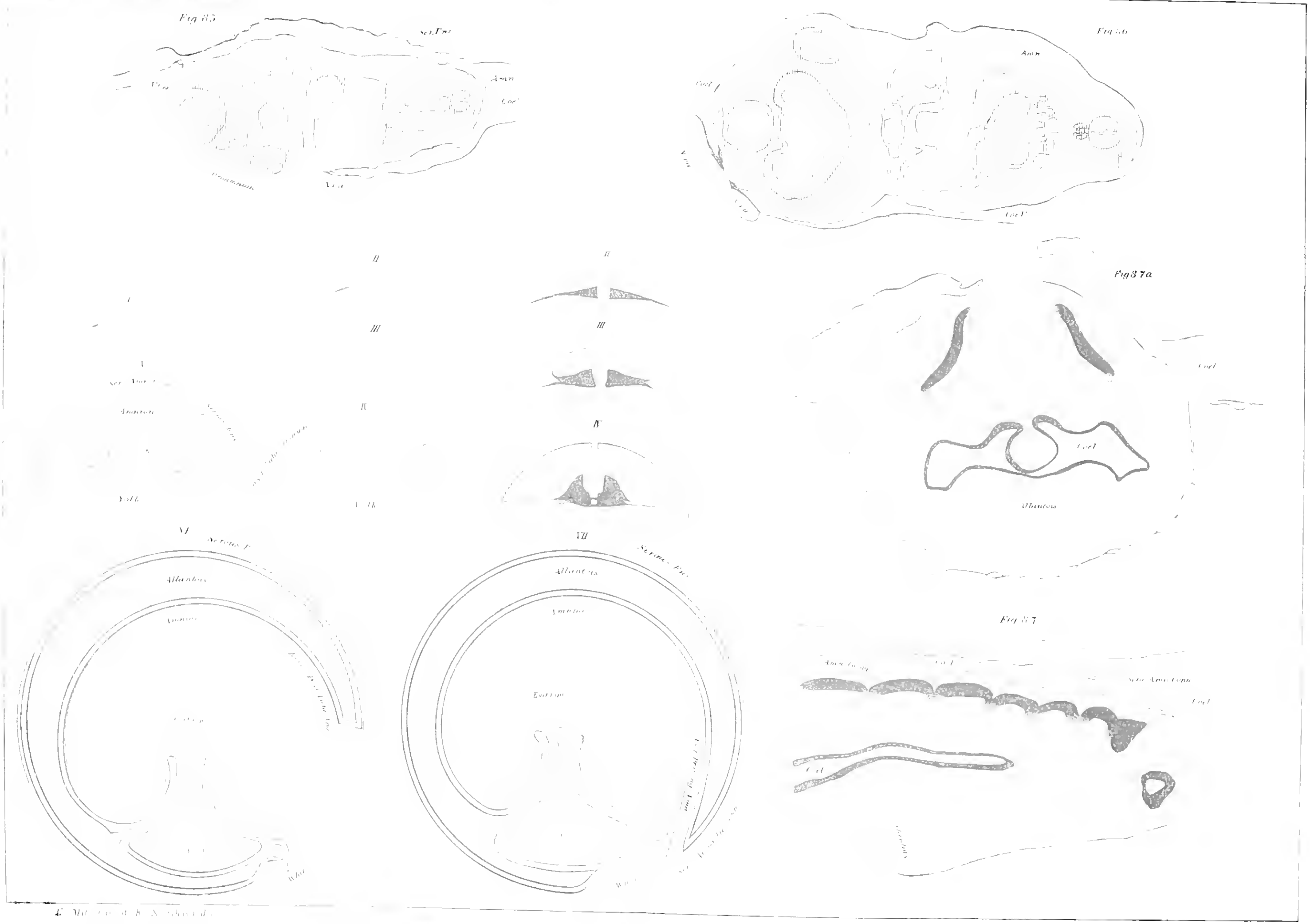
Fig 87a
Coel
Allantois
Amnion
II
III
IV
VI
VII

On the Development of Araneina.

by

Kamakichi Kishinouye, *Rigakushi.*

Science College, Imperial University.

With Plates XI—XVI.

The following observations on the development of Araneina were made in the Zoological Laboratory of the Imperial University during the academic session of 1888–9. Some of the results I have arrived at seem to be not without interest. Before going further I wish to express my thanks to my teachers, Dr. K. Mitsukuri and Dr. I. Ijima for their kind and valuable advice during my work.

The materials used for the investigation were all collected by myself during the summer of 1888 in the grounds of the university. The genera that have been most carefully studied are Lycosa and Agalena, while Theridion, Epeira, Dolomedes, Pholcus were more or less examined for comparison. A species of Lycosa which is very abundant among grasses breeds constantly from the end of March to the latter part of September, and carries about the cocoon so that we are able to obtain its eggs in various later stages with great ease. It, however, failed to breed in captivity, and for this reason, in the study of earliest stages recourse was had to the eggs of a species of Agalena which breeds very freely in captivity. The statements made in the following pages refer to all the species examined unless otherwise specified.

A few words about the methods of investigation may be of use. Eggs of later stages were killed by heating in water to 70–80°C., while segmenting eggs were plunged directly in hot water. Heating was stopped when the eggs became somewhat opaque and white. They were then allowed to cool and transferred to 70% alcohol. After 24 hours, they were examined one by one under a dissecting microscope and those with unburst egg-membranes were perforated with the point of a needle to facilitate the penetration of reagents. They were then hardened in ascending grades of alcohol. I have always found this method to be excellent for all spider eggs.

Staining was done with alcoholic cochineal, picrocarmine, alcoholic carmine, or hæmatoxylin. Alcoholic cochineal and picro-carmine have given best results. It is a remarkable fact that paraffin penetrates into eggs stained with picro-carmine more easily than into those stained with any other reagent. Alcoholic cochineal proved to be especially good for staining sections on the object glass. Imbedding for section-cutting was done in paraffin.

Composition of the Freshly Laid Egg.

The egg has two investing membranes, the inner of which is the vitelline membrane, and the outer the chorion. The external surface of the latter is covered with a crust of minute spherical granules, insoluble in alcohol. In a species of Epeira, these granules are comparatively large and closely encrust the surface of the eggs, in some places in two or three layers, making the examination of the inside almost impossible. They were easily removed by gentle rubbing with the fingers. In species of other genera examined, the granules were tolerably crowded in one layer, but being smaller than those of Epeira did not seriously obstruct the view of the inside.

The composition of a freshly laid egg has been tolerably accurately described by previous writers, their opinions differing only in some points of details. It may be conceived of as a scanty network of protoplasm in the wide meshes of which yolk granules are imbedded. There is always more or less concentration of protoplasm toward the centre which may be called the *centroplasm*. An extremely thin layer of protoplasm is found on the external surface of the egg, directly inside the vitelline membrane and may be distinguished as the *periplasm*. The centroplasm and periplasm are no doubt connected with each other by a scanty protoplasmic network, although not always apparent in sections. The space between the centroplasm and periplasm is almost entirely taken up by large yolk granules which are arranged in characteristic radiate columns. In each column the yolk granules are in several rows, one placed outside another, and in each row there are generally two granules abreast. The granules near the centroplasm are much smaller than those placed more to the outside. In a freshly laid egg I was unable to detect the germinal vesicle in any part. The first segmentation nucleus appears in the centroplasm a few hours later. In Lycosa, the so-called yolk-nucleus of the usual appearance was distinctly seen in the centroplasm. In Agalena, I could not find it.

The periplasm when seen from the surface presents the appearance of being divided into irregular polygonal areas (Pl. XI, fig. 1). The cause of this appearance has been a point of dispute, Ludwig* even maintaining that there is no such. That the periplasm is marked out into irregular polygonal areas, there can be no doubt. I agree with Locy** in assigning the cause of this marking to a pressure which is exerted on the periplasm and presses it against

* Ludwig—Ueber die Bildung des Blastodermes bei den Spinnen, Zeit. für wiss. Zool. XXVI.

** Locy—Observations on the Development of Agelena naevia, Bull. Mus. Comp. Zool. XII.

the peripheral end of the underlying yolk columns, thus causing the former to receive the impression of the latter. The fact that in freshly laid eggs the polygonal areas correspond with the underlying groups of yolk granules favours this view. I must, however, differ from Locy as to the cause of this pressure brought to bear on the periplasm. Locy ascribes it to the contraction of the egg. This can hardly be, for I could find in no case any trace of contraction, the eggs being always very closely covered by the two membranes. I think it much more probable that the polygonal markings are the effect of the pressure to which the eggs are subjected as they pass through the narrow oviduct. Locy states moreover that at an early stage a number of faintly marked areas made their appearance at the animal pole, while they could not be detected upon the opposite hemisphere. I can not corroborate this statement, for I found the polygonal marking covering the whole surface of the eggs from the earliest period after being laid. It should be stated that after a while when segmentation begins, the yolk granules more or less shift their places ; hence we no longer find the coincidence of polygonal areas with groups of yolk granules. The polygonal areas do not seem to change their positions nor do they vary in number after they are once formed.

From the Segmentation of the Ovum to the Formation of the Germinal Layers.

According to Ludwig*, who gives a detailed description of the segmentation of the ovum in Philodromus, the nucleus and the yolk divide simultaneously first into two, then into four, eight, sixteen, and so on. Morin** who studied Theridion, Pholcus, Drassus and

* Ludwig—loc. cit.

** Morin—Zur Entwicklungsgeschichte der Spinnen, Biolog. Centralbl. VI.

Lycosa, states that there is no division of the yolk before there are formed eight nuclei. In the species studied by myself, the yolk columns are grouped into as many masses (yolk-pyramids or rosettes) as there are nuclei, from the time when there are only two of the latter.

In Pl. XII, fig. 8, I have represented a section of an egg in which there are two nuclei. It will be seen that the yolk is already evidently divided into two masses or segments. In the lower segment, the nucleus is distinctly seen. In the upper, the nucleus does not happen to be in the section, but there is seen the yolk-nucleus (*y. n*). The latter does not divide and was often found even in eggs of the 4 cell stage, always by the side of one of the segmentation nuclei. The segmentation cavity (*seg. cav*) is already present. The yolk granules immediately adjoining the perinuclear protoplasm are split up into small particles at whose expense the protoplasm evidently seems to increase in bulk (Pl. XII, figs. 8. 9. 10). This process of assimilation is no doubt continued during the whole process of segmentation.

From this stage on, as the nuclei divide, the yolk masses also divide, assuming characteristic rosette or pyramidal shape (Pl. XI, fig. 2). Strictly speaking, the segmentation is not total but syncytial, as the periplasm remains undivided. Nor is it entirely regular, as stages with 3, 11, 22, 34, 85 &c. nuclei were found. Nevertheless the nuclei, after repeated division, are distributed fairly uniformly in the egg.

As the process of segmentation goes on, the segmentation cavity which was already present in the 2-cell stage gradually enlarges so that in stages represented in figs. 9 and 10 the centre of the egg is occupied by a large cavity.

Side by side with their increase by division the nuclei together with their surrounding protoplasm gradually travel toward the periphery of the egg through the yolk pyramids (Pl. XII, figs. 8, 9, 10). When about 30 in number, they all reach the surface. When they are almost at the surface, the continuity of the perinuclear protoplasm with the periplasm by means of pseudopodia-like processes can be demonstrated on surface views. Figs. 3, 4, Pl. XI. are two figures giving such views in which the radially arranged processes of the perinuclear protoplasm (represented in the figures as dark lines) become lost in the periplasm whose polygonal markings are still visible. Soon after such a stage the perinuclear protoplasm and the periplasm are entirely mixed together forming a nucleated layer at the surface. So far as my observations go, the nuclei emerge simultaneously all over the surface of the egg—not, as Locy states, earlier at the animal pole than at the opposite pole. When there are formed about a hundred nuclei, this nucleated layer separates itself from the underlying yolk, and then by the continual division of the nuclei the one-cell layered blastoderm is established (Pl. XIII, fig. 15). Coincidently the polygonal markings disappear and the egg recedes from the investing membranes. Probably this is due to the swelling of the membranes and not to the contraction of the egg.

Whether the yolk still contains nuclei or is entirely free from nuclei when the blastoderm is established has been a matter of dispute. In my own sections, I could not at this stage detect any nucleus at all in the yolk, thus confirming the views of Morin in opposition to Balfour's.* Yolk granules are, however, still aggregated into masses.

The change that comes next is of great importance. The cells of the blastoderm when it is at first established are of uniform spherical shape throughout its extent. While these cells gradually assume a

* Balfour—Notes on the Development of the Araneina, Quart. Journ. Micr. Sci. XX.

flattened shape over the greatest part of the blastoderm, there is one spot where the nuclei become conspicuously spherical and multiply rapidly. The spot may be distinguished by reflected light as a round whitish area (Pl. XI, fig. 5, *prim. th*). It is often a little depressed at first; but it soon becomes flat and eventually a little elevated. Sections through this spot show a large accumulation of blastodermic cells about seven cells deep (Pl. XII, fig. 11). I shall call this thickening the *primary* thickening.

Shortly after this another thickening appears, close to the primary thickening, on the future median line (Pl. XI, fig. 6, Pl. XII, fig. 12, *sec. th*). This is also slightly elevated above the general surface of the blastoderm (Pl. XII, fig. 13). I shall call it the *secondary* thickening. The primary thickening now gradually extends itself in all directions and forms a whitish disc-like area of the blastoderm, the centre of which is thicker than the periphery (Pl. XI, fig. 7). This white area is the first trace of the ventral plate. The primary thickening as it spreads out surrounds and pushes away the secondary thickening, so that the latter now lies at the margin of the white area but is further from the centre of the primary thickening than before (Pl. XI, fig. 7).

There has been much confusion in regard to the nomenclature of these two thickenings of the blastoderm. The secondary thickening corresponds to the primitive cumulus as described by Claparède.* This appears at least very probable when we compare my fig. 7, Pl. XI, with figs. 3 and 4, Planche I, of this author. Balfour was of the opinion that the primitive cumulus becomes lost in the caudal thickening. What is called the primitive cumulus by Locy is undoubtedly the primary thickening above described, while his "caudal thickening" is the secondary thickening. Morin admitted

* Claparède—Recherches sur l'Évolution des Araignées, Naturk. Verhandel. I.

the existence of a blastodermic thickening giving rise to germinal layers, but denied the identity of it with the primitive cumulus. He says that the primitive cumulus is formed after the formation of the germinal layers and is composed of mesoderm cells. My observations on Lycosa show that the secondary thickening, or the primitive cumulus of Claparède, is formed after the formation of the primary thickening and that both are formed before the distinction of germinal layers is possible. Both are accumulations of indifferent cells, not yet referable to any germinal layer (Pl. XII, figs. 11–14). I can not tell whether the position of the secondary thickening corresponds to the anterior or to the posterior of the future ventral plate. This much is certain, that it entirely disappears at the time when the germinal layers are established.

These two thickenings, the primary and secondary, are of a great significance, as the germinal layers are established from them, the primary thickening contributing the largest part in their formation. In a longitudinal section, these two thickenings are as in figs. 12 and 14, while in a cross section they appear as in fig. 11. From these figures it is evident that they together form along the median ventral line of the future embryo a ridge-like thickening which sticks out into the cavity of the yolk. Cells from the top of this ridge (the lowest part of the ridge in the figures) proliferate into the yolk and become scattered without any definite arrangement through the entire yolk. These are the endoderm cells. They become large by taking nourishment from the yolk as they pass through it. The cell-layer of the ridge nearest the external face of the egg becomes established as the definite ectoderm. The cells of the ridge which are left close under the ectoderm form the mesoderm (Pl. XIII, fig. 17). They soon spread horizontally below the ectoderm. The mesoderm is at first in a single median mass on the ventral face and does not extend to the dorsum of the embryo which is composed of the ectoderm only.

As to the nature of these two thickenings, the primary and secondary, it is difficult to state anything definite. The stage in which the one-cell layered blastoderm is established on the surface of the egg is to be looked upon as the blastosphere stage. When the ridge appears in this blastosphere along the line which becomes the median ventral line of the future embryo and sends off cells into the yolk cavity, the whole process must be regarded as a modified form of invagination and the ridge is to be looked upon as the blastopore. Why there should arise two thickenings instead of one remains inexplicable to me. The primary thickening is without doubt the remnant of the blastopore. Whether the secondary is to be looked upon as a part of the same, I cannot decide.

From the Formation of the Germinal Layers to the Reversion of the Embryo.

After the establishment of the ventral plate, its anterior part becomes marked off as the cephalic, and its posterior part as the caudal lobe, and the middle region between the two lobes is divided by transverse ridges into segments. The least number of segments observed between the cephalic and caudal lobes was five. The foremost of these corresponds to the segment which bears the pedipalpi and the four following are the thoracic segments, each of which subsequently produces a pair of ambulatory appendages. The segment which is to bear the chelicerae is soon after cut off from the cephalic lobe and the abdominal segments are gradually cut off from the caudal lobe, the process proceeding posteriorly, until there are formed eight abdominal segments (Lycosa).

In this process of segmenting the mesoderm of the ventral plate shares (Pl. XIII, fig. 16), and is divided into as many parts as there are segments in the body of the embryo. Moreover it divides itself into two longitudinal bands at the median line except at the cephalic and caudal lobes. Thus there is formed in each segment a pair of mesodermic plates. After a while, each of these paired mesodermic plates produces a cavity—the cœlom—apparently by its splitting into two layers (Pl. XIII, fig. 18). The outer of the two layers is the somatopleure, and the inner the splanchnopleure. The cœlom therefore consists at this time of a number of paired cavities (Pl. XIV, fig. 22), which are separated from one another. Cœlomic cavities in the cephalic and caudal lobes appear only later on.

Shortly after the formation of the cœlom, a pair of protuberances appear on each segment. They are the first traces of the appendages (Pl. XIV, fig. 23, *th. app*). The order of their appearance corresponds to the order of appearance of the segments to which they belong. The appendages are formed on segments of the cheliceræ and pedipalpi in all the thoracic and the second, third, fourth, and fifth abdominal segments (Pl. XIII, fig. 20, Pl. XIV, fig. 22). The cephalothoracic appendages are formed at the lateral ends of the segments, while the abdominal appendages are formed nearer the median line (Pl. XIII, fig. 20). The abdominal appendages are little round protuberances, and do not elongate as rapidly as other appendages. The first abdominal segment bears no appendages, as Schimkewitch* has correctly observed. This segment is gradually aborted, and is not distinctly visible at the time of the reversion of the embryo. The cœlomic cavities of each segment extend into the appendages.

The foundations of the nervous system are laid soon after the

* Schimkewitch—Étude sur le Dévelopment des Araignées, Arch. de Biolog. VI.

establishment of the ventral plate during this period. The ectoderm of the cephalic lobe is very much thickened as shewn in figs. 22 and 23. This process of thickening proceeds backwards as two longitudinal bands, one on each side of the body, along the inner side of the attachment of the appendages in the thoracic and abdominal segments, finally meeting each other in the caudal lobe. These two bands are the first rudiments of the ventral nerve chain. Thus it is continuous from the first with the cephalic thickening above mentioned which becomes the brain, as in the case of scorpions observed by Kowalevsky and Schulgin.* This is not in accordance with the view of some authors who maintain that the brain and the ventral nerve cords are formed independently of each other. The cells composing the ventral cords aggregate in each segment and give rise to the ganglia.

The cephalic thickening of the ectoderm is now divided into two semicircular lobes (Pl. XIII, figs. 20, 21). Near the front edge of these lobes, there is formed on each side a semicircular groove (*sem. gr.*). This paired groove which is cut off from the ectoderm is the chief origin of the brain. Bruce** compares it with the amniotic fold of insects; but the comparison is certainly not justifiable. Kowalevsky and Schulgin found that in Scorpions the ectodermic invagination comparable to the amniotic fold of insects is distinct from and formed earlier than the semicircular groove, which is no doubt homologous with the similar groove of the spider, as it also gives rise to the brain. Sections of the semicircular groove are represented in fig. 23, Pl. XIV.

Besides the semicircular grooves, there is a pair of small ectodermic invaginations in the posterior part of the head near the outer border (Pl. XIII, fig. 20, Pl. XIV, fig. 23, *lat. v*). So far as I

* Kowalevsky and Schulgin—Zur Entwicklungsgeschichte des Scorpions, Biolog, Centralbl. VI.

** Bruce—On Insects and Arachnids.

know these invaginations have been till now entirely overlooked. In fig. 19, Pl. XXI, of Balfour's work, I find one of these invaginations represented; but he gives no information about it. It is globular in form; henceforward I shall call it the *lateral vesicle*. The lateral vesicles, which are also gradually constricted off from the ectoderm, go to form a part of the brain (Pl. XV, figs. 44–46).

The stomodæum is formed as an ectodermic invagination at the anterior margin of the cephalic region (Pl. XIII, fig. 20, Pl. XIV, figs. 24, 25). At this stage it is easy to see that all the appendages are postoral in origin.

Late in this stage a number of large cells appear at the dorsal part of the embryo. They are never found in the ventral plate. They are very easily recognised by their large size and the peripherally situated nuclei, their central portion being filled with fat (Pl. XV, figs. 40, 41, *f. c*). Undoubtedly they are nourishing cells, wandering everywhere, and some of them are changed into blood corpuscles. They were called by Balfour the secondary mesoderm, by Schimkewitch the secondary endoderm, and by Locy the endoderm cells. These three authors ascribed the origin of these fat cells to the cells in the yolk, whereas according to Morin they are formed in Pholcus from dispersed mesoderm cells originally composing the so-called primitive cumulus,* and in Theridion which wants the cumulus probably from cells of the mesodermal somites. Schimkewitch, Locy, and Morin observed that these cells become blood corpuscles. For my own part, I am inclined to agree with Balfour, Schimkewitch, and Locy and to derive them from the endoderm. For in the first place, they are found immediately above the yolk, and in some cases between yolk granules presenting the appearance as

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* Morin states, what I have before referred to, that the primitive cumulus is formed after the formation of germinal layers, and consists of mesoderm cells.

if they have just emerged from the yolk. In the second place, their nuclei agree in their large size with those found in the yolk.

At the end of this stage the mesoderm in the caudal lobe is faintly divided into two layers, between which an unpaired cavity makes its appearance (Pl. XIV, fig. 24). In the cephalic lobe also the mesoderm is faintly divided into two layers on each side (Pl. XIV, fig. 23), enclosing the rudiments of the cœlomic cavities. It is still undivided in the median line. The cœlomic cavities in the thorax secondarily fuse together into a single cavity. They remain, however, quite distinct in the abdominal region.

The Period of the Reversion of the Embryo.

The stage in which the reversion of the embryo occurs is as difficult to study as it is important, since many organs arise at the same time. At the end of the last stage, the ventral plate had reached the maximum limit of dorsal flexure, the cephalic and the anal lobes almost touching each other (Pl. XIV, figs. 24, 25). As Balfour states, the reversion of the embryo is due to the expansion of the dorsum; and the expansion of the dorsum is due to the horizontal increase of cells which compose that part. The head and the tail are pushed away from one another further and further. As the dorsum is very rapidly expanding and the cells are pressed for room, a groove is produced immediately behind the tail lobe to increase the surface of the dorsum, and the tail lobe then stands out as a conical process (Pl. XIV, figs. 26–29). The cœlomic cavities belonging to the segment in front of the tail lobe being pressed from the dorsal side by the increase of cells in the dorsum are compressed horizontally and pushed into the conical tail process, enveloping the unpaired cœlomic cavity of that process from the dorsal side. The caudal lobe stands out gradually more and more prominent, until the stage represented in fig. 27 (surface view, fig. 21) is reached. After this, the tail process gradually shortens (figs. 28, 29) until after a while there is no tail projecting from the general body surface (fig. 32).

At about the same time with the increase of cells of the dorsum, the two nerve cords begin to diverge from each other. They are most widely separated from each other at the anterior part of the abdomen and gradually approach each other anteriorly and posteriorly until they meet in the cephalic and tail lobes (fig. 21). Their divergence together with the expansion of the dorsum makes the embryo assume the ventral flexure.

The cœlomic cavity of the caudal lobe now becomes gradually conspicuous. This unpaired cavity is transformed into the so-called stercoral pocket (Rectalblase, Kloake) of the adult spider. Hence the stercoral pocket does not arise from the swelling of the internal end of the proctodæum, as has been supposed by other authors. This organ is purely mesodermic in origin and nothing more than a remnant of cœlomic cavities. This may be understood by examining figs. 24–32, Pl. XIV. From these figures it will be seen that the proctodæum is formed in the caudal lobe later than the stercoral pocket.

The fact that any part of the adult alimentary canal should be derived from the cœlom seemed to me so remarkable that I have repeatedly examined my series of sections and am convinced of the correctness of the observation. I do not know how to interpret this fact unless it be that the stercoral pocket is a part of the primitive excretory system—a supposition which is strengthened by its peculiar relation to the remaining part of the digestive tube (Pl. XVI, fig. 55) and by the fact that the Malpighian tubes open into it.

At this period the mesodermic somites and the ganglia of the anal lobe and of the four appendage-bearing abdominal segments have attained their utmost development. The first abdominal segment and those between the fifth and the last abdominal segments are aborted.

The mesodermic somites which are produced at first in the ventral plate now grow on dorsalwards and meet at the dorsal median line (Pl. XV, figs. 40–43). They first meet at their dorsal part, enclosing some of the large fat cells and their derivatives between them. The ventral part fuses later. Thus the dorsal circulatory tube is formed, the wall of which is produced from the mesoderm, while the blood corpuscles are produced from large fat cells (endodermic in origin). I am inclined to believe that both the aorta and the so-called heart are formed as stated above and not separately as many authors believe. The fusion of the mesodermic somites to form the dorsal vessel does not take place throughout the entire length, as there are left paired lateral slits between each two consecutive somites. The blood aerated at the lung-book returns to the heart through these lateral slits. These slits shut and open as the heart beats. They are found in the abdomen only.

In the basal part of the first abdominal appendage of each side, there arises an ectodermic invagination whose opening faces away from the median line. It is neither deep nor spacious but is a little pocket-like invagination. This is the beginning of the lung-book. The development of this organ, briefly stated, is as follows: Of the wall of the invaginated pocket, that which faces the distal end of the appendage is much thicker than the opposite wall, filling the interior of the appendage. The cells composing it become after a while arranged in parallel rows (figs. 34 and 47). Each two of these parallel rows adhering together produce the lamellæ of the lung-book. The external epithelium of the appendage which cover these lamellæ becomes the operculum of the lung-book after it is depressed in height. Judging from figures (figs. LXXIX and LXXIX') given in "On Insects and Arachnids," Bruce seems to have mistaken the caudal prominence of the early period of this stage (see my figs. 24–28) as the operculum of the lung-book. According to him the abdominal appendage is invaginated to form the lung-book, but as we have seen, it is not so. Locy has correctly described the formation of the lung-book lamellæ. He says that the lungs arise from infoldings; but he is silent about the place where these infoldings arise.

In the basal part of the second abdominal appendage on the interior side, another ectodermic invagination is produced. It assumes the shape of a deeply invaginated tube and remains in this condition till after the time of hatching. The appendage itself is not invaginated and becomes from this time gradually shorter.

It is very probable that the lung-books were derived from the gills of some aquatic arthropodous animals such as Limulus; for the lung-books are nothing more than the lamellar branchiæ of Limulus sunk beneath the body surface. The tubular trachea may afterwards have been derived from the lung-books. The branchial lamellæ of Limulus are formed as outgrowths of the ectoderm at the lower (posterior) surface of abdominal appendages, and those of spiders are also produced really in the lower surface of the first abdominal appendage (in the dipneumonous spider). Hence I think that the spider with two pairs of lung-books is the most primitive one, and the one with one pair of lung-books and the other pair transformed into the tubular tracheæ is more primitive than the spider with only one pair of lung-books. I cannot agree with the view of some authors who maintain that the lung-book is derived from a cluster of tracheæ.

The third and fourth pairs of the abdominal appendage are modified into spinning mammillæ (Pl. XV, fig. 34). At the distal end of each of these appendages a solid proliferation (*sp. gl*) of ectodermic cells is formed. This becomes the spinning gland. Spiders have generally three pairs of spinning mammillæ; two of which are modified abdominal appendages, while the remaining one is added very late, after the hatching of the embryo. The primitive spider must have had only two pairs of spinning mammillæ. Some tetrapneumonous spiders have only two pairs.

The two semicircular halves of the cephalic lobe, between which there is at first a deep median notch (Pl. XIII, fig. 20), now fuse with each other at the median line above the stomodæum, so that the notch becomes much shallower (fig. 21). The grooves formed along their anterior margin during the preceding stage separate from the ectoderm beginning from their external end and sink down beneath the body surface. They are cut off from the ectoderm latest at the hindermost parts of their inner limbs (Pl. XVI, fig. 48). The lumina in the two separated semicircular grooves come to communicate with each other at the anterior median part (Pl. XV, fig. 45).

At the last point of separation there is left a shallow invagination or rather sac on the surface. The invagination is paired. The openings of these sacs are directed towards the mouth of the embryo, and the invaginations are directed anteriorly. They are the first traces of the *posterior* median eyes (see below) or the 'Hauptaugen' of Bertkau* (Pl. XV, figs. 44–46, 48, *P. M. E.*). The *anterior* wall of the sac is thicker than the posterior, the former being two to several cells deep, the latter only one cell deep. The formation of

* Bertkau—Beiträge zur Kenntniss der Sinnesorgane der Spinnen, Arch. f. Mik. Anat. XXVII.

the posterior median eyes in connection with the brain in spiders is quite analogous to the similar process in scorpions as observed by Kowalevsky and Schulgin. This interesting relation was not observed by Locy who studied the spider, or by Parker* who studied the scorpion.

Hitherto these eyes were called the anterior median eyes ; but morphologically speaking, this nomenclature is not correct. For all the eyes of spiders are formed in reality in the ventral plate, never in the dorsum, and gain their apparently dorsal position in later stages only by the bending upward of the ventral plate. Hence, in this last position the eyes that composed the posterior row in the ventral position come to occupy the anterior position, while those that formed the anterior row in the ventral position are thrust further backward by the curving upward of the ventral plate and thus become the apparent posterior row. Hence those I called the posterior median eyes are in the apparent anterior row of the adult.

The three remaining pairs of eyes are formed later than the posterior median pair and in a different manner. Their first traces are the local thickenings of the ectoderm of the cephalic region. Anterior lateral eyes (*A. L. E.*) appear above the lateral vesicle (Pl. XV, fig. 46).

At this time the lateral vesicles are completely cut off from the general ectoderm (Pl. XV, figs. 44, 46). Their walls are thick and their lumen is conspicuous. In development and position they very much resemble the eyes of Peripatus.

The cheliceræ are now two-segmented. They have shifted their position a little anteriorly and have approached toward the median line (Pl. XIII, fig. 21). Their ganglia are placed at the sides of the stomodæum and form the commissural part between the supra-

* Parker—The Eyes in Scorpions, Bull. Mus. Comp. Zool. XIII.

and infra-œsophageal ganglia. They are in contact with each other at the anterior part. The basal joint of the pedipalpi is very broad, the maxillary part being easily distinguished. The ganglia of the pedipalpi and of the succeeding four thoracic segments are well developed and are in close contact with each other, thus forming the large sub-œsophageal ganglion. The ganglia belonging to the abdominal segments are also well developed.

The stomodæum elongates itself obliquely upwards and is surrounded externally by the well developed upper and lower lips (Pl. XIII, figs. 19–21 ; Pl. XIV, figs. 24–26). The ectoderm forming the wall of the stomodæal invagination is thick.

The ectoderm of the ventral part of the anal lobe is conspicuously thicker than that of the dorsal part, being continuous with the two ventral bands. At the beginning of the reversion, it is uniformly two or three cells deep (Pl. XIV, fig. 27); but when the reversion is fairly advanced, so that the elongated anal lobe begins to become short again, the cells in the middle part of it are elongated and there they are only one cell deep (fig. 28). At this part an invagination takes place (fig. 29). From this stage the ectoderm of the ventrum of the anal lobe, placed anterior to the invagination becomes two or three times thicker than the posterior part, and is differentiated to form the anal ganglia (figs. 29–32, *G*). The invagination is the proctodæum. It is very shallow and small, and its bottom is in direct contact with the wall of the stercoral pocket. The wall of the proctodæum is thinner than that of the stomodæum. It is remarkable that the proctodæum is not formed at the extreme hind end of the ventral plate but somewhat in front of it directly behind the anal ganglia, and that both the stomodæum and the proctodæum are produced at the two extremities of the nervous system simultaneously with the development of the latter near them. The portion of the ventrum, posterior to the proctodæum, gradually thins off, and after the process of reversion is completed it can not be distinguished from the dorsum (Pl. XIV, figs. 31, 31).

The posterior part of the mesenteron is formed by an accumulation of endoderm cells at the anterior ventral part of the stercoral pocket. It is a wide open funnel-shaped tube, resting above the mesoderm (fig. 32, *Post. mesent*).

The stercoral pocket produces paired diverticula from its lateral sides (fig. 33). At first, I was inclined to think that these diverticula become the Malpighian tubes, as these tubes were formerly thought to arise as a pair of outgrowths from the stercoral pocket. But I found that these diverticula give rise to no definite structure in the adult, and that the Malpighian tubes arise in a different way, as will be explained further on.

At this stage a very important organ is produced, which has been almost entirely neglected by embryologists. I mean the *coxal gland*, which is formed from an ectodermic invagination at the internal posterior base of the coxal joint of the first ambulatory appendage (Pl. XV, fig. 38, *Co. gl*). The invagination opens into the cœlomic cavity (figs. 35, 36). Its development is traced further in the next stage.

After the formation of the circulatory system the cœlomic cavities atrophy, except the one of the anal lobe forming the stercoral pocket, and some part of the thoracic ones in connection with the coxal gland. The so-called body cavity of the adult is not the remnant of the cœlomic cavity; but it is a secondarily produced blood-space. The mesodermic cells which formed the wall of these cavities form the covering of the nervous system, the alimentary canal and other organs.

Some mesodermic cells at the base of the cephalothoracic appendages become rounded in outline (Pl. XV. figs. 35, 36). They are easily distinguished from the fat cells by their centrally located nuclei, and from other cells by their well-defined spherical form and slightly stainable protoplasm. They appear first in the chelicerae, then in the pedipalpi, and so on gradually backwards. These cells have no relation whatever with the coxal gland nor with the poison gland. Their function is unknown. It seems to me that Locy has mistaken these cells at the base of the chelicerae for the first rudiments of the poison gland. He says that these cells are probably derived from an infolding of the ectoderm.

From the End of the Reversion to the Hatching of the Embryo.

This stage is characterized by the appearance of a constriction separating the cephalothorax from the abdomen. The yolk in the ventral part of the abdomen is absorbed, so that the abdominal appendages of both sides approach each other at the median line.

The semicircular grooves of the cephalic lobes formed in the preceeding stage are no longer grooves, nor semicircular in form. Now they are completely constricted off from the general ectoderm, and are consequently tubes. Their inner limbs approach each other in the median line and they form as a whole a T-shaped body (Pl. XV, fig. 45). The lumina of the two tubes communicate with one another at the anterior median part. They as well as the lumen of the lateral vesicle begin to atrophy by the thickening of their walls and finally disappear. At the same time the transverse bar of the T-shaped mass becomes curved on each side to a peculiar shape shewn in profile in fig. 45a. This and the disappearance of the lumen change the brain into a compactly packed mass, instead of having its various parts standing apart as heretofore. The transverse bar (fig. 44, *a*) of the T-shaped brain is separated from the median stem just behind the point where the lumina of the two sides communicate with each other, while the median stem is in its turn transversely divided into two segments (Fig. 44, *b*, *c*). Thus the spider's brain consists of three segments, as Patten* claims. These three segments may be called the transverse dorsal (Fig. 44, *a*), the anterior vertical (Fig. 44, *b*), and the posterior ventral section (Fig. 44, *c*). The lateral vesicles are in the level of the third segment. From his description, Patten seems to mean that in scorpions and spiders the three segments of the brain are formed from three separate invaginations; but I cannot corroborate this statement. Moreover he says that the anterior median eyes (my posterior median eyes) belong to the second segment, while the three remaining pairs belong to the third segment. Supposing that his second segment is anterior to the third segment, I cannot corroborate this statement either, as according to my own observations all the eyes belong to the third segment. It seems to me impossible that the posterior eyes should arise in a segment anterior to that in which the anterior eyes are produced.

The opening of the sacs of the posterior median eyes becomes gradually smaller and is finally closed (Pl. XVI, fig. 49). The anterior wall of the sac becomes enormously thick and obliterates its lumen. The ectodermic cells which lie upon the sac elongate and form the vitreous body (figs. 49, 54, *vit*). The anterior wall of the sac forms the retinal part (fig. 49, *R*). The retinal cells elongate *anteriorly*. The anterior surface of the anterior wall of the posterior median eyes, is morphologically the inner side of the ectoderm though it faces externally. The lens is formed by a local thickening of the cuticula, which is secreted from the epithelium at this stage

* Patten—Segmental Sense-organs of Arthropods, Journ. of Morph. II.

(Pl. XVI, fig. 49, *L*). The nerve does not enter the posterior median eyes even a few days after the hatching of the embryo. Probably the nerve is sent out from the retina from the anterior (morphologically inner) surface of it, as this is the case in the adult. The development of the posterior median eyes is comparatively slow. They are homologous with the median eyes of scorpions, as the development is quite the same.

The three remaining pairs of the eyes or 'Nebenaugen' of Bertkau* are formed later than the posterior median eyes; but their development is completed earlier. They arise from ring-like depressions of the ectoderm (fig. 50). The walls surrounding these depressions grow over them and finally meet (fig. 51). The spot where the walls meet is one-cell layered. This spot gradually extends to a certain extent and forms the vitreous body which is characterized by elongated cells (figs. 51, 54, *vit*). The growth of the walls of the depressions is not uniform in every direction and therefore the point of closure may not correspond with the centre of depression. Thus the 'Nebenaugen' are also formed from ectodermic sacs; but these sacs are different from the sacs of the posterior median eyes. While it is the *anterior* wall of the sac that becomes the retina in the posterior median eyes, it is in the case of the 'Nebenaugen' the *posterior* wall of the sac, which, forming a central elevated portion thicker than the anterior wall and surrounded by a ring-like depression, gives rise to the retina (figs. 50–54, *R*). Also retinal cells elongate *posteriorly* instead of *anteriorly*, as in the posterior median eyes, and form nerve fibres (figs. 50, 51, *N*). These nerve fibres are subsequently connected with the fibrous portion of the brain. The retinal portion is cut off from the general ectoderm at about the time

* Bertkau, loc. cit.

of hatching, and at the same time becomes concave (fig. 54), instead of being convex as heretofore (fig. 51).

In the 'Nebenaugen'—but not in the posterior median eyes—there are formed transverse bars and a circumferential ring (figs. 51-54, *tap*) of chitinous nature, posterior to the retinal cells and secreted by these cells. These chitinous bodies (the tapetum) are transparent and lightly yellowish by transmitted light and silvery glittering by reflected light. The lens is formed in a similar manner as in the case of the posterior median eyes. The tapetum and the lens are equally secretion products of the ectoderm and both of them are chitinous in nature, but they are not homologous. The former is produced at the proximal end of the ectoderm cells, while the latter is formed at the distal end.

I know of only two authors who have studied the development of the spider's eyes by recent modes of investigation. They are Locy and Schimkewitch. The results obtained by these authors are not entirely satisfactory. Locy could not find the difference in the mode of development between the two different types of eye. He says that the 'Nebenaugen' originate in substantially the same way as the anterior median eyes (my posterior median eyes). Moreover he states that the development of the eyes begins by a local thickening of the hypodermis and a backward directed infolding which inverts the thickened region. Schimkewitch says only that the retinal part of the eyes originate from a pyriform enlargement from the brain, upon which the ectoderm invaginates in the form of a ring.

Patten recently gave a short account of the spider's eyes in an article entitled the "Segmental Sense-organ of Arthropods" in the Journal of Morphology, Vol. II.; but his account differs from mine in many points, as I have already mentioned. He says that there are segmental sense-organs, homologous with the eyes, at the base of the legs. Unfortunately I could not find any trace of such an organ, though I carefully searched after it.

The development of the pigment begins from the cephalic region backwards, after the differentiation of the vitreous body (fig. 51). In the case of the 'Nebenaugen' the pigment is first produced in those cells which form a kind of a cup around the retinal portion (figs. 51–53), and it seems to me most probable that these cells wander in to the retinal portion, first among the nerve fibres beneath the tapetum (fig. 53), then among those above the tapetum (fig. 54). In the case of the posterior median eyes, however, the pigment is produced from the beginning in retinal cells, below the vitreous body.

As we have already seen, all the eyes of the spider are formed in the ventral plate and near its anterior margin.

The concentration of the nervous system towards the cephalothorax goes on further in this stage than in the previous stage. In the thoracic region the two lateral ganglionic chains are united into one and form the subœsophageal ganglion. The inner portion of the ganglion becomes finely fibrous. The abdominal ganglia gradually atrophy and attach themselves to the posterior end of the subœsophageal ganglion. At this stage the whole nervous system is completely cut off from the ectoderm.

The stomodæum has developed very much. After elongating itself obliquely upwards, it takes the horizontal backward direction and reaches to about the segment of the fourth ambulatory appendage. It is lined with a cuticular covering which is continuous with the cuticula of the general body surface. In the pharynx, the cuticular lining is thick and transversely ridged. The ridges run parallel with each other and appear in the sagittal section like teeth, the pointed edge turning dorsalwards. The wall of the stomodæum is very thick. The stomodæum gives rise to the pharynx, the œsophagus, and the stomach.

Early in this stage some endoderm cells accumulate at the posterior end of the stomach and form the anterior part of the mesenteron. These cells are arranged as a funnel-shaped tube wide open posteriorly. The posterior funnel has united with the wall of the stercoral pocket at its hind end (fig. 55). The anterior and the posterior funnels of the mesenteron do not at this stage unite with each other.

Locy says that on each side of the stomach are given off cæca, which extend into the bases of the limbs. He adds that the cellular elements composing the walls of these tubes are flattened ; but he gives no account concerning the time of their appearance Though I have carefully examined embryos of all the stages, I could not find such tubes.

The proctodæum is lined with a cuticular covering as the stomodæum ; but the stercoral pocket has no such covering. This fact confirms my observation that the stercoral pocket is not a portion of the proctodæum. The communication between them is formed at this stage. The communicating canal is very narrow. In the last stage, the stercoral pocket was somewhat globular in shape (Pl. XIV, fig. 32), now it is elongated anteriorly and is oblong (Pl. XVI. fig. 55). Its lateral diverticula have disappeared.

I could not make out the development of the Malpighian tubes satisfactorily ; but I am certain that they do not originate from the ectoderm. Also it is certain that they are not outgrowths from the stercoral pocket. It seems to me probable that they originate from mesodermic cells belonging to the abdominal somites in front of the anal lobe. At this stage they are solid paired cords of cells (fig. 55, *Malp. t*) extending from the anterior end of the second abdominal segment to the sides of the confluent point of the posterior mesenteron with the stercoral pocket.

The mesodermic cells of the coxal gland, which was formed in the preceeding stage, are very much differentiated from the ectodermic cells of it. They are the glandular cells, their size becoming large and their protoplasm granular and unstainable (Pl. XV, fig. 37). The ectodermic cells form the duct.

At the distal end of the cheliceræ a solid growth inward of ectodermic cells takes place. These cells are surrounded by mesodermic cells. The distal half of the former becomes the glandular portion, and its proximal half the duct, of the poison gland, while the mesodermic cells form the muscular wall of the gland (fig. 39).

In this stage four paired transverse septa are formed between the four appendage-bearing segments of the abdomen by the sinking of the mesoderm into the yolk. A median unpaired septum, similarly formed, also stretches forward from the posterior end. These septa are formed after the disappearance of the cœlomic cavites in the abdomen. In fig. 34, Pl. XV., two anterior septa are represented. The first pair of septa probably give rise to the generative organ, and all or some of the others to the so-called liver.

After undergoing one or two moults, the embryo hatches. The body of the embryo is covered with cuticular hairs. At the end of the pedepalpi and the four ambulatory appendages, the claws are produced, and at the end of the cheliceræ the poison fangs, by thickenings of the cuticula.

Summary.

(1) The polygonal areas are on the periplasm, and are probably formed when the eggs pass through the oviduct.

(2) In the process of segmentation the yolk and the nucleus are divided at the same time. The segmentation is syncytial.

(3) The yolk nucleus is found in segmenting eggs on to the four-cell stage.

(4) After the segmentation all the nuclei are found only at the surface of the egg, and none of them remain in the yolk.

(5) The primary blastodermic thickening may be considered as a modified gastrean mouth, the formation of which was obstructed by the abundance of yolk.

(6) The secondary blastodermic thickening or 'primitive cumulus' of Claparède plays a secondary part in the formation of the germinal layers.

(7) The brain and the ventral nerve cords are formed as a continuous ectodermic thickening.

(8) All the appendages are postoral in origin.

(9) The first abdominal segment bears no appendages.

(10) The large fat cells are derived from the endoderm. They form blood corpuscles.

(11) An invagination at the posterior base of the first abdominal appendage gives rise to the lung-book. A similar invagination at the base of the second gives rise to a tube—abortive trachea.

(12) The unpaired cœlomic cavity, belonging to the anal lobe, changes to the so-called stercoral pocket. Probably it is excretory in function, not a part of the alimentary canal.

(13) The dorsal circulatory vessel is formed by the fusion of the mesoblastic somites at the dorsal median line.

(14) The so-called body cavity of the adult animal is not the descendant of the cœlomic cavity, but it is a secondarily formed space.

(15) The brain is composed of the semicircular grooves and the lateral vesicles cut off from the ectoderm. Later it is divided into three segments.

(16) The development of the posterior median eyes is connected with that of the brain. Their development is quite different from that of the other eyes; but all the eyes are dermal in origin, not neural. And the nerves of the eyes enter always from the inner ends of the ectoderm cells.

(17) A pair of coxal glands opens at the base of the third appendage. The glandular portion of it is formed from a portion of the cœlom, while its duct is formed from an ectodermic invagination.

(18) The alimentary canal of the spider is formed from the ectoderm and the endoderm. The pharynx, the œsophagus, the stomach, and the anus are produced from the former, and the intestine from the latter.

(19) The Malpighian tubes are produced neither from the ectoderm nor from the stercoral pocket. They are mesodermic in origin.

Explanation of Plates.

The figures are all exact representations of preparations, the outlines, the nuclei, and other details being drawn faithfully by myself with the use of the camera lucida, and they are not diagramatic, except in the case of a few figures expressly so stated.

List of References.

a, first segment of brain.
abd. app., abdominal appendage.
a. l., anal lobe.
A. L. E., anterior lateral eye.
ant. mesent., anterior portion of mesenteron.
b, second segment of brain.
c, third " " "
ceph. l., cephalic lobe.
ch., cheliceræ.
ch. g., cheliceral ganglion.
co. gl., coxal gland.
cut., cuticula.
d, dorsal side.
dor., dorsum.
ect., ectoderm.
end., endoderm.
f. c., fat cell.
G, ganglion.
inv., invagination of lung-book.
L, lens.
lat. v., lateral vesicle.
Malp. t., Malpighian tube.
mes., mesoderm.
N, nerve.
pedip., pedipalpi.
P. M. E., posterior median eye.
post. mesent., posterior portion of mesenteron.
prim. th., primary thickening.
proct., proctodæum.
R, retina.
sec. th., secondary thickening.
seg. cav., segmentation cavity.
sem. gr., semicircular groove.
sp. gl., spinning gland.
sterc. p., stercoral pocket.
stom., stomodæum.
tap., tapetum.
th. app., thoracic appendage.
v, ventral side.
vit., vitreous body.
y. n., yolk nucleus.

Explanation of Figures.

Fig. 1. An unsegmented egg, showing the polygonal areas above yolk granules. (*Lycosa*). 2 B (*Zeiss*).

Fig. 2. A segmentation egg of the four-cell stage, showing the rosette-like yolk pyramids. (*Lycosa*). 2 B.

Fig. 3. A segmentation egg, shewing the union of the polygonal areas with the segmentation nuclei. (*Lycosa*). 2 B.

Fig. 4. The same as above, but of a little later stage. This shows that the yolk pyramids become very small and that the polygonal areas do not correspond in position with the yolk granules. (*Lycosa*). 2 B.

Fig. 5. An egg shewing the primary thickening of the blastoderm. (*Lycosa*). 2 A.

Fig. 6. An egg having the secondary thickening of the blastoderm, produced at the margin of the primary thickening. (*Lycosa*). 2 A.

Fig. 7. An egg in which the primary thickening has extended enormously, and the secondary thickening is at the margin of the primary one as before. (*Lycosa*). 2 A.

Fig. 8. A section of an egg of the two-cell stage, shewing the division of the yolk. and also yolk columns, the segmentation cavity, and the yolk nucleus. (*Lycosa*). 2 C.

Fig. 9. A section of an egg of the sixteen cell stage. (*Lycosa*). 2 C.

Fig. 10. A section of a segmentation egg in the stage of Fig. 3, containing twenty two nuclei. (*Lycosa*). 2 C.

Fig. 11. A portion of a section of an egg in the stage of Fig. 5. (*Lycosa*). 2 C.

Fig. 12. A portion of a section of an egg in the stage of Fig. 6. (*Lycosa*). 2 C.

Fig. 13. A section of the secondary thickening. (*Lycosa*). 2 D.

Fig. 14. A portion of an section of an egg, a little more advanced than the egg in the stage of Fig. 12. (*Lycosa*). 2 C.

Fig. 15. A section of an egg after segmentation showing the absence of the nucleus in the yolk and a number of small yolk balls. (*Lycosa*). 2 B.

Fig. 16. A longitudinal section of an egg of the protozonite stage. (*Agalena*). 2 B.

Fig. 17. A portion of a cross section of an egg of the protozonite stage. (*Agalena*). 2 D.

Fig. 18. A cross section of an egg showing the separation of the mesoderm into two lateral halves, the formation of the cœlomic cavity, and the appearance of the appendage, in the thoracic region. The mesoderm of the cephalic region is not yet divided. (*Agalena*). 2 B.

Fig. 19. The median longitudinal section of the embryo in the reversion stage. (*Agalena*). 2 B.

Fig. 20. A diagram of the ventral plate (imagined as unrolled) of an embryo in the stage of the maximum dorsal flexure.

Fig. 21. A diagram of the ventral plate (imagined as unrolled) of an embryo in the stage of reversion.

Fig. 22. A longitudinal section of an egg in the stage of Fig. 20, showing the appendages and cœlomic cavities. (*Agalena*). 2 B.

Fig. 23. A cross section of an egg in the same stage as of the previous figure, showing the semicircular groove, the lateral vesicle, the continuous mesoderm of the head, and the cœlomic cavities and thoracic ganglia. (*Agalena*). 2 B.

Figs. 24, 25. Portions of median longitudinal sections, showing closeness of the cephalic and anal lobes, and the formation of the stomodaeum (*Agalena*). 2 B.

Fig. 26. A portion of the median longitudinal section of an egg in the reversion stage, showing the expansion of the dorsum. (*Agalena*). 2 B.

Figs. 27–32. Longitudinal sections of the anal lobe in successive stages, showing the formation of the proctodaeum and the change of the cœlomic cavity of the anal lobe to the stercoral pocket. (*Agalena*). 2 D.

Fig. 33. A cross section of the anal lobe, showing its unpaired cœlomic cavity and ganglion, and its two lateral diverticula. (*Agalena*). 2 D.

Fig. 34. A sagittal section of the abdomen of an embryo after the reversion stage. Two anterior abdominal septa are represented. (*Agalena*). 2 C.

Figs. 35, 36. Sagittal sections of the coxal joint of the first thoracic appendage, showing the communication of the cœlomic cavity with the exterior by an ectodermic invagination. (*Agalena*). 2 D.

Fig. 37. The glandular portion and the outlet of the coxal gland. (*Agalena*). 2 D.

Fig. 38. A cross section of the cephalothorax, showing the position of the coxal gland. (*Agalena*). 2 B.

Fig. 39. A cross section of the poison gland of an embryo, a little before hatching. (*Agalena*). 2 D.

Figs. 40–43. Portions of cross sections of the abdomen, showing the formation of the dorsal circulatory organ. (*Agalena*). 2 D.

Fig. 44. A portion of a frontal section of an embryo in the reversion stage, showing the three segments of the brain. (*Agalena*). 2 B.

Fig. 45. A diagram of the brain and the cheliceral ganglia.

Fig. 45a. A diagram of the profile view of the brain and the cheliceral ganglia of an embryo in the reversion stage.

Fig· 45. A frontal section of the brain of an embryo in the reversion stage, showing the formation of the eye. (*Agalena*). 2 C.

Fig. 47. A portion of a cross section of the abdomen in the reversion stage, showing the formation of the lung-book lamellae. (*Agalena*). 2 F.

Fig. 48. A sagittal section of the brain of an embryo in the reversion stage, showing the formation of the posterior median eye. (*Agalena*). 2 D.

Fig. 49. A sagittal section of the posterior median eye of a hatched embryo. (*Agalena*). 2 D.

Figs. 50. 51. Portions of frontal sections of the cephalothorax in different stages of growth after the reversion of the embryo, showing the development of the anterior eyes and the formation of nerve fibres, the tapetum, and the vitreous body. (*Lycosa*). Fig. 50. 2 F. Fig. 51. 2 D.

Fig. 52. An oblique frontal section of the anterior lateral eye of an embryo about the time of hatching. (*Lycosa*). 2 F.

Fig. 53. A longitudinal section of the anterior median eye about the time of hatching. (*Lycosa*). 2 F.

Fig. 54. A frontal section of the anterior median eyes of a hatched embryo. (*Lycosa*). 2 D.

Fig. 55. A sagittal section of the abdomen about the time of hatching. (*Lycosa*). 2 B.

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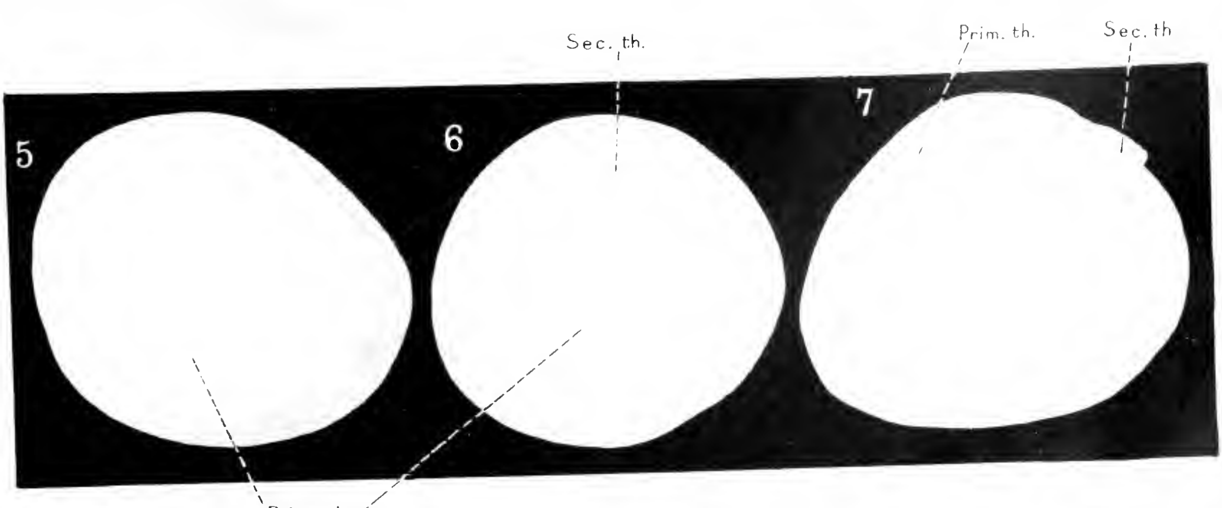


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Observations on Fresh-water Polyzoa.

(Pectinatella gelatinosa, nov. sp.)

by

A. Oka.

Imperial University, Tōkyō.

with Plates XVII—XX.

The present paper embodies the results of my investigations on a new species of Fresh-water Polyzoa that lives in a large pond in the grounds of the Imperial University, Tōkyō, and is published with the hope that it may throw some light on certain points in the structure and development of the order Phylactolaemata, which have hitherto remained obscure in spite of many efforts of former investigators. The researches were begun, in the spring of 1888, at the suggestion of Prof. I. Ijima, and I am indebted both to him and to Prof. K. Mitsukuri for useful advice. My thanks are also due to Mr. S. Watase, now of the Johns Hopkins University, who, while here some years ago, studied the same species, for kindly sending me his drawings showing the formation of the statoblast.

Although the species which I have studied does not agree in some points with the generic description of Pectinatella in Hyatt's Observations (5), it can belong to no other genus. The statements given there were made when only one species, viz Pect. magnifica, was known, and must certainly be modified to receive the new one. The diagnostic characters of the present species to which I give the name of Pect. gelatinosa, are as follows:

Colony oval, hyaline; branches of cœnœcium dichotomous; no septa between the cells; ectocyst gelatinous, fills up the space between the branches, forms a common base for many colonies; invaginated fold obsolete; alimentary canal straight when retracted; tentacles 90-98; statoblast saddle-shaped, curved in two axes; marginal spines minute, only seen under a moderate power of microscope.

The colonies grow among aqueous plants and on the underside of floating logs just below the surface of water, and seem to flourish in direct sunshine as well as in shadow. They are found together in a large number forming a luxuriant mass of gelatine, sometimes two metres in length. The outline of each colony is irregularly hexagonal on account of mutual pressure. The gelatinous ectocyst of neighboring colonies coalesce, and form a common base 2-3 cm. thick.

This species furnishes very favorable materials for the student of this group of animals, the transparency of its gelatinous ectocyst, the unequalled large size of the polypide and the promptness with which they evaginate, giving great facility for investigation.

The general appearance of a group of colonies is represented in natural size in fig. 1, Pl. XVII. The color of the cœnœcium and the lophophore is slightly yellowish, the œsophagus and the stomach are brown, and the rectum usually contains dark grayish refuse matter, otherwise of light brown color.

The largest colony that I have seen measured 7 cm. in diameter. The polypides are most crowded and in fullest vigor along the margin of a colony, and much less crowded in the middle portion, say about one in each four square millimetres. The more centrally situated polypides being older are the first to die, so that in old colonies, the polypides are found only on the outer part, leaving the inner part bare and only marked with dark spots, the remains of dead polypides. When agitated the polypides retract only for a short time, and soon expand their tentacular crown again. Even in being transferred from one vessel to another, some of the polypides of a colony do not retract at all. In confinement, however, they seem to become more timid and, once retracted, remain in that state for a longer time than when free.

Each colony originates from a single individual that comes out of the statoblast in the first weeks of July, becomes larger and larger by successive budding, attains its full growth in October, and continues to live until the end of December. Compared with a species of Plumatella living in the same pond, the times of the first appearance and of the total disappearance are each about two months later. As I have not found this species anywhere else, I can say nothing about its geographical distribution.

Methods of Investigation.

Before proceeding further, I may here give a brief account of the methods of investigation employed. To kill the animal in a fully expanded condition was in this case very easy, although it is the principal difficulty met with in the preservation of all other genera. When 70% alcohol is gradually poured into a vessel containing the colonies, more than half the polypides die protruded. If we use such stupefying reagents as chloral hydrate or cocain chlorhydrate, every one of the polypides dies in a fully expanded condition.

The colonies after being killed were put into alcohol to be hardened. Some of them were fixed with a saturated solution of corrossive sublimate or a weak solution (0.1°/₀) of chromic acid, previous to hardening. For staining, borax-carmin and picro-carmin were chiefly used. In cutting sections, I imbedded sometimes a whole colony, sometimes separate polypides, in celloidin and paraffin.

In studying the development of the polypide within the statoblast, I proceeded in the following way. First, a statoblast was put into alcohol to harden its contents which in the fresh state consist of a thick milky fluid. Then it was held between two pieces of elder pith, and the edge was cut with a sharp razor so as to make an opening in the chitinous shell. Next, it was stained and kept in alcohol until it was to be cut. In cutting the statoblast, celloidin was indispensable. for, the shell being too hard, it was impossible to get good sections with paraffin only.

For examining fresh specimens, the only thing I had to do was to put a colony (stupefied with cocain) or a part of it on a slide, and cover it, putting a wire ring under the cover-glass to prevent over-pressure. In this condition, the polypides had no power to retract, and the ciliae were in vigorous motion.

To study their habits, I kept colonies alive in a glass vessel. I kept also the statoblast in a vessel, in which a contrivance was made to have water always flowing. At last the shells burst, and the little polypides peeped out of the sutures, carrying about the shells like a tiny bivalve. Each of them floats about for a very short time, and then attaches itself by means of the gelatinous ectocyst to any object it may meet with, and gives rise to a new colony.

A. Anatomy.

The branched membranaceous tube (cœnœcial endocyst) forming the greater part of the mass of a colony, together with the gelatinous covering (ectocyst) over it, constitutes the cœnœcium. The terminal portion of each branch is turned nearly vertical to the plane of the colony and is capped by another short tube (polypidal endocyst), through the pellucid wall of which is seen the alimentary canal contained within. This terminal tube, with the tentaculate lophophore at its free end, and several delicate organs in its cavity, is called the polypide (fig. 2, Pl. XVII.).

Besides this division of the colony into the cœnœcium and the polypides, we may divide it into a number of equal parts, each consisting of a polypide and a portion of the cœnœcium. For the sake of convenience I shall call such a part "*polyzoöid*," and the portion of the cœnœcium belonging to it "*cystid*." We thus consider a colony as being made up of as many polyzoöids, all structurally alike, as there are polypides.

In all genera with chitinous ectocyst, the cœnœcium is divided by more or less developed septa into a number of compartments or cells, each destined to receive a polypide when the latter is retracted. Such septa are not found in forms with gelatinous ectocyst, and the cystidal cavities stand in open connection with one another.

When a polypide is retracted by the contraction of the muscles that connect it with the bottom of the cystid, its tubular wall invaginates and be comes a sort of sheath for the tentacles, known as the tentacular sheath. In the process of evagination, the tentacular sheath begins to reflect upon itself from the lower end. The evagination generally stops when the lower end of the polypide is still within the cystid. In other words, the evagination is incomplete, thus leaving a permanent fold at the boundary between the cystidal and the polypidal endocyst. In this genus, however, the polypides are often stretched out their whole length, and then no such fold is to be seen.

The shape of the polyzoan colony is different in different genera and species, but it is characteristic for each species. The manner of branching of the cœnœcium in *Pect. gelatinosa* is shown in fig. 3, Pl. XVII. It is dichotomous with a short branch at each axil. The branches are so bent that all the polypides stand upright and as the plumous tentacles cover the whole surface of the colony, their regular symmetrical arrangement cannot be discerned without close examination.

The general plan of the structure of a polypide and its relation to the cystid are shown in fig. 4, Pl. XVII. The alimentary canal is bent in the shape of the letter V, and hangs freely in the perigastric cavity. The mouth guarded by a tongue-like epistome (*Epist.*) is surrounded by a number of tentacles (*Tent.*) arranged along the entire margin of a horse-shoe shaped lophophore (*Loph.*). The anus opens outside the tentacular area near the mouth. on that side of the body on which the arms of the lophophore stretch out. A nervous ganglion (*N. Gang.*) is seen on the anal side of the œsophagus. A thin hollow tube, called funiculus, in which the statoblasts are developed, joins the angle of the alimentary canal with the cystidal wall. An ovary (*Ovr.*) is seen inside the tip of the cœnœcial branch. The length of a polypide from the tip of the tentacles of the angle of flexure of the alimentary canal is about 4 mm.

Although the term "individual" as applied to such forms as polyzoa is very difficult to define, yet homologously with its nearest relative, the Brachiopods, each polyzoöid might be regarded as an individual in the ordinary sense of the word. Polyzoan individuals show a close analogy to "phytons" of plants.

The polypide and the cystid that constitute a polyzoöid, are respectively vegetative and reproductive in function. As will be seen further on, all the functions for the preservation of the species are performed by the latter, the funiculus being regarded as a part of it, while the former serves to procure nourishment to the cystid.

All fresh-water Polyzoa are annuals, the vegetative and the reproductive portions undergoing entire decomposition every year, while in marine forms, several generations of the vegetative portion, i.e., the polypides, form and decompose themselves on the perennial cystid, like leaves on the branches of a tree. This singular phenomenon led many naturalists (Allman and others) to regard the polypide and the cystid as two distinct individuals. In the present species also, the duration of vitality of the two portions is by no means the same. The polypides invariably die after a certain period of existence, usually after the formation of younger polyzoöids of the fourth or the fifth order, but the cystids remain until the colony itself disintegrates in winter. In the central portion of a large colony, therefore, we often see only bare cystids, each with a dark grayish mass, the remains of the dead polypide, hanging in its cavity, and yet with statoblasts continuing their development in the funiculus.

About the application of the terms "anterior," "posterior," "dorsal," "ventral," &c., there is much diversity of opinion. For instance Allman calls the free end of the polypide "anterior," and the fixed end "posterior"; while Hyatt, following E. S. Morse, calls the fixed end "anterior," and the free end "posterior." Huxley homologizes Polyzoa with Tunicata, and names that side on which the anus opens "neural," and the side opposite to it "haemal," although there exists no heart. Again, if we were to compare this animal with Phoronis, we should have to call the narrow space between the mouth and the anus "dorsal," and all other parts "ventral." In fact, every one might give different sets of names in orienting the animal, according to his conception of the homology which exists between Polyzoa and other animals in which the anterior and posterior, or the dorsal and ventral poles are universally recognized. In the following pages, I shall call the fixed end "lower," and the free end "upper," the side on which the anus opens "anal," and the side opposite the anus "oral."

The organs that constitute the Polyzoan body may be classified in the following way.

A. Organs for the preservation of the polyzoöids or the colony.

1. Dermal System, consisting of the ectocyst and the endocyst.
2. Digestive System, consisting of the epistome, the œsophagus, the stomach, and the intestine.
3. Tentacles.
4. Excretory Organs (?), consisting of two short ciliated tubes.
5. Muscular System, consisting of five groups of muscles.
6. Nervous System, consisting of a ganglion with two arms for the lophophore.

B. Organs for the Preservation of the species.

7. Ovary and Testis.
8. Funiculus, in which the statoblasts are developed.
9. The part of the endocyst that produces buds.

1. Dermal System.

The integument of Polyzoa consists of two layers, quite different in their nature, the outer "ectocyst" and the inner "endocyst" (see fig. 4). The latter is not everywhere covered by the former, but is exposed on the polypides.

The ectocyst is gelatinous in this species. It fills up the space between the branches of the cœnœcial endocyst, whereas in Pect. magnifica, Leidy, there is no ectocyst between them. In this respect as well as in the erect position of polypides, this species comes nearer the genus Lophopus. The gelatinous substance is formed by the secretion of cells of the outer layer of the endocyst. Numerous cells, some oval, others irregular in their shape, are scattered in it (fig. 6, Pl. XVIII.). Their nucleus and nucleolus are distinctly visible. These cells seem to have wandered out of the outer layer of the endocyst, and may have helped in producing the gelatinous substance, reminding us of the cells in the test of the Tunicates. The gelatinous substance is adhesive and without taste; it serves apparently to protect the colony. On drying, it shrinks almost to nothing.

The endocyst consists of four layers (fig. 7, Pl. XVIII.)

a. Outer cell layer (*Out. lay.*).

b. Basement membrane (*Bas. membr.*).

c. Muscular layer (*L. mus. and Tr. mus.*)

d. Inner lining epithelium (*Lin. epith.*).

All of these layers are not present everywhere, nor is each of them of the same structure throughout its distribution.

The cells of the outer layer, which represents the ectoderm, are everywhere distinctly bounded, columnar on the cœnœcium, flat and horizontally elongated on the polypide, except on the tentacles and the upper surface of the lophophore. In the former, they are cubical, in the latter hexagonally prismatic, and distinctly ciliated in either case. Many of the cells on the cœnœcium contain a vacuole (fig. 7, *vac.*) filled with a very refractile fluid. The number of these vacuolated cells increases as we approach the tip of cœnœcial branches, where every cell shows a large vacuole, almost filling up the whole cell (fig. 33, Pl. XIX. *Out. lay.*).

In preserved specimens, the cells are more or less shrunk, often leaving spaces between them. The nuclei are oval, and have a distinct, well-staining nucleolus. The cells on the cœnœcium are

0.02–0.04 mm. high. The nucleus measures about 0.007×0.004 mm.

The basement membrane situated directly beneath the outer cell-layer is secreted either by this, or by the internal lining epithelium, or by both. In the greater part of the cœnœcium where this membrane is separated from the inner epithelium by the muscular layer, it would be natural to refer its origin to the outer cell-layer alone, but where the muscular layer is deficient, it is difficult to decide. On the other hand, in the wall of the funiculus into which this membrane and the inner epithelium, but not the outer cell-layer, are continued, it cannot but be the product of the inner epithelium only. Generally, the basement membrane and the muscular coat are treated as one layer under the name of Tunica muscularis, but as they are in reality quite distinct from each other, it will be better to regard them as two distinct layers. When a colony is treated with a weak solution of acetic acid, the basement membrane separates from the rest of layers. It is thin, tough, transparent, and homogeneous.

Next to the basement membrane comes the muscular layer, consisting of transverse and longitudinal fibres. The former run external to the latter. They are not very densely set, so that in a surface view they cross one another as in coarse linen. On the main part of the polypide, only the longitudinal fibres are present. In such genus as Cristatella, the muscular layer gives the colony the power of slow locomotion, but what function it has to discharge in fixed Pectinatella, I am not prepared to say. In the cœnœcium where this layer is best developed, it is 0.005 mm. thick. It is not found in that part of the endocyst where buds are formed, and is also absent in the walls of the lophophore and the tentacles.

The internal epithelial layer lines the endocyst everywhere. It is thickest in the cœnœcium, especially at those points where budding takes place, and is thinnest in the tentacles with nuclei scattered widely apart (figs. 16 and 17, Pl. XVIII.). The cells of this layer are fused, hence cell boundaries cannot be distinguished. The nucleus is oval, but I am unable to detect distinct nucleoli. The size of the nucleus is nearly the same everywhere, and is about 0.008 × 0.004 mm. This layer is furnished with short cilia, which set the perigastic fluid in motion. Average thickness of the layer in the cœnœcium is 0.008 mm.

2. Digestive System.

Minute algae and infusoria that pass by are caught in the whirlpool caused by the vibrating cilia of the tentacles, and sent into the œsophagus. The epistome that guards the mouth is furnished with special muscles which enable it to shut the oral aperture now and then. Perhaps the entrance of non-nutritive matters is prevented by this contrivance. The food, after staying for a short time in the œsophagus, pushes open the funnel-like valve (fig. 4, Pl. XVII. *funnel-like v.*) that intercepts free communication between the œsophagus and the stomach, and enters the gastric cavity where it is moved about by the peristaltic contraction of the wall of that organ. After being fully digested, the residue mainly composed of the cell-wall of diatoms and other algae, passes through the pyloric valve little by little, and accumulates in the intestine. Here, the refuse matter, usually of a dark-grayish color, is cemented together into a mass by a transparent gelatinous secretion of the intestinal wall. When the intestine is full, the contents are pushed out of the anus by the agency of the muscles of that part. The form of the excremental mass, characteristic of each genus, is the same in form as the lumen of the intestine which in our species is an elongated oval tapering toward the anus.

There are often certain amœboid cells to be found in the intestinal cavity. They stain very well, and are on that account very conspicuous among a mass of unstained matter. Judging from their shape and size, it is very probable that they are parasitic Protozoa.

The process of digestion is carried on very rapidly. When fresh colonies are brought from the pond and kept alive, all the polypides discharge their dark intestinal contents in a few hours. Gradually, new refuse matters begin to accumulate in that organ, but they are always a good deal lighter in color. These are again excreted in the next three or four hours. As the amount of food that these animals consume is considerable, it was impossible to keep them alive more than a week without furnishing them very often with water from the pond, which contained minute organisms.

The layers that constitute the walls of the alimentary canal are the same as those of the endocyst. In fact, they are direct continuations of the latter only slightly modified to serve special purposes.

The epistome is a tongue-like prolongation of the disc of the lophophore on the anal side of the mouth. Its cavity (see fig. 8, Pl. XVIII.) communicates with the general perigastric cavity by a comparatively narrow passage on the anal side of the cerebral ganglion. The cells of the outer layer of its wall are similar in appearance to those of the lophophore. They are prismatic, and the height increases nearer the mouth. The oval nucleus with distinct nucleolus lies near the base. The whole external surface is furnished with cilia. This organ has no muscular layer in the wall, but is furnished with special muscular fibres which traverse its internal cavity. These fibres are simply elongated cells with the uncleus at about the middle of their length. They are separate and never form bundles. The length of the epistome is about $\frac{1}{4}$mm.

The œsophagus is that portion of the alimentary canal that lies between the mouth and the funnel-like valve at the cardial opening of the stomach. Its upper and lower sections are lined by epithelia of quite different appearance. The cells of the upper section (fig. 9, Pl. XVIII) have cilia, and their nucleus lies near the base. Verworn says that the cells of this section do not come in to any contact with one another throughout their whole length, being separated by a narrow intervening space but I cannot find any such space in Pect. gelatinosa, except such as is in all probability due to the post-mortem contraction of cells. In the lower section. the lining cells have no cilia, and the nuclei lie irregularly near the middle (fig. 10, Pl. XVIII). In the upper section. the free end of cells is flat ; in the lower, it is rounded. In both the nucleus has a distinct nucleolus. The cells of the lower section do not stain well, and seem to contain a secretive substance, which may be comparable with the saliva of higher animals.

The length of the œsophagus is about 1mm. and its diameter 0.3 mm. The lumen of the œsophagus when expanded is round in section throughout its entire length. but in its upper section contraction changes it into a stellate shape. The muscular layer is but scantily developed in the œsophageal wall. The outer covering is the continuation of the lining epithelium of the endocyst with which it agrees in all respects.

The œsophagus in its downward course occupies an excentric position in the tubular body of the polypide, and where the latter is externally marked off from the lophophore by a slight constriction it actually comes in contact with the body-wall on the oral side. At this point, the lining epithelium of the polypidal wall is continuous with the outer covering of the œsophagus, and forms a sort of mesentery (fig. 15, Pl. XVIII.). This mesentery extends horizontally on both side for a short distance, and prevents over-invagination of the body-wall when the polypide is retracted. Thus the alimentary canal is attached to the body-wall at four points, viz. the mouth, the anus, the funiculus and the above mentioned mesentery.

At the entrance of the stomach there is as already mentioned a funnel shaped valve, with the free end pointing into the cavity of the stomach (fig. 11, Pl. XVIII.). It consists of a funnel-like prolongation of the basement membrane, on the œsophageal side of which are arranged the characteristic cells of the œsophagus, and on the gastric side, the pyramidal cells of the stomach. This valve, whose length is about 0.2 mm., prevents the passage of food from the stomach back into the œsophagus.

The stomach is a spacious saccular organ whose long axis is bent in the shape of V, bringing the pyloric opening near the cardiac. It measures 2 mm. in length, and 0.6 mm. in breadth at the widest part. The inequality of the length of the arms of V brings the cardiac opening about 0.5 mm. nearer the free end of the polypide than the pyloric.

The inner layer of the stomach has two kinds of cells; the long club-like cells (fig. 13, Pl. XVIII. *cl. c.*) and the short pyramidal cells (*pyr. c.*). As they are arranged in groups forming alternate longitudinal rows, the lumen of the stomach is stellate in cross-section. The number of the rows of each kind is generally twelve or more (fig. 12, Pl. XVIII.). In both, the nuclei lie at the base and the nucleoli are distinctly visible. The long club-like cells do not stain well, while the short pyramidal cells freely take up the coloring matter. In the fresh state, the longer cells contain a yellowish brown fluid and the shorter cells are of a light yellowish color, so that the stomach appears longitudinally striped with yellow and brown bands. As the alimentary canal has no distinct glandular appendage, the brown fluid contained in the longer cells probably performs the function of the digestive fluid. Hence they have been called hepatic cells by Allman. The function of absorption seems to be performed by the shorter cells. The length of the longer cells is various, the longest measuring 0.06 mm., while the shorter pyramidal cells measure approximately 0.02 mm. On the gastric side of the cardiac valve, and at the blind end where the stomach is continuous with the funiculus, the rows of the longer cells stop short, and only the short pyramidal cells are present.

The muscular layer of the gastric wall, composed only of the transverse fibres, is well developed, especially below. At the thickest part this layer is 0.007 mm. in thickness. At the blind end of the stomach, however, there is no muscle, and here the inner cell-layer comes in direct contact with the fluid contents of the funicular cavity (fig. 32, Pl. XIX.). At this point, the wall is generally pushed inward in the form of a shallow pit.

The outer epithelium does not differ from the corresponding layer of the œsophagus and the endocyst.

The pyloric valve is represented by a simple constriction of the entire wall of the alimentary canal. Its opening is very narrow, allowing the passage of only a small quantity of indigestible matter at a time.

The intestime is a tubular organ tapering toward the anus. It is about 1.2 mm. in length, and 0.3 mm. in width. The inner layer is composed of only one kind of cells, which are much shorter but somewhat broader than the longer cells of the stomach. The height of these cells is about 0.025–0.03 mm. The nucleus is at the base and the nucleolus is distinct (fig. 14, Pl. XVIII.). These cells do not stain well ; the gelatinous fluid they contain is probably the medium by which the excrement is cemented into a compact mass. The muscular layer of this part, in which only ring fibres are present, is weakly developed except near the anus, where it forms a sort of sphincter. The anus when expanded is as wide as the widest part of the intestine, but when contracted it closes altogether. The outer cell-layer is similar in all respect with that of other parts of the alimentary canal. At the point where the intestine is tightly pressed against the œsophagus, the outer layer of the former passes directly into that of the latter, bringing the cells of the inner layers of both organs in contact.

3. Tentacles.

The tentacles are arranged in one continuous series along the outer and the inner margin of a horse-shoe shaped lophophore, as mentioned before. They are hollow cylindrical organs measuring 1 mm. in length, and 0.03 mm. in breadth. They are to be considered as prolongations drawn out, as it were, from the endocyst. In the living state, they are freely movable in every direction at the will of the animal, but I have never seen them coil or contract. Generally, they stand nearly parallel to one another in graceful curves (fig. 2, Pl. XVII.).

The cross section of a lophophoral arm (fig. 30, Pl. XIX.) is almost semicircular in outline, slightly convex above and rounded below, measuring 0.3 mm. in breadth, and nearly as much in depth. The ciliation on the upper surface is distinctly visible on sections.

The cells of the outer layer of the tentacular wall have all the essential characters of those of the endocyst. They rest on a fine basement membrane and are furnished each with a long cilium (fig. 16, Pl. XVIII. Out. lay.), constantly vibrating in a certain fixed direction. The ciliation of that side of the tentacles turned away from the mouth drives the water upward, while that on the opposite side tends to drive it toward the mouth below. The inner layer of the tentacles (fig. 16, Pl. XVIII. Lin. epith.) is very thin and has the nuclei scattered at great intervals. I was not able to detect any trace of cilia on the lining epithelium, but the rapid motion of the perigastric fluid, going toward the tip along one side and coming back along the other in the narrow tentacular cavity, indicates their existence. The lumen is a little more than 0.01 mm. in diameter.

The account, given by Verworn, of the manner of junction of the tentacles with the lophophore and the tentacular membrane in *Cristatella* applies equally well to the species investigated by me. In fig. 18, Pl. XVIII, I have endeavored to show diagrammatically the relation of several parts at the bases of tentacles.

Externally to the row of tentacles there is a thin membrane, the tentacular membrane, 0.3–0.4 mm. in breadth, formed by a duplicature of the outer layer of the lophophoral wall along its outer edge. It consists of a basement membrane covered on both sides by a layer of flat cells, the direct continuation of the outer layer. The basal portion of each tentacle is joined to the tentacular membrane by another narrow triangular membrane.

Alternating with the bases of the tentacles, a series of duplicatures on each side of the lophophoral cavity is produced in the inner layer, so that if we were to cut across the arm and look into it, we should see a series of vault-like arches. The tentacular cavity opens into that of the lophophore between each two of such folds of the inner layer. These folds descend almost to the floor of the lophophoral cavity, and have been reckoned as part of the muscular system by Hyatt, under the name of "brachial contractors," but I see no ground for regarding them as such, since they consists simply of flat cells.

The bases of the tentacles are not in one plane. Those on the anal side near the epistome are the most elevated. The number of the tentacles is generally even, but in some individuals there is a median tentacle on the anal side, making the total number odd.

There can be no doubt that the function of the tentacles is three-fold, serving for respiration, for collecting food and for feeling. Of these, however, the first seems to be their principal office, when we consider the large extent of their surface exposed to water, and the constant current kept up in the latter by a special contrivance, as well as the perigastric fluid that circulates within their lumen. The Tentacles thus bear a close resemblance to the fringed arms of Brachiopods.

Circulation. The perigastric fluid contained in the general body-cavity may justly be regarded as representing the blood. Of its nature and the mechanism of circulation, little was known before. There are no special organs, such as heart and blood vessels, and the only means of driving the perigastric fluid is the supposed ciliation on the lining epithelium of the general body-cavity. The nutritive part of the food taken up by the alimentary canal is conveyed to all parts of the body by this fluid. It is transparent, colorless, and has no taste. Water seems to constitute the greater part of its constituents.

The fluid contains, floating in it, numerous round cells, each with a large vacuole almost filling up its body and filled with a refractile fluid (fig. 20, Pl. XVIII). The nucleus is pushed against the wall by the vacuole. The study of the development of polypides in the statoblast shows that these free cells are derived directly from the granular mass that constitutes the main contents of the statoblast, and in young stages they contain similar granules instead of the vacuole. It is therefore plain that they are, at any rate, nutriment carrying cells, which might be regarded as blood corpuscles.

Besides these, there are generally present a greater or smaller number of cells or fragments of cells of a quite different appearance, which have probably detached themselves from some part of the body.

The floating elements were observed by previous investigators (Allman, Hyatt, Verworn), but no great importance was attributed to what were brobably either parasitic organisms or detached cells. Hyatt, for instance, observed "numerous organisms, many of which probably parasitic, which float in the fluid, sometimes in such a number as to interfere with the examination of the internal structure." It is probable that at least some of these "organisms" were what I regard as the blood corpuscles.

The direction of the blood currents as observed in the natural state is shown in fig. 21. On the anal side of the body cavity the fluid is driven toward the free end of the polypide, evidently by ciliary action, which however could never be actually brought to view. In the lophophoral arms, the corpuscles travel along the floor to their ends, and either return directly along the ceiling, or enter the tentacles, in which they ascend on the side nearer the tip of the lophophore, and descend along the opposite side. In the cavity of the epistome, the fluid streams along the ceiling to its tip and coming back along the floor of that organ, either enters the epistome again, or goes to the tip of the lophophoral arm along its lower side. On the oral side of the polypide, the fluid is always seen flowing downward.

Allman and Hyatt deny the presence of cilia on the external wall of the alimentary canal, but Verworn saw them at the end of the stomach in *Cristatella*. My observations in living specimens of *Pectinatella* confirms the statements of the last author.

Both Allman and Hyatt observed that the cœnœcia of *Lophopus*, *Cristatella*, and *Plumatella vitrea*, readily emptied themselves of their perigastric fluid when taken out of the water. They assumed that the fluid passed out through pores in the endocyst, but they searched in vain for such communications.

It is certain that when a polypide retracts, a portion of the fluid contained must of necessity pass out at some place, since the cœnœcial wall does not expand beyond a very limited extent. Notwithstanding my special attention to this point, *Pect. gelatinosa* also gave no result, and I should prefer to go no further than to assume the presence of external openings in connection with the excretory organs.

4. Excretory Organ (?)

Joliet (6), in a paper entitled "Organe segmentaire des Bryozoaires Endoproctes," gives a pretty full description of two short funnel-shaped tubes in *Pedicellina* and *Loxosoma*, first noticed by Hatschek. In the division Ectoprocta, however, our knowledge on this subject is very limited. As far as I know, the two figures given by Farre, and the remarks by Hincks and Smitt, both of whom do not go beyond conforming the observation of the first, constitute the whole bibliography on this subject. They all noticed a ciliated pipe that opens between the mouth and the anus in *Alcyonidium* and *Membranipora*, both of which are gymnolæmatous. In regard to the order Phylactolæmata, if we except the short account given by Verworn, illustrated with two semi-diagrammatic figures, there exists no literature known to me. Verworn left the terminations of that organ undetermined, confining his attention to only the middle portion where it is most conspicuous. Braem touches on this subject in his note in the Zoologischer Anzeiger, but he too could not determine how the tubes terminate. Such being the case, I have investigated this organ with special attention.

There are two ciliated tubes just beneath the outer layer, on the anal side of the body, between the anus and the bases of the median tentacles of the inner row. The walls of these tubes are continuations of the epithelial lining of the invaginable portion of the endocyst. They open below into the body-cavity by funnel-shaped openings. They measure 0.15–0.19 mm. in length, though the portion where the wall is entire is much shorter (fig. 26 bis. Pl. XVIII). The shape of the funnel-like openings may be compared most appropriately with the obliquely cut end of a hollow tube.

The exact form of these tubes and their relation with other organs will be best undestood by referring to figs. 21–26, Pl. XVIII, which show their cross sections with the neighboring parts at various levels.

In a cross section passing through the middle part of the tubes, we see them as two oval sections lying side by side (figs. 24 and 24 A). The ciliated epithelial wall consists of cells which are cubical near the median plane of the polypide and flat on the opposite side. Consequently both the nuclei and cilia are densely set in the portion nearest the median plane of the polypide and scattered at some distance from one another on the outer side. The tubes are closely enveloped on the anal side by the outer layer of the invaginable tube (*Out. lay.*), and on the oral side by the lining epithelium (*Lin. epith.*) of the body-cavity. The diameter of the tubes measures about 0.03 mm.

Tracing these tubes downward, that part of the wall farther removed from the median line soon disappears. i. e., the tubes open into the body-cavity on that side (fig. 26). As the two tubes deviate from each other below, a part of the perigastric space appears between them (fig. 26, *epistom. car.*) This is the passage by which the cavity of the epistome communicates with the perigastric.

The median side of the wall ends abruptly on the anal side of the ganglion; below this point cross sections show only one continuous body-cavity. Thus, the body cavity is divided into three branches on the upper part of the polypide. The middle one (fig. 26, *epistom. cav.*), passing along the anal side of the ganglion, extends into the epistome, while the lateral ones are prolonged into the lophophoral cavity. The inner walls of these lateral branches pass gradually into the ciliated tubes.

If we now trace the tubes upwards, they are found gradually to approach each other, and their walls soon coalesce. A little higher the cavities of both open into each other, and there is seen a single flattened tube (figs. 23, *Nephr.* & 23 A). The whole inner surface of this part as well as that of the two deviating tubes below, show distinct ciliation in sections, the cilia being always directed toward the perigastric opening. If we trace this flat tube still further upwards, it again becomes divided in most individuals into two, in some into three tubes (figs 22 *t'* & 22 A), each of which is continous with tentacular lumen. In this part, the ciliation is no longer visible, but compared with the inner layer of the tentacles, there are more nuclei. But, further upwards, the nuclei are fewer in number and the lining epithelium presents similar appearance as that of ordinary tentacles (figs. 21 *t'* & 21 A). What can be the function of these ciliated tubes? The fact that they open into the perigastric cavity by ciliated funnel-shaped openings naturally reminds us of the segmental organs of certain worms. And thus many observers have been induced to regard the function of these tubes as being of an excretory nature. If such is really the case, there should be some orifice by which they open outwards, for the high degree of development they attain prove that they are not useless remnants. This makes me venture to assume the existence of minute apertures, at least on the two or three innermost tentacles of the anal side, presumably at their tips, although I am unable to produce any positive proof. The pores, if ever present, must be of very minute size, indiscernible by ordinary methods in a manner analogous to the pores at the tip of Actinian tentacles.

5. Muscular System.

The muscular system consists of five groups of muscles. They are:

a. Muscles of the funiculus.

b. Parieto-vaginal muscles.

c. Retractor of the polypide.

d. Muscular layer of the alimentary canal.

e. Muscular layer of the endocyst.

To these may be added the muscles of the epistome.

The first three are, as development shows, modifications of the last two, which in turn may be regarded as only locally differentiated forms of one and the same layer.

In the development of the polypide in the statoblast, the muscular fibres are formed from certain cells of the granular mass, and, in the process of budding, from the lining epithelium. In either case, the cells elongate, and become spindle shaped, with the nucleus at the middle. They lengthen more and more and the nuclei become indiscernible, although these can often be made visible by the aid of acetic acid. Excepting some fibres of the parieto-vaginal muscles, which remain in this state to the end, the muscular fibres are extremely thin, and do not show nuclei in their interior. It seems that these fine fibres arise by the longitudinal splitting of the original muscle-cells, as is known to take place in many other animals.

The muscles are never striated. Even in the retractor of the polypide, which is obviously of greatest physiological importance, the fibres are smooth. In marine Polyzoa, however, I have observed that the muscles of the avicularia and the vibracula are striated.

The muscular fibres belonging to the funiculus run longitudinally on the inner surface of the basement membrane, on which the cellular wall of the funiculus rests (fig. 31, Pl. XIX). They run separately without forming bundles, and present the same appearance as those of other parts. Their extreme fineness as well as their small number agrees with the fact that the funiculus contracts, if ever, in a very limited degree.

The muscles running between the cystidal wall and the bottom of the invaginated fold (at the junction of the cystidal and the polypidal endocyst) are called the Parieto-vaginal muscles (fig. 4, Pl. XVII, M^{II}). Their fibres run either solitary or in bundles, forming on an average 13–14 sets arranged somewhat radially. Their points of attachment to the cystidal wall is irregular. These sets of muscles cause the presence of the invaginated fold of the body-wall. In *Pect. gelatinosa* when the polypides fully expand, this fold, which is otherwise distinctly present, disappears, the muscles relaxing to their full extent.

The great retractors of the polypide consist of a pair of well developed muscular bundles, right and left in the perigastric cavity (fig. 4, Pl. XVII, M^{III}). The fibres are modifications of the muscular layer of the endocyst, extraordinarily developed to serve their special purpose. The point of attachment of each bundle to the bottom of the cystid is single, but the upper portion is split into a large number of smaller bundles which are inserted into the walls of the œsophagus and the stomach at various places, but most numerously at the upper part of the former. The bundle is ensheathed in a sort of fine sarcolemma, which could distinctly be demonstrated at such places where the fibres were mechanically torn away leaving the sheath uninjured.

In the muscular layer of the alimentary canal, only transverse fibres are well developed, and the longitudinal fibres, if ever there be any, are very scanty. The layer becomes thicker as we approach the blind end of the stomach. The musculature in question performs peristaltic movements, periodically on the œsophageal and fairly constantly on the gastric wall. The blind end of the latter is subject to stronger constrictions in accordance with the thickened muscle-layer of this part. The peristaltic movement of the gastric wall helps not only to move about the contents of that organ, but also to send the residue into the intestine. The muscular fibres of the intestinal wall are especially well developed near the anal opening; they serve to discharge the excrements out of the body and to keep the anus tightly closed. At the point where the blind end of the stomach joins the funiculus, there is no muscular layer (fig. 33, Pl. XIX).

The muscular layer of the endocyst has already been treated under the body-wall. The outer ring fibres are especially well developed around the orifice of the cœnœcial branches and form a sort of sphincter to close the opening produced when the polypides retract. When the polypide is extended, the cœnœcial branch becomes slender by the contraction of the ring fibres, but apparently it is not by their agency that the polypides are pushed out, for this process takes place even in a cœnœcial branch with its wall cut open, so that the fluid contained can transmit no pressure upon the invaginated polypide.

The muscles that move the epistome remain in a very primitive state of development, consisting of loosely distributed fibres which, as already mentioned, are mere elongated cells with the nucleus at the middle. They traverse the cavity of the epistome, joining its underside with the ceiling. As seen in cross sections, they are more closely set near the edge and almost entirely wanting in the central part of the epistome.

6. Nervous System.

This system has been described more or less fully in all works on Polyzoa, but the accounts given are very different from my own observations. Nearly all investigators describe the cerebral ganglion as a solid cellular mass. Nitsche, studying the process of gemmation, states that the ganglion has at first a ventricle, which, however, obliterates with the growth of the animal. Contrary to this statement, Saefftigen (10) recently discovered that in *Cristatella* and *Plumatella*, the cavity of the ganglion persists throughout life, and further that the ganglionic wall is not everywhere of the same thickness, being at some parts as thin as the lining epithelium of the body-wall. I have observed that in *Pectinatella* also the cavity exists in the mature state; it is so very large that at first sight it might be mistaken in sections for a part of the body-cavity.

In fig. 28, Pl. XIX, I have represented the form of the ganglion in *Pectinatella gelatinosa*. It may be compared with a spindle bent somewhat in the form of U, and fitted with its concavity to the anal side of the œsophagus, in rather an oblique position with the arms turned slightly upward. The end of each arm again makes a sharp bend in the anal direction and is continuous with a large nerve trunk which proceeds into each lophophoral arm. The ganglion is in direct contact with the inner cell-layer of the œsophagus, the outer layer of that tube enveloping it on all other sides; the ganglion is in fact situated between the two layers of the œsophagus (fig. 29, Pl. XIX). The lophophoral nerve trunks are likewise located between the outer and the inner cell-layers of the body-wall; they run, namely, immediately beneath the outer layer of the lophophoral ceiling, covered below by the lining epithelium.

As mentioned above, the ganglion is not a solid cell-mass as has been described by nearly all investigators. On the contrary, it contains a spacious ventricle, extending to the end of the arms, or horns, as is diagrammatically shown in fig. 30 *a*, *b*, *c*, Pl. XIX. The wall of the ventricle is very thin and of an epithelial nature on all sides except at the bottom somewhat on the anal side, where it is very thick, forming the ganglion *sensu stricto*,—a condition which reminds us of the Teleostian cerebrum.

This thick portion is distinctly bounded from the thin epithelial part of the wall, and is well seen in the fresh state as a somewhat reddish mass, with a slight constriction in the median plane of the polypide. It is this part that Hyatt took for the ganglion which he describes as composed of two lateral masses united by a very thick commissure. It is no wonder that he overlooked the thin epithelial portion, since this is hardly recognizable in surface views. As can readily be imagined by combining the three sections given in fig. 30, passing through the brain in different directions, the thick portion is a transversely elongate rounded mass, with a transverse slit-like depression, looking orally and upward. The whole mass is not of the same structure throughout, but shows a differentiation into peripheral and central portions. In the former, the nuclei (of ganglion-cells) are densely crowded, while in the latter we see a faintly stained granular mass (Punktsubstanz) containing only a few or no nuclei. The cell outline to each nucleus is not to be seen.

The thin part of the wall of the ventricle differs in nothing from an ordinary epithelium, being composed of a layer of flattened cells. It is continuous with the peripheral portion of the proper ganglionic part. How the nerve fibres, if there be any, pass out from the latter into the nerve-trunks, I have been unable to elucidate.

The cross-section of the lophophoral nerve trunk is kidney-shaped, with the concavity turned above (fig. 31, Pl. XIX, *nerve*). In it the nuclei of nerve-cells are seen much crowded. Longitudinal sections show that the nerve-cells in question are spindle-shaped (bipolar) with the nucleus at the middle, and closely packed together. A few fibres run amongst them; these are probably to be regarded as nerve-fibres. The trunks themselves are very thick and large in comparison with the mass of the central ganglion, and their structure gives the impression of an elongated ganglionic mass rather than of a nerve. The trunk gives off on each side a branch into each tentacle. Such a branch is of fibrous appearance and could be traced only for a very short distance after its departure from the trunk.

The presence of a circumœsophageal nervous commissure in fresh-water Polyzoa is a matter of obscurity, having been accepted by a few and denied by many. My observations on *Pect. gelatinosa* convinced me of its absence.

The colonial nervous system present in many marine Polyzoa, which keeps the action of the members of a colony in harmony, seems to be altogether wanting in this species, as is probably the case in all other fresh-water Polyzoa. Special attention to this point showed no trace of nervous connections between the polypides in preparations of sectioned colonies. The fact agrees with the behavior of the polypides in a living colony, in which only directly disturbed polypides retract, while all the rest remain protruded as if nothing had happened.

7. Ovary and Testis.

Pectinatella gelatinosa has a distinct ovary, although it developes only in very rare instances. When present, it is situated inside the cystid near its tip on the oral side. It is a solid club-shaped outgrowth of the internal lining epithelium, and usually contains ten or more ova in different stages of development (fig. 33, Pl. XIX), the space between them being filled with connective tissue stroma. Ripe eggs can fall into the perigastric cavity only by the rupture of the ovarian wall. The largest ovarian ovum measured 0.35 mm. The length of the ovary is about 0.9 mm., and the breadth 0.5 mm. No doubt can ever be entertained about the ovarian nature of the body in question. That the funiculus has nothing to do with the production of eggs has also been ascertained by Braem for *Cristatella* and *Plumatella*.

As to the testis, my investigations gave no result. I searched for it in hundreds of polypides, but in vain. I once saw something like spermatozoa within the tip of a cystidal branch, but I failed to make it sure. At any rate, true sexual organs are very imperfectly developed in accordance with their secondary importance in the reproduction of this species.

8. Funiculus.

The funiculus is a hollow tubular organ, about 5–6 mm. long, which connects the blind end of the stomach with an opposite point of the cystidal wall. Its wall is composed of three layers, but the innermost one, consisting of a few longitudinal muscular fibres, hardly deserves to be called a layer (fig. 32, Pl. XIX). The outermost layer is the continuation of the outer lining of the alimentary canal or the lining epithelium of the endocyst, from either of which it differs in nothing. The cells of this layer rest on the outside of a tube of basement membrane, which forms the middle layer, and are rather thickly set, every cross section of the tube showing from nine to twelve nuclei. Thus my observations on this organ are identical with and only confirm Nitsche's. Verworn denies the existence of muscular fibres in *Cristatella*. In *Pectinatella* they are decidedly present, although few in number and isolated, so that they are liable to be overlooked if not specially searched for. The outermost layer is the only cell-layer in the wall of this organ. I cannot but assume that Kræpelin had fallen into error in describing the funiculus as made up of two cell-layers, the equivalents of the outer layer and the lining epithelium of the endocyst respectively.

The diameter of the lumen is about 0.02 mm., and the thickness of the wall about half as much.

The narrow lumen of this tubular organ, whose wall must be regarded as entirely mesodermal, is bounded at its upper end by the inner cell-layer (entoderm) of the stomach, and at the lower end, by the outer layer (ectoderm) of the endocyst (figs. 33 and 34, Pl. XIX). It is in this organ that the statoblasts are developed. That the funiculus should not be regarded as the ovary, as was done by some former investigators, is self-evident, at least in the present species as well as in those in which a distinct ovary has been demonstrated in quite another region of the body.

9. The part of the Endocyst that produces buds.

Budding takes place at a certain fixed position as Braem asserts, namely, at a definite area on the oral side of the cystidal endocyst. Here the endocyst is somewhat thicker than other parts of the same wall, and the outer cell-layer and the lining epithelium are clearly distinguishable from each other, as at other places, although no muscular layer intervenes between them. At this place, the cells of the outer layer are wanting in vacuoles and both layers stain more deeply than anywhere else. The area is comparable to the growing point in plants. How the buds arise, shall be treated under a special chapter later on.

B. Reproduction.

In fresh-water Polyzoa, reproduction may take place sexually or asexually in three different ways, as tabulated below :

	Reproduction by		
	1	2	3
	Ovum	Statoblast	Budding
Nature :	sexual	asexual	
Function :	to form primary polyzoöid giving rise to a new colony.		to form a number of new polyzoöids, thus increasing the extent of a colony.
New individual originates from :	one cell	many cells	
The number of body-layers that enter into the formation of the new individual :	one	two.	

By the first mode, an ovum should undergo segmentation, and passing through a series of metamorphosis give rise to a new primary polyzoöid. This mode, however, seems to take place very rarely, if ever, in the present species.

By the second mode, germs enclosed in hard chitinous cases (statoblasts) are produced in the funicular cavity of polyzoöids. They are set free by the decay of the parent colony, and float on the surface of water during winter, sometimes packed in ice. Next summer a primary polyzoöid is developed in each, serving as a foundation for a new colony. Thus, this and the first mode perform the same purpose, in so far as both serve to establish new colonies, and the withdrawal of the latter is supplanted by the great activity of the former.

By the third mode, a certain part of the endocyst adds, by growth in a certain definite manner, new polyzoöids to the primary polyzoöid. This mode of reproduction increases the size and determines the form of the colony.

In certain cases the colony may propagate itself by simple division. For instance, Allman and Hyatt observed that in old colonies of such genera as *Cristatella*, *Lophopus* and *Pectinatella*, all of which have gelatinous ectocyst, the branches separate themselves from the cœnœcial trunk by constriction. In *Pect. gelatinosa*, however, I have never met with the same phenomena. On the contrary, all the colonies collected by me showed no sign of such fissiparity, all of them being entire and of the form characteristic to this species. In most of them, the shell-halves of the statoblast in which the primary polyzoöid has developed were seen sticking to the underside somewhere about the centre.

With regard to the first mode of reproduction, I had no chance of making observations any further than determining the presence of ovaries in certain polyzoöids. The phenomena of reproduction by the remaining two modes shall be treated, for sake of convenience, under the following four heads:

1, Statoblast,
2, Development of the Statoblast in the Funiculus.
3, Development of the Polypide in the Statoblast, and
4, Budding.

1. Statoblast.

The general structure of this seed-like body, differing in shape and size in different species, is now well-known and the following description refers specially to the statoblast of *Pect. gelatinosa.* In winter the dead colony is soon decomposed and the statoblasts contained in it are set free. During winter and spring months, they may be found on the surface of the water in large numbers, clinging to floating logs, bamboo sticks or trunks of aquatic plants. They are of a dark brownish color with a wide marginal zone of a lighter tinge.

Let us take one of them and examine it more minutely. Its shape is, properly speaking, like a flat lens. The outline, as it lies flat, is quadrate-oblong, about 1.5 × 1.3 mm., and about 0.3 mm. in thickness. I may here mention that this species has the largest statoblast among all known Phylactolæmatous Polyzoa. It presents double curvature after the manner of a saddle (fig. 5, Pl. XVII). For conveniences sake, we may call that side on which the longer axis is convex as the "convex surface," and the opposite side as the "concave surface," although these terms do not hold good with regard to the shorter axis. On both sides, the whole surface is beautifully marked into hexagonal areas, more distinct in the marginal zone than in the central portion. The extent of the central darker area is various in different statoblasts, and it may also differ on different sides of the same statoblast. Generally it ranges from 0.5 mm. to 0.6 mm. in diameter.

Closer examination shows that what appeared as a distinctly reticulated marginal area is a sort of broad rim around a chitinous body of compact nature. This rim consists of a number of prismatic caskets filled with gas, the diameter of the caskets increasing as we approach the margin. The hollow caskets have their axis vertical to the plane of the statoblast and are arranged in two horizontal layers. They serve as a buoy to float the central body, which is the most important part of the statoblast.

If the free edge of this rim, or the annulus as it is called, be examined under a strong power, we see a great number of minute hooks projecting from it (fig. 35, Pl. XIX). They are found most abundantly where the margin is somewhat angular. Some of them are complex, while others are simpler, but all are formed by the combination of simple hooks in various ways. They are mere outgrowths of the edge of the annulus, and have no direct connection with the central body, as is the case in *Cristatella* and *Pect. magnifica*. They are short and stout, and the tips are rounded. They measure about 0.02–0.03 mm. in length and are too minute to be of much functional importance. When the annulus splits horizontally, as it does of itself when the polypide begins to develope within, these spines are found only on the margin of the concave side.

The curvature of the annulus and the presence of hooks on the free edge seem to be worth careful consideration. In all statoblasts, the annulus serving as buoy performs an effectual service in distributing the species as well as in enabling the establishment of colonies near the surface of water. Where the annulus shows curvature, the distributive power is evidently enhanced, exposing its curved surface to the influence of the motion of water, or, if dried up, of wind. As to the hooks I have no doubt that, as Kraepelin has said, they serve as anchors to secure attachment for the colony that is to grow. At the same time they must be looked upon as assisting distribution to a great extent. By their means, for instance, the statoblasts have a chance of clinging to the feathers of some water-birds or to floating logs or weeds and of being carried away to distant localities. The strongly developed hooks on the statoblasts of *Cristatella* or of *Pect. magnifica*, in which the annulus is but weakly developed and cannot serve more than as a mere buoy, may perhaps have in this respect a great importance. In the present species, the extreme insignificance of the hooks as distributing organs is probably sufficiently counterbalanced by the extensively developed annulus with its double curvature, so marked a feature of this as compared with all other species. Braem regards the hooks as protective organs, but as such they can have no great value in the case of *Pect. gelatinosa*.

The annulus, as studied on sections (fig. 46, Pl. XIX), is made up as usual of two horizontal strata, each consisting of a single layer of upright hollow prisms which remind us of cells in a honeycomb. The central part showing indistinct reticulation in surface-views proves to be the exposed surface of a thick chitinous capsule of spheroidal shape (*centr. caps.*). This central capsule is made up of two watch-glass like valves tightly apposed with rims, the demarcation between them being visible as a faint line. The wall is composed of two distinct layers of chitin, which may be called the outer and the inner stratum respectively. The outer is darker in color, and by far the thinner of the two. This stratum is the continuation of the chitinous wall of the annulus, and its exposed surface is raised into low ridges that form a network with hexagonal meshes.

The thick inner stratum of the chitinous capsule looks bright yellow on sections. Directly beneath this capsule, there is a membranous envelope (*env. membr.*) distinctly composed of flat hexagonal cells with centrally situated small nuclei. This cellular envelope completely encloses a granular mass of protoplasm (*gran. mass.*) in which are scattered minute nuclei. These nuclei measure only 0.001×0.003 mm. in average, and are thus several times smaller than the nuclei of body tissues. They are very flat with their plane parallel to that of the statoblast.

The granular contents and the cellular envelope form the essential part of the statoblast, while the chitinous capsule, the annulus and the marginal spines are all accessory organs for its preservation and distribution.

2. Development of the Statoblast.

The knowledge of the origin of statoblast is certainly of vital importance in determining the true nature of this gemmule-like body, but in the rather scanty literature on this subject the statements given are widely different from one another. As to my own observations, I have seen in the lumen of the funiculus sometimes a single cell and at other times a loose group of two or more cells, representing the earliest stages of development of statoblasts. They are round in outline, and each supplied with an oval nucleus. Neither in size nor in general appearance do they perceptibly differ among themselves, or from those of neighboring tissues. This circumstance deprives me of all grounds to share Verworn's view that the increase of cells is due to continued division of an originally single cell. This author sums up the earliest steps in the development of a statoblast in the following words: An einer bestimmten Stelle des Funiculus vermehren sich die Epithelzellen desselben zu einer kleinen Aufschwellung and drängen dadurch gegen das Lumen. Eine Zelle davon tritt in das Lumen hinein and wird zur Eizelle, während die anderen sich zu einen Follikel formiren. Die Eizelle macht einen regelmässigen Furchungsprocess durch, dessen Resultate eine solide Morula ist. Wie man sieht, wird also auch durch diesen Furchungsvorgang die Knospennatur der Statoblast widerlegt." Hence he concludes: "Die Statoblasten sind als parthenogenetische Wintereier aufzufassen welche sich im Gegensatze zu befruchteten Eiern am Funiculus entwickeln." I did not find this view corroborated by facts. Neither the thickening of the funicular epithelium nor an "Eizelle," which to judge from his figures must have been several times larger than any ordinary cell of the funiculus, could be found.

On the contrary, what I have seen in *Pectinatella gelatinosa* leads me to the conclusion that each statoblast originates from at least eight cells of separate derivation. Where they come from is a question which I cannot answer from direct observation. However, that it receives no element from the entoderm is evident from the fact that where there are many statoblasts in the same funiculus, the older ones always lie nearer the stomach, completely shutting up the passage. The question then reduces itself to whether the original cells are derived from either the funicular wall (mesoblast) or the outer layer of the endocyst (ectoblast) at the point where it bounds the funicular cavity below, or from both. As will be seen later on, the intrastatoblastic development of a polyzoöid essentially agrees with the process of development by budding, differing only in such points as are necessitated by the mechanical conditions of each case. Wes hould then expect similar elements in the "anlage" of a statoblast as in a bud, that is, both the funicular wall and the outer layer of the endocyst should *a priori* give their contingents to form a statoblast. The correctness of this assumption is proved by the observations of Braem (Zool. Anz. 1889.). According to this author, the primitive statoblast consists of two kinds of cells, which are genetically different, one deriving itself from the funiculus and the other from the ectoderm. It is needless to say that in the above light, a statoblast cannot be anything else than a specially modified form of bud, in other words, a portion of both layers of the endocyst protected against severe climate by special contrivances for the preservation of the species.

But to return to the process of development, a certain number of cells, probably from the two sources referred above to, assemble in the funicular lumen and arrange themselves into a group at first loose and irregular. During this early stage, the funicular wall nowhere shows thickening, contrary to Verworn's observations. Very soon the group becomes compact and assumes a morula-like form. It can now be safely asserted that new additions of cells no longer take place, but that the morula henceforth increases in size by multiplication of its own cells. The mass bulges out the funicular wall as it enlarges.

Arrived at a stage when the morula measures about 0.05 mm. in diameter, a certain number of cells (8–12 as seen in equatorial sections) on one side of it form a special group (fig. 38, Pl. XIX), at first very indistinctly distinguishable from the rest of the cells. Gradually, a small cavity appears in the centre of that spherical group of cells which are steadily increasing, changing it into a hollow, rather flattened sphere with distinct epithelial wall. This hollow sphere is the "cystogene Hälfte" of German authors, so called on account of its giving rise to the chitinous covering of the statoblast, and the remaining mass of cells constitutes the "Bildungsmasse." According to my observations, these two portions are not morphologically distinguishable from each other at a very early stage, but become secondarily distinct. This is also the view held by Nitsche and Verworn, while Braem saw them originate sharply separated from the outset in *Cristatella*. According to the last-mentioned author the cystogenous sphere, which consists solely of cells of ectodermal origin, is the first to form and to this is added the Bildungsmasse by proliferation of (mesodermal) cells of the funicular wall. Provided that in either case the two portions are respectively ectodermal and mesodermal products, it would be of but secondary importance whether they are distinct from the beginning or become outwardly indistinguishable for a time. More study of this point is exceedingly desirable.

Further history of the development corresponds in the main with what is already known. The cells of the two portions are constantly increasing in number and the entire mass in size. Meanwhile, the cystogenous cells attain the character of columnar epithelium; the whole cystogenous sphere flattens, and soon takes the form of a shallow watch-glass, the internal cavity disappearing (fig. 40, Pl. XIX. *cyst. c.*). We may speak of it as the cystogenous cup. The concavity of the cup grows deeper, always closely clasping the mass of the remaining cells. i.e., the "Bildungsmasse." The cells of the latter begin to present a granular appearance by the deposition of refractile spherules in the protoplasm, comparable in nature to the deutoplasm of eggs or of yolk-cells in Plathelminthes. Braem could not convince himself of the truth of Nitsche's and Verworn's opinion that the granules are direct products of the nuclei; nor could I find any support to this view. About this stage, the cells in question assume a spindle-shape, the axis standing vertical to the cavity of the cystogenous cup (fig. 39, Pl. XIX, *gr. m.*). This state was also noticed by Braem in Cristatella. However, as the granulation advances, they become rounder again, until each cell is represented by a globular mass of granules with a nucleus at the centre (fig. 41, Pl. XIX, *gr. m.*).

As the cystogenous cup grows in size, its rim begins to close around the granular cell mass. This occurs after the latter has almost attained its maximum size. In the meantime, a thin sheet of chitin is secreted between the two layers of the cystogenous cup; it is difficult to say whether it is the product of one or of both layers. This chitinous sheet subsequently attains considerable thickness. We may speak of it as the chitinous cup, as it has that shape along with the cystogenous cup. As the latter expands, its mouth narrows and the whole body of the young statoblast somewhat flattens, taking the form of a spheroid, the axis of which corresponds with that of the cystogenous cup. The two layers of the cystogenous cup were at first of the same thickness, but now the outer begins to thicken by the increase in height of its cells while the inner undergoes a contrary change. The cells of the latter begin to flatten first at the bottom-portion of the cystogenous cup.

Along the equatorial line of the spheroidal mass, the outer layer of the cystogenous cup is thrown into a fold, which encircles the young statoblast belt-like all around. The belt becomes more and more extensive, and consists, as seen in sections, of two closely opposed strata of cylindrical cells.

Meanwhile, a second chitinous layer is formed over the chitinous cup already present. Thus, the chitinous cup comes to consist of two layers; the outer of which is by far the thinner. Simultaneously and directly continuous with this outer chitinous layer a thin plate of the same nature is also deposited between the two epithelial strata of the belt. It may conveniently be designated the belt plate.

The elongated prismatic cells of the outer cystogenous layer, secrete around their basal ends thin chitinous wall continuous with the belt plate or the outer chitinous cup, on which they all sit. They thus bring forth hexagonal caskets open at one end, into which every one of them abuts with their bases. But the wall of these cells does not develope everywhere to the same extent. It keeps very low on the exterior of the bottom of the cystogenous cup, and when the cup closes into a complete capsule, as it does later, the same condition is also seen on the opposite side, so that on a mature statoblast the polar surfaces show only a network of very low ridges. However, on both sides of the belt plate and of the capsular surface immediately adjoining them, the chitinous wall of cells attains considerable height, but never reaches the surface of the cell-layer. The open ends of chitinous tubes thus formed are finally closed by the formation of what is called the lid-plates. This process proceeds on the one hand centrifugally from the outer layer of the chitinous cup, at a line which circumscribes the reticulated polar area, and on the other in the opposite direction starting from the marginal edge of the belt-plate, so that the tubes on the midway are closed last. A glance on figs. 43–46 will make the matter clear at once. Moreover, the lid-plates divide the prismatic cells on either side of the belt-plate into an outer and an inner portion. The latter is completely enclosed in chitinous caskets, while the former conjointly with the epithelium covering the polar area invests the entire outer surface of the young statoblast. This investment is to be seen as long as the statoblast remains at the place of its development, but decays when the latter is set free by the dissolution of mother-polypides. As the lid-plates are developing, the marginal spines appear. Also at about this stage, the closure of the mouth of the cystogenous cup takes place. It thus completely encloses the granular cell-mass, followed by closure of the two layers of the chitinous cup, which then is turned into a perfect capsule. After this, the two polar areas present no point of structural difference.

The portion of the prismatic cells that are enclosed within the chitinous wall soon undergoes decomposition and gives place to a gas filling up the caskets. Thus the formation of the swimming-belt is complete. Nitsche's statement that the cells evacuate the caskets before their closure is probably an error.

As already said, the inner cystogenous layer thins out by the flattening of its cells, and when the chitinous plates completely inclose the granular mass it forms a thin epithelial covering to the latter directly within the central capsule (figs. 42–46, Pl. XIX, *Enc. m.*). The size of the nuclei becomes smaller as the height of cells decreases, and reaches at last the dimensions given before when the mature statoblast was described. The cells of this membrane are distinctly bounded and hexagonal in shape.

Returning to the stage represented in fig. 41, the granular spheres, composing the mass contained within the cystogenous cup, have each a centrally placed nucleus, and growing larger (fig, 42, Pl. XIX.) press upon one another so that they assume a polyhedral form. They remain distinctly bounded as long as the rim of the chitinous cup remains open, but fuse together after the latter closes. It is a singular fact, that in some statoblasts, either the granular mass is produced in over-quantity, or the capsule formed is too small, so that a portion of the mass is left outside the statoblast as the capsule closes, afterwards disappearing.

The nuclei of the granular mass become smaller as the development of the statoblast advances. Arrived at a stage represented in fig. 42, Pl. XIX, the nuclei almost lose their peculiar chromatin reaction, and stain very faintly, so that in some preparations it is very difficult to detect them. This condition, however, lasts for a very short interval, and in all the later stages the nuclei are again distinctly visible. This peculiar behavior of the nuclei may have lead Verworn to assume that the granules are the product of the splitting of nuclei and that the latter as such are not found after the complete development of the granules.

The statoblast at the earliest stage of its development is of a milky-white color. The chitinous parts as they form themselves at first present light yellow color, which, as the development advances, darkens to the characteristic hue of the mature statoblast.

On attaining a certain size, the statoblast bulges out the funicular wall chiefly on one side, with its plane always parallel to the axis of the funiculus. When many statoblasts develope in the same funiculus, they generally lie alternately disposed, by which means economy of space is effected. It is on that side of the statoblast with which it joins the funicular tube that the cystogenous cup closes.

The number of statoblasts that develope in a single polyzoöid is usually five or six, in some cases as much as eight. Of these, the uppermost one is the oldest and the lowest the latest formed, so that at a certain period statoblasts in various stages of development in serial order may be seen in the same funiculus. In those old polypides that occupy the central part of a colony all the statoblasts usually attain maturity, while in the peripherally situated younger polypides the latest formed statoblast is generally still in quite an early stage of development at the time when the colony begins to dissolve away. These immature statoblasts undoubtedly suffer common decomposition with the mother-colony. As every polyzoöid produces statoblasts, their number in the entire colony is really very great. Once I counted no less than 870 statoblasts in a very small colony of about 1.5 cm. in diameter.

3. Development of the Polyzoöid in the Statoblast. *

As the mature statoblast floats on the surface of water, the belt-plate of the annulus splits horizontally, so that the shell may now be said as being composed of two valves. These however remain tightly apposed during winter. On the arrival of warm temperature, they separate from each other, but holding the whitish contents between. The two valves have then very much the appearance of a pair of cymbals. The separation takes place at a stage when no change is yet perceptible in the contents ; hence I am inclined to ascribe its cause to some external influence rather than to internal pressure.

The contents of the statoblast, i. e., the granular mass with its enveloping epithelium, form a spheroidal mass. All along the outer margin or the equator of the spheroid, where the separation of the shell-valves has brought it in direct contact with water, the enveloping epithelium becomes thicker (figs. 48, *Out. lay.* and 48 A, Pl. XX.), owing to increase in height of cells, accompanied by great increase in size of the nuclei, which are now as large as those of grown-up polypides. The process of thickening thus begun at the equator proceeds gradually toward the two poles of the spheroidal mass, so that the membrane thickens latest at these places.

Meanwhile, the cells at two opposite areas on the equator become especially taller, so that the enveloping membrane acquires a marked thickness at these places. The areas in question are oblong

* After finishing the manuscript of this paper, I received No. 324 (1889) of the Zoologischer Anzeiger containing Braem's preliminary report entitled "Die Entwickl. d. Bryozoen-colonie im keimenden Statobl." His statements differ in many fundamental points from mine. There is sufficient ground to assume that very considerable variation of development obtains among different species of Polyzoa.

in shape, lying with their long axes along the equator, although no sharp boundary can be fixed. From an early stage, they show differences in the appearance of their cells and take quite different directions in their future development. The axis joining the centres of these areas corresponds, as will be seen later on, with the longitudinal axis of the future polyzoöid. With regard to the relation of this axis with the longer or shorter axis of the statoblast, there seems to be no constant rule, although in the majority of cases the former corresponded with the shorter axis of the statoblast.

In one of the two areas, the cells acquire distinctly cylindrical form, and vacuoles are formed in some of them. In fact, they soon take the form and character of the cells of the outer layer of the endocyst. They begin to secrete gelatinous ectocyst of a sticky nature, by which means the germinating statoblast attaches itself to anything it may meet with, be it the wall of an aquarium, floating wood, or shells of other statoblasts.

The other area gives rise to the polyzoöid. Its cells are of less height and vacuoles develope in them later than in the other area, At about the middle point of the area, the cells multiply, and a group of them sinks into the granular mass below, forming a solid club-shaped body, which a little later on becomes hollow by the retreat of its cells toward the periphery. We have now a hollow closed sac bounded by an epithelial layer of cells and connected with the superficial thickened area by means of a very short solid stalk (fig. 49, Pl. XX). Soon after, the latter also acquires a lumen, and the cavity (fig. 49, Pl. XX. *prim. l.*) of the hitherto closed sac comes to communicate with the exterior. Some cells of the granular mass lose a part of their granules, and arrange themselves into a sort of layer on the outside of the sac (fig. 49, Pl. XX. *Lin. epith*). The nuclei of these cells become larger as the granules lessen in quantity, and approach those of ordinary cells in size and appearance. The outer limit of this layer is by no means definite, gradually losing itself in the granular mass.

As the sac elongates, it becomes constricted at the middle, dividing into an outer and an inner chamber. The constriction between the two chambers is the future mouth, and the inner chamber represents the future oesophagus and the stomach. The outer chamber soon acquires the form of a hollow cone, at the base of which the mouth opens and which tapers towards the outer opening. At the base of this conical chamber the epithelium is especially thickened and eventually gives rise to the lophophore and the tentacles, the chamber itself being the tentacular sheath. The investing layer derived from the granular cells (*lin. epith.*) become more and more conspicuous, and lines the entire outer surface of both chambers.

The lophophore is at first a semicircular ridge, clasping the mouth on that side which corresponds to the original bottom of the cystogenous cup (convex side). The ridge arises by the folding of the wall, in which process both layers are concerned. The ends of this semicircular ridge are prolonged in the form of free finger-like processes, the rudiments of lophophoral arms. The interior of the lophophoral rudiment is occupied by the granular mass as soon as it is formed. The developing polypide lies on its anal side when the statoblast is placed on its concave side.

Another constriction divides the lower chamber into the oesophagus and stomach. The stomach begins to send a hollow process upward to form the intestine (fig. 51, Pl. XX. *Intest.*).

The free edge of the lophophoral rudiment is divided into a series of knobs, which are conspicuous nearer the median line, becoming gradually smaller towards the tips of the arms. These knobs are the origin of the outer row of tentacles. In the meanwhile, a second ridge running parallel with, but less extensive than, the first one, developes on the anal side of the mouth. Its extremities soon meet and fuse together with the limbs of the first-formed semicircular ridge. Tentacles are formed on the new ridge in the same way as described above; the range of their row extending on either side to tips of lophophoral processes. Thus the inner row of tentacles is established on the lophophore.

The hollow process sent up by the stomach grows larger, and finally its cavity opens into the upper chamber or the tentacular sheath, which, when evaginated, forms the tubular body of the polypide.

The account given above may suffice to show how the general shape of a polypide is formed in the contents of a statoblast. In the meantime rudiments of many other organs, of which the brain, the muscles, and the funiculus are the most important, have begun their development.

The cerebral ganglion arises as a pit-like invagination of the inner layer of the oesophageal wall, which is continuous with the outer layer of the body-wall. The process begins to take place at a stage when the stomach sends up the process that afterwards becomes the intestine, on the anal side of the oesophagus, just inside the mouth. The invagination is soon constricted off, turning it into a closed sac, which as it is being formed, carries with it the outer layer of the oesophageal wall, so that the latter invests it externally, at the same time connecting it with the oesophagus. The cavity of the sac persists as a sort of ventricle. The lower portion of the wall of the sac early begins to thicken, which process does not of course concern the investing layer, and finally developes itself into that portion which constitutes the main ganglionic mass (vide p. 115). The remaining portion of the sac-wall, except at two points, becomes thinner and thinner as the entire ganglion increases in size. The two exceptional points just referred to, are where the sac-wall produces a pair of solid horn-like processes, each of which gradually elongates towards the tip of the lophophoral arms, passing between the two layers of their ceiling. The position of the lophophoral nerve-trunks directly beneath the outer layer led me at first to assume their origin from the latter, in a way analogous to the development of the central nervous system in vertebrates. A careful study, however, convinced me that such is not the case.

At the time when the intestinal cavity becomes continuous with the exterior at the anus, the whole body-cavity is still filled up with the granular mass. Some of the cells of the latter are seen to differentiate themselves from the rest, at two regions as seen in a median sagittal section (fig. 51, Pl. XX.), the one extending between the involuted tentacular sheath and the cystidal wall, and the other between the lower part of the oral side of the oesophagus and the part of the cystidal wall opposite to it. At these places, the cells lose their granules, elongate, and become spindle-shaped joining the two points between which they lie. Their further development has been already treated under the muscular system. The muscles that develope in the above mentioned regions are the parieto-vaginal and the retractors of the adult polypide respectively. The muscular layer of the endocyst and the alimentary canal developes itself later, probably from the cells of the lining epithelium in a similar way.

Almost simultaneously with the first appearance of muscles, the cells of the granular mass lying between the blind end of the stomach and the coenoecial wall opposite to it, lose a portion of their granules, and aggregate into a solid rod, which is, in sections of stained specimens, readily recognizable on account of the deeper coloring of its cells in contrast with the surrounding faintly colored granules.

Afterwards, what remains of the granules in these cells is entirely absorbed, and a lumen is formed inside the rod, converting it into a tube, the rudiment of the funiculus. Thus, it will be noticed that both the muscles and the funiculus are produced *in situ* from the granular mass in the statoblast.

When the development of the polypide is complete, two buds are already present on the oral side of the cystidal wall, one on each side of the median plane. These buds are first seen in the stage when the intestine is still blind. The manner of their development will be treated under the budding.

As noticed before, the granular cell mass compactly fills up the entire body-cavity until after the formation of all the important organs of the polypide. The cells then loosen themselves, as the consequence of the decrease of granules, which are being constantly used up, while the enhanced growth of the cystidal wall makes the body-cavity more and more spacious. When the young polypide begins to evaginate and expand their tentacular crown, naked conglomerates of granules, each with a nucleus at the centre, are seen scattered in the body-cavity. Mixed with these conglomerates, we see some others which have obtained a distinct wall, with the nucleus pressed against it. In a somewhat later stage, the granules are no longer visible in those cells with peripherally situated nuclei ; instead of them we see a large vacuole in each cell, which has thus acquired the characters of what I have proposed to call blood-corpuscles.

It is perhaps worth noticing that the developing polypide carries the shell halves on the anal and the oral side of its body, presenting an appearance comparable to the condition of shells in Brachiopods.

4. Budding.

This mode of reproduction in Polyzoa has been studied by numerous investigators, but their opinions are more or less divided, especially as to the origin from which the bud receives its hypoblastic elements, and consequently, with regard to the relations of the germinal layers. Most of them derive the hypoblast from the outer layer of the endocyst, while a few are inclined to believe that the bud receives it from the gastric organ of the mother polypide.

According to Allman (1), who describes the process of budding in *Lophopus* and *Alcyonella*, the outer layer of the endocyst gives rise to all the lining cells of the alimentary canal, while the lining epithelium of the mother polypide becomes also the lining epithelium of the bud.

Metschnikoff (7) gives an account of budding in the embryo of *Alcyonella*. He found that after continued segmentation of the egg, the cells arrange themselves into a two layered hollow sphere, both layers of which enter into the constitution of the bud, the outer giving rise to the outer layer of the tentacles, the inner lining of the alimentary canal and probably also to the nervous ganglion, and the inner, to the lining epithelium and all the muscles.

Nitsche (8) studied the process of gemmation in *Alcyonella fungosa* and *Cristatella mucedo*. In both species, the wall of the alimentary canal is formed from a part of the endocystic invagination of the mother polyzoöid. In other words, the lining layer of the alimentary canal is derived from the outer layer of the body-wall. Both Metschnikoff and Nitsche regard the outer layer of the endocyst as the ectoderm and the inner as the entoderm.

Hatschek's (4) account of budding in *Cristatella* is as follows. A hollow sac lies directly beneath the outer layer, invested by the inner layer of the body-wall on its inner side, at the position in which the buds are constantly developing. When a bud is to be produced, a portion of this sac is constricted off and gives rise to the inner layer of the alimentary canal, while all other parts of the young polypide are formed by an invagination of the body wall. Thus, the sac is being constantly constricted off, as long as new buds are added to the colony.

Reinhard (9) studied the first budding in the embryo of *Alcyonella fungosa* and *Cristatella mucedo.* The cells formed by the segmentation of the ovum produce a true gastrula by invagination. The blastopore, however, soon closes. The gastrula is comparable in all respects to the type of some other animals, and, therefore, he regards the inner layer as the entoderm. In the development of the bud, the entodermal cells seem to push into a certain thickened portion of the ectoderm, and form a part at least of the wall of the alimentary canal.

Salensky (11) also states that the outer layer of the zoœcium (cystid) gives rise to the lophophore and to the internal cells of the digestive tract, while the inner layer becomes the lining epithelium of the new polypide. He believes that the entoderm of the alimentary canal originates from the ectoderm of the zoœcium.

Haddon (3) who studied the gemmation of some marine Polyzoa, came to the conclusion, on theoretical grounds rather than from actual observation, that the alimentary canal is derived from the entodermic tissue of mother polypides.

To the position and the order of budding, the previous workers seem to have paid but little attention, except Bræm who dwells on the matter at some length. To this author we owe much of the exact knowledge of the process of budding. As will directly be seen, the process of budding takes place at certain definite polyzoöids and in a certain definite manner, thus determining the shape of the colony so characteristic for each species. What Bræm describes for Cristatella on this point does not apply in all its details to the present species.

At the place where buds appear, there is no muscular layer, as already observed by Nitsche, and the endocyst may here be represented as consisting of only two layers, viz. the outer cell layer and the inner lining epithelium. The latter, in direct contact with the former, passively follows all the changes in form undergone by the outer layer of the endocyst. So, it must be borne in mind, that when in describing different stages of budding, the changes of the outer layer (which is the inner layer of the bud as will be seen further on) alone are mentioned, similar changes are repeated by the lining epithelium (the outer layer of the bud).

At first, some cells of the outer layer push their way inward in the form of a solid knob covered by the lining epithelium (fig. 57. Pl. XX). At a certain observed stage in which the knob consisted of eighteen cells, many more were on their way of entering.

A cavity ultimately appears in the centre of the knob (fig. 58, Pl. XX.) and the cells arrange themselves regularly around it in epithelial order. The cavity soon comes to communicate with the exterior by means of a canal formed by the gradual retreat of cells at that part (fig. 59. Pl. XX.). The bud now represents a double-walled sac whose inner and outer layers are respectively continuations of the outer and inner layers of the endocyst. Thus it is plain, that the bud originates not by direct invagination of the two layers of the endocyst, but by the formation of a closed sac which secondarily opens outward.

As the bud grows in size, it inclines downwards and its oral side is connected to the cœnœcial wall along its whole length by a mesentary-like membrane which is the continuation of the lining epithelium. A glance at fig. 56, Pl. XX. will make this clear. The middle portion of this mesentery-like membrane becomes thinner, and is finally perforated as shown in fig. 57, Pl. XX. The sac is then joined to the cystidal endocyst at two points, viz. at its opening and at the bottom. Rudiments of new buds are produced in the region lying between these two points, which separate more and more from each other.

The solid rod-like part of the lining epithelium which now joins the bottom of the sac-shaped bud with the cystidal wall, is the rudiment of the funiculus. It gradually lengthens, and a lumen is secondarily formed in it, turning it into a tubular organ. It grows in size, and with the early appearance of scanty muscular fibres inside its cavity the development of the funiculus is complete. Thus the result of my observations on the formation of this organ seems to agree essentially with that of Bræm (2) who describes the process in the following words: "In der Mediane erheben sich die Zellen des äusseren Blattes in Gestalt einer an der Oralseite der Primärknospe herablaufenden Längsleiste, welche seitlich von den Fortsetzungen der Magenfalten begrenzt erscheint. Indem sich die Zellen des Knospenhalses dann nach vorn umschlagen und an der Bildung des Integuments betheiligen, löst diese Leiste sich von dem Muttergewebe, welches hinter ihn zusammenfliesst, als selbstständige Strang los und verdindet einen oral und median vor dem Primärknospe gelegenen Punct der Leibeswand mit dem Grunde des Knospensackes."

A constriction is formed in the middle part of the sac-like bud, dividing it into two chambers. The constricted opening is the mouth of the future polypide, and the lower chamber developes into the alimentary canal. The upper chamber becomes somewhat conical in shape tapering toward the orifice of the bud. At the basal disc of this chamber, where the mouth is situated, the cells of the inner wall are prismatic while elsewhere they are flat.

We now recognize all the parts that we have seen at a certain stage of intrastatoblastic development. The lophophore with its tentacles, the nervous system and the intestine, all develope just in the same way as described in the previous chapter. One important difference exists in this, that in the one case the lining epithelium is produced from cells of granular mass, while in the other it is the result of the increase in extent of the same layer of the mother cystid. It will be noticed from above statements, that the entire inner layer of the alimentary tract is derived from the solid knob sunk in from the outer layer of the endocyst. The hollow process (the intestine) sent up from the stomach meets with and opens into a pit sent in from above outside the tentacular area, on the side turned toward the centre of the colony. The lophophoral arms of every individual always project toward the anal side of the polypide; consequently they are all directed toward the centre of the colony.

While new polypides are thus being developed, their cystids are also growing in size, and some cells of its lining epithelium gradually give rise to the muscular layer. At first, when the young polypide is still represented by a simple sac, the portion of the mother cœnœcium around its orifice is only slightly elevated above the rest of the wall, but as the growth of the polypide advances, it becomes more and more prominent, growing in such a manner as to form at last a cell for the young polypide.

The retractor muscles of the polypide begin to appear when the bud is still a simple sac, shortly after the formation of the rudimentary funiculus. At the point of junction of the rudimentary polypide and the cœnœcium, some cells of the lining epithelium becomes differentiated from the rest by assuming a spindle-shape. These cells gradually separate from their mother-layer and form two loose bundles which join the cœnœcium with the middle portions of the now two-chambered bud. The parieto-vaginal muscles also originate in a similar way, but at a considerably later stage, when the lophophore already shows a certain number of knob-like tentacles at its median portion. Thus, in the process of budding, both the funiculus and the muscles are developed as differentiations of the lining epithelium.

The young polypide, as it first evaginates, is a very pretty little animal with less than thirty tentacles. The more medianly situated tentacles are best developed, while they are yet knob-like nearer the tip of the lophophoral arms, where new tentacles are being added by degrees.

The buds arise on the marginal cœnœcial branch alone, on the side facing away from the centre of the colony, i.e., on the oral side when we take the polypide into consideration. They always develope in pairs, one on each side of the median plane. Hence the dichotomy of the cœnœcium, with a polypide-bearing branchlet at each axil. The colony as a whole is consequently fan-shaped at first. With continued budding, it grows toward the periphery, its radius lengthening in arithmetical, and the marginal line in geometrical ratio. The two extremities of the latter soon touch each other in a complete circle; after this the growth of the colony throws its marginal line as well as its hitherto flatly expanded surface into folds, which make the regular arrangement of polypides unrecognizable at a glance.

The upper series of diagrams in fig. 62, Pl. XX, show early stages in the development of a colony, each circle indicating an individual. These figures represent for sake of simplicity each individual as giving off only two buds at a time, and each of these buds again performing gemmation after some time. In reality, however, such is not the case. On the contrary, we usually see in an actively budding individual at the margin of a colony, not only buds of the first order but also those of second and third order already formed. Buds of the first order are present, as already stated, in a single pair, while those of the second occur in two pairs, and the next order, the most rudimentary, in four pairs. When the buds of the first order have grown sufficiently to be regarded as new individuals, those of the second and the third order occupy the grade of the first and the second order, while those of the third order arise anew. A comparison of the lower series of diagrams in fig. 62. with the upper series will help to make the matter clear. The blackened spots in the lower diagrams show the gemmiparous portion of the endocyst. This spot might appropriately be compared with the growing point of plants. With the growth of the colony, it advances centrifugally, splitting dichotomously at regular intervals. In this way, the colony grows as long as the condition is favorable.

It need scarcely be pointed out that the development of the first polyzoöid in a statoblast essentially agrees in process and condition with that of later polyzoöids by means of budding. In fact the first polyzoöid is similarly budded off from the statoblastic contents, the whole of which is to be seen in the light of a primary cystid derived of and containing all the essential elements of cystids of the previous year. Whereas in marine forms the cystids winter as such, those of fresh-water forms persist only in the form of statoblasts to germinate in the following year as do the perennial cystids of the former. In the budding of fresh-water Polyzoa, a cystid and a polypide are formed simultaneously and an intrastatoblastic primary cystid is to be considered as a particular sort of bud in which the formation of a polypide remains latent until the next year.

With regard to relations ef germinal layers in a primary cystid, all the granular cells of the "Bildungsmasse" might with propriety be called the mesoblast on grounds of their genesis and of their future history. For the same reasons, the enveloping epithelium might be looked upon as the ectoblast except at the growing point, i.e. where the buds are formed. At this point the cells are still in undifferentiated embryonal condition comparable to cells of a blastula which differentiates into Ectoblast and Entoblast for the first time at its invagination. As the colony grows, the growing point of the primary cystid is split and transmitted into each succeeding bud, very much like the growing point of a plant; in other words all the growing points seen in marginal polyzoöids of a polyzoan colony have started. I believe Bræm is of the same opinion. Considering, on the contrary, the outer layer of the ectocyst at the growing point as strictly epiblastic, the conclusions, to which Nitsche, Joliet, Salensky, &c. were led, that no hypoblast enters into the bud and that it is formed as a secondary product of the epiblast, are certainly unavoidable. But such a conclusion does not accord, as was pointed out by Haddon, with the generally accepted nature of budding in the animal kingdom. In my opinion the budding in Polyzoa is only so far exceptional as the Epiblast and hypoblast take part in an undifferentiated embryonal condition.

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Explanation of Plates.

Plate XVII.

Fig. *1.* A small group of colonies. nat. size.

Fig. *2.* A polypide. × 10.

Fig. *3.* Shape of the cœnœcial endocyst.

Fig. *4.* Diagrammatic representation of a polypide and a portion of the cœnœcial endocyst.

Tent. Tentacles. Epist. Epistome.
N. Gang. Nervous ganglion.
Oesoph. Oesophagus.
Invag. tube. Invaginable tube.
Over. Ovary. Stato. Statoblast.
M. I. Muscles of the funiculus.
M. II. Parieto-vaginal muscles.
M. III. Retractor of the polypide.
M. IV. Muscles of the gastric wall.
M. V. Muscular layer of the endocyst.
M. VI. Muscular fibres of the epistome.
Nephr. Nephridia. Loph. Lophophore.
Tent. membr. Tentacular membrane.

Fig. *5.* Statoblast. *a.* Front view. *b.* View in profile.

Plate XVIII.

Fig. *6.* Cells in the ectocyst. F × 2.*

Fig. *7.* Section of the endocyst. F × 2.

Out. lay. Outer layer.

* Zeiss' powers.

Bas. membr. Basement membrane.

Tr. mus. Transverse muscular fibres.

L. mus. Longitudinal muscular fibres.

Lin. epith. Lining epithelium.

Vac. Vacuole.

Fig. *8.* Longitudinal section of the epistome, with the ganglion and the excretory organs. B × 4.

Gang. cav. Ganglion cavity.

Fig. *9.* Cells of the upper half of the œsophagus. F × 2.

Fig. *10.* Cells of the lower half of the œsophagus. F × 2.

Fig. *11.* Section of the cardiac valve. B × 4.

Fig. *12.* Cross section of stomach.

Fig. *13.* Cells of the inner layer of the gastric wall. F × 2.

pyr. c. pyramidal cells.

cl. c. club-shaped cells.

Fig. *14.* Cells of the rectum. F × 2.

Fig. *15.* *a.* Diagram showing the extent of the mesentery.
b. Section of the mesentery. D × 2.

Fig. *16.* Cross section of a tentacle. F × 2.

Fig. *17.* Longitudinal section of the tentacle. F × 2.

Fig. *18.* Diagram showing the base of tentacles.

Fig. *19.* Diagram showing the direction of the currents of the perigastric fluid.

Fig. *20.* Cells floating in the perigastric fluid. F × 2.

Figs. *21, 22, 23, 24, 25, 26.* Sections at various levels of the upper portion of a polypide. B × 4.

Figs. *21A, 22A, 23A, 24A.* Sections of the excretory organs. F × 2.

Fig. *26 bis.* Entire form of the excretory organs.

Plate XIX.

Fig. 27. Nervous ganglion.

Fig. 28. Saggittal section of the ganglion. E × 2.

Fig. 29, a, b, c. Diagrammatic Sections of the ganglion, showing the extent of the ganglion cavity.

a, sagittal, *b*, horizontal, *c*, frontal, sections.

Fig. 30. Cross section of a lophophoral arm. D × 2.

Fig. 31. Cross section of the funiculus. F × 2.

Fig. 32. Longitudinal section of the upper extremity of the funiculus. D × 2.

Fig. 33. Longitudinal section of the lower extremity of the funiculus. D × 2.

Fig. 34. Section of Ovary. F × 2.

Fig. 35. Marginal spines of statoblast. F × 2.

Fig. 36. The Enveloping cell-layer of the statoblastic content. F × 2.

Figs. 37-45. Various stages in the development of the statoblast. 37-39. F × 2. 40. D × 2. 41-45. B × 4.

Fun. Funicular wall. Cyst. c. Cystogenous cells. Gr. m. Granular cell-mass. Caps. chitinous capsule. Env. m. Enveloping cellular membrane.

Fig. 46. Section of a mature statoblast. B × 4.

Fig. 46A. A portion of the statoblastic content. F × 2.

Plate XX.

Figs. 47-52. Various stages in the development of Polypide in the statoblast. B × 4.

Prim. l. Primitive lumen.

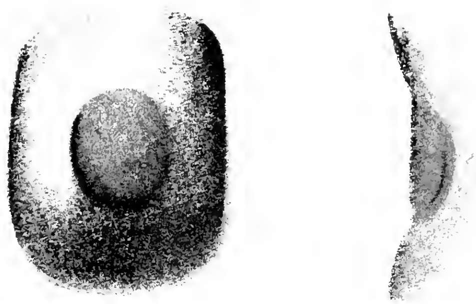
Bl. c. Floating cells.

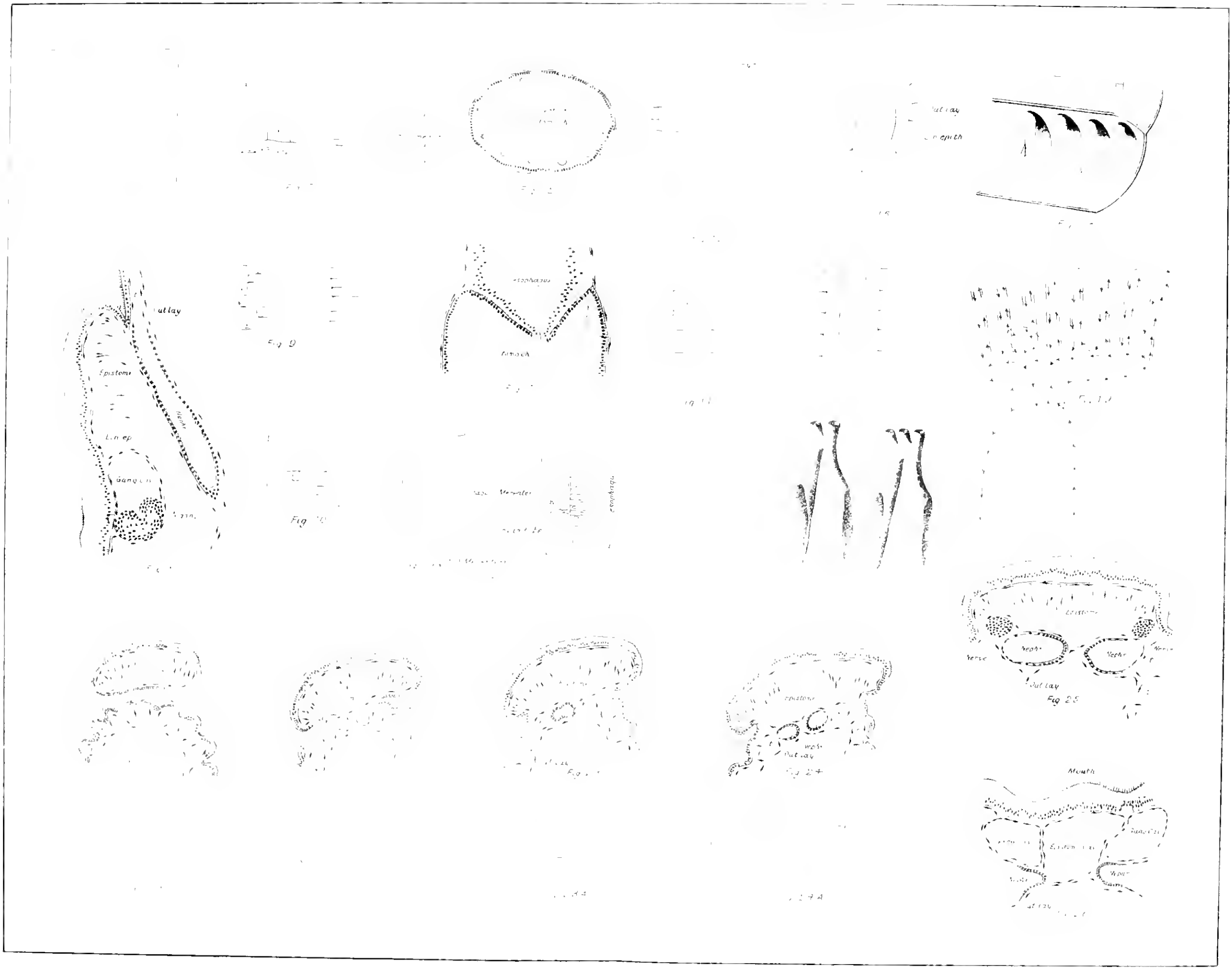
Figs. 47A, 48A. Portions of the statoblastic content in the stages corresponding to Figs. 47 and 48. F × 2.

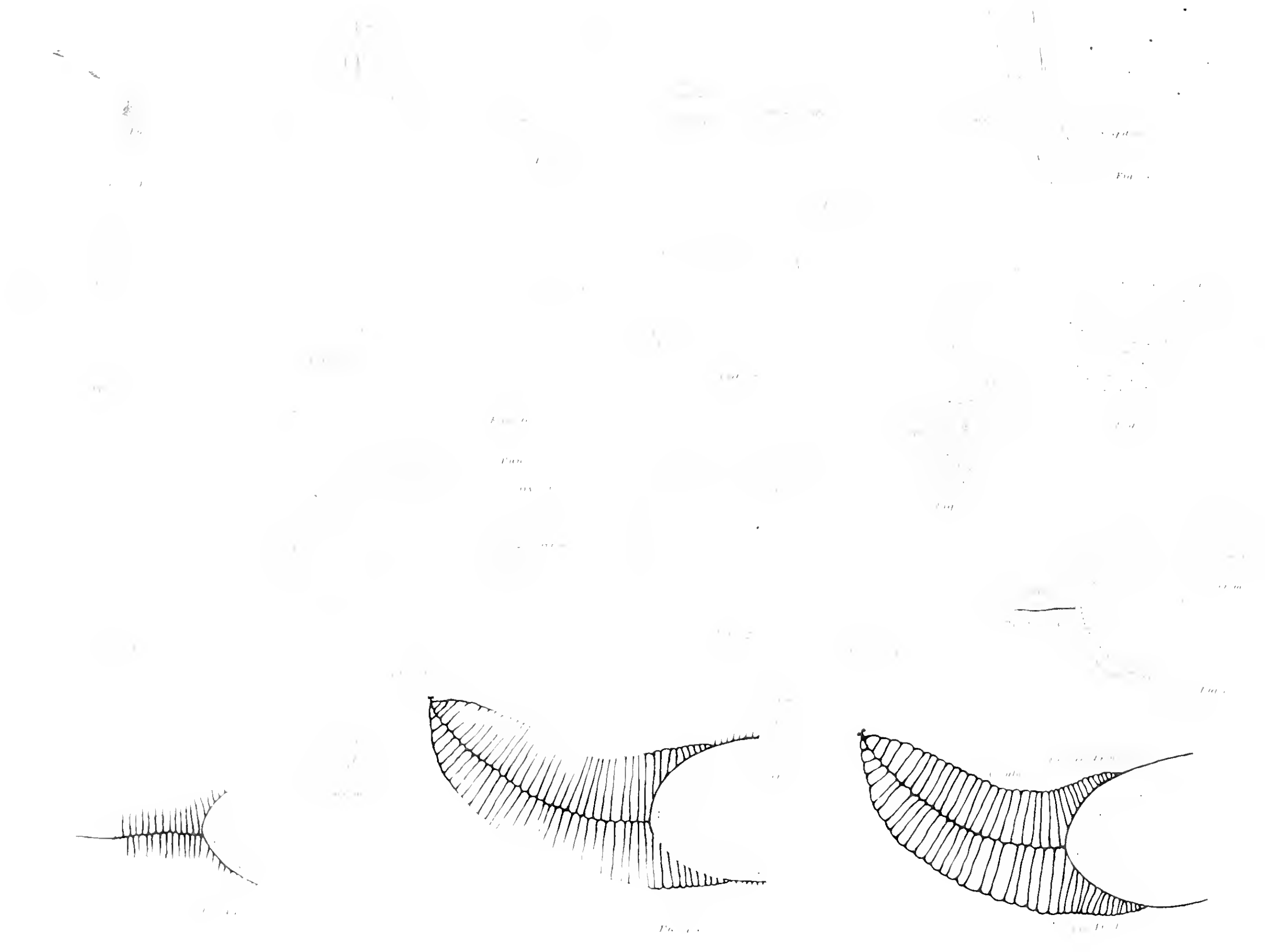
Fig. 52. Floating cells. F × 2.

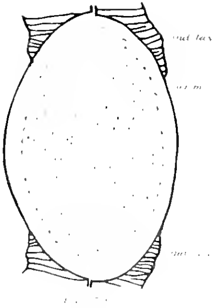
Figs. 53-60. Stages in Budding. 53, F × 2. 54-56, D × 2. 57-60, B × 4.

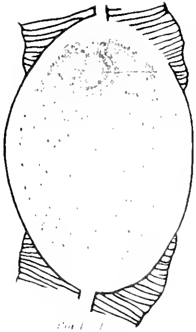
Fig. 61. Diagrams showing the manner of budding. The Roman numerals show the order of the individuals.

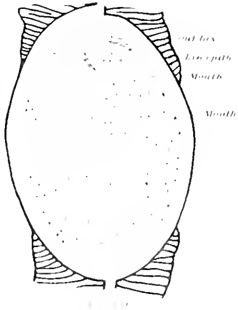


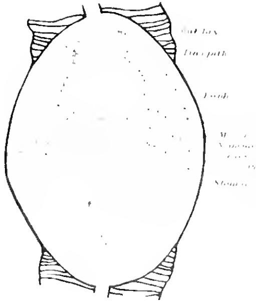

Out lay
Epistome
Ganglion
Fig 9
Fig 10
oesophagus
stomach
oesophagus
Out lay
Nerve
Nephr
Nephr
Nerve
Out lay
Fig 23
Epistome
Out lay
Fig 24
Mouth

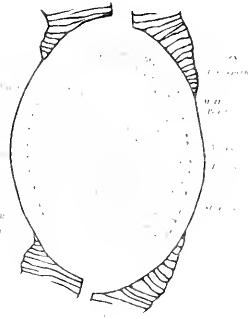




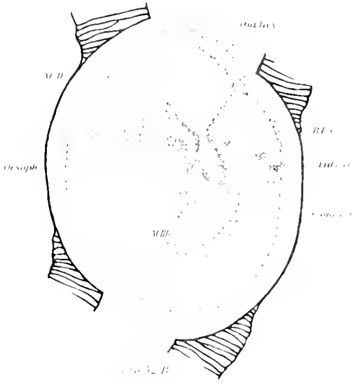



Mouth
Mouth






Stomach


Out lay
Oesoph


Stomach

On Diplozoon nipponicum, n. sp.[1]

by

Seitaro Goto, *Rigakushi,*

Post-graduate Student in Zoology, Imp. Univ.

With Plates XXI—XXIII.

Since *Diplozoon paradoxum* was first discovered and described by v. Nordmann,[2] it has been made the object of special investigations by many eminent naturalists. But our knowledge of the anatomy and especially the histology of this interesting genus, hitherto with but a single species, is, notwithstanding the publications of Paulson, Zeller, and others, by no means as complete as could be desired. I have, therefore, undertaken, at the suggestion of Prof. Ijima, to subject it to a renewed investigation. I at first believed that the Japanese species was identical with the European; but as I went on with my work, many points came to view, that made me doubt this identity; and a close comparison with some preparations of the European species taken from *Leuciscus rutilus*, and brought back from Germany by Prof. Ijima, has led me to erect it into a new species, for which I propose the name of

Diplozoon nipponicum.

Before proceeding any farther, I must here discharge the pleasant duty of acknowledging my deepest obligations to

1) This paper was originally presented as a graduating dissertation.

2) Nordmann—Mikrographische Beiträge. I. Heft. 1832. p. 56.

Professor Ijima, already named, not only for constant supervision of my work, but also for lending me his books and preparations pertaining to the subject at hand. He has also handed over to me his unfinished manuscript, in which the anatomy and external features of many ectoparasitic Trematodes have been made out to a great extent —a circumstance for which I here express my warmest thanks.

Dipl. nipponicum is very common on the gill of *Carassius vulgaris*. Its differential characters as compared with *Dipl. paradoxum* are 1) the smallness of the posterior suckers, 2) the greater length of the posterior half of the body, 3) the shortness of the "connecting canal" between the intestine and the oviduct, 4) the presence of a pair of glands at the entrance of the mouth, and 5) the fact that the intestin, does not present lateral branches in the posterior portion of the body.

"Comment la réunion des Vers, a-t-elle lieu? sont-ils réunis comme les frères Siamois, ou bien sont-ils croisés comme les deux jambes d'un X?" By the investigations of v. Siebold[1] and Zeller,[2] it has been established beyond doubt that the double animal results by the union of two *Diporpae* in the form of a cross—a fact which had already been anticipated by Dujardin[3] their discoverer. The manner in which the two individuals are united, and the details thereof have already been made out by Zeller, who has also discussed the various opinions of his predecessors, and corrected their errors. I shall however, add a few remarks on some points not noticed by him, some of which are perhaps peculiar to the new species. For examining the external features of the worm, as well as for other purposes, it is best to kill it with boiling sublimate, in a watch-glass in which just sufficient water has been placed to cover its body. The worm which

1) v. Siebold—Ueber die Conjugation des Dipl. paradoxum. Ztschr. f. wiss. Zool. Bd. III. 1851. p. 62.

2) Zeller—Untersuch. ü. d. Entwicklung d. Dipl. paradoxum. Ztschr. f. wiss. Zool. Bd. XXII. 1872. p. 168.

3) Dujardin—Histoire naturelle des helminthes. 1845. p. 316.

has been killed in this way, preserves a natural position corresponding to its condition of rest, and can be examined when convenient.

Each individual, if considered separately, is elongated and lanceolate in form, with a deep notch on one side a little posterior to the middle of its whole length, by means of which it is united with the other individual; so that we may hereafter speak of the anterior and posterior halves of the body. The anterior half is widest near the place of union, and becomes narrower anteriorly, where it ends with a rounded outline, and where the mouth is situated on the ventral side. In cross-section it presents an oval outline, which gradually becomes more circular as we proceed anteriorly. If the worm has died in a contracted state, the surface of the body is thrown into numerous transverse folds; otherwise the surface is entirely smooth, except where little conical elevations, hereafter to be described, exist. The posterior half may briefly be described as an elliptic cylinder in the anterior portion, which, posteriorly, passes irregularly into a rectangular prism. It is also much slenderer than the anterior half. Seen in profile, the surface of the posterior portion is always, in specimens killed with hot sublimate, thrown into a number of strong folds, due no doubt to the powerful development of the diagonal muscular fibres in this region; so that here the margin is deeply crenate or even zig-zag (Pl. XXI, Fig. 1). A cross-section through one of the posterior zig-zag folds presents nearly a rectangular outline. The folds suddenly come to a close at a short distance before the beginning of the posterior suckers. In this portion the cross-section presents a flattened ellipse; and this part is, on surface view, distinctly marked off from the sucker-bearing portion which directly follows it, and still more so from the strongly folded more anterior portion, by a sudden change of level (Fig. 1). The lateral margins of this sucker-bearing portion are suddenly thickened on the ventral side, so that a cross-section through it is somewhat ⊔⊔-shaped. Under the pressure of a cover-glass, this portion assumes a somewhat oval form—a circumstance which probably induced v. Nordmann[1] and Paulson[2] to indicate it as an oval "Scheibe." Van Beneden[3] further speaks of "un pédicule" by which the "deux organes", which carry the suckers, are attached to the body; but I have not observed any such structure in my species, and it is probably due to a deformation caused by pressure and the extreme mobility of this part. The posterior margin of the body shows either a nearly straight line or, more commonly, a slight concavity (Fig. 2).[4] Toward this concavity, the body again becomes thicker, the thickening beginning this time in the median line, and thence spreading toward the sides, as indicated in Fig. 2, where the shading is made as if this portion were seen from the ventral side. On a longitudinal section, therefore, which does not pass through the lateral suckers, the body is seen to present posteriorly a club-like thickening, and end suddenly as if it were cut off. Van Beneden speaks of an "excavation plus ou moins profonde," by which he no doubt means the hollow, just spoken of, between the suckers.

The peculiar sudden bend (Knickung) towards the ventral side, which the body of the worm suffers at the place of crossing, has already been noticed by Zeller. There is, however, another feature not observed by him. If the worm, namely, is viewed from the posterior end, or if sections of this part are cut, it will easily be noticed that the bodies of the two individuals do not stand exactly opposite each

1) Nordmann—l. c. p. 60.

2) Paulson—Zur Anatomie v. Dipl. paradoxum. Mém. d. l'acad. St. Petersbourg. VII. Sér. T. IV. 1862. p. 4. I have not been able to gain access to this work, and am indebted for its account to Prof. Ijima's notes.

3) P. J. v. Beneden—Mémoire sur les vers intestinaux. p. 41.

4) The European species shows a decided convexity.

other, but that one is always a little either to the left or to the right side of the other, according as the worms are united by the corresponding sides of their bodies. This feature is usually less noticeable in the anterior halves, but it can easily be brought to view by bringing them close to each other. It is caused, no doubt, by the fact that the bodies of the two individuals are closely united *only* at the point of crossing; as may be seen, if one places two pieces of straw against each other in the form of a cross, and presses them together between two fingers at the point of crossing. Beside this imperfect apposition of the corresponding halves of the two individuals, must also be noticed the twist, to which each is subjected at the place of crossing, in consequence of the fact that one grasps with its ventral sucker the dorsal papilla of the other. To this twist, though very small in degree owing to the presence of the notch already mentioned, must be attributed the common occurrence that, when the worm is killed under the pressure of a cover-glass, the anterior and posterior halves of the same individual present to view opposite sides of the body—the anterior half presenting the dorsal if the other half presents the ventral side, and *vice versa*. The two individuals are united with each other by their sides, so that here a deep indentation arises—the notch already spoken of. Here the epidermis is absent, and the muscular layers of the two individuals are directly applied to each other. Zeller describes a direct connection between the vas deferens and "Laurer's canal" of the two individuals; but a careful examination has convinced me that this view is erroneous. I find Laurer's canal to open distinctly into the intestine, and the vas deferens of one individual into the yolk-duct of the other, as will be proved later on. In this connection, it may be mentioned that the same writer thinks the *Diporpa* incapable of "eine noch weiter gehende Entwicklung ohne dass zuvor die Copulation mit einer zweiten Diporpa zu Stande gekommen wäre."[1] But last summer I met with two *Diporpae* which were already producing eggs, but which were not united. They were attached to the same gill very near to each other. They were quite as large as any average *Diplozoon*, and measured about 6 mm. in length in a completely outstretched condition.[2] They were provided with four pairs of posterior suckers, but there was no trace either of the ventral sucker or of the dorsal papilla. In place of the ventral sucker, the longitudinal muscular layer was very strongly developed in the corresponding part ; and the body shewed a sudden increase of breadth just anterior to the anterior end of the ovary, looking as if this part were bandaged. I have used the utmost care in detaching the worms from the gill, inasmuch as I carefully scraped off the gill-slime with a spatula, avoiding as much as possible any direct contact with the worms. The *Diporpae* in question were observed to be quite independent of each other from the moment they were detached from the gill ; nor have I been able to detect any mechanical injury, or the notch by which they might have been united to each other ; so that the chance of their being detached *Diplozoon* is, I believe, almost entirely excluded. Such a case of isolation is of course exceptional ; but it shews that the *Diporpa* can, under certain conditions, become mature without uniting with another *Diporpa*.

It would have been interesting and instructive could I have determined where, in this abnormal case, the vas deferens opened. But unfortunately, owing to my inexperience then, I killed both the *Diporpae* under the pressure of a cover-glass and prepared them for gross mounting ; and when I afterward cut one of them into sections,

1) Zeller—l. c. p. 176.

2) The size of the common Diporpa varies according to its stage of development. Dujardin gives it as 0.26—0.56 mm. in length and 0.18—0.35 mm. in breadth (l. c. p. 317). A specimen of the Diporpa of Dipl. parapoxum lent me by Prof. Ijima and possessing three pairs of suckers measured about 0.6 mm. in length. That of Dipl. nipponicum of the same stage is of about the same size.

I could no longer trace the course of such a delicate canal as the vas deferens.

Remark :—In Prof. Ijima's manuscript I find the following passage which I have his permission to publish.

"Ich will mir endlich noch eine Bemerkung über die von Heller[1] beschriebene Monstrosität erlauben. Dieser Forscher lässt, obschon ihm das Verhältniss des *Copulatio lateralis decussata* (Siebold) nicht fremd blieb, sein interessantes Exemplar sich dadurch erklären, dass die Verwachsung der beiden Diporpen sich über die ganze vordere Körperhälfte ausgedehnt hätte. Paulson, der sich übrigens mit die Ansicht Leuckart's theilt, dass die Diporpen einfach mit Bauchfläche zusammenhängen, hebt die Unmöglichkeit des Zustandekommens jener Monstrosität durch *Copulatio lateralis decussata* hervor, und nimmt an, es handele sich um eine Missbildung *per defectum* eines Diplozoons, bei welchem sich einer der Vorderleiber gar nicht entwickelt hätte. Dabei kam er sehr nah an die richtige Interpretation der Heller' schen Monstrosität, die meiner Ueberzeugung nach, nichts anderes sein kann, als eine Diporpa, nicht Diplozoon, mit in doppelter Anzahl angelegtem Schwanzende, also eine Missbildung *per adjectum*. Dies darf man nicht Wunder nehmen, denn wir wissen zahlreiche Fälle ähnlicher Missbildungen unter den Planarien. Ich kenne selbst einen Fall von ganz jungen, eben ausgeschlüpftem *Dendrocœlum lacteum* mit zwei hinteren Hälften, deren je eine einen Mund und einen Pharynx besitzt."

I shall now proceed to the consideration of the various parts.

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1) Heller—Merkwürdiger Fall vorderer Verwachsung an Dipl. paradoxum. Sitzungsber. d. k. Akad. d. Wiss. Wien. 1857. p. 109.

I. The Epidermis.

The nature of the integument of the Trematodes has been variously represented by various authors. This subject I hope to discuss more fully in a later work which shall treat of our ecto-parasitic Trematodes in general. Zeller[1] tells us that if no occasion is offered the embryos to attach themselves to the gill, "schon nach Verfluss von 5 Stunden (after the embryos have left the egg) einzelne der Wimperzellen reissen sich los, bald mehrere und schliesslich alle, flimmern aber auch abgetrennt noch eine Zeit lang fort." The embryos finally die. It is not clear from his statements whether this throwing off of the "Wimperzellen" is a normal process or not. In *Polystomum* he merely says that they "schrumpfen," but does not describe their exact fate. In the case of *Distomum*, however, it has been proved by Schwarze[2] and Biehringer[3] that the so-called "cuticula" consists originally of cells which undergo one by one a peculiar transformation, and which do not at any time possess the typical epithelial arrangement. After the first rough manuscript of these pages had been finished, I received the article of Braun[4] in "Centrbl. für Bakteriologie u. Parasitenkunde," in which the writer brings forward some strong and interesting evidences as to the epidermal nature of the integument. In view of these facts established by the preceding investigators, I believe I may regard the integument of the monogenetic Trematodes as a modified epidermis,— the more so from the consideration that it has a distinct cuticle and

1) Zeller—l. c. p. 173.

2) Schwarze—Die postembryonale Entwicklung der Trematoden. Ztschr f. w. Zool. Bd. XLII. 1886. p. 49.

3) Biehringer—Beiträge zur Anatomie u. Entwickl.-geschichte d. Trematoden. Arbeiten a. d. zool.-zoot. Inst. in Würzburg. Bd. VII. 1885. p. 4.

4) Braun, Max—Einige Bemerkungen ü. d. Körperbedeckung ectoparasitischer Trematoden. Centralbl. f. Bakteriol. u. Parasitenkunde. Bd. VII. 1890. p. 594 (Nr. 19.)

sits on a basement membrane. An embryological study, however, of the transformations which the original epidermis undergoes is, as Braun maintains, very desirable.

The integument of *Dipl. nipponicum* is composed of two layers, the cuticula and the underlying matrix. The cuticula, when examined in a living worm, is a very thin, structureless, refractive membrane. In sections of hardened specimens it appears as an insignificant line bounding the subcuticular (= epidermal) layer against the external world. It is very well seen in a living specimen which has been allowed to macerate in water for some time under the cover-glass. Numerous watery blisters then form in the epidermis, and separate the cuticula from the underlying layer. The former can then be examined as a separate structure. Transverse canals have been described in the cuticula of many Trematodes, but I have not observed any in the new species. The cuticula is reflected inward for some distance into the mouth.

Directly under the cuticula lies the epidermal layer, a uniform, granular matrix in which no nuclei are to be observed. I believe I have observed indistinct dark lines traversing the breadth of this layer but not quite reaching the cuticula. The epidermal layer, like the cuticula, is continued into the cavity of the mouth, and the sticky glands hereafter to be described (p. 166) are but local modifications of it. Wierzejski[1] describes the "Haut" of *Calicotyle Kroyeri* as consisting of "einer feinen Cuticularschicht mit den darunter liegenden kleinen, runden Matrixzellen"; but judging from his figure, I believe he has mistaken the nuclei of the connective tissue for his "Matrixzellen." The epidermal layer rests on a basement membrane, which eagerly takes up coloring matter, and is very conspicuous in cross-

1) Wierzejski—Zur Kenntniss des Baues von Calicotyle Kroyeri. Ztschr. f. wiss. Zool. Bd. XXIX. 1877. p. 552.

sections as a dark line with indistinct borders, separating the epidermal from the muscular layer. It is also much thicker than the cuticula. The total thickness of the integument, with the cuticula and basement membrane taken together, is about 0.004 mm.

It has already been mentioned that little conical elevations exist here and there on the surface of the body. These are more abundant on the ventral than on the dorsal side, and are entirely absent in the posterior half of the body. They are simple elevations of the epidermis with an almost homogeneous mass of connective tissue under it. Here the muscular layers do not touch the basement membrane, but pass straight on; so that these elevations are somewhat subject to changes of form. I have represented one of them in section in Fig. 7 (Pl. XXII). As will be seen, they are pointed at the end. A very similar structure has been described in *Sphyranura Osleri*,[1] where it seems to act as a sense organ. But although I directed my special attention to the point, and applied the highest magnifying power at my disposal (Zeiss Imm. L.), I could not discover any canal opening at the apex, or any hair-like projection, or any fibrils such as have been observed in the above-mentioned species to supply these conical bodies.

II. The Muscular System.

The muscular system is constituted by the muscular wall of the body, the dorso-ventral muscles, and the muscles pertaining to the various organs.

The muscular layer of the body consists of three layers. These are, counted from outside inwards, the circular, the diagonal, and the longitudinal muscles. The circular fibres run everywhere immediately

1) R. Wright and Macallum—Sphyranura Osleri: a Contribution to American Helminthology. Journ. of Morph. Vol. I. 1887. p. 9.

beneath the basement membrane. They run isolated without forming bundles. This layer is most strongly developed at the anterior extremity of the body in the region of the anterior suckers, and immediately anterior to them, especially on the ventral side (Fig. 9), where its thickness amounts at some places to 0.01 mm. In the posterior part of the body it is very weakly developed, and in the region of the posterior suckers the fibres are very difficult to detect.

Closely applied to the circular layer of muscles run the second or diagonal fibres (Fig. 10). In the anterior half of the body these, like the transverse fibres, run isolated without forming bundles; and those coming from opposite sides of the body cross each other at an angle of nearly 120°. In the posterior half of the body, this layer is strongly developed in the region of the folds already mentioned, where the fibres run in flat bundles and close to one another. According to Taschenberg,[1] the diagonal fibres are situated innermost in *Tristomum;* but in all the species of ectoparasitic Trematodes I have hitherto examined, viz., in *Microcotyle*, *Axine*, *Octobothrium*,[2] *Dactylogyrus*, and a new genus not yet named, the diagonal fibres are situated between the transverse and longitudinal muscular layers. Lorenz,[3] who includes the transverse and diagonal muscles under one head, also places the "zärteren Fasern" (by which he means the two sets of muscles just mentioned) outward; and an examination of the sections of *Tr. molae*, kindly placed at my disposal by Prof. Ijima, has convinced me of the error of Taschenberg, occasioned perhaps by the circumstance that in *Tristomum* the longitudinal fibres describe a

1) Taschenberg—Beiträge zur Kenntniss ectoporasitischer mariner Trematoden. Halle, 1879. p. 11.

2) In a species of this genus which I have examined, there are in addition isolated longitudinal fibres between the diagonal and circular muscles.

3) Lorenz—Ueber die Organisation der Gattungen Axine u. Microcotyle. Arbeit. a. d. zool.-zoot. Inst. d. Univ. Wien etc. Bd. I. 1878. 3. Heft.

curve in the lateral portions, corresponding to the circular or oval outline of the worm. The same writer did not observe the diagonal fibres in *Onchocotyle appendiculata* and *Pseudocotyle squatinae*[1]; but since they are present in all the species I have examined, they were probably overlooked by him.

Internal to the diagonal muscle, and separated from it by a greater or less amount of connective tissue, run the longitudinal muscular fibres in parallel bundles of greater or less strength. They are more strongly developed on the ventral than on the dorsal side of the body, as is usual in most Trematodes, and cause a slight curve of the body on the ventral side when the worm is killed with hot sublimate. The fibres that constitute the bundles are but loosely united together by connective tissue, and form by no means such compact muscular bundles as we see in some other Trematodes. They appear in cross-section as dots, separated from one another by a greater or less amount of connective tissue between. Some of the fibres of a bundle often diverge from their previous course, and enter into the formation of a neighboring bundle. Most of the longitudinal fibres combine toward the posterior part of the body to form a certain number of strong bundles, which proceed posteriorly, and are inserted one to each sucker on the median chitinous piece of the posterior wall (Fig. 5).

The dorso-ventral muscles (dvm in Figs. 11, 13, 16, 24) are well developed. Each muscle generally breaks up into a few branches dorsally and ventrally before being inserted into the basement membrane. They traverse the brain, vitelline body, and other internal organs. In longitudinal (sagittal) sections of a specimen, in which the vitelline body has not yet well developed, the dorso-ventral muscles are seen to be placed at pretty regular intervals. In

1) Taschenberg—Weitere Beiträge zur Kenntniss ectopar. mar. Trematoden. Halle, 1879.

specimens with fully developed vitelline body, these muscles are obscured to a great extent.

III. The Organs of Attachment.

The organs of attachment are constituted, posteriorly by the four pairs of suckers already mentioned and a pair of hooks, and anteriorly by a pair of suckers and sticky glands. Each posterior sucker (Figs. 3, 4. 5) may briefly be described as a short-ovate, flat bag with its wide mouth directed ventrally, its walls very thick, and the line of its greatest breadth directed transversely to the long axis of the body; so that we may speak of the anterior (aw), posterior (pw), and lateral walls. The first two walls are very thick, and are directly continuous with each other at the bottom of the bag (Figs. 4, 5). The lateral walls are very thin, and seem to consist of a cuticula-like refractive membrane only. The entire structure is supported by a framework of chitinous rods, which are by no means so numerous or complicated as Nordmann has represented them. They are five in number: a U-shaped median piece (pm), a pair of curved pieces (ppa), (resembling in form certain fishing-hooks), to support the anterior wall, and a pair of similar pieces (ppp), with a large process (pp) at the base, to support the posterior wall. Having thus given a general idea, I shall now proceed to the explanation of the three figures already referred to, by which I hope to make clear the structure of the suckers. Fig. 3 represents the chitinous rods as very commonly seen in a specimen observed under the pressure of a cover-glass, with the mouth of the sucker directed below in the figure and the rods belonging to the anterior wall shaded more deeply. Fig. 4 represents a section made in the direction indicated by the line ab in Fig. 3, whereby it is to be remarked that the median piece has been cut nearer the fundus of the sucker. This section shews the thickness of the anterior and posterior walls, as well as their fibrous structure. The prismatic fibres, of which these walls are composed, are strongly refractive, and are scarcely colored by haematoxylin. They seem, therefore, not to be of the same nature as the muscles of the body; these being well stained by the same coloring fluid. In fact, they seem to be not contractile but elastic fibres. The supporting rods are all of them hollow, with, the inner surface, however, not quite smooth, but with irregular projections, which sometimes unite with those of the opposite side, and form septa-like partitions (Fig. 3). The paired rods are somewhat triangular in section, and are imbedded in their respective walls along the margins. The rods of the posterior wall are articulated at their bases each with another piece (pp), which is imbedded in the substance of the wall, and imparts greater strength to it—a fact well in accordance with the circumstance already mentioned that the main bundle of muscle is attached to this wall. Fig. 5 represents a section made in the direction indicated by xy in Fig. 3, i. e., in an antero-posterior direction. In this section, the direct continuity of the anterior and posterior walls is clearly seen; the U-shaped median piece has been cut but in part, as also the extremities of the paired pieces at the entrance of the sucker. The median piece exhibits, in the posterior wall, a deep cut, where the main bundle of muscle is attached for controlling the varied movements of the sucker. Beside this bundle, weaker ones are attached to the paired pieces. The fibrous substance of the wall is bounded by a cuticula both against the external world and the surrounding mesenchyma. The supporting rods are very easily broken into fragments when the animal is subjected to too much pressure; and this takes place pretty regularly in the manner represented by Nordmann, who, however, describes the fragmentary pieces as "Bügel, zahnförmige Vorsprünge, Rippen, u. s. w." All the posterior suckers are of the same build; but they vary somewhat in size, the last pair being always smaller than the anterior ones,[1] and the first pair very often smaller than the following two pairs. Measurements on five individuals gave the average breadth of the suckers as 0.093 mm.[2]

Besides the suckers just described, there is, on the dorsal side, a pair of solid chitinous pieces (Fig. 6). Each piece consists of two parts. The basal portion, to which a small bundle of muscle is attached, is straight, and acts as a handle. To this is articulated a hook-like piece, whose end alone sticks out from the surface of the cuticula; the handle as well as the other part of the hook lying in the integument. The straight handle-like portion and the hook constitute a single piece, and not two pieces as v. Beneden[3] thinks. The total average length of the piece is 0.072 mm.

The anterior suckers are either round or egg-shaped, according to the different states of contraction, and are situated right and left at the entrance of the mouth. Like the posterior suckers, the walls (Fig. 9) are composed of prismatic fibres placed at right angles to the investing membrane, which lines the whole internal cavity, and bounds the wall from the surrounding mesenchyma. In cross-section, the sucker is generally circular in outline. Each is provided with a number of special muscles for the control of its movements in suction. These muscles I have represented in Fig. 12, where there will be seen three bundles coming from the dorsal side, two of which are attached to the anterior border of the sucker, and the remaining one to the

1) This fact must not be taken as proving that the hindermost pair is formed last.

2) A corresponding measurement on the European species of about the same size gave the average result as 0.144 mm. fort he sucker, and 0.084 mm. for the total length of the handle and hook.

3) P. J. v. Beneden—l. c. p. 42.

posterior ventral border. A bundle, which soon divides itself into two smaller bundles, proceeds from the ventral side, and is attached, one of the branches to the same point as the posterior dorsal bundle, the other branch a little more ventrally and anteriorly. Two weaker bundles start, in addition to the above, from the upper and lower lips of the mouth, and are attached to the corresponding borders of the sucker. I have observed some of the fibres of these various bundles directly continued through the substance of the wall, and inserted on the cuticula that lines the cavity of the sucker. By the combined action of these muscles, the worm can exercise a strong suction on the gill of the host, and extract its blood.

Besides these suckers, there is a pair of glands at the entrance of the mouth, just anterior to the suckers, which seem to be peculiar to *Dipl. nipponicum*. They can be seen well in a living specimen under the cover glass, or in preparations of the entire worm, as a round, paired body. One of them is seen in section in Fig. 8, which shews it to be a gland formed by the invagination and local modification of the epidermis. It has generally a reniform cavity, which opens into the mouth by a canal, just anteriorly and close to where the sucker opens into the mouth. The epidermis is continued into the canal for a certain distance, and then changes its character, becoming firmer and refractive like the cuticula. The cavity of the gland is destitute of any distinct epithelium, but is generally filled with a granular mass, which stains very well. This mass is densest near the wall, and gradually becomes thinner towards the centre, where there is generally an empty space. I have often observed the exit canal filled with a deeply stained granular mass, very similar in appearance to the contents of the sticky glands of *Dactylogyrus* and other allied forms, and which is doubtless the sticky secretion of the gland. Next the granular content is a basement membrane. The wall is exceedingly thick and muscular. The muscular fibres are mostly arranged meridionally, i. e. if we suppose the ventral and dorsal pole of the gland to correspond to the two poles of the earth, the muscular fibres are arranged nearly in the plane of the meridians. Fibres also come from the dorsal side of the animal, and enter the wall. Between the muscular fibres, I have sometimes observed nuclei, which are to all intents and purpose exactly similar to those of the general mesenchyma of the body, and probably belong to it.

IV. The Mesenchyma.

Of the mesenchymatous connective tissue of the Trematodes, Leuckart[1] distinguishes two forms. In the first form, the mesenchyma consists of a "fast homogene helle und feinkörnige Substanz mit zahlreich eingelagerten kleinen Kernen" ; in the second form of the mesenchyma, we see "Zellen von mehr oder minder ansehnlicher Grösse, die mit einer meist wasserhellen Masse gefüllt sind" and generally of a polyhedral form, with a fibrous net-work between. Taschenberg[2] regards the mesenchyma "als ein Bindegewebe, welches zu einem Maschenwerke entwickelt ist, in welchem die ursprünglichen Bildungszellen theils noch vorhanden sind, theils aber nur an dem Protoplasma mit darin eingelagerten Kernen sich erkennen lassen." All these forms of the mesenchyma, however different they may seem to be with one another, can, in my opinion, be derived from the differentiation in different directions of a single primitive form. The strong resemblance of the mesenchyma of the Trematodes to the chorda dorsalis of the vertebrates has already been observed by Leuckart ; and I believe the former is formed just in the same manner as the latter. But first the mesenchyma of *Diplozoon*.

1) Leuckart—Die Parasiten des Menschen. II. Auflage. I. Bd. 3. Liefg. p. 13 *et seq.*

2) Taschenberg—l. c. p. 13.

In this tissue are imbedded all the organs hereafter to be described, as also some of the organs already described. Owing to the presence of the vitelline body, the mesenchyma in the anterior half of the body is mainly confined to the peripheral portion, but is also present in a scanty quantity between the lobes of the vitelline body and the cells of which they are composed. When one takes it up for study, he finds great perplexity and difficulty in making out the true nature of the elements that compose it, until he compares it with the mesenchyma of other allied species. In *Diplozoon*, it consists of a fibrous substance, in which are seen nuclei each with a distinct membrane of its own. These nuclei always enclose one or more deeply stained nucleoli. The nuclei are of various size and shape. In the anterior portion and generally in the anterior half of the body, they are generally of a comparatively small size (Figs. 7, 8, 9, 25) ; in the posterior half of the body, however, they are generally of a larger size (sometimes having the diameter of about 0.01 mm.) and have a circular or oval outline (Fig. 13). In the vicinity of the internal organs, where the connective tissue is generally more or less compressed, the nuclei are smaller and often fusiform in shape. Around the pharynx, the fibres form a fine close net-work (Fig. 11).

Beside these elements, we see here and there, scattered apparently without any regularity in the parenchyma, large vesicular bodies of a circular or oval outline (Fig. 13), with a large conspicuous nucleus in the centre surrounded by a mass of granular protoplasm, which on close inspection betrays a fibrous structure, and which gradually thins out peripherally, and leaves an empty space between it and the wall. These vesicular bodies are sometimes drawn out towards one end, and are very abundant in the posterior half of the body, posterior to the testis. In the region situated between the ovary and the testis, the mesenchyma consists of distinct cells with a granular, generally well-stained protoplasm, of a polyhedral form, and leaving irregular intercellular spaces between (Fig. 14).

In *Axine*, the mesenchyma is distinctly seen to consist of large, vesicular cells, each with a nucleus generally in the centre, but sometimes attached to the wall, and filled with a hyaline fluid containing numerous almost uncolored granules. The nucleus as in *Diplozoon*, has a distinct membrane, and encloses a deeply stained nucleolus, but is considerably smaller. Beside these cells, there are, as Lorenz[1] has already observed, in the neighbourhood of the vagina, cells whose contents take up the staining fluid very eagerly and appear like ganglion cells. In *Microcotyle*, the mesenchyma presents somewhat different aspects in different parts of the body— a statement that holds good to a greater or less extent in all other allied forms. Around and outside the vitelline body, the mesenchyma presents an appearance very similar to that of *Diplozoon*. Nearer the median line, it consists of large cells with the nuclei in the centre, from which protoplasmic fibres radiate to the wall, whose cavity is filled with a clear fluid without any granule. Along the median line, finally, the mesenchyma consists of cells with a granular somewhat fibrous protoplasm which deeply stains with haematoxylin.[2] Here in *Microcotyle*, I believe, are manifested the transitional steps through which the mesenchymatous connective tissue such as that of *Diplozoon* has been differentiated from the primitive parenchyma cells. These primitive cells are, I believe, very nearly represented by the cells of the median portion of *Microcotyle*. The next step onward toward the differentiation of connective tissue is, according to my view, represented by such a form of mesenchyma as that of *Axine*, or that portion of the same in *Microcotyle* situated just inside the vitelline body— composed of cells of a vesicular appearance

1) Lorenz—l. c. p. 7.

2) In appearance, these cells are very similar to the yolk-cells of *Diplozoon* during the winter season. *Vide* Fig. 20, Pl. XXII.

and filled with a hyaline fluid. A step further onward in the same direction would result in the formation of abundant fibres, and the boundaries of the original cells would be partly absorbed and entirely obliterated ; so that we should then have a ground-mass of irregular fibrous substance, with nuclei scattered therein— in fact just such a form of mesenchyma as we really see in most parts of the body of *Diplozoon*. The large, round, vesicular bodies above mentioned (Fig. 13) are in fact the remnant cells of the original parenchyma, and the portion, already referred to, situated between the ovary and the testis, seems to have undergone but little transformation, and to have preserved the original cellular structure. According to the view here stated, the so-called pseudocoel of the Trematodes would be *not* spaces formed by the departing of the cells from one another leaving intercellular spaces between them, but spaces which were before truly *intra*-cellular. I do not, indeed, entirely deny the presence of truly *inter*-cellular spaces, but these are, I believe, comparatively insignificant.

Similarly, of the two typical forms of Leuckart, the first results apparently by a simple obliteration of the boundaries of the original cells. The second form can be derived by a process similar to that which we have seen to have taken place in *Microcotyle*, in which some of the cells (the larger vesicular ones) have maintained their cellular nature more completely, while others have been more or less completely transformed into connective tissue, and pressed in, forming the "Maschengewebe," between the former ; as already proved embryologically by Schwarze.[1] The two forms above mentioned, are connected by numerous intermediate forms, and an actual transition between them has been observed in some species.[2]

1) Schwarze—l. c. p. 59.

2) Looss —Beiträge zur Kenntniss der Trematoden. Ztschr. f. w. Zool. Bd. XLI. 1885. p. 432.

Beside the various elements hitherto described, there are, in the neighborhood of the brain and pharynx, large cells of a roundish or polygonal outline, easily distinguishable from the surrounding elements of the parenchyma (Fig. 25). They are of a gigantic size, and in some sections they seemed as if they were drawn out into fibres in more than one direction. They have conspicuous vesicular nuclei enclosing each a deeply stained nucleolus, which again generally encloses a vacuole. They are entirely destitute of cell-walls, and have a finely granular protoplasm. Their very appearance suggests their nervous nature. But more than that, careful examinations have convinced me that these large cells are very constant in their position and number. They are found, namely, laterally and behind the pharynx, and can be seen in living specimens under the cover-glass, especially well after the water has evaporated to a certain extent. As will be seen from the figure, they are situated symmetrically, right and left, on both sides of the pharynx. Besides the four cells on each side and a median ventral one, drawn in the figure, I have counted another pair and a median unpaired one more posteriorly. There are also similar cells, which are scattered apparently without symmetry, around the brain, but always outside it in the mesenchyma. Two of these are shewn in Fig. 17.

Considering the form and appearance of these cells, the constancy and symmetry of their position and number (at least in the more anterior ones), together with the circumstance that there are no nervous cells *in* the brain or nerves, I am strongly inclined to attribute nervous functions to these gigantic cells; but I have not been able to trace any direct connection with the nervous system. I have tried methyl-violet and cochineal stain. By the latter, they are but slightly colored, and neither of these stains affords any better clue into their exact nature. They seem to be different from the remnant cells of the parenchyma already described (Fig. 13); but I must leave the exact nature and function of these cells undetermined.

V. The Digestive System.

The digestive system consists of the mouth (Fig. 2, mo), the prepharynx (pph), the pharynx (ph), the oesophagus (oe). and the intestine (int).

The mouth is a funnel-shaped opening situated on the ventral side of the anterior extremity of the body, at the entrance of which are placed the glands and suckers already described. Its cavity is lined by the continuation of the cuticula of the general surface of the body. The fundus of the funnel leads directly into an expanded cavity, the prepharynx, into which the anterior half of the pharynx protrudes. This latter is an ellipsoidal body which has a narrow tubular cavity passing through the centre, and whose major axis is directed antero-posteriorly. In cross-section (Fig. 11) it is circular. The internal tubular cavity is lined by a comparatively thick structureless membrane. The thick wall is composed of muscular fibres arranged in regular groups, and of connective tissue, in which nuclei, very similar to those of the general mesenchyma, are to be observed. Most internally, and separated from the structureless membrane lining the internal cavity by a sort of basement membrane, is a thin layer of circular fibres (mci). Most externally, and directly internal to the cuticula-like membrane that envelopes the whole pharynx and separates it from the surrounding mesenchyma, is another layer of circular fibres, about double as thick as the first. Besides these, there are radial fibres extending between the internal basement membrane and the external cuticula of the pharyngeal wall. These radial fibres are weakly developed, and do not run in bundles, as they have been observed to do in some other Trematodes. Between these fibres is found a mass of connective tissue with conspicuous nuclei. These nuclei are doubtless the remnants of the cells that produced the muscular fibres and the connective tissue of the pharynx. Strong dorso-ventral muscular bundles (Fig. 11, dvm) are closely applied to the wall of the pharynx, and no doubt assist in its action. The total thickness of the pharyngeal wall, the internal membrane inclusive, is about 0.02 mm.

The cavity of the pharynx leads directly into the oesophagus, a simple, slender, tubular portion, which is directly continued into the median trunk of the intestine. This median trunk sends out in the anterior half of the body, right and left, lateral branches, which ramify dichotomously once or twice. Some of these lateral branches are distinctly paired, but I have also observed others which are as distinctly unpaired. Posterior to the place of crossing of the two individuals the lateral branches are absent. Here the median trunk divides into two, one of which retains nearly the median position, while the other proceeds more laterally towards the ovary. Posterior to the testis these two branches unite, and thenceforth the intestine proceeds towards the suckers as a simple unbranched tube, and ends between and a little anterior to the first pair of suckers, where it generally presents a rounded enlargement. "A l'endroit ou les deux corps s'unissent, les coecums digestifs semblent atrophiés, mais en dessous de l'appareil générateur, dans le bout postérieur du corps, chaque tube présente de nouveau ses ramifications régulières et complètement séparées, comme dans la partie antérieure," says v. Beneden,[1] and I can confirm his observation with my own on the European species ; but in *nipponicum* I have found this part of the intestine always simple. The wall of the intestine is destitute of an epithelium

1) P. J. v. Beneden—1, c. p. 40.

such as we are wont to see in the Distomes. In its stead, we find large cells (Figs. 14, 16, 19, dc) separated from one another by a considerable interval, and filled with dark-brown or sometimes even black granules. I have not observed any wall or nucleus in these cells, although Zeller[1] points to the presence of the latter in *Polystomum*, and I could distinctly observe it in *Octobothrium*. These black pigment-containing cells I hold, in agreement with Taschenberg,[2] to be digestive cells, and the pigment-granules to be food-particles taken in from the cavity of the intestine. Digestion, therefore, takes place in the allied forms intracellulary, as in the Turbellarians. The intervals between these cells are usually destitute of any distinct membrane in the anterior half of the body, so that here the digestive system consists of mere hollows in the mesenchyma ; but in the posterior part, where the intestine is simple, I could usually distinguish a more or less distinct membrane of compact connective tissue.

VI. The Excretory System.

The excretory system of the Plathelminthes has been minutely examined by Fraipont,[3] Lang,[4] Pintner[5] R. Wright and Macallum,[6] and some others. By these investigations two points seem to have been firmly established : 1) That the excretory system

1) Zeller—Untersuch. ü. d. Entwick. u. d. Bau. d. Polystomum integerrimum. Ztschr. f. w. Zool. Bd. XXII. 1872. p. 19.

2) Taschenberg—Weitere Beiträge. p. 11.

3) Fraipont—Recherches sur l'appareil excréteur des Trématodes. Archiv. d. Biologie. T. I. I have not been able to gain access to this work, and am indebted for its account to J. V Carus's " Zoologischer Jahresbericht " (1880. 1. p. 277) and to Looss (l. c.).

4) Lang—Der Bau von Gunda segmentata u. d. Verwandtschaft etc. Mittheil. a. d. zool. Station z. Neapel. Bd. III. 1882. p. 187.

5) Pintner—Untersuch. ü. d. Bau. d. Bandwurmkörpers, mit bes. Berücksichtigung etc. Arbeit. a. d. zool.-zoot. Inst. d. Univ. Wien, etc. Bd. III. 1880. 2. Heft.

6) R. Wright and Macallum—l. c. p. 20.

of this class consists of vessels with a distinct wall, 2) that these vessels are of two kinds, the larger ones serving mainly for leading out the contained fluid, and the capillaries which end in funnel-shaped little bodies shewing the so-called "Wimperflamme" in the interior, and which are the most important part of the system.

In *Dipl. nipponicum*, as in *Dipl. paradoxum*, two main canals can always be distinguished on each side of the body, one of which is larger than the other and opens to the exterior by means of a circular opening on the dorsal side[1], close to the lateral margin, a short distance posterior to the pharynx (Fig. 2, eo). Immediately at the entrance of the opening, the vessel presents an enlargement (the so-called "Sammelrohr"), then proceeds anteriorly to about the level of the pharynx, where it bends backward and proceeds posteriorly, winding more or less on the way, and giving off but a few branches. On reaching the posterior suckers, it bends inward to them and reaches nearly the posterior margin of the body. Here it turns on itself and proceeds anteriorly, following closely its former course, but this time liberally sending out branches which anastomose with one another and with those from the opposite side of the body. Anteriorly this main vessel reaches the upper lip of the mouth, where it divides itself into numerous branches, having also become smaller during its course. These two main vessels follow closely in their course that of the ventral nerves, on whose dorsal side they are situated except where they make windings towards one side or the other. I have sometimes observed a direct connecting vessel between the two main ones. Within these vessels as well as the branches that proceed from them are seen, in a living specimen, active vibratory movements, which generally come to view only after the animal has been left for

1) Cf. Braun—Ueber die Lage d. Excretionspori bei d. ectopar. Trematoden. Zool. Anz. Jahrg. XII. 1889. p. 620.

some time under the cover-glass, and which are executed in such a way as to drive the contained fluid towards the excretory pores. These movements are probably due to the presence of vibratile flaps in the wall, but I have not been able to observe them in sections. The wall is seen, in section, to be formed by a compact refractive membrane with double contour, which does not stain with haematoxylin (Fig. 16, as). Evidences have been advanced by Lang[1] and Ijima[2] that the excretory vessels of the Turbellarians are "nichts Anderes als durchbohrte Zellen." In the Cestodes, Pintner[3] has observed a well-developed epithelium on the wall of the main vessels, "das zweifelsohne als Matrix ihrer glashellen, homogenen Membran aufzufassen ist." According to Schwarze[4], the central excretory vessel of the Distomes is at first a solid string of cells, which afterward acquires a lumen. He also supposes that the finer branches originate in the same way, and that the structureless condition of their walls in the adult worm may be explained by supposing "dass nach der Resorption des Inhaltes der primären Zellen keine äussere, muskulöse Zellenlage gebildet wird, *sondern die Wandung sich allein aus der äusseren Zellmembranen der ursprünglichen Anlage zusammensetzt.*" Whether the walls of the excretory vessels of *Diplozoon* is to be regarded as similar to those of the Turbellarians, with the difference that the protoplasmic remnants of the original cells have been transformed into a structureless membrane, or whether they had been produced by a distinct epithelium which afterwards underwent degeneration and finally disappeared, or whether they were formed by such a process as Schwarze[5] supposes

1) Lang—l. c. p. 212.

2) Ijima—Untersuch. ü. d. Bau u. d. Entwickl. d. Süsswasser-Dendrocoelen. Ztschr. f. w. Zool. Bd. XL. 1884. p. 397.

3) Pintner—l. c. p. 21.

4) Schwarze—l. c. p. 58. The italics are mine.

5) In the extreme case, viz. where the cells are arranged in a single row, the view of Schwarze reduces itself to that of Lang and Ijima.

to have taken place in the smaller excretory vessels of the Distomes, I must leave entirely undecided, with the single remark, however, that in *Diplozoon* I have observed no trace of nuclei in the wall.

The capillaries, furnished like the larger vessels with a distinct wall of compact refractive membrane, proceed from the smaller branches of the main vessels, and continue throughout their whole course without undergoing any perceptible diminution of their calibre. They are especially abundant in the layer of the mesenchyma just under the muscular wall of the body. They do not, like the branches of the larger vessels, anastomose with one another, and no vibratory movement is to be observed within. They branch freely, and each of the branches ends with a minute funnel-shaped enlargement (Fig. 15), within which is to be seen an active vibratile flap, the so-called "Wimperflamme." Various structures have been described in connection with these funnels, but, although I directed my utmost attention to the point and applied the best lenses at my disposal (Seibert apochr. syst., 4mm × 8),I could not observe any of them. The majority of the writers who have specially investigated this subject seem to agree in excluding any direct communication between the cavities of the funnels and those of the surrounding mesenchyma. In this respect, however, Fraipont makes an exception. He observed "fenètre ovale" in the wall of the funnel, by which its cavity was put in direct connection with the surrounding pseudocoel. I had at first supposed the end of the funnel completely closed; but on repeated observations with the apochromatic system of Seibert, it seemed to me very probably open, and to communicate with the cavities of the mesenchyma. I have not observed any of those peculiar cells described by preceeding writers.[1]

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[1] On reading Wright and Macallum's description, the question naturally arises if the writers have not mistaken the ciliated portions of the capillaries, such as have been described

VII. The Nervous System.

With the excellent investigation of Lang[1] on the nervous system of the Trematodes before me, I directed my special attention to this system, and can confirm his statement in its general aspect, though it seems to me to require modification when the writer extends it to the Trematodes in general. Let us begin with the brain.

As to its position, Lang says, "Ich glaube überhaupt, dass bei allen Trematoden das Gehirn diese Lage hat, dass es nämlich bogenförmig über den vorderen Theil des Pharynx verläuft und ich zweifle, ob sich die abweichenden Angaben bei erneuter, genauer Untersuchung bestätigen würden." Leuckart[2] is inclined to explain those cases where the brain has been observed behind the pharynx "durch eine Lagenveränderung" of the latter, "die um so leichter eintreten kann, als das Nervenband nirgends ringförmig geschlossen ist, obwohl das für einzelnen Arten behauptet wurde." I find, however, after careful and repeated observations, with these statements full in view, that in *Diplozoon* and also in *Axine*, *Microcotyle*, and *Octobothrium*, the brain is a band-shaped nervous body arching over the oesophagus on the dorsal side and *behind* the pharynx. In a fresh specimen, it is seen to be composed of very thin fibres ; but sections shew that in addition to these fibres the brain contains a finely granular substance doubtless identical with the "Punktsubstanz" of the Turbellarians (Fig. 17). The fibres in the brain are seen to run mainly in two groups, one on

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by Looss, for the funnels, and overlooked these latter. I also belive that they go too far when they endeavor to attribute excretory nature to the large cells observed by Looss and others in the pharynx of many Trematodes.

1) Lang—Untersuch. z. vergleich. Anatomie u. Histologie d. Nervensystems d. Plathelminthen. Mitth. a. d. zool. Station z. Neapel. Bd. II. 1881. p. 28.

2) Leuckart—l.c. p. 22.

its dorsal side, the other more on the ventral side. close to the dorsal side of the oesophagus. These I have marked in the figure with a lighter shade. They unite at the two ends of the brain where the nerves take their rise. The brain is traversed by numerous dorso-ventral bundles as already mentioned.

From the brain are given off nerves both anteriorly and posteriorly. One pair (Fig. 2. nai) proceeds anteriorly near the median line embracing the pharynx, near the anterior part of which it is lost in the mesenchyma. A second pair (nae) proceeds more laterally, and can be followed as far as the suckers, externally to which it proceeds and there withdraws itself from view. These internal and external anterior nerves are connected with each other by a commissure at a little distance from their origin in the brain.

Two pairs of nerves also proceed posteriorly, one of which may be called the ventral pair and is by far the stronger pair. The other pair (nvl) may be called the ventro-lateral nerves and proceeds posteriorly just at the angle between the ventral and lateral borders of the body, and can be followed as far as where the two individuals cross each other. The ventral nerves (nv) take their rise in the brain at its postero-lateral corner, and can be followed to near the posterior border of the body. They become, however, more and more indistinct as they proceed posteriorly, and finally become invisible at about the level of the hindermost pair of suckers. They closely follow in their course the main excretory vessels, on whose ventral side they are situated at a little distance from the muscular layers. At the place where the two individuals cross each other and where the ventro-lateral nerves withdraw themselves from view, the ventral nerves take a more lateral position, and this position they keep throughout the remainder of their course. The ventral nerves are connected with each other and with the ventro-lateral nerves by a number of commissures occurring nearly at regular intervals; and in such a way that each commissure between the ventral nerves lies in a line with that between them and the ventro-lateral nerves. The ventro-lateral nerves, again, sends out branches towards the lateral margin of the body, just at those points where they receive the commissures from the ventral nerves; so that all the nerves form a regular rectangular net-work, and divide the whole ventral surface of the body into a number of distinct areas. At the points where the commissures cross the main nerves, the course of the fibres is interesting. From any main nerve, namely, which we may be considering, fibres are given off on both sides to the neighboring nerves. Beside these, there are also fibres coming from the latter and proceeding directly past the main nerve without mingling with its fibres, so that the four main nerves are probably put in direct connection with one another. I have counted as many as thirteen commissures in the anterior half of the body, in addition to the pair of commissures between the anterior nerves. In the posterior half the commissures seem to be less numerous. I have been able to count only a few; but this is perhaps due to the presence of the strong folds already mentioned and the special development of the diagonal muscle in this region, which greatly increases the difficulty of following the course of the nerves. I have not been able to make out the plexus which the nerves probably form on the dorsal side.

As to their histological character, the nerves present typical "Balkenstränge" (Fig. 16). In some of the meshes are to be seen sections of nervous fibrils as exceedingly minute dots, which are visible only in the most favorable cases. Pintner[1] maintains that the "Bälkchen selbst" which form the mesh-work are the sections of the fibrils which are probably arranged "reihenweise, nebeneinand-

1) Pintner—l.c. p. 71

erstehend." Poirier[1] describes the nervous fibres of *D stomum clavatum* as filling up the entire cavity of the meshes. But an examination of the nerves in a fresh state shews very distinctly the exceedingly fine fibrils. They do not seem to be so regularly arranged as Pintner supposes, and are not at all large enough to fill up the entire cavities of the meshes. Without doubting the correctness of Poirier's observation, I am convinced that in *Diplozoon* the nerves consist of a frame-work of connective tissue, in the meshes of which run the true nervous fibrils. I have not observed any of the nervous cells described by Lang and others in the nerves. This set me to a careful search after ganglion cells, as these were not also to be found in the brain, where in other species they make such a conspicuous figure especially in the peripheral portion. But I have not been able to find out any to which I could decidedly point as nervous cells (*Vide supra* p. 171).

VII. The Reproductive System.

We now come to the consideration of the most complicated system, the reproductive organs. Of these the female portion consists of the vitelline body, the ovary, the oviduct, and the uterus, with a "connecting canal" the nature of which is not at all clearly known. The male portion consists of the testis with a single vas deferens. I shall begin with the latter.

The Male Organs—The testis is a nearly globular or ovoid body situated about midway between the point of crossing of the two individuals and the posterior margin of the body, and is composed of many lobes. Each lobe is separated from its neighbour and from

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[1] Poirier—Contribution à l'histoire naturelle des Trématodes. Arch. d. zool. expérimentale 2e. Série. T. III. 1885. p. 603.

the surrounding mesenchyma by a layer of dense connective tissue (Fig. 2, t & Fig. 18). During the winter season, it is a solid mass of vesicular cells that have assumed a polyhedral form by their mutual pressure. Each cell encloses a conspicuous round nucleus, which seems to be provided with a wall of its own, and in which numerous chromatin particles are to be observed. The cytoplasma is a hyaline fluid which scarcely takes up any color. The nuclei are of various sizes in the same lobe, some being very small, leaving abundant space for the cytoplasma, while others are of such a size as nearly to fill up the entire cavity of the cell.

From the anterior end of the testis proceeds a single vas deferens, which passes anteriorly in a straight course dorsal to the oviduct and ventral to the yolk-duct. During the first part of its course, it lies ventrally to the uterus ; but at about the level of the anterior end of the ovary, it turns dorsal to it and *opens into the vitelline duct of the other individual* a little more anteriorly than the anterior end of the ovary. Zeller[1] represents the vas deferens of one individual as standing in direct connection with the "Laurer's canal" of the other. But my observations contradict this view entirely. I have traced the course of the vas deferens in more than one series of the sagittal sections of the worm. One of these series is reproduced without interruption on Pl. XXIII. The opening of the vas deferens of one individual into the yolk-duct of the other is seen in Figs. XI. & XIII. By the same series of sections, the opening of the connecting canal of the oviduct into the intestine is distinctly seen (Figs. V & XIX). The vas deferens is destitute of any distinct wall of its own. It seems to be merely a continuous tube-like cavity in the general mesenchyma, and to collapse entirely during the winter season.

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1) Zeller—Ueber den Geschlechtsapparat des *Dipl. paradoxum.* Ztschr. f. w. Zool. Bd. XLVI. 1888. p. 233.

The Female Organs—The ovary (Fig. 2, ov) is a long conico-cylindrical body which is doubled on itself by its middle portion, so that the two ends come close to each other, and placed on the dorsal side of the body just anterior to the testis, to which its smaller end is closely applied; the anterior end where it is doubled on itself reaching as far as where the dorsal papilla formerly was. From its larger end, where ripe ova are found, proceeds the oviduct. As we approach the other end, the ova become smaller and smaller until finally we see a mere assemblage of round nuclei imbedded in a common mass of protoplasm. The whole ovary lies in a mere cavity of the mesenchyma without any distinct wall of its own. A section through the larger end (Fig. 21) shews the ovary to be a solid body consisting of large ova which are either polygonal or wedge-shaped according to the direction of the section. Each ovum is destitute of any membrane, and consists of a mass of homogeneous deeply stained protoplasm, in which lies a large vesicular nucleus provided with a distinct wall and containing a hyaline fluid in which float numerous deeply stained dots, the chromatin particles. Each nucleus again encloses a large deeply stained nucleolus in which are again to be observed one large or a few smaller vacuoles. Zeller[1] mentions and figures in the ovum of *Polystomum* and *Diplozoon* a thick, elastic "Hülle"; but I have no doubt that the ovarian ova of *Diplozoon* are destitute of any membrane. This is also the case in *Axine*, *Microcotyle*, *Octobothrium*, *Dactylogyrus*, in fact in all the species of ectoparasitic Trematodes I have hitherto examined. Willemoes-Suhm[2] mentions no "Dotterhaut" in *Polystomum ocellatum*; Taschenberg[3] asserts

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1) Zeller—Ztschr. f. w. Z. Bd. XXII. p. 5 & 169 foot-note; Bd. XLVI. p. 235. Is not the elastic membrane the result of fertilisation?

2) Willemoes-Suhm—Zur Naturgesch. d. Polyst. integerrimum u. Polyst. ocellatum. Ztschr. f. w. Z. Bd. XXII. 1872. p. 33.

3) Taschenberg—Beiträge. p. 36.

the absence of any membrane in the ovum of *Tristomum*; so also Wierzejski[1] in that of *Calicotyle Kroyeri*; and I believe the same is true of the ova of all ectoparasitic Trematodes. As we proceed nearer the smaller end of the ovary, the ova and their nuclei become smaller and smaller, the vacuoles within the nucleolus disappear and finally the nucleolus itself, until we see only spherical nuclei crowded together and surrounded by a common mass of uniform protoplasm. Fig. 22 shews a section through this part.

The oviduct proceeds from the larger end of the ovary and takes its course posteriorly and to the right, ventral to the vas deferens and the testis. At a short distance from its origin, it receives a canal (Fig. 2, *cc*) which proceeds anteriorly and, after making a slight winding or two, opens into the intestine (Figs. V & XIX). This is the "Laurer's canal" of Zeller which he represents as standing in direct connection with the vas deferens of the other individual. In *Polystomum integerrimum*[2] he asserts a direct connection between the ovary and the testis; and in proof of this he alleges his observation of the ova passing through the oviduct and Laurer's canal and entering the cavity of the testis. But it has been pointed out by Ijima[3] that the canal in question distinctly opens into the intestine, and that a similar canal is present in many other species of the group; and I can confidently state from my own study that the "dritte Dottergang" of Lorenz in *Axine* and *Microcotyle* distinctly opens into the intestine. A similar connecting canal is also present in a species of *Octobothrium* which I have examined.[4] The fact cited by Zeller can be explained

1) Wierzejski—l. c. p. 558.

2) Zeller—Weiterer Beitrag z. Kenntniss d. Polystomeen. Ztschr. f. w. Z. Bd. XXVII. 1876. p. 245.

3) Ijima—Über den Zusammenhang d. Eileiters mit d. Verdauungscanal bei gewissen Polystomeen. Zool. Anz. Jahrg. VII. 1884. p. 635.

4) Voeltzkorw (Arb. a. d. zool.-zoot. Inst. in Würzburg. Bd. VIII. 1888. p. 267) describes an evidently homologous canal in Aspidogaster conchicola. According to him it ends blindly near the dorsal surface of the worm. He calls it Receptaculum vitelli.

if we consider that the intestine is destitute of any distinct wall, and that when the testis is nearly empty there is almost nothing that would prevent the entrance of the ova into the cavity of the testis by way of the intestine. I therefore believe, notwithstanding his positive statement to the contrary, that the canal in question opens also in *Polystomum* into the intestine at the point where he represents it as arising from the testis. In *Dactylogyrus* a similar canal opens externally on the dorsal side, at a short distance from the right lateral margin of the body. In *Dipl. paradoxum* this canal is very long and undergoes numerous convolutions, but in *nipponicum* it is shorter and nearly straight, and the internal surface is clothed with cilia. Its nature and function, if it has any, I hope to be able to treat of later. At a little distance from the point where it receives this canal, the oviduct receives also the yolk-duct (yd). After this it continues its former course, and then, making a sudden turn anteriorly, opens into the uterus.

The uterus, under which I include both the "Ootyp" and the "Eiergang" of the German writers, is a cylindrical tube with a distinct wall which is thickly beset for the greater part of its length with long cilia on its internal surface. It shews an ovoidal enlargement at its origin, the "Ootyp," then diminishing in diameter proceeds anteriorly, following the same course as the vas deferens, and opens externally by a small aperture on the ventral side just at the angle formed by the ventral side of one individual with the dorsal side of the other, at the top of a conical elevation which is sometimes very small, sometimes larger and very conspicuous. Just before opening, it presents a second enlargement in which a single egg is usually found during the period of reproductive activity. "Il y a à l'origine de ce conduit (i. e., of the uterus) une sorte de pylore," says v. Beneden.[1]

1) v. Beneden—l. c. p. 43.

This is caused by the opening at this point of numerous flask-shaped unicellular glands (shg), the shell-glands. The wall of the uterus proper (Ootyp, Fig. 24) is lined by a distinct epithelium, whose cells contain each a round nucleus projecting into the internal cavity. The protoplasm is granular and no cell-boundaries are to be seen. The epithelium sits on a distinct basement membrane and is destitute of cilia. The remainder of the uterus (Eiergang) is provided with a similar wall (Fig. 23), with the nuclei, however, more separated from one another. Here, as already stated, the wall is beset with long cilia.

The vitelline body is an extensive lobed body (Fig. 2, vb) situated exclusively in the anterior half of the body, all around the intestine both on its dorsal and ventral sides. In specimens in which reproduction is going on, each lobe is seen, when fresh, to contain a dark granular mass. Sections (Fig. 19) shew that each lobe consists of a number of cells containing numerous yellowish granules, each with a nucleus and a nucleolus in the centre, and a thin cell-wall. These are the ripe yolk-cells, and when freed take up a globular form. In the peripheral portion are seen smaller cells with a deeply stained protoplasm, a nucleus and a nucleolus. The protoplasm is homogeneous, finely or coarsely granular according to their different stages of development. They are the young yolk-cells ; and there are also to be observed cells intermediate between these two kinds—cells one half of whose content has already been changed into yellowish yolk-granules while the other half still consists of granular protoplasm. During the winter months, the yolk-cells present a quite different appearance (Fig. 20). They are then scarcely to be distinguished from the cells of the mesenchyma of certain species of *Microcotyle*. They are then of a polygonal form, with a distinct cell-wall, a round nucleus and nucleolus, and a granular protoplasm which stains very well. In this granular protoplasm there are fibrous structures radiating from the central nucleus to the cell-wall and more or less forming a net-work. The steps by which these cells are changed into ripe yolk-cells and the origin of the deeply stained young yolk-cells I must leave at present unexplained.

As will be immediately seen from the above investigation, the union of *Diplozoon* is, as Zeller maintains, a permanent copulation. But the relation in which he has represented the parts of the two individuals to stand to each other requires correction. We have seen that the vas deferens of one individual opens into the yolk-duct of the other. This is well in accordance with the probable mode of copulation in some allied forms. In *Microcotyle*, which seems to be very closely allied to *Diplozoon*, there is a dorsal vagina which leads into a canal opening into the yolk-duct. In this canal I have often observed spermatozoa, and as during the period of reproductive activity yolk-cells are constantly going down the yolk-duct and push down before them anything that might come up from below, it is very probable that these spermatozoa had found their way here from the dorsal vagina. Hence the supposition is very natural that in copulation the penis of one worm is directly applied to the dorsal vaginal opening of the other. Now if this very probable supposition be true, and if we further imagine such a relation to persist permanently, we should have just the case that we actually see in *Diplozoon*, with the only difference that the copulation is not cross-wise. Whether in *Microcotyle* also, as in *Polystomum*, the copulation is normally cross-wise and mutual is well worthy of our attentive observation, since if this be the case, the copulation of *Diplozoon* would be nothing more or less than *the regular mode of copulation in allied forms made permanent.*

In conclusion I wish to express my best thanks to Prof. K. Mitsukuri and Prof. C. G. Knott for kindly looking through my paper and making suggestions.

Tokyo, October 1890.

Explanation of Figures.

Abbreviations common to all the figures.

as.........ascending stem of the excretory vessel (according to the direction in which the contained fluid moves).

br.........brain.

cc.........connecting canal between the oviduct and the intestine.

dvm.......dorso-ventral muscle.

ds.........descending stem of the excretory vessel.

dc.........digestive cell.

eo..........excretory opening.

int.........intestine.

mce........external circular muscle } of the pharyngeal wall.

mci........internal ,, ,, } of the pharyngeal wall.

mo.........mouth.

nae........external anterior nerve.

nai........internal anterior nerve.

nv.........ventral nerve.

nvl........ventro-lateral nerve.

ov.........ovary.

ovd........oviduct.

oe.........oesophagus.

ph.........pharynx.

pph........prepharynx.

pm.........median piece		of the posterior suckers.
ppa........paired anterior piece		
ppp........ „ posterior „		
pp.........process of the posterior piece		

sa.........anterior sucker.

sp.........posterior sucker.

sg.........sticky gland.

shg.........shell gland.

t...........testis.

ut..........uterus.

vd.........vas deferens.

vb.........vitelline body.

yd.........yolk-duct.

All the figures, if not otherwise stated, were drawn with cam. luc., Zeiss E × 2.

Pl. XXI.

Fig. 1.—Dipl. nipponicum killed with boiling sublimate; free-hand, surface view, × about 14. The black dots represent the digestive cells seen through the tissues.

Fig. 2.—The same, free-hand, from a specimen killed under the cover-glass, shewing the internal organs, half-diagramatic. The right anterior half presents the ventral, and the corresponding posterior half the dorsal aspect; and *vice versa* with the other individual. The nerves are colored yellow; the excretory vessels indigo-blue.

Fig. 3.—Chitinous frame-work of the posterior sucker as seen in a specimen under the cover-glass.

Fig. 4.—Section of the posterior sucker in the direction indicated by ab in Fig. 3.

By inadvertence of the printers, the nucleoli in Figs. 8, 9, 11, 13, 16, 17, 18, 19, 20, 23, and 24 are represented either as lying outside the nuclei or quite eccentrically in them, whereas they ought to occupy more central positions. Their true positions are indicated in most of the figures by weakly shaded dots.

Fig. 5.—Section of the same in the direction indicated by xy in Fig. 3.

Fig. 6.—Hooks between the posterior suckers.

Pl. XXII.

Fig. 7.—A part of a cross-section of the worm passing through one of the conical elevations of the epidermis. It also passes through one of the transverse folds into which the surface of the body is thrown when the animal contracts ; hence the longitudinal muscles are separated from the circular by a rather thick layer of connective tissue.

Fig. 8.—Section of the sticky gland, from a cross-section of the worm.

Fig. 9.—Section of the anterior sucker, from a cross-section of the worm.

Fig. 10.—To shew the direction of the diagonal muscular fibres, from a horizontal section of the worm.

Fig. 11.—Cross-section of the pharynx.

Fig. 12.—Diagram shewing the muscles accessory to the pharynx.

Fig. 13.—A part of a cross-section of the worm, from the posterior half of the body, a little posterior to the testis ; to shew the character of the mesenchyma.

Fig. 14.—The portion of the mesenchyma situated between the ovary and the testis, from a sagittal section of the worm.

Fig. 15.—Excretory funnel, Seibert apochr. sys. 4 mm. × 8.

Fig. 16.—Cross-section of the ventral nerve.

Fig. 17.—The brain, from a cross-section of the worm.

Fig. 18.—The testis, from a longitudinal section of the worm.

Fig. 19.—The vitelline body, from a longitudinal section of a worm collected in September.

Fig. 20.—The same, from a cross-section of a worm collected in May; the yolk-cells not ripe.

Fig. 21.—Section of the ovary near its larger end.

Fig. 22.—The same near its smaller end.

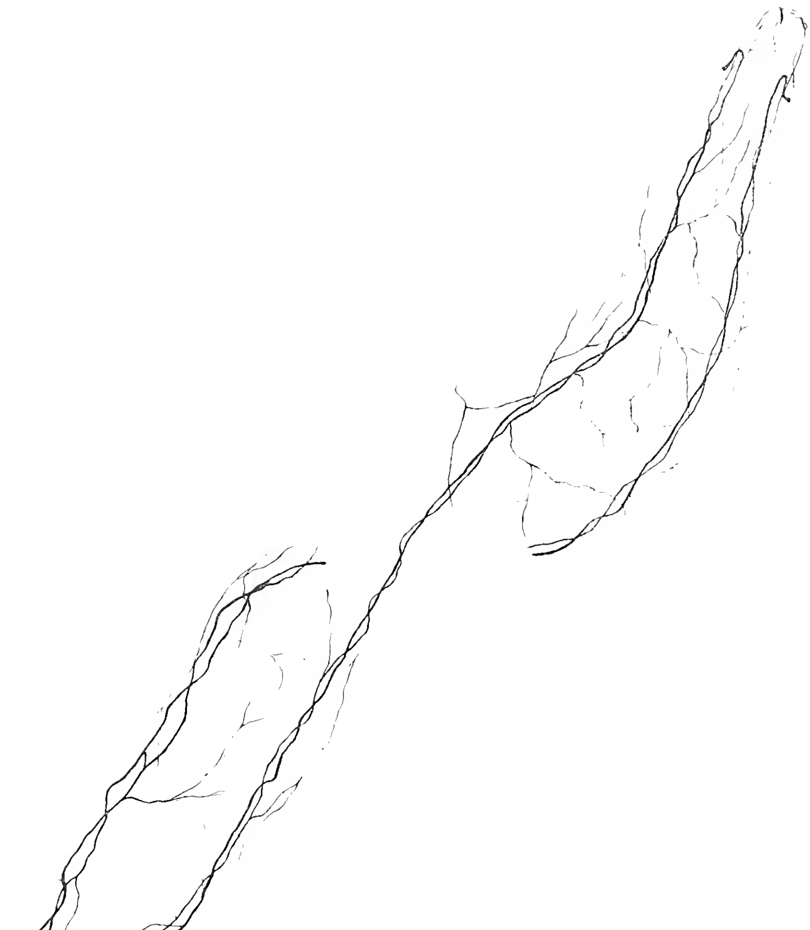
Fig. 23.—Longitudinal section of the uterus (Eiergang).

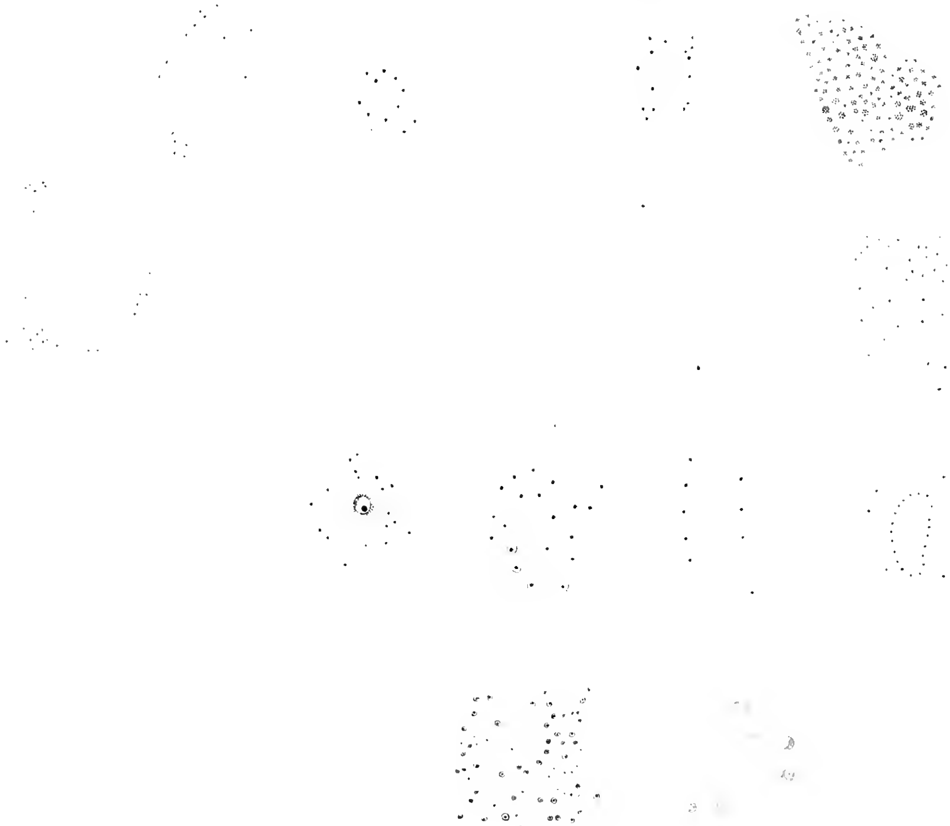
Fig. 24.—Cross-section of the uterus proper (Ootyp).

Fig. 25.—A cross-section of the worm through the region of the pharynx ; to shew the peculiar gigantic cells. Zeiss D × 2.

Pl. XXIII.

An uninterrupted series of sagittal sections of the worm. To the respective abbreviations is subjoined the letter *r* or *l* according as the parts belong to one or the other individual. Zeiss B × 2.





A New Species of Hymenomycetous Fungus Injurious to the Mulberry Tree.

by

Nobujirō Tanaka.

With Plates XXIV—XXVII.

In Japan the mulberry tree has been widely cultivated, from time immemorial, for rearing silkworms. Although the methods of its culture have much improved, yet its diseases, especially those caused by fungus parasites, have been overlooked even by skilful cultivators. The chief reason for general neglect regarding these points is the want of accurate knowledge of the nature and biology of fungi. One of the most serious diseases of this kind is that which is known under the name of "Mompa-byō."* This disease has produced much distress at various intervals for about eight years, in the experimental farm of the Agricultural College at Komaba, Tōkyō. Some distinguished biologists and agriculturists have investigated its nature, and stated that it was due to the ravages of a sterile mycelial stage of a fungus of some other form, but its true nature has never yet been fully explained. I have lately had the good opportunity to study this disease under the direction of Prof. R. Yatabe. The object of this paper is to deal with one or two of the unsettled questions regarding it, namely, the morphology of the perfect condition of the fungus which causes the disease, and its systematic position.

* *Mompa*, a kind of nappy cotton-cloth; *byō*, disease.

Towards the end of last year, I obtained specimens of mulberry trees attacked by the disease, but unfortunately the specimens were so far advanced in decomposition that the course of the mycelium of the fungus in its relation to the internal tissues of its host was not clearly definable, and also the fructification of the fungus could not be found. Since then I have examined many other specimens, up to the beginning of April of this year, and at length found the perfectly developed condition of the fungus. Its specific characters are as follows:——Pileus sessile, resupinate, somewhat orbicular or oblong, often irregularly lobed, 5–10 cm. across, 2–4 mm. thick, at first velvety and membranaceous, then subcoriaceous, somewhat convex, incrustate, purplish brown, at length albo-pruinose; hymenium white; basidia curved, 1–3-septate, tetraspored; sterigmata elongated; spores ovoid, curved, hyaline, 10–12 μ. long, 5–7 μ. broad.

By the above characters, especially by its peculiar form of basidia and by its nature, I consider that this fungus belongs to the genus *Helicobasidium* in the family *Thelephoreæ* of the *Hymenomycetes*. It has much resemblance in its characters and habit to many species of its allied genera; but it can be distinguished from *Thelephora* and *Corticeum* chiefly by having an intermediate stratum in the pileus, and from *Stereum* by having a usually superior hymenium. Of the species of the genus *Helicobasidium* but few are known; in Saccardo's *Sylloge Fungorum** only two species, *H. purpureum (Tul.) Pat.* and *H. cirratum Pat. et Gail.*, are given. By comparing my description of the fungus with that of the above named species, it can be distinguished from the former chiefly by the colour of the pileus and the number of spores borne on a basidium, and, from the latter, by the diameter of the pileus, the number of spores borne on a basidium,

* Vol. VI. p. 666.

and their size. An allied fungus on the mulberry tree in South Carolina, North America, was described by Prof. Berkely under the name of *Stereum moricolum;* and two other species of *Stereum*, viz. *S. subcruentatum B. et C.* and *S. contrarium Berk.*, are given in Saccardo's *Sylloge.** These are Japanese species, but unfortunately I have never yet found them. They must, however, be very distinct from my species. For these reasons I venture to call it *Helicobasidium Mompa* † from the well known Japanese name of the disease.

The fungus at first attacks the root of a living tree, and the diseased tree shows external symptoms of the disease on portions above ground: usually the growth of shoots is arrested, the newly developed leaves become gradually smaller and at length die off; then the lower part of the shoots begins to die, though the bark higher up may preserve its normal appearance. It takes a tree one or two months to reach this state, after it has first shown the external symptoms of the disease.

On uprooting a young mulberry tree badly attacked by the fungus, the roots are found to be killed from below upwards, and present the appearance represented in Plate XXIV, Fig. 1. The tree figured there is three years old; the roots marked *a* have grown three years, and those marked *b* and *c* are of this year. The portions marked *a'* are dead roots, whose bark was already severely injured and so loose that it was separated by the act of uprooting. As these dead roots were of no use to the tree, it produced the new roots *b* to absorb nourishment from the soil. But the newly formed roots were also injured as the disease advanced, and became unfit to perform their function; and at length another crop of newer roots *c* was produced higher up, by means of which the tree was enabled to

* Vol. IV. pp. 507 and 579.

† See p. 193.

sustain its life. In the state just described no fructification of the fungus is yet observable, although its subterraneous vegetative mycelia are actively growing.

After the fungus has been growing in this manner for some time, flat irregular disks of mycelia begin to form under certain circumstances on the aerial portion of the tree at the bases of the shoots. These disks are the first stages of the pileus. The successive stages of growth of the pileus are shown in Plate XXIV, Figs. 2, 3, and 4. It first appears as a thin effused mass of mycelia of a dark purplish brown colour, having a paler margin of definite outline, and presenting a smooth velvety appearance (PL. XXIV, Fig. 2, *a*). It surrounds the basal part of the shoots of the diseased tree to a height of 15 cm. or more, sometimes leaving here and there small narrow portions uncovered. It often encloses in its embrace some extraneous matter, such as decayed leaves, branches, and the like, together with particles of soil. As it gradually develops, it forms generally an irregular roundish flat disk, one part of which stands out at right angles from the surface of the shoot, while the other remaining part is firmly attached to it. The projecting part of the pileus then expands laterally either on one side of the shoot or on both sides ; and as the shoot is usually bent horizontally at the base, the pileus becomes also horizontally expanded. The hymenium is produced on the free surface of the pileus, on the upper and lower sides of the projecting parts, as well as on the exposed side of the part fastened to the shoot. The fully developed pileus is of a whitish colour tinged with violet ; the projecting part is about 5 mm. thick, and its upper surface is more uneven than its lower surface (PL. XXV, Figs, 1, 2).

By carefully detaching the young pileus from the substratum, numerous mycelial strands of unequal thickness may be observed on its lower margin (PL. XXV, Fig. 3). These strands are found on almost every portion of the diseased roots, forming irregular networks of various complexity (PL. XXV, Fig. 4). They are ½–1 mm. thick and of a purplish brown colour like the young pileus; and as to their mode of ramification there seems to be no regularity. Without destroying even their finest branches, they can be very easily detached, with a needle, from the roots upon which they grow, to a length of several centimetres (PL. XXV, Fig. 5). They are often found free, either forming large groups in spaces left between the partly detached cork layers of old diseased roots, or solitarily in the soil.

The microscopical structure of the mycelial strand is different from that of *Agaricus melleus*, whose minute details are now well known from the excellent description given by the late Prof. De Bary.* In the present species the axial portion of the mycelial strand consists of thick-walled hyphæ, 3 μ. in diameter, mixed with a few finer ones; and the peripheral portion consists entirely of finer hyphæ (PL. XXVI, Fig. 1). In the transverse section of the strand this is more clearly seen (PL. XXVI, Fig. 2). In the mycelial strand of *Agaricus melleus* the hyphæ are so compactly arranged as to form a tissue as is clearly seen in the cross section;† but in the present species the hyphæ composing the strand are so loosely put together that they easily separate from one another, and in the cross section they present a circular and not angular form, since they are not pressed together so as to assume the latter form. Moreover the form of the cross section of the strand in *Agaricus melleus* is round, but in this species it is flattened. The thickening of the strand is effected either by the copious branching of a single hypha or by the coalescence of two or more strands. In the group of hyphæ formed by the first method, there is always an axial or original thick hypha

* De Bary, Vergl. Morphol. u. Biol. d. Pilze; Eng. trans. p. 23-29

† See Fig. 11, p. 24, of the same book.

surrounded by finer ones which have been produced by its ramification (PL. XXVI, Fig. 3). As the strand grows, the branches of the original hypha also ramify ; and the secondary branches thus produced surround the primary branches, just as the latter surround the original hypha. In this way branches of higher orders are successively produced, and surround the branches of the next lower order. Ordinarily the branches of the hyphæ grow in one direction, but occasionally there are found those that grow in two opposite directions from the point of origination (PL. XXVI, Fig. 4). The older hyphæ or those lying towards the center of the strand are much more darkly coloured than the younger or those of the periphery. The mycelial strand of the fungus is found only on the surface of the host. When it makes its way into the tissues of the latter it usually forms longitudinally elongated masses, such as are seen in the interstices between the cork layers of the host (PL. XXVI, Fig. 9). Similar masses are also found on the surface. These masses of the hyphæ spread widely in the cambium zone and in the young bast, forming membrane-like expanded networks of whitish mycelia. These mycelia send out single colourless hyphæ, 1.5–1 μ. in diameter (PL. XXVI, Fig. 5), into the rind and wood, and especially into the dotted vessels. They also send out masses of coloured hyphæ to the surface of the host, from which are again developed ordinary external mycelial strands.

Crystalline spheres of calcium oxalate, $\frac{1}{10}$–$\frac{1}{2}$ mm. in diameter (PL. XXVI, Fig. 6), are found in great numbers on those places where the white mycelial membranes abound. They consist of an enormous number of somewhat radially arranged wedge-shaped crystals (PL. XXVI, Figs. 7, 8), each of which is 20–30 μ. long and 10–15 μ. broad. If we examine one of these crystalline spheres under the microscope, taking care not to crush it, we see only the sides and broader ends of the wedge-shaped crystals ; and by crushing it we can recognize the radial arrangement of the crystals. Prof. De Bary has described crystalline spheres of a similar nature found in the narrow cylindrical hyphæ of the mycelium of *Phallus caninus*.* Crystals of calcium oxalate of other forms, such as regular quadrate octohedra, rod-shape, &c., are also found in great abundance in the same place where the crystalline spheres are found.

The mycelia of the fungus form an enormous number of sclerotia in all parts of the diseased portion of the roots (PL. XXVII, Fig. 1, *a*). The sclerotia are irregularly roundish bodies 1–4 mm. in diameter, and are dark purplish brown in colour. If the nourishment in the sap-containing layers of the host plant becomes scanty by the parasitic action of the fungus, and also when the vegetative activity of the host plant is diminished in autumn, the interior of the lenticels and the interstices between the cork layers become filled with the sclerotia of the fungus, while the mycelial strands which remain outside spread widely on the surface of the roots. By carefully detaching the mycelial strands we can ascertain that they have no direct communication with the sclerotia. The number of sclerotia is different in different parts of the roots, according to the degree of the injury done by the fungus; and the greater the degree of the injury, the greater the number of the sclerotia. The formation of sclerotia does not take place on the outside of the host plant, but always in the inside or in the spaces partly exposed by the formation of fissures (PL. XXVII, Fig. 2). The sclerotia have a dark brown rind (PL. XXVII, Fig. 3, *b*), and a medulla of white soft tissue (Fig. 3, *a*) with a few air-conducting passages. The hyphæ of the medulla are cylindrical and septate, anastomosing with one another in a rather loose manner (Fig. 4, *a*), and are 4–5 μ. in diameter. Towards the surface of the sclerotia, the medulla passes gradually into the rind,

* De Bary, Vergl. Morphol. u. Biol. d. Pilze, Eng. trans. p. 11.

which consists of thicker-walled and shorter-celled hyphæ, forming a compact tissue without interstices (Fig. 4, *b*). In its younger stage the surface of the rind is felted over with the remains of dead hyphæ (Fig. 4, *c*). A series of five different colours—white, yellow brown, dark brown, rose violet, and dark violet brown—may be seen in the order stated, from the centre outwards in the section of the sclerotium.

As the mycelial strands gradually grow upwards, they aggregate into a few flat thick strands, more than 1 mm. broad. These strands spread themselves from the apices and unite into a thin broad layer, consisting of reticulated hyphal filaments and covering the base of the shoots of the host plant. As the development of this layer proceeds, the pileus is formed from it. The pileus is an irregularly roundish flat disk with a smooth velvety surface, and takes a purplish brown colour, leaving its margin whitish (PL. XXIV, Fig. 2, *a*). Thin radial sections of a fully developed pileus, show that its medullary stratum is composed of loosely anastomosing branched hyphæ, dark violet brown in colour, and 3–4 μ. in diameter (PL. XXVII, Fig. 5). Towards the outer surface of the pileus these hyphæ take a vertical position, and produce short and blunt branches (PL. XXVII, Figs. 6, 7). These branches of hyphæ are colourless and shortly septate, and form the hymenial layer. Some of them elongate here and there, and form the basidia, which are curved and 5–8 μ. in diameter. From the convex surface of the basidium are produced four sterigmata, which are pointed, slightly curved and 6–10 μ. in length (PL. XXVII, Figs. 8, 9, 10). The spores are formed singly on the apices of the sterigmata; they are ovoid, curved, 10–12 μ. long and 5–7 μ. broad (PL. XXVII, Fig. 11). The portion of the pileus attached to the substratum produces hairs or rhizoids on its inner surface, which penetrate into the substratum. But the horizontally projecting part of the pileus produces the hymenium on both surfaces, when it does not lie flat on the ground. The internal structure of these two portions is, however, essentially the same.

In the medullary stratum of the pileus which lies on the ground, an immense number of minute algae, belonging to the genera *Conferva* and *Protococcus* (PL. XXVII, Fig. 16) are found in groups, very much like the gonidia of Lichens. On the higher parts of the stems and branches of old mulberry trees, are frequently found orbicular and brownish purple patches, from 1–10 cm. in diameter; they are commonly called "Kōyaku-byō" * of the mulberry tree. They resemble very much in their structure the young pileus of the speciees of *Helicobasidium* in question, except that the hyphæ in the pileus of the former are more slender than those of the latter, being only 2–3 μ. in diameter (PL. XXVII, Fig. 12). The sterigmata of the former are also very minute; and I have not been able clearly to determine their number on a basidium (PL. XXVII, Figs. 13, 14). Besides the ordinary slender basidia, 3 μ. in diameter, much thicker and segmented basidium-like extremities of hyphæ bearing no sterigmata are often seen in the hymenium (PL. XXVII, Fig. 15). Whether the orbicular patches just described simply represent a form of the present species or not can only be determined after further investigation. But I venture to say that it is probably a poorly nourished form of the latter.

In conclusion, I wish to express my thanks to Prof. R. Yatabe who has helped me throughout my work with valuable suggestions.

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* The Japanese word *kōyaku* means a medical plaster; *byō*, disease.

Explanation of Figures in Plates XXIV—XXVII.

Plate XXIV.

Fig. 1. Sketch of the base of a young mulberry tree, injured by the disease at the roots *a*, *b*. The upper portion *a'* and the roots *c* are free from the disease ; the lower portion *a'* of the roots *a* is completely disorganized. *Reduced.*

Fig. 2. Portion of the base of a shoot, showing the young pileus *a* of the fungus. *Natural size.*

Fig. 3. More advanced stage of a similar pileus with its projecting parts *a*. *Natural size.*

Fig. 4. Mature form of a similar pileus ; *a* its projecting part ; *b* its basal part. *Natural size.*

Plate XXV.

Fig. 1. Mature form of the pileus of the fungus, showing its upper surface. *Natural size.*

Fig 2. Lower surface of the same. *Natural size.*

Fig. 3. Young stage of the pileus carefully detached from its substratum. *Natural size.*

Fig. 4. Portion of a diseased root, with mycelial strands of the fungus. *Natural size.*

Fig. 5. Portion of the mycelial strands detached. *Natural size.*

Fig. 6. Group of mycelial strands. *Natural size.*

Plate XXVI.

Fig. 1. Hyphæ of mycelial strands. × 140.

Fig. 2. Cross section of the same. × 440.

Fig. 3. Hyphæ of mycelial strands, showing the mode of ramification. ×440.

Fig. 4. A kind of branching in a similar hypha. ×440.

Fig. 5. White hyphæ in the tissues of the host plant. ×440.

Fig. 6. Crystalline spheres of calcium oxalate. ×5.

Fig. 7. A similar sphere much magnified. ×240.

Fig. 8. Wedge-shaped crystals *B* of the same; *A* showing their radiating structure. ×240.

Fig. 9. Masses of coloured mycelia *a* in the interstices of cork layers *b*. ×10.

Plate XXVII.

Fig. 1. Portion of a diseased root, with numerous sclerotia *a* of the fungus. *Natural size.*

Fig. 2. Longitudinal section of the bark of a root, showing the formation of sclerotia. ×5.

Fig. 3. Vertical section of a sclerotium; *a*, medulla; *b*, rind; *c*, remains of hyphæ. ×50.

Fig. 4. Portion of the same, showing its tissues; the letters correspond to those in Fig. 3. ×440.

Fig. 5. Hyphæ in the medullary stratum of the pileus. ×440.

Figs. 6, 7. Hyphæ in the hymenial layer of the pileus. ×440.

Figs. 8, 9, 10. Basidia with sterigmata and young spores. ×440.

Fig. 11. Mature spores. ×440.

Fig. 12. Hyphæ in the medullary stratum of the orbicular

patches on the higher parts of the stem and branches of an old mulberry tree. ×440.

Figs. 13, 14. Basidia of a similar patch. ×440.

Fig. 15. Basidium-like hypha of a similar patch. ×440.

Fig. 16. Algæ in the medullary stratum of the pileus ; *A*, *Conferva ; B*, *Protococcus*.

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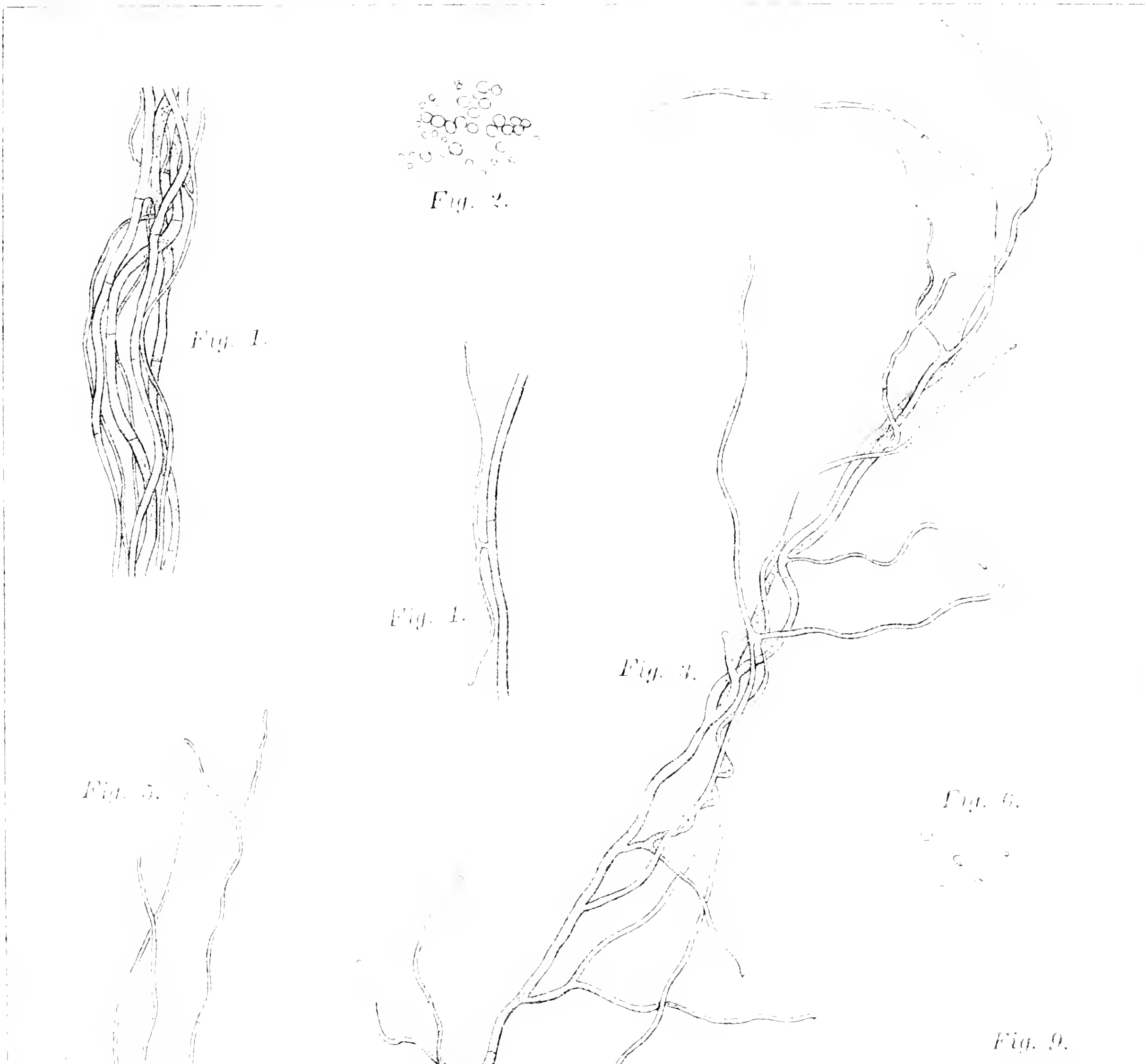

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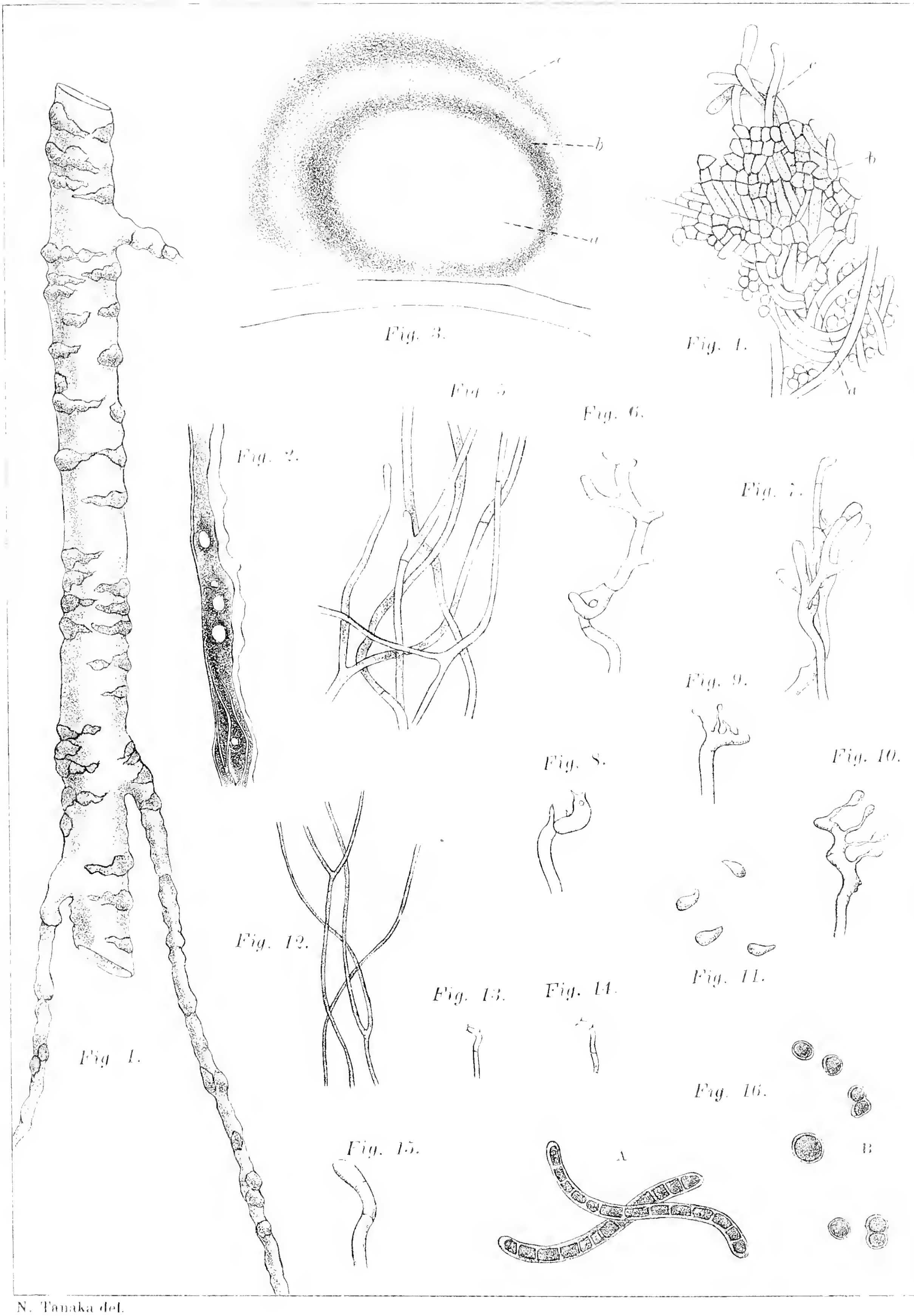

Fig. 1.
Fig. 2.
Fig. 3.
Fig. 4.
Fig. 5.
Fig. 6.
Fig. 7.
Fig. 8.
Fig. 9.
Fig. 10.
Fig. 11.
Fig. 12.
Fig. 13.
Fig. 14.
Fig. 15.
Fig. 16.
a
b
c
A
B

N. Tanaka del.

Notes on the Irritability of the Stigma.

by

M. Miyoshi, *Rigakushi.*

With Plates XXVIII—XXIX.

It is already known by the researches of Heckel* and others that the bifid stigmas of certain plants, such as *Martynia*, *Bignonia*, and especially of some *Scrophularineæ*, e.g. *Mimulus*, *Torenia*, *Gratiola*, are irritable to touch. But as our knowledge on the subject is still scanty, it will not be superfluous here to state some of my observations on this subject. The plants I studied were *Mazus rugosus*, Lour., var. *macrantha*, Fr. et Sav., *Mimulus nepalensis*, Benth., *M. sessifolius*, Maxim., *M. moschatus*, Doug. I shall give in detail only the case of

** Mazus rugosus, Lour., var. macrantha, Fr. et Sav. (Pl. XXVIII, Fig. 1.)

The plant belongs to *Scrophularineæ*, and may be briefly described as follows:—

A low annual. Branches prostrate, 5-40 cm. long, often rooted at the nodes. Leaves exstipulate, sparingly hairy, coarsely and irregularly dentate; the radical sessile, cuneate-spathulate, 1-4 cm. long, 0.5-1 cm. broad; those of the branches opposite, sometimes alternate, obovate, narrowed into the cuneate base, smaller than the radical leaves. Flowering stems, erect, more or less

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* E. Heckel:—Du mouvement dans les stigmates bilobiés des Scrophularinées, des Bignoniacées et des Sésamées. (Comptes rendus, t. LXXIX. 1874. No. 12, P. 702-704.)

** The Japanese name of this plant is *Sagigoke*.

pubescent. 5-25 cm. high. Flowers distant; pedicels bracteate, minutely pubescent, 1-2.5 cm. long; bracts minute, scaly, acute. Calyx (Fig. 3) 5-lobed, campanulate, persistent, 0.7 cm. long; lobes ovate, acute, at length spreading. Corolla (Fig. 2) bilabiate, light blue or often deeper-coloured, sometimes snowy white. Upper lip erect, or curved upward, bifid at the apex. Lower lip deflexed, 3-lobed, 1-1.5 cm. broad and long; the two lateral lobes broader than the middle; its palate convex, beset with delicate hairs, whitish or yellowish, with yellowish brown or deep brown spots. Stamens (Fig. 2) 4, didynamous, inserted in the tube of the corolla, distinct at first, each pair connivent and adhering by the anthers at maturity; anthers whitish, 2-celled. Pollen-grains (Fig. 6) whitish yellow, elliptical, with 3 longitudinal grooves. Style (Fig. 3) longer than the stamens, ascending under the upper lip of the corolla. Stigma (Fig. 3) 2-lobed, lobes semicircular, 1 mm. long. Ovary superior, globose, 2-celled. Capsule compressed, loculicidal. Seeds numerous, minute, brown.

The plant is common everywhere, especially on sunny lawns, and bears flowers from early spring to mid-summer. When I happened to notice* the irritable property of the stigma and began my observations early in April, I visited daily certain spots in the University grounds where I found the plant in profusion, some growing in positions very convenient for examination.

To observe the phenomenon, take the flower of this plant, and touch the lower lobe of the stigma with the point of a needle or the like; we shall then see the affected lobe move steadily upwards with uniform speed until it comes in close contact with the upper lobe (Pl. XXIX, Figs. 7, 8, 9). We may cause the same action with the least

* A few weeks after, I was informed by Mr. T. Yoshinaga of Tosa, of the same fact which he had himself observed.

possible touch as, for example, with the tip of a bristle or hair. On the other hand, placing a small drop of water on the stigmatic lobes or blowing upon them does not induce the motion. Again, mere rubbing on the style or on the outer surface of the lobes does not show even the least sign of motion, though a slight touch on the inner surface is very effective. Moreover, this curious property is not confined to the lower lobe only, as may at first sight appear, but it is possessed by the upper lobe as well. Since the lower lobe is widely reflexed, the motion there is very manifest; but the upper one being nearly in the same line with the style shows no decided motion other than a slight bending down.

I made these experiments on the natural position of the flowers, and measured the time required for the closing and reopening of the lobes. The results varied not only in the flowers of different stocks, but in different flowers of the same stock, even in the same flower in different stages of development, in different hours of the day, and also in different states of temperature and weather. Generally speaking, the closing and reopening in a given flower are more rapid at the middle of a clear warm day than at other times and in other states of weather. Complete closing is performed usually in 3-6 seconds, but may sometimes take 7, even 10, seconds. Complete reopening takes place usually after 7-12 minutes, but sometimes sooner, sometimes later. Some flowers which I examined on a very warm day, reopened only after 5 minutes. I also found that in young flowers, the closing is more rapid, while the reopening is much slower, requiring about 13-15 minutes. But in mature flowers, closing takes place in the usual interval of time, while reopening is quicker (7-10 minutes). In all cases the movement of closing may easily be observed, but that of reopening is so gradual that we cannot recognise it without careful observation. The experiments may be repeated several times in a given flower apparently without any sign of decrease in irritability. The experiments may also be made on the plants kept in the house with just as good results as on those in their natural habitats. Of the flowers detached from the shoot, the same holds good as long as they are prevented from withering.

*The stigmatic lobes, when magnified are seen to be made up of bundles of filaments (Pl. XXIX, Fig. 10, 11, loos. tiss.) composed of cells full of granular protoplasm. The filaments are very loosely aggregated, passing below to the closer conducting tissue (cond. tiss.) of the style. The inner surface (Fig. 10) of the lobe is quite naked but studded with many papillæ (pap.) or the clavate apices (clav. ap.) of the above-mentioned filaments, among which the pollen-grains (pol. gr.) take lodgement. The outer surface (Fig. 11), on the contrary, is loosely covered with a very thin layer of epidermis (directly continuous with that of the style), the cell-walls of which are more or less cuticularized and marked with minute longitudinal wrinkles (Fig. 11). Besides, there may be seen differences in the outlines of the component cells of the epidermis, as we pass from the lobes of the stigma (stig.) to the stylar portion (styl.) below—those of the former being irregular and sinuate, while those of the latter are almost rectangular.

As has been pointed out by Pfeffer, Sachs, and others, cells forming irritable parts of plants, when acted on by external stimulus, allow water to pass out of their protoplasm, thereby suffering diminution of volume; and this contraction affecting the extensive and elastic cell-walls makes the motion visible to the naked eye. This, I believe, may also explain the irritability in the present case,

* The structures of the style and stigma have been studied by J. Behrens. (Untersuchungen über den anatomischen Bau des Griffels und der Narben. Göttingen, 1875.)

although I am as yet unable to detect any decided structural peculiarity.

The following observations were made to ascertain the significance of the movement and to know in what relations, if any, it stands with respect to the visits of insects.

April 16, 17. Rainy. I visited certain spots where the plants were abundant. Many flowers were open. I saw no single insect near, and the stigmatic lobes of almost all the flowers were deflexed.

April 18. Clear warm day; 22°C. at noon. At one o'clock P. M. I went to the same places and found that many of the flowers had their stigmas closed. Soon I saw two or three bees come with a buzzing note. They alighted on some of the flowers, thrusted their mouth-parts deep into the throat of the corolla which had honey stored in the basal part of the lower lip. In so doing the heads of the insects unavoidably struck against the open lobes of the stigma which at once closed. The heads were then thrust in deeper and came in contact with the anthers. In a few minutes they visited no less than a hundred flowers and then flew away.

At 3 P. M. On the same day I revisited the same places and found a similar occurrence.

At 6 P. M. Comparatively small number of flowers (about one-third) had their stigmas closed; no insects were flying about.

At 9 P. M. Dark night. The flowers did not close, and the stigmas were wide open.

April 19. Foggy morning. At 7 A. M. I saw the stigmatic lobes quite reflexed.

At 9 A. M. A few insects were found entering the flowers.

April 20. Clear but very windy day. At noon I visited the same place without noticing a single insect, and most stigmas were open.

During these days I likewise examined the same species in the Botanic Garden of the University at Koishikawa, and found almost the same state of things.

In all cases I observed that those growing in shady places and those kept in the house had their stigmas always open, while those on open sunny lawns had the parts mostly closed,—the differences seeming to be due to the relative frequency or total absence of the insect-visitors.

These insect-visitors belong almost exclusively to the Hymenoptera, a species of *Eucera* (Pl. XXVIII. Figs. 4, 5) of Apidæ, identified for me by Dr. C. Ishikawa, being the chief visitor. The visit of this bee, however, is not confined to the flower of Mazus, for I often noticed that the insect burdened with yellow pollen dusts of other flowers, probably of *Taraxacum*, thrust its body into the lips of the flower smearing the stigma as well as the corolla with the golden yellow powder.

So far as my observation extends, I may conclude that the irritability of the stigma of this plant is not for the purpose of protection against wind and rain, of which the stigma may be tolerably well kept out by the overhanging upper lip of the corolla, but—as has been suggested by Hermann Müller* in the case of *Mimulus luteus*—for a more important purpose, i.e. for cross-fertilization, which no doubt takes place in the following manner.

A bee laden with the pollen of one flower enters another flower of the same species for honey, and thus comes with its head in contact with the lower lobe of the stigma which just overhangs the

* Die Befruchtung der Blumen druch Insecten und die gegenseitigen Anpassungen beider. Leipzig, 1873.

stamens. Soon after the contact (by which the stigma receives the pollen), the lower lobe folds up, opening the way for the bee which then enters deeper and becomes dusted with a new supply of pollen. That reopening of the lobe takes place in about 10 minutes after the closing seems to be well adapted to the requirement of the case, when we consider the interval of time which usually elapses before the bee revisits the same flower. The usual deep bluish purple, or rarer snowy white, colour of the corolla serves no doubt to attract the insects, while the hairs on the floor of the lower lip seem to assist the visiting insects in alighting.

In *Mimulus nepalensis*, Benth., *M. sessifolius* Maxim., and *M. moschatus*, Doug., all of which I have observed, the mechanism is precisely similar and adapted for the same purpose as Mazus, so that it is hardly necessary to enter into details.

Explanations of Plates XXVIII and XXIX.

Indications of Reference Letters.

u. l., upper lobe of the stigma ; *l. l.*, lower lobe of the stigma ; *sty.*, style ; *stig.*, stigma ; *loos. tis.*, loose tissue of the stigma ; *cond. tis.*, conducting tisssue of the style ; *pap.*, papillæ ; *pol. gr.*, pollen-grains.

Plate XXVIII.

Fig. 1. *Mazus rugosus*, Lour., var. *macranthus*, Fr. et Sav. (natural size).

Fig. 2. Corolla cut open along the middle line of the central lobe of the lower lip. showing 4 didynamous stamens (magnified 3 times).

Fig. 3. Calyx cut open showing the pistil and its bilobed stigma (magnified 3 times).

Fig. 4. *Eucera sp.* which visits the flower of *Mazus.* (magnified 1.5 times).

Fig. 5. Upper and lower wings of the same, showing the veins (magnified 3 times).

Plate XXIX.

Fig. 6. Pollen-grains in different positions (magnified 540 times).

Fig. 7, 8, 9. Stigmatic lobes in the successive stages of closing (magnified 22 times). Fig. 7, at the moment of a shock given. Fig. 8, after 3 seconds. Fig. 9, after 5 seconds.

Fig. 10. Portion of the inner surface of the stigmatic lobe showing the papillae or clavate apices of the loose filaments together with some pollen-grains developing pollen-tubes. The minute globules in the cells represent the granular aspect of the protoplasm (magnified 540 times).

Fig. 11. Outer surface of the stigmatic lobe together with a portion of the style; the epidermis is shown as broken along the middle line so as to show the loose tissue inside. The cells of the epidermis on the stigmatic portion are sinuous, those on the stylar portion nearly rectangular (magnified 230 times).

Fig. 4

Fig. 5

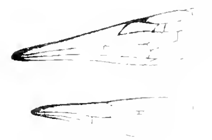


Fig. 1

Fig. 2

Fig. 3

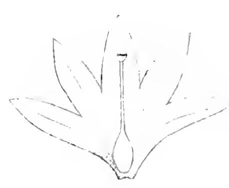


Fig. 10

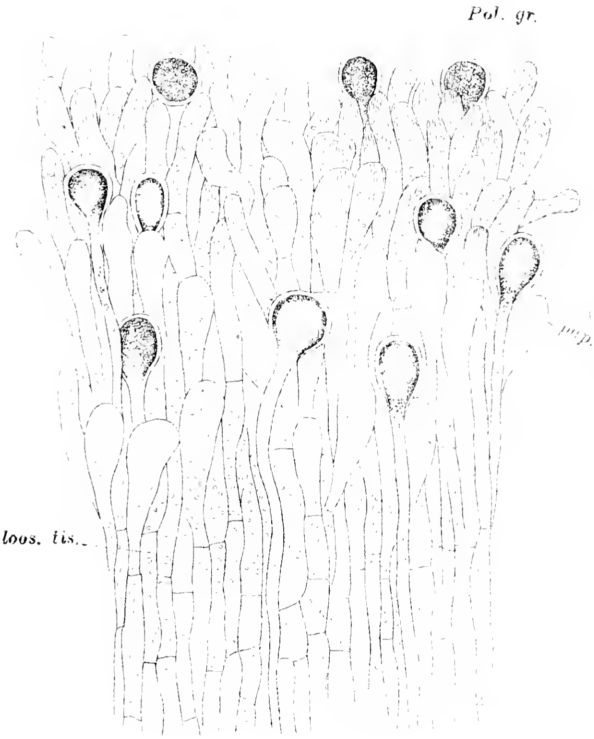


Fig. 11

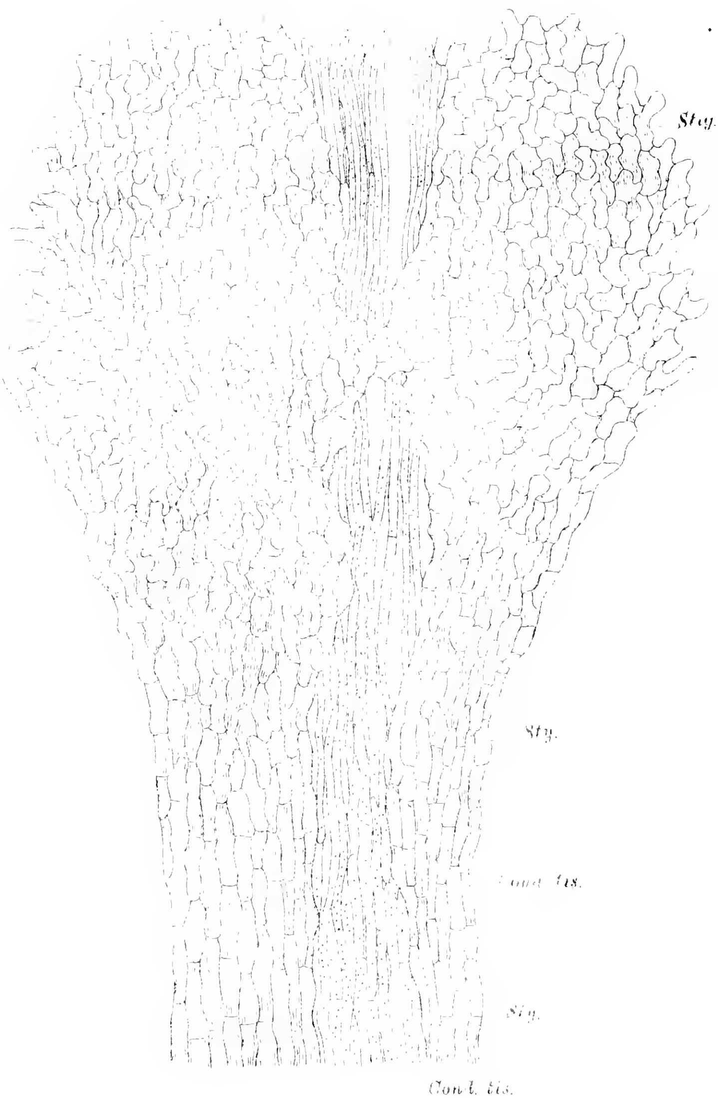


Fig. 9

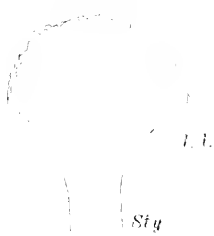


Fig. 7

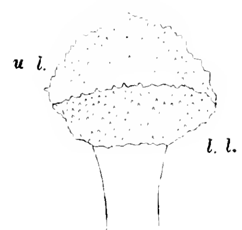


Fig. 8

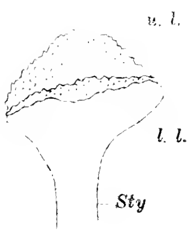


Fig. 6

Notes on the Development of the Suprarenal Bodies in the Mouse.

By

Masamaro Inaba, *Rigakushi.*

With Plates XXX–XXXI.

It has long been known that the suprarenal bodies of the vertebrata consist of two substances, the medulla and the cortex. As to how these two substances arise and in what relations they stand to each other the opinions of previous investigators are divided. During the academic year, 1888-89, I studied the development of the organ in the common domesticated mouse, a variety of Mus musculus, and came to the conclusion that the cortical cells are derived, as Janosik stated, from the peritoneal epithelium, and the medullary substance arises, as described by Mitsukuri, from the sympathetic elements. The following is a brief account of my investigation. I must here express my sincere thanks to Profs. Mitsukuri and Ijima, for their constant encouragement and valuable suggestions, without which I could not have finished the work.

As to the method of investigation I preserved after Selenka the specimens, young and adult, in Kleinenberg's picro-sulphuric acid mixed with chromic acid in the ratio 8 : 1. Some of the adult specimens were also preserved in bichromate of potash, but as Gottschau justly remarked, it is not necessary to use the chromic acid, at least in the case of the mouse, to demonstrate the distinction between the medullary and cortical elements. In the preparations of the chromo-picro-sulphuric acid the medulla is not coloured brown ; this seems to be due partly to the shortness of the interval during which the embryos were exposed to the action of the reagent ($1^1/_4$ hours) and partly to the presence of the picro-sulphuric acid. To stain embryos, I used a weak solution of Kleinenberg's haematoxylin, as it gives the clearest and most differentiated figures. With picrocarmine I also obtained good preparations of the suprarenal bodies of the young mouse. The objects were stained in *toto* before imbedding in the celloidin paraffin. In all cases I took pains to stain deeply and to cut sections as thin as possible.

I am not quite sure of the age of the embryo, since I could not observe any actual copulation. After the method of Selenka, I separated the individuals of two sexes for from ten to fifteen days, then put a pair together for a night, and separated them again the next morning. I counted the day of separation as the first day of gestation, the next the second day, and so forth. From a number of preserved embryos I determined the approximate size (from the tip of the head to the root of the tail) of the embryo in each stage as follows :

11th day	3–4.5 mm.
12th day	4.5–6 mm.
13th day	6–8 mm.
14th day	8–10 mm.
15th day	10–12 mm.

In cases of embryos older than this stage, I opened their abdomen as quickly as possible before immersing them into the killing fluid, and could not make any reliable measurement.

Suprarenal Bodies of the Mouse, from the new-born to the adult.—I commenced my study with the young mouse about one month old. In these specimens, the two substances of the suprarenal bodies are already well marked. In cross sections, the organ is elliptical, consisting of two concentric zones (Pl. XXXI. fig. 21); the inner central zone (med.) stains somewhat less than the outer zone (cor.). Under a high power, the central zone is found to be composed of irregular cord-like cell-aggregates, each of which is bounded by strong connective tissue fibres. The cell-protoplasm is faintly stained; the nuclei are large (6 μ. on an average) and slightly granular. The nuclei of the cells of the outer zone are smaller in size (5 μ.) and highly granular. Their cells are smaller than those of the central zone; this is especially the case in the middle portion of the outer zone where the cell-protoplasm is stained deeper than in any other part, so that the outer zone is subdivided into these minor concentric zones. But these three zones gradually merge one into another without presenting any distinct limit. The transition from the outer (cor.) to the central zone (med.), on the other hand, is very sudden; the limiting line is distinct and tolerably even, forming an elliptical outline. Evidently the central zone is the medulla, and the outer the cortex.

Turning now to the mouse ten days old (Pl. XXXI. fig. 18), a considerable difference is observed in the structure of the medulla. The medullary substance (med.) projects irregularly into the cortex (cor.), and the boundary is not yet even, though its elliptical outline can already be made out. The cells and nuclei of the medulla are stained deeper than before, so that the distinction of it from the cortex is obscure in some parts where the former projects into the latter. The difficulty is further increased by the fact that the cord-like arrangement of the medulla is as yet very weakly developed, and the respective sizes of the nuclei in the two substances are approximately equal. But tracing carefully the margin of the medulla, we can find here and there the distinct groupings of its cells into cords (fig. 19), where the nuclei are larger and the protoplasm is less stained, than in the adjoining cortical cells. This stage seems to be the formation of the medullary cords. The three minor zones of the cortex are already to be found, though less distinct than in the stage described before.

In the mouse three days old (fig. 16), the medulla is very irregular in its outline. Along its margin the cells are greatly mingled with the cortical cells, but the distinction is clear, the cells and nuclei of the medulla being stained more deeply and packed more closely, than in the cortex. The three minor cortical zones are not yet distinguishable.

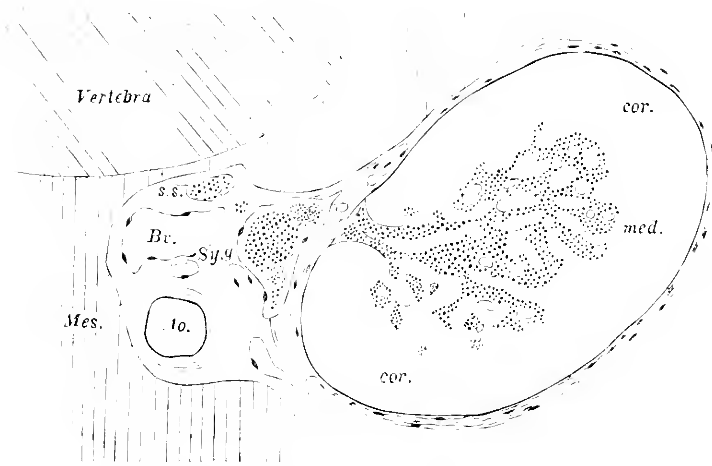
In the newly-born mouse (wood-cut 1 and Pl. XXXI. fig. 15), the medulla no longer forms any compact mass, but has cortical cells, intermixed throughout its substance. The distinctions between the two substances can however be easily made out as before.

The relative size of the nuclei in the two substances is interesting. In figs. 15 and 16 (Pl. XXXI.), the nuclei of the medullary cells are evidently smaller than those of the cortical cells, while in fig. 21, the case is reversed. I measured the nuclei of cells in the two substances near their boundary line at various stages. The following gives the average size (in μ) of those nuclei.

	1 day old.	3 days.	10 days.	29 days.	adult.
Medulla	5.2 —	5.6 —	5.6 +	6 —	6 —
Cortex	6.5 —	6. —	5.4 —	5 —	5 +

It will be seen from the table that for about a month after birth, the cortical nuclei are gradually decreasing in size ; at the same time the medullary nuclei are growing though very slightly. This is, I believe, due to the formation of the cord-like arrangement on the part of the medulla, and of the zona reticulata on the part of the cortex.

Woodcut 1.



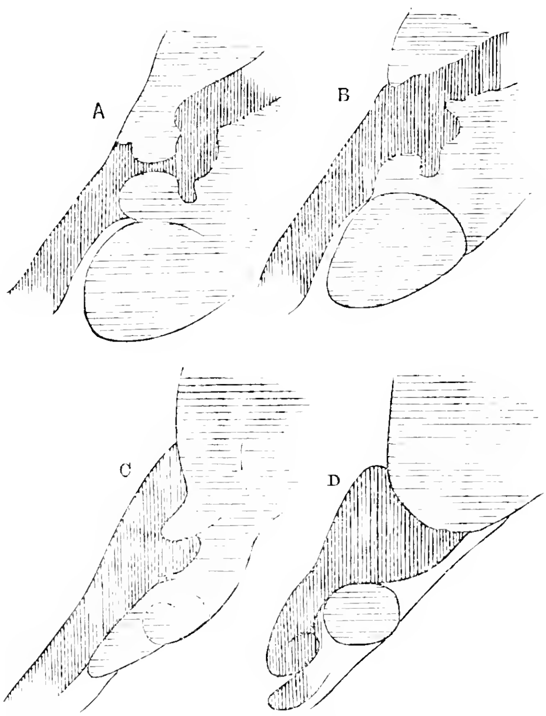
From a mouse one day old. The left suprarenal body is represented. Ao=Aorta, Bv.=Veins. Cor.=cortex, Med.=Medulla, Mes.=Mesentery, s. s.=Main mass of Sympathetic ganglia, sy. g.=ganglion of sympathetic origin. 2×BB.

So far as traced, the medulla is always distinct from the cortex. and its origin cannot be decided. But some interesting (and evidently a little abnormal) cases were met with. In one mouse just born (woodcut 1), the roughly elliptical medulla (med.) situated in the centre of the organ sends off an offshoot at one place toward the medial side, actually reaching the connective tissue capsule. Outside the organ lies a large ganglion (sy. g.), which is found on tracing sections to be continuous with the main sympathetic system (s. s.). The medullary cells of the suprarenal body and the true ganglion cells are very similar in their size and colouration. This condition was observed only on the left suprarenal.

In a three-day old mouse (woodcut 2), again on the left side, I observed an actual connection of the medulla with the ganglion. In fig. 17 (Pl. XXXI.), which is a more magnified figure of the woodcut 2 B, a mass of cells with small and deeply stained nuclei (med.) eads out of the organ, and directly joins the ganglion cell mass (sy. g.)

lying close to it. In another mouse at the same stage, a similar condition was observed; the ganglion besides being joined by a nerve coming from the neighbourhood of the kidney.

Woodcut 2.



4 successive sections (not consecutive) from the posterior end of the left suprarenal, a 3-day old mouse. Horizontally shaded part=Cortex. Vertically shaded part=Medulla.

Guided by these facts, I examined again the ten-days old mouse, and found in one case the medulla projecting on its medial side and actually touching the connective tissue capsule (Pl. XXXI. fig. 20.), but it was not traced to the sympathetic ganglion. These facts plainly show that the medulla is derived from the ganglion cells. When and how the nervous elements enter the organ, will be described below.

In passing, it may be remarked that in woodcut 2, a small portion of the cortical substance is projecting far posteriorly and is separated from the main mass by the sympathetic ganglion. In fig. 17, the part (ac. cor.) is distinctly separated from the main mass by strong connective tissue cells. This is the so-called accessory suprarenal body. From the mode of the entrance of the nerve into the organ, as seen in this and other cases, I am inclined to believe that the introduction of the nervous elements into the organ greatly influences the formation of the accessory suprarenal body, though it may not be the sole cause.

Of the adult suprarenal body (Pl. XXX. fig. 22), I have little to say, as it does not differ much from that of the one month old mouse (fig. 21). One feature interesting from the embryological point of view is the occasional presence of the ganglionic remnants. In one specimen (fig. 23), I found at the margin of the medulla on its medial side, a mass (sy. g.) of indistinct cells, highly granular and deeply stained. Their nuclei are smaller than those of the medulla or cortex cells but decidedly larger than those of the connective tissue cells. By tracing sections, I found the mass to project pyramidally into the cortex and finally reach the capsule. In comparison with the ten-days old suprarenal body (fig. 20) this mass may be considered as a part of the nervous elements, which has not been transformed into the true medulla. Of the large ganglion cells such as seen outside the adult suprarenal body, I could find none present within the adult organ.

Development of the Medullary Substance, in the 13th–18th day Embryos.—Balfour[1] remarked in his monograph on elasmobranch fishes that the suprarenal bodies of

1. Older erature I had not access to.

Vertebrates consist of two substances distinct in their origin. This Braun[2] has confirmed in Reptiles, and Mitsukuri[3] in Mammalia. Mitsukuri says that in the 16th day embryo rabbit the medullary substance is already distinct; sympathetic nerve cells closely applied to the inner side of the suprarenal blastema send in a process partly composed of nerve fibres into the ventral end of the suprarenal; the cells thus carried in become gradually transformed into the medulla. Gottschau[4] and Janosik[5] dispute this statement. Though these authors do not deny the entrance of the nerve fibres into the suprarenal, they state that the two parts of the suprarenal substance cannot be distinguished at the time of the entrance, and the medullary substance is gradually differentiated from the cortical substance at a considerably later stage. Gottschau even states that in some mammals the medulla is developed only after birth. Yet from the descriptions of the two authors, the exact mode of the formation of the medulla is not yet clear, and it is also necessary to trace the ultimate fate of the nervous fibres sent into the suprarenal blastema.

The suprarenal blastema is already distinct in the 13th day embryo. It is a somewhat elongated mass of cells lying between the 16th and 17th body-segments, just behind the lobes of the lungs. The anterior end of the blastema lies on about the same level as the 2nd tubule of the mesonephros, while the 3rd segmental tubule lies on about the middle portion of the suprarenal. In cross sections (woodcut 3 and Pl. XXX. fig. 8), the blastema

2. Bau und Entwicklung der Nebennieren bei Reptilien. Arb. aus dem Zool. Zoot. Inst. in Würzburg. Bd. V. 1882.

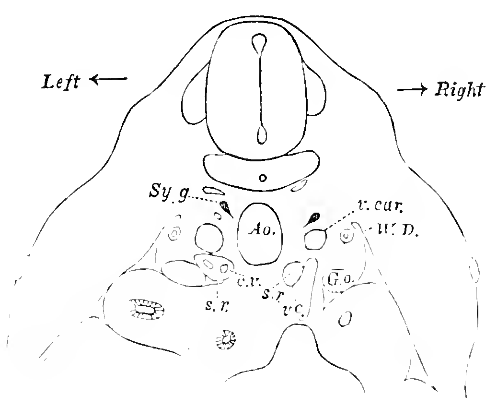
3. On the Development of the Suprarenal Bodies in Mammalia. Quart. Journ. of Microscop. Science. XXII. 1882.

4. Structur und embryonale Entwicklung der Nebennieren bei Säugethieren. Arch. f. Anat. u. Physiol. 1883.

5. Bemerkungen über die Entwicklung der Nebenniere. Arch. f. Mikr. Anat. XXII. 1883.

(s. r.) is seen as a rounded mass (about $\frac{1}{4}$ mm. thick) of cells lying between the aorta (Ao.) and the mesonephros (st.), immediately below the cardinal veins (v. car.). Already at this stage, a blood vessel (c. v.) is seen in the posterior portion of the blastema, coming from the cardinal vein; this vein is ultimately transformed into the central vein of the adult suprarenal. The suprarenal blastema (s. r.) is distinguished from all neighbouring tissue cells by the densely packed state of its large and faintly granular cells. Cell boundaries within the blastema are only faintly indicated, but a careful observation shows that cells are collected into irregular groups, separated by scanty connective tissue cells. The cell nuclei are slightly granular and their size varies between 5-7 μ. These characters of the cortical cells are retained during the subsequent developmental phases and are useful in distinguishing them from the medullary cells.

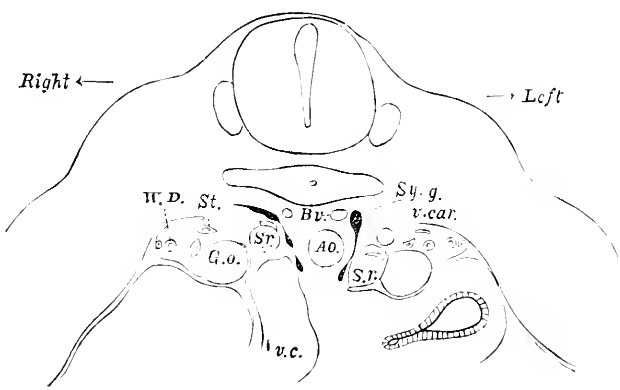
Woodcut 3.



A cross section taken near the posterior end of the suprarenal bodies—13th day embryo. Ao.=aorta, c. v.=central vein of the suprarenal, G. O. generative organ, s. r.=suprarenal blastema, sy. g.=sympathetic ganglia, v. c vena cava, v. car= cardinal vein. 2×aa.

The sympathetic ganglia (woodcut 3 sy. g.) are well developed on the upper lateral corner of the aorta, and a strong branch from the spinal nerve enters each ganglion. The ganglia send out branches downwards between the aorta and the cardinal vein, but they are very fine, often consisting of a single row of cells and cannot be clearly traced. Yet on the medial side of the suprarenal blastema, closely applied to it, there is seen a small irregular group of deeply stained cells (fig. 8, sy′. g′.), whose nuclei are a little smaller and more granular than those of the suprarenal, and similar to the cells of the sympathetic ganglia. Probably these cells are of the nervous nature.

Woodcut 4.

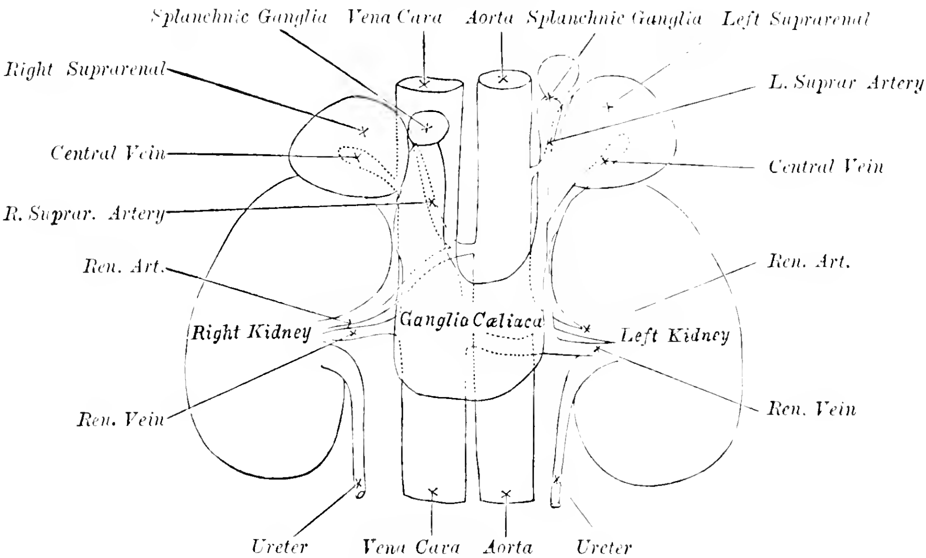


A cross section taken near the posterior end of the suprarenal bodies.—Later stage of the 13th day. Ao.=aorta, Bv.=veins, G. O.=generative organ, s. r.=suprarenal blastema, s. t.=segmental tubulus, sy. g.=sympathetic ganglia. v. c.=vena cava, v. car.=cardinal veins, W. D.=Wolffian duct. 2 × aa.

Towards the close of the 13th day (woodcut 4). the cardinal veins greatly retrograde, on the right side almost completely. Thus the central vein of the right suprarenal becomes now the direct continuation of the vena cava, and the left central vein becomes a side branch from the great vein. The suprarenal blastemas of the two sides are now placed not ventrally, but laterally to the aorta. The mesonephros is pushed laterally and Müller's duct is distinct. In the 14th day embryo, the blastemas have a considerable size, a little projecting into the coelom cavity. The kidneys appear at the posterior and dorsal side of the suprarenal. By dissecting the embryo, the suprarenals are seen as a pair of oval shaped bodies, flattened antero-posteriorly as if pressed by the developing kidney. The inner end of each suprarenal is attenuated and thus overlaps the anterior inner corner of each kidney,—a state of things retained and more distinctly seen in later stages. In the 15th day embryo (woodcut 8), the suprarenal bodies have shifted their position, further dorsalward, being now placed just laterally to the vertebral body and dorsally to the aorta. Thus at no stage, are the suprarenals of the two sides connected together as some writers state. As Mitsukuri and Gottschau well remarked, it is the ganglion placed inside of each suprarenal, which is posteriorly joined to its fellow by a cross bar.

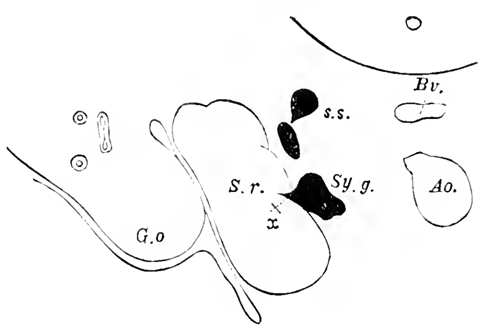
The nerves sent out from the sympathetic ganglia are distinct in the later stage of the 13th day (woodcut 4). Two or three branches are successively given out from the ganglia and all are united into the splanchnic plexus lying inside of, and closely applied to, each suprarenal. A branch is further sent downwards from the plexus to the front of the aorta, where it is connected (in the next day) with its fellow of the other side. From the 14th day onward (woodcut 5), we can distinguish in each splanchnic plexus at least two ganglia, the larger anterior and the smaller posterior ones. The posterior ganglion on the right side is elongated and becomes continuous with the caeliac ganglion, so that the latter may be said to be the direct continuation of the right splanchnic plexus. From the ganglion closely applied to each suprarenal (that is the second ganglion of the plexus), some fibres enter the organ. Though very fine, these fibres can be traced for a certain distance within the organ. Woodcut 6 and fig. 9, taken from the 14th day embryo, represent the state of things, when the nervous elements are just entering the organ. It is seen only for one section.

Woodcut 5.



Semi-diagramatic figure, showing relations of suprarenals to ganglia and bloodvessels.

Woodcut 6.

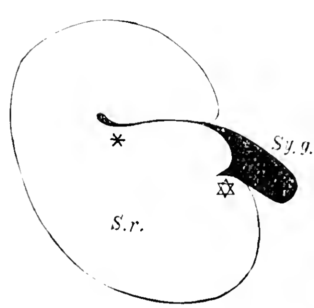


From a 14th day embryo, representing the right suprarenal. The place marked × is more magnified in fig. 9 (Pl. XXX). Ao.=aorta. Bv.=veins, G. O.=generative organ, s. r.=suprarenal blastema, s. s=main mass of sympathetic ganglia, sy. g.=ganglion of the sympathetic origin.

In the 15th day embryo, the nerve fibres within the organ are stronger and more easily to be ascertained. These branches are tolerably constant in number. Generally into the left suprarenal (woodcut 8), one very strong bundle enters at about the middle and ventral portion of its inner margin. At the corresponding point of the right suprarenal (woodcuts 7 and 9 A) a strong bundle (but more slender than that of the left side) is seen; on the same level and somewhat dorsal to the one just mentioned another smaller bundle runs in from the same ganglion. Besides these, a small bundle may sometimes be seen entering the organ at its posterior end (woodcut 9 B). All these bundles are very delicate, and can be seen only for three or four consecutive sections.

It will be necessary here to describe the characters of the nervous cells to distinguish them from the cortical cells. The protoplasm in these cells is not so rich as in the cortical cells, and is very granular; their nuclei are comparatively small (4.5 μ on an average), thickly packed, and deeply stained due to the presence of many granules.

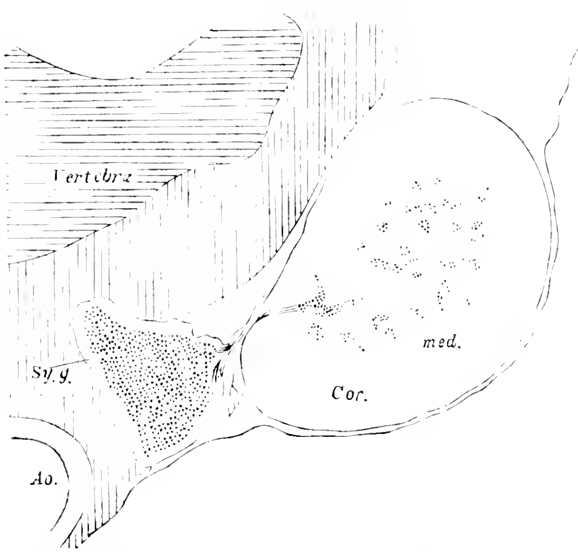
Woodcut 7.



A cross section taken from a 15th day embryo, right suprarenal. S. r. = suprarenal blastema, Sy. g. = ganglion of sympathetic origin. 2 × B.
The place marked ✡ is more magnified in fig. 10. A. (Pl. I.) The place marked * is more magnified in fig. 10. B.

In fig. 10 A (which represents a portion of the woodcut 7 under a higher power) taken from a 15th day embryo, a mass of nervous cells is seen insinuating itself into the cortex. The other smaller bundle (marked in the woodcut with a *) is interesting. It is very delicate and scarcely visible, running deeply into the cortex, and finally ending in a small cluster of cells, which are distinctly of nervous nature (Pl. XXX. fig. 10 B).

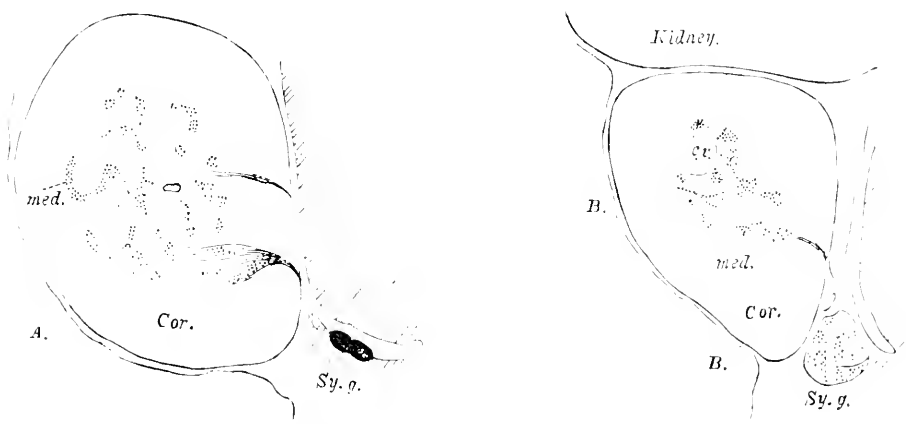
Woodcut 8.



A cross section of a 16th day embryo, left side. Ao. = aorta, cor. = cortical substance, med = medullary substance. Sy. g. = ganglion of sympathetic origin. 2×BB.

In the 16th day embryo, the nervous elements carried in the organ are considerable (woodcuts 8 and 9). They form now a reticulated network imbedded between the cortical cells, appearing in sections as small scattered groups of cells. Though the main mass of the nerve cells is clustered in the centre, some cell groups (Pl. XXXI. fig. 11) are found in the periphery of the organ at its medial side and send out their fibres, which actually piercing through the connective capsule become continuous with the ganglion near the organ. In others (fig. 12), although the fibres pierce through the capsule, they can not be traced to the ganglion, but are lost on the way; in others again, they are lost in the connective tissue capsule of the organ. From this stage onward we can call the nervous elements within the suprarenal more appropriately the medulla. I believe this and the previous stage are sufficient to show the nature of the medullary substance. Probably these two stages were not observed by Gottschau and Janosik, who thus concluded that the medulla is differentiated gradually from the cortical substance.

Woodcut 9.



Cross section taken from a 16th day embryo, right side suprarenal.
A, at the middle of the organ. B, near the posterior end
c. v.=central vein, cor.=cortex, med.=medulla, sy. g.=ganglion of sympathetic origin. 2×BB.

As to the further growth of the medulla, I have little to describe. It consists merely in the increase of the medullary cells which gradually form a compact mass in the centre of the organ, the cortical substance becoming in consequence scanty in the centre and pushed to the periphery. (Pl. XXXI. 14)

The severance of the nervous connection commenced in the previous stage is usually complete in the 18th day embryo, which was the oldest one I investigated. The process takes place simply by the growth of the connective tissue capsule around the piercing nerve which is consequently reduced to a narrow neck and finally cut off (fig. 13). Still the direct connection of the medulla with the sympathetic ganglion is retained in some cases, especially on the left side. In all such cases observed, the connective link which persists is enormously strong, so much so that sometimes the ganglion itself may be immersed in the organ. This is one reason why the connection persists longer. Further as before stated, on the left side the nervous fibres enter the organ mostly as a single conspicuous bundle, while on the right side they are usually divided into several smaller clusters, which will more easily be cut off. Hence the connection when it persists in the newly born mouse is always found on the left suprarenal as before described.

As to the general appearance of the histological elements of the suprarenal bodies in this stage, it does not much differ from those of the newly born animal.

Development of the Cortical Substance in the 11th-12th day Embryos.—As regards the origin of the cortical substance the attention of earlier writers has been principally directed to the indifferent mesoblast. Kölliker[6] stated that the suprarenal bodies in the rabbit first appear in the 12th or 13th day embryo as masses of somewhat large round cells on each side of, and ventral to the aorta, on the inner side of the Wolffian bodies and dorsal to the mesentery. Mitsukuri confirmed this and added that dorsally this mass is tolerably distinct from the other mesoblastic cells, but ventrally its termination is indefinite. Brunn[7], Braun, and more recently Gottschau derived

6. Entwicklungsgeschichte des Menschen und der höheren Thiere. 1879.

7. Ein Beitrage zur Kentniss des feineren Baues und der Entwicklungsgeschichte der Nebennieren. Arch. f. Mikros. Anat. VIII. 1872.

the cortical cells from the mesoblast, but in connection with the walls of the blood vessels (aorta, cardinal veins, vena cava, or vena renalis).

Recently for the first time Janosik stated that the suprarenal body takes its origin from the peritoneal epithelium, and it is in fact in the closest connection with the beginning of the sexual organ: this connection persists for a tolerably long time until it is cut off by the entrance of blood vessels, especially the vena vertebralis posteriori and other veins emptying into the same from the Wolffian bodies. Weldon,[8] on the other hand, derived the blastema from the Wolffian bodies. According to his statement, a cell-mass proliferates from the walls of the glomerulus and separates into two masses: the one travelling backwards becomes the suprarenal body, the other growing downwards and entering the sexual organ becomes the tubuli seminiferi (in the male). Mihalcovics[9] also affirmed like Weldon the connection of the suprarenal blastema with the sexual "strang" (=segmental "strang" of Braun), which he derives, however, from the germinal epithelium. At this point he agrees with Janosik, but differs in the statement that the suprarenal body is only the undifferentiated anterior continuation of the sexual organ. In front of the anterior end of the generative ridge the suprarenal cells are said to be directly proliferated from the peritoneal epithelium, and posteriorly they are said to be continuous with the sexual strang but not in direct connection with the peritoneal epithelium. In birds and mammals, the direct proliferation of the peritoneal epithelium to form the suprarenal blastema is said to be confined to a very small tract, so that it might be overlooked if series of sections were not studied.

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8. Suprarenal Bodies of Vertebrates. Quart. Jour. of Micros. Science XXV. 1885.

9. Untersuchungen über die Entwicklung des Harn- und Geschlechts-apparates der Amnioten. Inter. Monatschr. f. Anat. u. Hist. II. 1885.

To trace the origin of the cortical substance is in fact extremely difficult, as its cells are faintly distinguished from the other tissue cells. The cortical blastema in the mouse is tolerably well seen in the early stage of the 12th day of gestation. The mesonephros in the mouse is very weakly developed. Only the anterior two or three segmental tubules actually open to the Wolffian duct; following these can be traced five or six blind tubules, which lessen in size one after another, until finally no tubular structure is seen beyond the 8th or 9th one, the cells being merely clustered in proper places. The suprarenal blastema extends from about the middle of the anterior two segmental tubules to about the 6th or 7th tubule. In cross section, it is large anteriorly and gradually lessens in size posteriorly. It is placed just at the angle of the mesentery (Pl. XXX. figs. 5 and 6), occupying the space enclosed by the aorta and the cardinal vein on the medial and dorsal side, and by the mesonephros and the generative organ on the lateral size. Medially the blastema is distinctly bounded by connective tissue cells. Where the S-shaped segmental tubules are projected in medial direction, they approach the dorsal end of the suprarenal blastema; in other cases they are far removed from the suprarenal. In no cases do the tubules send out cells medially. The walls of the cardinal vein show no signs of proliferation. Branches of the vein to the suprarenal are not yet developed.

The relation of the suprarenal blastema with the beginning of the generative organ is interesting. These two blastemas are placed side by side, their anterior extremities reaching about the same level, but posteriorly the generative blastema extends far beyond the end of the suprarenal. The cell elements of the two are very similar, consisting of large cells with large round nuclei, which are stained slightly deeper than those of the connective tissue cells. But the two blastemas are separated from each other in all places, except at the anterior parts, by an intervening thin septum of connective tissue cells. This septum, consisting of the two or three rows of cells, runs from the peritoneal epithelium in dorsal direction, and finally separates itself into two branches, the one bending laterally and covering the generative organ, the other bending medially and covering the dorsal end of the suprarenal.

The cells of the peritoneal epithelium which touches the suprarenal blastema are arranged in a single row (fig. 6). But as we proceed anteriorly (fig. 5) the epithelium cells are evidently proliferating; they are actually pushed upwards and are even continuous with the suprarenal blastema. Tracing sections still anteriorly, the connection becomes more intimate, till near the anterior end of the suprarenal (Pl. XXX. fig. 4) the peritoneal epithelium cannot be distinguished from the suprarenal blastema itself. Here the septum no longer exists between the suprarenal and generative organs. The cells of the two blastema are laterally continuous with each other, the two being indicated only by the two rounded eminences projected dorsalward; ventrally they are both seen to be the proliferation of the peritoneal epithelium.

In a stage somewhat earlier than that above described, the suprarenal blastema is not yet so distinct. Figs. 1-3 were taken from an embryo in the later stage of the 11th day of gestation. Fig. 2 taken from near the anterior end of the left suprarenal blastema corresponds with fig. 4, and figs. 1 and 3 taken on both sides at the middle of the organs correspond with fig. 5. From the somewhat detailed description of the previous stage, any further remarks will not be needed. Only it may be added that the proliferating cells are very indistinctly bounded dorsally, but a careful study shows that they are proliferated from the epithelium. Why I do not consider these proliferating cells as the sole beginning of the generative organ is simply that the position of that organ is always in the following stages a little removed from the angle of the mesentery. Further in figs. 1 and 3 the proliferation of the peritoneal epithelium can be roughly separated into two parts, the medial and lateral.

From the above description, I think that Janosik's statement as to the origin of the cortical cells is quite correct. My figure 1 corresponds with his figure 1. The only difference is that the mesonephros in the mouse is not so well developed as in the case of the pig. Thus Janosik stated that the cells proliferate in the medial direction to the aorta, which condition is observed in the mouse only on the right side. The mesentery in the mouse being shifted from the medial line a little to the right side, its angle on the left side is carried far to the medial line, so that on this side the suprarenal blastema is projected upwards and a little lateralwards in the direction of the mesonephros (compare figs. 1 and 3). I cannot determine whether the suprarenal body is really the anterior continuation of the generative ridge or not. The state of things as seen in the figure given by Mihalkovics from a sheep embryo (his fig. 167) I could not find at the corresponding point of the mouse. But from the fact that the peritoneum is proliferated and the suprarenal blastema is placed side by side with the generative organ in its entire length, it is more likely to be the lateral separation, and not the anterior continuation of the generative organ.

Further growth of the suprarenal blastema consists simply in its separation from the peritoneum and clustering into a more compact round mass, as will be seen in fig. 12. The proliferation of the peritoneum, though slight, is still observed towards the close of the 12th day. Beyond the anterior end of the suprarenal bodies, a slight proliferation of the peritoneum was sometimes observed (Pl. XXX. fig. 7). I think that the compact suprarenal blastema is formed rom the main mass of the proliferated cells, while a small portion may be left behind, which seems finally to disappear without entering into the formation of the suprarenal bodies.

To sum up:

1. The Medulla and the cortex are distinct in their origin.

2. The cortical blastema appears in the later stage of the 11th day of gestation, as a proliferation of the peritoneum at the angle of the mesentery and laterally continuous with the beginning of the generative organ. The separation from this connection is complete on the 13th day.

3. The medulla is derived from the sympathetic elements, which enter the organ in the 14th day embryo. They increase and form a reticulated mass at the centre, from which the cortical cells are gradually pushed aside. The connection with the sympathetic system is usually cut toward the close of gestation, but in some may be retained until after birth.

Explanation of Figures.

ac. cor. = accessory suprarenal. Ao = Aorta. Art. c. = cœliac artery. Bv. = Veins. cor. = cortical cells. c. v. = central vein of Suprarenal bodies. Diag. = Diaphragm. G. o. = Generative organ. Kid. = kidney. Med. = Medullary cells. Mes. = Mesentery. S. r. = Suprarenal body. S. t. = Segmental tubules. Sy. f. = Sympathetic nerve fibres. Sy. g. = Sympathetic ganglion cells. v. car. = cardinal veins. v. c. = vena cava. W. D. = Wolffian duct.

Fig. 1. From the 11th day embryo. Right side. Taken from the level of the 2nd segmental tubule. 2 × E.

Fig. 2. From the 11th day embryo. Left side. Taken from near the 1st segmental tubule. 2 × E.

Fig. 3. From the 11th day embryo. Left side. Near the 2nd segmental tubule. 2 × E.

Fig. 4. From the 12th day embryo, early stage. Left side. Near the anterior ends of the suprarenal and generative organs. 2 × E.

Fig. 5. From the 12th day embryo, early stage. 10 sections behind. 2 × E.

Fig. 6. From the 12th day embryo, early stage. About the level of anterior one third of the left suprarenal. 2 × E.

Fig. 7. From the 12th day embryo, late stage. Left side. Beyond the anterior end of the suprarenal bodies 2 × F.

Fig. 8. From the 13th day embryo, early stage. Right side. 2 × E.

Fig. 9. From the 14th day embryo. Right side. The place marked × in woodcut 6. 2 × F.

Fig. 10. From the 15th day embryo. Right side. A. the place marked ✡ in the woodcut 7. 2×E. B. the place marked *. 2×F.

Fig. 11. From the 16th day embryo. Left side. More magnified figure of woodcut 8. 3×DD.

Fig. 12. From the 16th day embryo. Right side. More magnified figure of woodcut 9 A. 3×DD.

Fig. 13. From the 18th day embryo. From the posterior part of the left suprarenal. 2×E.

Fig. 14. From the 18th day embryo. From another embryo. Central portion of a section, taken near the posterior end of the right suprarenal. 3×DD.

Fig. 15. From the 1 day old mouse. Right suprarenal. 3×D.

Fig. 16. From the 3 days old mouse. 2×E.

Fig. 17. From the 3 days old mouse. Another specimen. Posterior end of the left suprarenal. More magnified figure of woodcut 2. B.

Fig. 18. From a mouse about 10 days old. 2×E.

Fig. 19. From a mouse about 10 days old. Medulla is weakly developed. 2×F.

Fig. 20. From a mouse about 10 days old, another specimen. The remnant of the connection with the sympathetic. 2×E.

Fig. 21. From a mouse about 1 month old. 2×E.

Fig. 22. From an old wild mouse. 2×E.

Fig. 23. A part of the right suprarenal from an old mouse. 2×E.

M Inaba del

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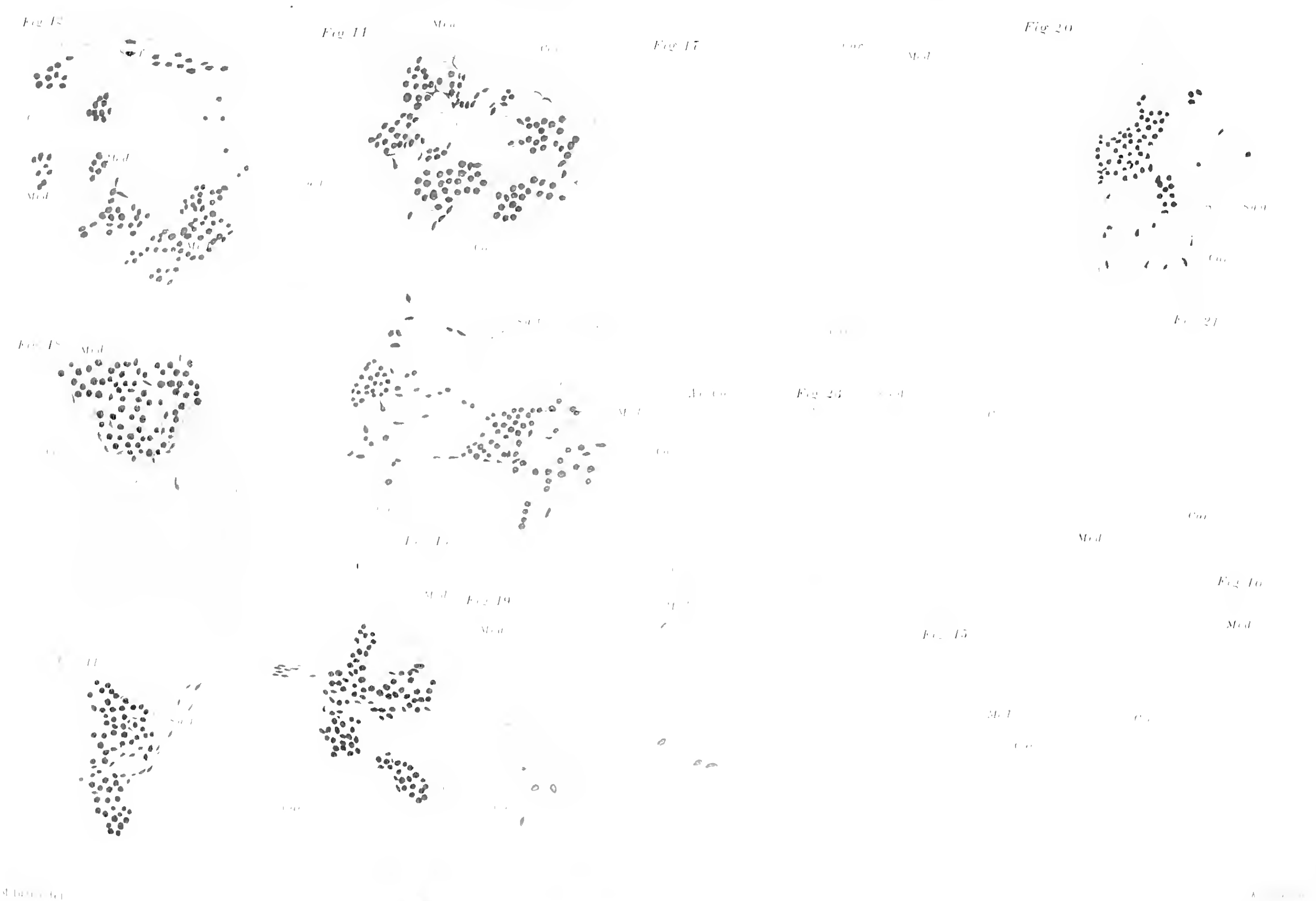
Fig 12
Fig 11
Fig 17
Fig 20
Fig 19

ERRATA.

Page 245, line 10, for *Prof. Schenk* read *Schimper.*
,, 246, ,, 20, ,, *D. Kochibe* read *D. Koehibei.*
,, 300, ,, 5, from end, for "nickel" read "bismuth."

On some Fossil Plants from the Coal-bearing Series of Nagato.

By

Matajiro Yokoyama.

With Plates XXXII—XXXIV.

In the spring of 1890, Mr. Kochibe of the Geological survey discovered some plant remains in the coal-bearing series of Nagato at a place called Yamanoi, some 30 kilometers east of the city of Akamagaseki.[1] These plants he recognized as Mesozoic, and subsequently sent them to me for examination. On looking at these plants, I was at once struck by the occurrence of forms which are quite foreign to our Middle Jurassic flora, lately worked out[2] by myself, and which are hitherto known only as occurring in the Rhaetic. Interested in this discovery, I visited the locality myself in the summer of the same year, in order to obtain, if possible, a larger number of species which, as I thought, would be quite indispensable for the determination of their exact age. Sorry to say, however, I did not succeed in making any great additions to the number of species, nearly all the plants which I found having been already represented in the collection of Mr. Kochibe. Still my collection proved to be very useful, for I had thus a larger number of individuals for comparison.

The coal-bearing series of Nagato occupies a limited area in the southern portion of that province bordering the Inland sea, and con-

1) This city is better known under the old name of *Shimonoseki*.

2) Yokoyama, *Jurassic Plants from Kaga, Hida, and Echizen, Journal of the College of Science. Imperial University, Japan, vol. III, part I, 1889.*

sists of a thick complex of sandstones, clay-slates and shales, with subordinate layers of schalstein and anthracite in its lower part and of browncoal in its upper part. These strata which form a low hilly country surrounded by mountains of granite and of Palaeozoic formation strike generally from east to west, and show steeper dips in the northern than in the southern part of the district, where they gently slope towards the sea. Owing to the repeated foldings to which these strata have been subjected, their geological structure is complicated, and has not yet been clearly made out. It will be only added here that our fossils were discovered in the lower or schalstein-bearing part of this formation.

The fossil locality lies on one side of a road which leads from the village of Yamanoi to the town of Habu, in a valley surrounded by hills. Here in a space of about 4 meters, I observed four fossil horizons. The lowest of them is a yellowish grey argillaceous sandstone yielding only *Dictyophyllum japonicum*, but in great numbers. The plants of this horizon are easily distinguishable from those of the others, being coloured dark green as if the vegetable matter were still remaining on them. The next horizon is that of a light greyish argillaceous sandstone which on weathering also assumes a yellowish colour. In this horizon all the species below described were found, Mr. Kochibe's plants having been probably taken also from this layer. The two upper horizons have yielded only some fragments of *Dictyophyllum japonicum*. Besides these two horizons there is, I presume, another, as I found some pinnae of the same species in a black slate situated more to the north and occupying probably a higher position than the sandstones. From this, we can see that there are several fossiliferous zones in the coal-bearing series of Nagato. But at present as the number of species found in them is very small, it is not possible to make any palaeontological distinctions in them.

Fossils, where there they are found in abundance, are generally very well preserved. Owing, however, to the brittle nature of the rock containing them, it is very difficult to obtain any large specimen.

After these brief preliminary remarks I shall first pass to the description of the species, and then to the conclusions which can be drawn from them.

Description of the Species.

1. Asplenium Roesserti *Presl sp.*

Pl. XXXII, Fig. 1–5, Pl. XXXIV, Fig. 2.

Asplenium Roesserti Schenk, Fossile Pflanzen aus der Albourskette gesammelt von E. Tietze, p. 2, pl. I, fig. 2–4, II, 8–10, IV, 19, VI, 33, VII, 36.

Asplenites Roesserti Schenk, Foss. Flora d. Grenzschichten d. Keupers u. Lias Frankens, p. 49, pl. VII, fig. 6–7a, X, 1–4. Zeiller, Examen de la Flore foss. des Couches de Charbon du Tongking, p. 302, pl. X, fig. 3, 3a.

Chladophlebis nebbense var. Roesserti Nathorst, Floran vid Höganas och Helsingborg p. 42, Helsingborg pl. II, fig. 1–3.

All of our specimens excepting fig. 3, 4, pl. XXXII agree so well with the figures of *Asplenium Roesserti* given by Schenk and Nathorst, that I have not the slightest doubt about their identity with this well known species. The pinnules are more or less falcate and inclined forward, with secondary veins only once forked. As to the form of the pinnules, I must say that they are very variable, being sometimes long and finger-like, sometimes short and triangular, as may be sufficiently seen from the specimens here figured. The arrangement of pinnae along the principal rhachis is in our specimens opposite or subopposite which according to Schenk is said to be the case in the lower part of the frond.

Specimens represented in fig. 3, 4, pl. XXXII, differ from others in having twice forked secondary veins in spite of the smaller size of the pinnules, much as in figures commonly given of the typical forms of *Asplenium whitbiense Brgt.* (e. g. in Heer's Beitr. z. Juraflora Ostsib, u. d. Amurl. 1876, pl. I, III. and in Schenk's Jurassische Pflanzen in Richthofen's China, vol. IV, pl. LII.). But as it has been already shown by eminent authorities, that *Asplenium whitbiense* is synonymous with *Alethopteris indicum Old. et Morr.*,[1] which in turn exhibits no difference from our *Asplenium Rœsserti*,[2] so it would be now quite objectionable to separate the above specimens into distinct species. Still however, as I obtained no transitional forms between the two, I should prefer to describe forms with bifurcate secondary veins as *Asplenium Rœsserti var. whitbiensis.*

Asplenium Rœsserti occurs in the Upper and Lower Gondwana System of India, in the Rhaetic of Europe, Persia and Tongking, and in the Lower Oolite of various countries.

This fern is very common at Yamanoi, being the most abundant fossil next to *Dictyophyllum japonicum.*

2. Dictyophyllum cf. acutilobum *Braun sp.*

Pl. XXXII, Fig. 6.

Dictyophyllum acutilobum Schenk, Foss. Pflanzen a. d. Albourskette, p. 5, pl. II, fig. 7. Foss. Flora d. Grenzschichten, p. 77, pl. XIX fig. 3–5, XX, 1. Nathorst, Floran vid Hoganas och Helsingborg, p. 14, Hoganas aldre pl. I, fig. 8, p. 44, Höganäs yngre, pl. I fig. 10–13, Helsingborg pl. I fig. 6–10. Zeiller, Exam. de la flore foss. du Tongking, p. 311, pl. X, fig. 11.

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1) Feistmantel, *Fossil Flora of the South Rewah Gondwana Basin*, p. 29, 1882, Calcutta. Heer, *Beitr. zur Juraflora Ostsib. u. d. Amurl.* 1876, p. 38.

2) Saporta considers in his "Plantes Jurassiques" (Paléont. franc. Terr. Jurass., Végétaux) p. 301, *Chladophlebis (Asplenium) Rösserti* Presl as identical with *Pecopteris (Asplenium) whitbiensis* Brgt.

A fragment of a coarsely toothed pinna, with teeth triangular, obtusely pointed at apex and slightly inclined forward, and with reticulate venation, is undoubtedly a species of *Dictyophyllum* which is at least very closely akin to *Dictyophyllum acutilobum* of the Rhætic of Europe. In our only specimen the teeth are closer together than in most of the figures given of this species, and the secondary veins slightly zigzag.

Besides occurring in the Rhætic of Europe, this species has been also described as occurring in that of the Albours Chain in Persia and of Tongking.

3. Dictyophyllum japonicum *n. sp.*
Pl. XXXIII.

Although this is the most abundant of all the plants found at Yamanoi, yet not a specimen was obtained representing a complete frond, all being isolated pinnae, which may be characterized as follows:

Pinnæ linear-lanceolate, broadest near the middle, slightly tapering towards both ends, lobed except near the base where they are simply wavy or entire; lobes more or less inclined forward, triangular in shape, with the anterior margin straight or concave, with the posterior margin usually convex, and the apex obtusely pointed. Rhachis very strong, straight or somewhat curved, running to the apex of the pinnae; secondary veins, coarse, slightly crooked or zigzag, directed forward and going up to the apex of each lobe, thus forming its median vein; tertiary veins distinct, somewhat inclined anteriorly and dichotomizing, the branches forming by their union with those of the neighbourring ones coarse pentagonal or hexagonal nets, which are usually drawn out in the direction of the median vein; quaternary veins very fine, forming secondary nets within the primary ones.

A glance at the plate with show that a great resemblance exists between this species and *Thaumatopteris Münsteri var. abbreviata* Göpp. (Schimper, Traité de Paléont Véget, vol. I, pl. XL, fig. 7) from the Rhætic of Franconia. So great is this resemblance, that I was at first inclined to treat the two species as identical; but a careful comparison between Schimper's figure and many tens of specimens at hand seems to show that the secondary veins in our plant are not so strong and rigid as in the European. Besides, none of our specimens had the lobes linear and finger-like as in the figure of Schimper, but always had them more or less triangular. Under these circumstances, I deem it more advisable to treat it as a new species.

Dictyophyllum japonicum is also not unlike *Camptopteris serrata* Kurr (Nathorst, Floran vid Bjuf, pl. V, fig. 3) in the general appearance of its pinnæ. But the latter is said to have very indistinct secondary veins.

A *Spiropteris* shown in fig. 5, pl. XXXIV, I believe to belong to *Dictyophyllum japonicum*, as it was found in the lowest fossil horizon, where no other species occur.

4. Dictyophyllum Kochibei *n. sp.*

Pl. XXXIV, Fig. 1, 1a.

Pinnæ elongated, deeply pinnatifid; pinnules ovate or ovately lanceolate, crenate at margin, obtusely pointed at apex, passing off either at right angles from the rhachis, or slightly inclined forward. Rhachis moderately strong; secondary veins quite distinct, somewhat zigzag, one in each lobe; tertiary veins also distinct, forming by their union two to three rows of irregularly polygonal nets; quaternary veins very fine, forming secondary nets within the primary ones.

Judging from the size of the rhachis and the weaker impression made by the lobes on stone, this fern seems to have been more delicate than the preceding one.

The only European species which can be compared with it is *Thaumatopteris Schenki* Nath. (= *T. Brauniana* Schenk) from the Rhætic of Sweden (Nathorst, Flora vid Höganäs och Helsingborg, p. 46 Höganäs yngre, pl. I, fig. 1, Helsingborg, pl. II, fig. 4) and Franconia (Schenk, Flora der Grenzschichten, p. 73, pl. XVIII, fig. 1–3, pl. XIX, fig. 1.). It has also crenate pinnules; but these are generally linear and much longer, and the crenations finer.

As to the generic denomination of our species, I follow Prof. Schenk, who considers *Thaumatopteris* Göpp, as identical with *Dictyophyllum* Lindl. et Hutt. (Handbuch der Palaeontologie, II. Abtheil. p. 138).

The figured specimen is the only one found.

5. Podozamites lanceolatus *Lindl. sp.*
Pl. XXXIV, Fig. 3, 4.

Podozamites lanceolatus Nathorst, Floran vid Bjuf p. 73, pl. XVI, fig. 2-10a, Heer, Juraflora Ostsibiriens, 1876 p. 45, 106, pl. I, fig. 3a, pl. XXIII, 1c, 4abc, XXVI, 2-10, XXVII, 1-8. Beitr. 1878, p. 6, 20, pl. V, fig. 1-11. Foss. Flora Spitzbergens, p. 35, pl. VII, fig. 1-7c,d. Schmalhausen, Juraflora Russlands, p. 29 pl. V, fig. 3-5c. Schenk, Jurassische Pflanzen, in Richthofen's China, vol. IV, p. 248, pl. XLIX, fig. 4, 5, p. 255, LI, 3, LII, 8, p. 258. LI, 7, p. 261, LIV, 2c. Yokoyama, Jurassic Plants from Kaga, Hida and Echizen, p. 45, pl. IV, V, VI, 1, VII, 8b, XII, 18, XV, 12b.

Podozamites distans Zeiller, Exam. flore foss. du Tongking, p. 320, Pl. XL, fig. 2. Nathorst, Beitr. z. foss. Flora Schwedens p. 23, pl. XIII. fig. 6-16, XV, 20.

Zamites distans Schenk, Flora d. Grenzschichten p. 158, pl. XXXV, fig. 10, XXXVI.

Now and then occur leaflets of a *Podozamites* which are to be identified with the well known cosmopolitan species above named. Our specimens are all in fragments, that represented in fig. 3 being the best, but wanting the tip. Judging from its general outline, it seems to belong to the variety *genuina* of Heer in which the leaflets are drawn out into an acuminate apex. Fig. 4 appears to have been much shorter, and I am not quite sure whether it really belongs here.

6. Baiera ? sp.

Pl. XXXIV. Fig. 6.

Fragments of long, parallel-sided leaves, apparently representing lobes of a Baiera or of a Ginkgo, occur in some cases thickly scattered on faces of stone. In one case they were observed arising from a common base, as shown in the figure, each having 3–4 parallel veins. It is much to be regretted that the specimens are so imperfect as not to allow any precise determination.

As to the results to be drawn from the study of the above plants, I must say that the number of species is yet too limited to allow us to form any very definite conclusions. Some of them however seem to be tolerably characteristic. *Dictyophyllum acutilobum*, has hitherto been restricted to the Rhætic of Europe and the similar formations of Persia and Tongking. *Dictyophyllum japonicum*, although new, exhibits a great relationship to *D. Münsteri var. abbreviata* Göpp., which occurs only in the Rhætic. A third *Dictyophyllum*, *D. Kochibe*, is quite new, showing only a distant relation to the Rhætic form *D. Schenki* Nath. *sp.*. It cannot therefore, strictly speaking, be employed in the determination of the age. The two other well determinable species, *Asplenium Roesserti* and *Podozamites lanceolatus*, are widely diffused in the Rhætic as well as in the Jurassic. Thus we have here two species pointing to the Rhætic, and two species pointing to the Rhætic or to the Jurassic. From these facts, I am inclined to believe, at present, that this little flora is somewhat older than that of the Middle Jurassic of Central Japan, corresponding either to the Liassic or, as it seems more probable, to the uppermost Trias or Rhætic of Europe. Only the discovery of a greater number of species can decide the question. It is here interesting to note that a similar flora is already known to exist in Tongking, (Zeiller l. c.) and perhaps also in China. [1] Nathorst having recently mentioned *Dictyophyllum Nilssoni Brgt. sp.* and *Podozamites lanceolatus distans Prest.* as occurring in the "Upper Yangtszi." Another point to be noted in our flora is the comparative frequency of species of *Dictyophyllum*, a genus which had its maximal development in Europe during the Rhætic time.

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1) Nathorst, *Om förekomsten af Dictyophyllum Nilssoni Brgt. sp. i Kinas Kolförande Bildningar.* Oefversigt. af Kongl. Vetenskaps-Akademiens Forhandlingar, 1890, No. 8.

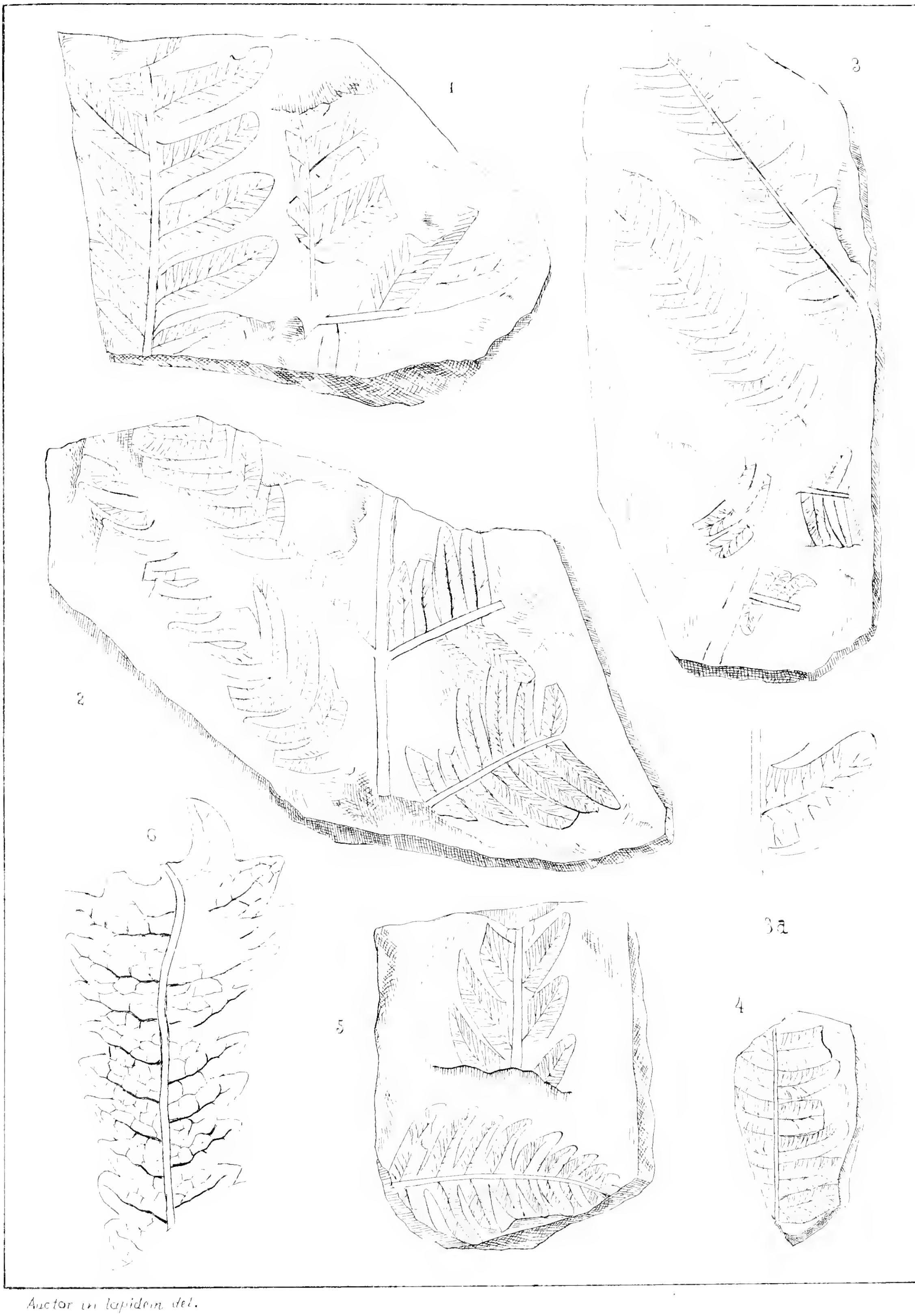
PLATE XXXII.

Plate XXXII.

Fig. *1, 2, 5.*—Asplenium Rœsserti *Presl. sp.*

" *3, 3a, 4.*—Asplenium Rœsserti *Presl.* var. whitbiensis *Brgt.*

" *6.*—Dictyophyllum cf acutilobum *Braun sp.*



Auctor in lapidem del.

PLATE XXXIII.

Plate XXXIII.

Fig. 1–7.—Dictyophyllum japonicum *n. sp.*; 2 left represents the basal part and 5 the apical part of a pinna.

Auctor in lapidem del.

PLATE XXXIV.

Plate XXXIV.

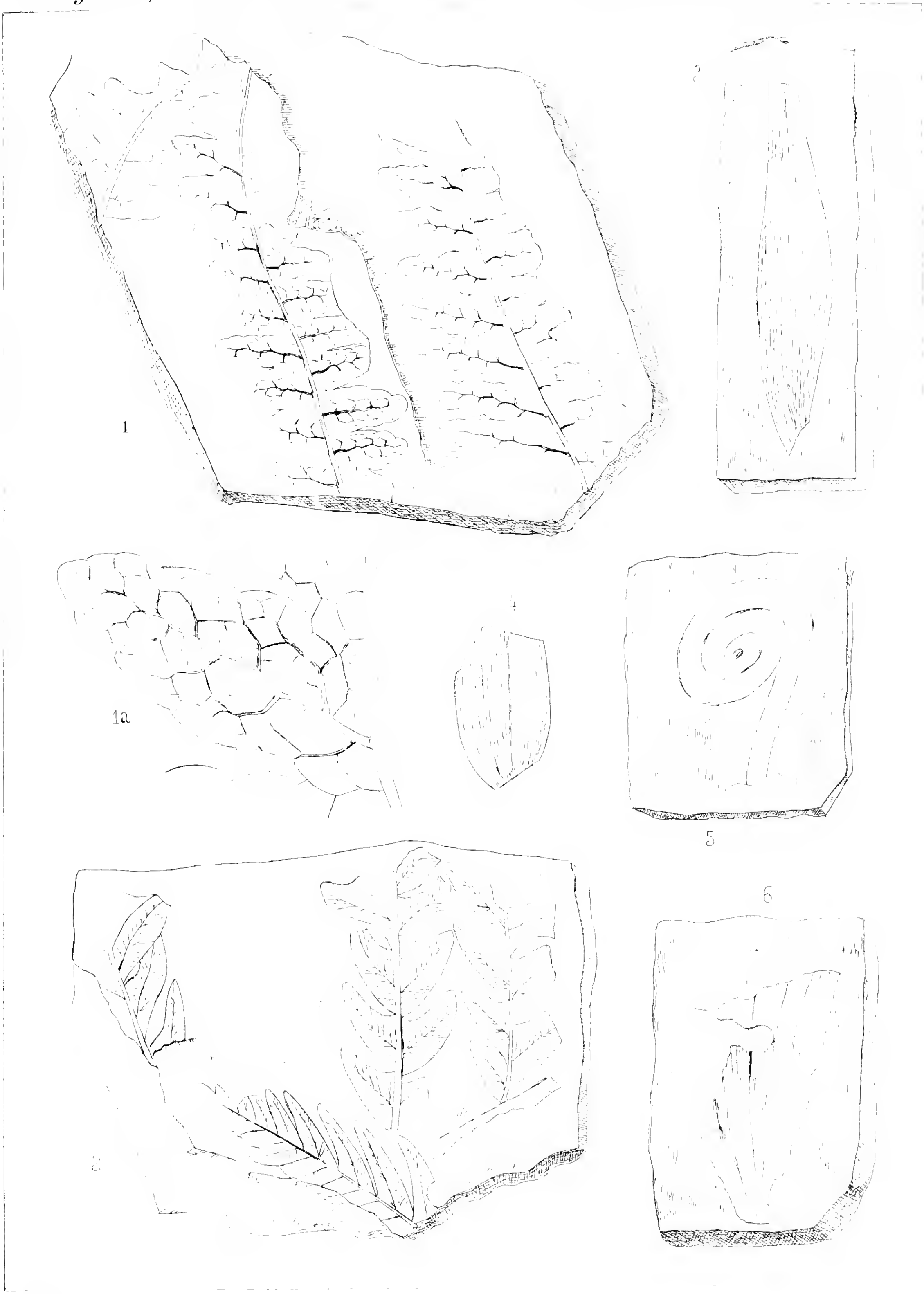
Fig. 1. 1a.—Dictyophyllum Kochibei *n. sp.*

" *2.*—Asplenium Roesserti *Presl. sp.*

" *3. 4.*—Podozamites lanceolatus *L. et H. sp.*

" *5.*—Spiropteris.

" *6.*—Baiera ? sp.



Auctor in lapidem del.

Comparison of Earthquake Measurements made in a Pit and on the Surface Ground.

By

S. Sekiya, *Professor,*

and

F. Omori, *Rigakushi.*

Imperial University, Japan.

In certain earthquake reports it is stated that there has been comparatively little or no movement felt at the bottom of a deep pit or excavation, while great damage was done on the surface of the ground,* and it seems to be generally believed that shocks are felt less intensely in mines. It is not easy to make instrumental measurements in a mine, and, in fact, we have very little exact knowledge of underground shakings. From a practical point of view, however, with reference to the building of houses, it is more interesting to investigate the shakings in pits or excavations such as might be made for foundations. The only instance of such actual measurements as yet published, as far as we are aware, is that described by Prof. John Milne in a paper entitled "On a Seismic Survey made in Tokio in 1884 and 1885" (Trans. Seis. Soc. Vol. X.) He made observations in a pit 10 feet in depth, whose bottom was dry and consisted of hard natural earth. Comparing the maximum amplitudes, maximum velocities and maximum accelerations obtained in the pit during the tolerably severe earthquake of

* For instance, see Trans Seis. Soc. Vol. VIII page 98. "The Earthquakes of Ischia."

March 20th, 1885, with those obtained on the surface ground about 30 feet distant he found that they were in the ratios of 1 : 34, 1 : 52 and 1 : 82 respectively. But for small disturbances, the records in the pit did not differ much from those on the surface. The observations we have made are really a continuation of Prof. Milne's, the same method being adopted in both cases. The results contained in the present paper also show in certain cases some difference of movement on the free surface and in the pit.

The observations were made in the Imperial University at Hongo, Tokyo, where the soil is hardened alluvium. The pit is 4 feet square and 18 feet deep, and is situated only a few yards distant from the instruments in the Seismological Observatory. Its bottom is paved with bricks to a thickness of about 2 feet. The soil appears here to be very homogeneous, so that there will be little difference in earth-shakings arising from the heterogeneity of ground between the surface and the bottom of the pit.

Comparison of the Instruments used on the Surface and in the Pit.

The comparison in the present paper is restricted to the horizontal components of earth movements. The instruments employed were Prof. J. A. Ewing's Horizontal Pendulum Seismographs. For earthquakes which are not too great these instruments give diagrams which represent practically absolute motions of the ground.*

The instruments used in the pit and on the surface were made as much alike as possible. To compare their action, they were placed on a shaky table, and their diagrams for the same motion were

* See Memoirs of the Science Dep., Univ., Tokyo: No. 9, and the Jour. Science Coll., Imp. University, Vol. I.

taken. Specimens of such comparison diagrams are given in Pl. XXXV. The multiplying ratio of both sets of instruments was intended to be five. If we go through the diagrams, we see that for moderate motions both give waves of almost exactly the same amplitudes and periods. Even small and irregular ripples are faithfully recorded. Fig. 1 is for the East-West component instruments, and Fig. 2 is for the North-South component instruments. In the following tables is given the numerical comparison of the amplitudes of some of the corresponding waves as recorded by the pit and surface seismographs.

For E.W. Component Instruments.

Amplitudes in mm. given by		Ratio.	Amplitudes in mm. given by		Ratio.
The Surface Instrument s.	The Pit Instrument p.	$\frac{s}{p}$	The Surface Instrument s.	The Pit Instrument p.	$\frac{s}{p}$
1.3	1.4	.9	1.3	1.45	.9
.92	.92	1.0	.9	.9	1.0
.6	.75	.8	1.2	1.2	1.0
.85	.9	.9	2.5	2.45	1.0
1.2	1.2	1.0	2.1	2.6	.8
1.65	1.55	1.1	.67	.67	1.0
.4	.4	1.0	1.3	1.3	1.0
.3	.3	1.0	1.05	1.2	.9
.15	.15	1.0	.9	.9	1.0
.4	.35	1.1	1.45	1.45	1.0
1.4	1.4	1.0	1.5	1.55	1.0
2.1	2.3	.9	1.45	1.6	.9
2.9	2.6	1.1	1.5	1.5	1.0
1.2	1.05	1.1	.26	.26	1.0
.23	.20	1.2	1.3	1.25	1.0
.15	.15	1.0	1.03	1.2	.9

For E.W. Component Instruments. *(Continued.)*

Amplitudes in mm. given by		Ratio.	Amplitudes in mm. given by		Ratio.
The Surface Instrument s.	The Pit Instrument p.	$\frac{s}{p}$	The Surface Instrument s.	The Pit Instrument p.	$\frac{s}{p}$
.1	.1	1.0	1.1	1.05	1.0
.2	.22	.9	.4	.48	.8
2.65	2.85	.9	.1	.1	1.0
2.5	2.35	1.1	.25	.13	1.9
2.2	2.0	1.1	.12	.10	1.2
.65	.85	.8	.2	.2	1.0
.82	.7	1.2	.27	.30	.9
2.7	2.55	1.1	.36	.4	.9
3.05	2.8	1.1	.4	.4	1.0
1.75	1.6	1.1	.55	.55	1.0
1.85	2.0	.9	1.9	1.8	1.1
1.1	1.1	1.0	.9	1.0	.9
.18	.17	1.1	1.8	1.8	1.0
1.4	1.35	1.0	2.1	2.0	1.1
1.55	1.55	1.0	1.82	1.9	1.0
1.9	1.9	1.0	.9	.9	1.0
Average of all the ratios...					1.01

For N.S. Component Instruments.

Amplitudes in mm. given by		Ratio.	Amplitudes in mm. given by		Ratio.
The Surface Instrument s.	The Pit Instrument p.	$\frac{s}{p}$	The Surface Instrument s.	The Pit Instrument p.	$\frac{s}{p}$
1.9	1.7	1.1	2.9	2.75	1.1
2.1	1.9	1.1	1.35	1.4	1.0
1.8	1.7	1.1	1.3	1.25	1.0

For N.S. Component Instruments. *(Continued.)*

Amplitudes in mm. given by		Ratio.	Amplitudes in mm. given by		Ratio.
The Surface Instrument s.	The Pit Instrument p.	$\frac{s}{p}$	The Surface Instrument s.	The Pit Instrument p.	$\frac{s}{p}$
1.4	1.3	1.1	1.1	1.15	1.0
1.15	1.15	1.0	.58	.55	1.1
1.4	1.45	1.0	.7	.66	1.1
1.15	1.2	1.0	.92	.89	1.0
1.2	1.4	.9	.9	.8	1.1
2.5	2.4	1.1	.2	.2	1.0
1.7	2.0	.9	.65	.61	1.1
2.1	2.4	.9	.18	.13	1.4
1.2	1.6	.8	.74	.74	1.0
1.5	1.4	1.1	.71	.69	1.0
1.8	2.2	.8	.3	.3	1.0
2.15	1.65	1.3	.65	.65	1.0
1.3	1.15	1.1	.42	.42	1.0
2.1	1.8	1.2	.4	.4	1.0
1.5	1.7	.9	.31	.31	1.0
2.0	2.1	1.0	.21	.20	1.1
1.9	1.8	1.1	.16	.15	1.1
1.7	1.7	1.0	.1	.08	1.3
1.9	1.9	1.0	.76	.76	1.0
2.85	2.6	1.1			
Average of all the ratios...					1.04

In the above tables, the numbers are the actual semi-ranges of motion as recorded by the instruments each divided by 5. These shew that the two sets of instruments give on the whole results which are practically identical, so that their records are at once comparable.

It should be stated that the surface-ground and the pit instruments were interchanged with each other in June, 1888.

The quantities calculated for the different earthquakes are:—

(1). The number of waves in 10 seconds, marked n.

(2). Amplitude, (r), or semi-range of motion in mm.

(3). Complete Period, (T), or the time taken to make a complete for-and-back motion of the ground in sec.

(4). Maximum Velocity in mm. per sec., (V), or $\frac{2\pi r}{T}$.

(5). Maximum Acceleration in mm. per sec. per sec., (A) or $\frac{V^2}{r}$.

In (4) and (5), it is assumed as usual that the motion of the ground is simple-harmonic. It is rare, however, that any complete wave presents a very good simple-harmonic character during the whole of its course, but usually differs in extent of motion and in the corresponding time of describing it in the first and second semi-phases of the motion, and so in some cases we have calculated V and A for the two different semi-phases of a wave. Sometimes also we give the maximum period during the 10 seconds interval.

The East-West and North-South components of the horizontal motion are not compounded, but the same components in the pit and on the surface are compared separately. It is a well known fact that motions of very quick periods and of small amplitudes generally occur at the beginning of earthquakes, and in the diagrams appear superposed on the principal undulations. In severe earthquakes, such as those of January 15th, 1887, and of February 18th, 1889, these ripples are very prominent; and, being very quick in period, though small in amplitude, they have maximum accelerations very much greater than those of the principal waves, which are longer in period though greater in amplitude. We have also made calculations on some of these ripples, which can sometimes be identified in the two sets of diagrams. As may be imagined their calculation is very difficult, especially in the estimation of their periods, so that any great exactness is not to be obtained. The calculation will, however, give some approximate idea as to the state of things. Hence, for some of the earthquakes, "large waves" and "ripples" are separately calculated. "Large waves" are those principal undulations for which calculation is usually made in earthquake reports, and "ripples" are the irregular wavelets superimposed on them. In doubtful cases the amplitudes only are given. With respect to n, the number of waves in 10 seconds, there is no difference to be found between the large waves of earthquakes observed on the surface and those observed in the pit; but, for ripples, the number is often very much less in the pit diagram, because of the reduction of amplitude and the consequent unification of some of them amongst themselves. The quantity n is therefore given only for ripples and not for large waves. The distinction between large waves and ripples is often very doubtful and does not exist for small earthquakes.

We may here remark that the maximum acceleration, A, is a quantity which approximately measures the overturning and fracturing effect of the shocks. In the case of a ripple, whose period is very short, this effect might probably be also measured by the total amount of impulse communicated to a body during a semi-phase of the wave, which is found to be proportional to the maximum velocity.

Records.

For the materials of the present paper we examined the records of thirty actual earthquakes. Of these, three interesting shocks have their diagrams shewn in Pl. XXXVI. and Pl. XXXVII., and their peculiarities are discussed. The other twenty-seven shocks were comparatively small and the different quantities, measured and deduced from the actual diagrams, are arranged in tabular form. Notwithstanding the frequent occurrence of earthquakes in Tokyo, simultaneous records of the pit and the surface instruments have been obtained for a comparatively small number of earthquakes. This was owing to the difficulty of managing the underground instrument.

(1.)—January **15th, 1887.—**This was an earthquake of unusual severity a full account of which has already been given.* The beginning portions of the surface and pit diagrams are given in Pl. XXXVI.,† and these for the convenience of comparison are placed side by side. Fig. 3 is for the E.W. component, and Fig. 4 is for the N.S. component. The glass plate which received the record of the surface instrument made one revolution in 128 sec., and that of the pit instrument in 68 sec., so that the latter moved nearly twice as quick as the former. Such a difference of the rate of revolution would however cause no material difference in the diagram. In these, as well as in the following diagrams, the corresponding parts are marked with the same *alphabets*, and the short radial lines mark the successive seconds counted from the beginnings of shocks.

The earthquake begins as usual with tremors. After a few seconds, the motion becomes suddenly great. The character of the motion is striking. The ripples are very prominent, and these are superimposed on slower undulations, whose period is about 2 sec. in the E.W. component, and about 3 sec. in the N.S. component. After a short time the ripples become less evident but the amplitude of the motion continues to be great, and the maximum displacement occurs at a point marked *o* in the E.W. component. Comparing now the surface and pit diagrams, we see that the latter is much smoother

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* See the Journal of the College of Science, Imperial University, Japan, Vol. I., Part III. or Transactions of the Seismological Society of Japan, Vol. XI.

† The complete diagram of the surface instrument is given in the same volumes as cited above.

than the former, especially near their beginnings. The numbers, 1, 2, 3, etc., in the first column in this and other tables are merely given for convenience.

(1.) Large Waves. E.W. Component.

No.	Amplitude. Surf.	Pit	Surf./Pit	Period. Surf.	Pit	Surf./Pit	Max. Vel. Surf.	Pit	Surf/Pit	Max. Acc. Surf.	Pit	Surf./Pit
	mm											
1	1.6	1.35	1.2	...	...	...	...	...	...	...	...	...
2	1.1	1.26	0.9	...	...	...	...	...	...	...	...	...
3	1.58	1.45	1.1	...	...	...	...	...	...	...	...	...
4	2.05	1.93	1.1	...	...	...	...	...	...	...	...	...
5	1.75	1.54	1.1	...	...	...	...	...	...	...	...	...
6	1.7	1.25	1.4	...	...	...	...	...	...	...	...	...
7	.95	.93	1.0	.86	1.1	0.8	7.0	5.3	1.3	50.	30.	1.7
8	1.05	.8	1.3	.89	.93	1.0	7.4	5.4	1.4	52.	36.	1.4
9	2.4	1.75	1.4	2.0	2.2	0.9	7.6	5.	1.5	24.	14.	1.7
10	3.53	2.65	1.4	2.8	2.0	1.4	7.9	8.3	0.9	22.	26.	0.9
11	2.2	1.25	1.8	1.3	1.7	0.8	11.	4.6	2.4	52.	17.	3.0
12	1.35	.95	1.4	1.5	1.4	1.1	5.7	4.3	1.3	24.	19.	1.3
13	2.75	2.55	1.1	1.8	1.7	1.1	9.6	9.4	1.0	31.	35.	1.0
14	1.8	1.65	1.1	1.6	1.2	1.3	7.1	8.6	0.8	28.	45.	0.6
15	1.4	.65	2.2	.93	1.4	0.7	9.5	2.9	3.5	65.	13.	5.0
16	2.15	1.8	1.2	2.8	1.9	1.5	4.8	6.	0.8	11.	20.	0.6
17	.74	.1	7.4	1.1	.6	1.9	1.2	1.0	1.2	21.	10.	2.1
18	1.7	2.25	0.8	.97	2.7	0.4	11.	5.3	2.1	72.	12.	6.0
19	1.8	1.8	1.0	3.2	2.7	1.2	3.5	4.2	0.8	7.	9.8	0.7
20	1.3	.55	2.4	2.5	1.4	1.8	3.3	2.5	1.3	8.	11.	0.7
21	.7	.1	7.0	1.3	.9	1.4	3.4	0.7	5.0	17.	5.	3.5
22	1.6	.38	4.2	1.0	1.0	1.0	10.	2.4	4.1	63.	15.	4.2
23	1.3	.14	9.0	1.8	.9	2.0	4.6	1.0	4.7	16.	7.	2.4
24	1.65	.44	3.7	2.1	1.3	1.6	5.	2.1	2.4	15.	10.	1.5
25	1.6	1.5	1.1	1.9	1.5	1.3	5.3	6.3	0.9	18.	26.	0.7
26	1.83	.9	2.0	1.7	1.3	1.3	6.8	4.1	1.6	25.	22.	1.1
27	1.65	.85	1.9	3.1	3.2	1.0	3.4	1.7	2.0	7.	3.4	2.0
28	1.7	.55	3.1	1.5	1.5	1.0	7.1	2.3	3.1	30.	10.	3.0
Average.			2.3			1.2			2.1			2.1

(II.) Large Waves. N.S. Component.

No.	Amplitude.			Period.			Max. Vel.			Max. Acc.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
1	1.12	.85	1.7	...	...	...	...	...	...	...	...	...
2	1.65	1.25	1.3	...	...	...	...	...	...	...	...	...
3	1.65	1.3	1.3	...	...	...	...	...	...	...	...	...
4	1.85	2.1	0.9	...	...	...	...	...	...	...	...	...
5	1.85	2.4	0.8	...	...	...	...	...	...	...	...	...
6	1.5	1.8	0.8	1.5	1.7	0.9	6.3	6.7	1.0	26.	25.	1.0
Average.			1.1									

(III.) Ripples. E.W. Component.

No.	Amplitude.			Period.			Max. Vel.			Max. Acc.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
1	.95	.75	1.3	...	...	...	...	...	...	...	...	...
2	1.05	.94	1.1	.54	.73	0.7	12.	8.1	1.5	140.	70.	2.0
3	.6	.34	1.8	.39	.16	0.6	9.7	4.7	2.1	160.	65.	2.5
4	.6	.16	3.8	.29	.66	0.4	13.	1.5	9.3	280.	14.	25.0
5	.56			.25			14.			350.		
6	.5	.19	2.6	.25	.6	0.4	13.	2.	6.5	320.	21.	15.0
7	1.24	.78	1.6	.34	.6	0.6	23.	8.2	2.8	430.	86.	5.0
8	.51		...	.45	...	...	7.	...	...	100.	...	...
9	.92	not existing.	...	.4	...	...	15.	...	...	230.	...	...
10	.75		...	.4	...	...	12.	...	...	190.	...	...
11	1.2	.82	1.5	.75	.9	0.8	10.	5.7	1.8	83.	40.	2.1
12	.98	.90	1.1	.4	.7	0.6	15.	8.	1.8	240.	73.	3.3
Average.			1.9			0.6			3.7			7.8

(IV.) Ripples. N.S. Component.

No.	Amplitude.			Period.			Max. Vel.			Max. Acc.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
1	.56	.25	2.2	.2	.28	0.7	18.	5.4	3.3	550.	120.	4.6
2	.7	.64	1.1	.28	.55	0.5	16.	7.3	2.2	370.	83.	4.4
3	.32	.29	1.1	.4	.31	1.3	5.	6.	0.8	78.	120.	0.6
4	.59	.37	1.6	.32	.38	0.8	12.	6.1	2.0	230.	100.	2.3
5	1.05	.87	1.2	.5	.55	0.9	13.	10.	1.3	170.	120.	1.4
6	.41	.31	1.3	.25	.36	0.7	10.	5.4	1.9	260.	94.	2.8
7	.59	.65	0.9	.53	.8	0.7	7.	5.1	1.4	83.	40.	2.1
Average.			1.3			.8			1.8			2.7

In (III.), the two ripples marked 4 and 5 in the surface-ground diagram have united into one in the pit diagram, and those marked 8, 9, 10 in the former do not exist separately in the latter.

If these calculations be correct, or at least approximate, it would appear that the maximum velocities and maximum accelerations are considerably greater for ripples than for large undulations. Such a difference will be found also to be the case with other severe earthquakes.

(2.)—April 16th, 1887.—A very small earthquake.

	Max. Ampl.			Period.			Max. Vel.			Max. Acc.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
E. W. Comp.	.1	.13	0.8	...	...	...	...	...	...	...	...	...
N. S. Comp.	.1	.15	0.7	.6	1.2	.5	1.1	.8	1.4	12.	4.	3.

(3.)—May 2nd, 1887.—This is a good example of a small earthquake. The motion indicated by the pit record appears to be smaller than that indicated by the surface record.

N. S. Component.

n.			Aver. Period.			Max. Period.		
Surf	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
21.	21.	1.	.5	.5	1.	.7	.9	.8

Max. Ampl.			Period.			Max. Vel.			Max. Acc.		
Surf.	Pit.	Surf./Pit.	Surf.	Pit.	Surf./Pit.	Surf.	Pit.	Surf./Pit.	Surf.	Pit.	Surf/Pit.
.1	.06	1.7	.5	.6	.8	1.3	.6	2.	16.	6.	3.

E. W. Component.—Maximum amplitude is not greater than 0.1 mm. both in the surface and pit diagrams. The waves are too flat to be counted definitely.

(4.)—May 7th, 1887.—A small earthquake whose extent of motion appears to be rather greater in the pit than on the surface.

	n.			Aver. Period.			Max. Period.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf/Pit
E. W. Comp.	22.	19.	1.2	.46	.53	.9	.7	...	...
N. S. Comp.	19.	18.	1.	.5	.56	.9	.7	1.	.7

	Max. Ampl.			Period.			Max. Vel.			Max. Acc.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
E. W. Comp	.1	.1	1.	.6	.4	1.5	1.	1.6	.6	11.	25.	.44
N. S. Comp.	.15	.13	1.2	.7	1.0	.7	1.4	.9	1.6	13.	6.	2.2

(5.)—June 20th, 1887.—A small earthquake.

	Max. Ampl.			Period.			Max. Vel.			Max. Acc.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf/Pit
E. W. Comp.	.1	.07	1.4	.9	1.	.9	.7	.4	1.6	5.	2.8	1.8
N. S. Comp.	.1	.1	1.	.5	1.1	.5	1.3	.58	2.3	16.	3.4	5.

(6.)—June 30th, 1887.—A very small earthquake.

E. W. Component :—Almost insignificant, the maximum amplitude being not greater than .05 mm. in the surface diagram, and obscure in the pit one.

N. S. Component :—in the surface diagram, the maximum amplitude is .06 mm., and in the pit diagram probably not greater than .05 mm.

(7.).—July 2nd, 1887.—A small earthquake.

	Max. Ampl.			Period.			Max. Vel.			Max. Acc.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf/Pit	Surf	Pit	Surf/Pit
E. W. Comp.	.16	.16	1.	.5	.5	1.	2.1	2.1	1.	28.	27.	1.
N., S. Comp.	.25	.22	1.1	.6	.7	.9	2.6	2.1	1.2	27.	22.	1.2

(8.)—July 22nd, 1887.—An earthquake of average extent of motion, but of slow period. The character of this earthquake is interesting. Unlike most earthquakes, which begin with quick vibrations, this begins very gently, with waves of small amplitude and of long period. After about 10 seconds from the start, the motion becomes larger and irregular, and ripples appear superimposed on principal undulations. All the irregular wavelets are tabulated.

	n.			Aver. Period.			Max. Period.		
	Surf	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
E. W. Comp.	36.	14.	2.6	.3	.7	.4	1.	1.6	.6
N. S. Comp.	28.	20.	1.4	.36	.5	.7	.7	1.7	.4

E. W. Component.

No.	Amplitude.			Period.			Max. Vel.			Max. Acc.		
	Surf.	Pit	Surf./Pit	Surf	Pit	Surf./Pit	Surf	Pit	Surf./Pit	Surf.	Pit	Surf./Pit.
1	.15	.15	1.0	.5	.8	0.6	1.9	1.2	1.6	24.	9.4	2.6
2	.25	.21	1.2	1.1	1.0	1.1	1.4	1.3	1.1	8.5	8.	1.1
3	.11	.14	0.8	.64	.65	1.0	1.1	1.4	0.8	11.	14.	0.8
4	.21	.2	1.1	.95	.94	1.0	1.3	1.4	0.9	8.	10.	0.8
5	.15	.15	1.0	.7	.7	1.0	1.4	1.4	1.0	12.	13.	0.9
6	.18	.24	0.8	1.2	1.3	0.9	1.	1.2	0.8	5.	6.	0.8
7	.18	.11	1.6	1.2	1.1	1.1	1.	.6	1.7	5.	3.6	1.4
8	.14	.14	1.0	1.1	1.0	1.1	.8	.9	.9	4.6	5.5	0.8
9	.14	.09	1.6	.93	.9	1.0	.9	.6	1.5	6.5	4.4	1.5
10	.13	.11	1.2	.83	.75	1.1	1.	.9	1.1	7.4	7.7	1.0
11	.12	.12	1.0	.83	.94	0.9	.9	.8	1.1	7.	5.	1.4
12	.14	.15	.9	1.1	1.0	1.1	.8	.9	.9	4.6	6.	0.8
13	.15	.15	1.0	.83	.94	.9	1.1	1.	1.1	8.7	7.	1.2
14	.08	.05	1.6	.74	.8	0.9	.7	.4	1.8	6.	3.	2.0
15	.15	.12	1.2	1.0	.9	1.1	.9	.8	1.1	6.	6.	1.0
16	.08	.05	1.6	.7	.64	1.1	.7	.5	1.4	6.	5.	1.2
17	.20	.19	1.0	1.3	1.5	0.9	1.	.8	1.3	4.7	3.4	1.4
18	.21	.15	1.4	1.1	1.4	0.8	1.2	.7	1.7	7.	3.1	2.2
19	.16	.23	0.7	1.3	1.4	0.9	.8	1.0	0.8	3.8	4.4	0.9
20	.21	.25	0.8	1.3	1.6	0.8	1.	1.0	1.0	5.	3.8	1.3
21	.34	.31	1.1	1.5	2.0	0.8	1.1	1.0	1.4	6.	3.1	2.0
Average.			1.1			1.0			1.2			1.3

N. S. Component.

No.	Amplitude.			Period.			Max. Vel.			Max. Acc.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
1	.37	.35	1.0	.7	.9	.8	3.3	2.5	1.3	29.	18.	1.6
2	.13	.2	.7	.6	1.5	.4	1.3	.8	1.6	13.	3.5	3 7
Average.			.9			.6			1.5			2.7

In the latter part of the motion. the amplitude seems to be larger in the pit diagram than in the surface diagram. But the period was much longer in the former than in the latter.

(9.)—September 25th, 1887.—A moderate earthquake, like the preceding one. The extent of motion appears to be larger in the pit than on the surface, and consequently also the duration of motion is longer in the former than on the latter.

	n.			Aver. Period.			Max. Period.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
E. W. Comp.	28.	10.	2.8	.35	1.	.4	1.1	1.8	.6
N. S. Comp.	30.	17.	1.	.33	.6	.6	1.	1.	1.

E. W. Component.

No.	Amplitude.			Period.			Max. Vel.			Max. Acc.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
1	.25	.46	0.5	1.5	1.5	1.0	1.1	1.9	0.6	4.1	8.	0.6
2	.08	.1	0.8	.6	.7	0.9	.8	.9	0.9	8.8	8.1	1.1
3	.09	.22	0.4	1.4	1.5	0.9	.4	.9	0.4	1.8	3.9	0.5
4	.09	.15	0.6	1.2	1.3	0.9	.47	.73	0.6	2.5	3.6	0.7
5	.12	.21	0.6	.73	.76	1.0	1.	1.8	0.6	9.	15.	0.6
6	.05	.07	0.7	.5	.57	0.9	.6	.8	0.8	7.1	8.5	0.9
Average.			0.6			.9			0.7			0.7

N. S. Component.

No.	Amplitude.			Period.			Max. Vel.			Max. Acc.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
1	.17	.19	0.9	.56	.69	0.8	1.9	1.7	1.1	21.	15.	1.4
2	.2	.25	0.8	.51	.42	1.2	2.5	3.8	0.7	31.	58.	0.5
3	.1	.15	0.7	.46	1.0	.5	1.4	.95	1.5	19.	6.	3.2
4	.08	.1	0.8	.54	.6	.9	.9	1.	0.9	11.	11.	1.0
5	.13	.15	0.9	.7	.66	1.1	1.2	1.1	0.9	11.	13.	0.8
6	.1	.14	0.7	.6	.66	0.9	1.0	1.3	0.8	11.	12.	0.9
7	.11	.15	0.7	.8	1.0	0.8	.9	.95	1.0	6.9	6.	1.2
8	.05	.1	0.5	.44	.53	0.8	.7	1.2	0.6	10.	14.	0.7
9	.17	.2	0.9	.66	.6	1.1	1.7	2.1	0.8	17.	22.	0.8
10	.1	.15	0.7	.6	.6	1.0	1.0	1.6	0.6	11.	17.	0.6
11	.19	.18	1.0	.5	.48	1.0	2.4	2.4	1.0	30.	32.	0.9
12	.06	.08	0.8	.5	.57	0.9	.8	.9	0.9	10.	9.7	1.0
13	.06	.06	1.0	.45	.43	1.0	.8	.9	0.9	12.	13.	0.9
14	.09	.16	0.6	.6	.71	0.9	.9	1.4	0.6	10.	12.	0.8
15	.07	almost nul	...	.15	.11	1.0	1.	...	...	13.	...	...
Average.			.8			0.9			0.9			1.1

(10.)—December 16th, 1887.—An earthquake of moderate intensity. At a glance, the motion on the surface appears to be larger and more irregular than that in the pit.

	n.			Aver. Period.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
E. W. Comp.	11.	20.	2.	.24	.5	.5
N. S. Comp.	11.	18.	2.	.24	.67	.4

E. W. Component.

No.	Amplitude.			Period.			Max. Vel.			Max. Acc.		
	Surf.	Pit	Surf./Pit	Surf	Pit	Surf/Pit	Surf.	Pit	Surf/Pit	Surf	Pit	Surf./Pit
1	.77	.7	1.1	.9	.9	1.0	5.4	4.9	1.1	38.	34.	1.1
2	.2	.25	0.8	.5	.8	0.6	2.5	2.0	1.2	31.	16.	2.0
3	.25	.22	1.1	.65	.8	0.8	2.4	1.6	1.5	23.	22.	1 0
4	.07	no.	...	.2	...	...	2.2	...	...	70.	...	...
5	.1	.14	0.7	.5	.7	0.7	1.3	1.3	1.0	16.	12.	1.3
6	.14	.14	1.0	.7	.7	1.0	1.3	1.3	1.0	12.	12.	1.0
7	.15	.18	0.8	.6	1.2	0.5	1.6	.9	1.8	17.	5.	3.1
Average.			.9			0.8			1.3			1.6

N. S. Component.

No.	Amplitude.			Period.			Max. Vel.			Max. Acc.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
1	.55	.53	1.0	.53	.53	1.0	6.5	6.3	1.0	77.	75.	1.0
2	.3	.24	1.2	.55	.72	0.8	3.4	2.1	1.6	38.	18.	2.1
3	.33	.05	6.6	.4	.42	1.0	5.2	.75	7.	82.	11.	7.5
4	.25	.25	1.0	.5	.54	1.0	3.2	2.9	1.1	41.	34.	1.2
5	.25	.15	1.7	.55	.8	0.7	2.9	1.2	2.4	34.	10.	3.4
6	.24	.1	2.4	.8	.67	1.2	1.9	.95	2.0	15.	9.	1.7
7	.16	.03	5.3	.25	.26	1.0	4.0	.73	5.5	100.	18.	5.5
8	.2	.11	1.8	.42	.83	0.5	3.	.84	3.6	45.	6.4	7.0
Average.			2.6			0.9			3.0			3.7

(11.)—January 11th, 1888.—A very small earthquake. In each component on the surface, the maximum amplitude is 0.1 mm.; while for the motion in the pit, it is not greater them .06 mm. The motion seems here to be much more pronounced on the surface than in the pit.

(12.)—April 5th, 1888.—A tolerably severe earthquake, in which the amplitude is not very large, but the vibrations are very quick.

The difference of appearance between the surface and the pit diagrams is striking, the small sharp waves which exist in the former being mostly flattened in the latter.

	n.			Aver. Period.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
E. W. Comp.	57.	25.	2.3	.18	.4	.5
N. S. Comp.	54.	25.	2.2	.19	.4	.5

E. W. Component.

No.	Amplitude			Period.			Max. Vel.			Max. Acc.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
1	.4	.35	1.1	.7	.8	0.9	3.6	2.7	1.3	32.	22.	1.5
2	.65	.37	1.7	.52	.65	0.8	7.8	3.6	2.2	95.	34.	2.8
3	.3	.1	3.0	.2	.3	0.7	9.4	2.2	4.3	300.	50.	6.0
4	.35	...	...	.33	...	...	6.7	...	...	120.	...	...
5	.35	.25	1.4	.24	.42	0.6	9.	3.8	2.3	240.	60.	4.0
Average.			1.8			0.8			2.5			3.6

N. S. Component.

No.	Amplitude.			Period.			Max. Vel.			Max. Acc.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf	Pit	Surf./Pit
1	.4	.38	1.1	.43	.53	0.8	6.	4.5	1.3	90.	53.	1.7
2	.3	.1	3.0	.21	.27	0.8	9.	2.3	4.0	270.	53.	5.1
3	.22	.08	2.8	.2	.3	0.7	7.	1.7	4.1	220.	35.	6.3
4	.65	.35	1.9	.71	.7	1.0	5.7	3.2	1.8	50.	29.	1.7
5	.5	.26	1.9	.47	.7	0.7	6.7	2.3	3.0	90.	21.	4.3
6	.2	.26	0.8	.27	.56	0.5	4.7	2.9	1.6	110.	32.	3.4
7	.15	.15	1.0	.24	.35	0.7	3.9	2.7	1.5	100.	49.	2.0
8	.24	.15	1.6	.24	.44	0.5	6.3	2.2	2.9	165.	32.	5.2
9	.18	.23	0.8	.24	.45	0.5	4.7	3.2	1.4	120.	45.	2.7
10	.3	.16	1.9	...	...	...	...	...	...	...	...	...
11	.31	.2	1.6	.7	.75	0.9	2.8	1.7	1.7	25.	14.	1.8
12	.2	.2	1.0	.24	.56	0.4	5.3	2.3	2.3	140.	25.	5.6
13	.25	.15	1.7	.17	.8	0.6	3.4	1.2	2.8	46.	9.	5.1
14	.4	.18	2.2	...	...	...	...	...	...	...	...	...
15	.34	.2	1.7	...	...	...	...	...	...	...	...	...
16	.22	.25	0.9	...	...	...	...	...	...	...	...	...
17	.3	.18	1.7	.73	.7	1.0	2.6	1.6	1.6	22.	15.	1.5
Average.			1.6			0.7			2.3			3.6

(13.)—April 29th, 1888.—A severe earthquake. This is very like the preceding one, but much more intense. The beginning portions of both sets of diagrams are given in Pl. XXXVII, Fig. 5, and Fig. 6. The glass plate of the surface-ground instrument made one revolution in 88 sec., and that of the pit instrument in 70 sec. In the early part of the shock, the vibrations are very quick, and with the exception of the wave marked A in the E. W. component there is no prominently large wave, though the ripples are distributed more or less in groups. Here again the pit diagram appears much smoother than the surface one ; compare, for instance, the portions marked a, b, c, d, e, f, g, in the E. W. component. Towards the end, the motion becomes slow.

E. W. Component.

n.			Aver. Period		
Surf.	Pit	Surf./Pit	Surf.	Pit	Surf/Pit
49.	30.	1.6	.2	.33	.6

(I.)—Ripples.—E. W. Component.

No.	Amplitude.			Period.			Max. Vel.			Max. Acc.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
1	.55	.21	2.2	.23	.22	1.0	15.	6.	2.5	410.	170.	2.4
2	.3	.04	7.5	.2	.19	1.0	9.5	1.3	7.3	300.	40.	7.5
3	.27			.2			8.5			270		
4	.4	.55		.2	.8		13.	4.3	3.0	400.	34.	12.0
5	.35			.25			8.8			220.		
6	.25			.22			7.2			210.		
7	.5	.35	1.4	.17	.47	0.4	19.	4.7	3.9	690.	63.	11.0
8	.4	.25	1.6	.3	.23	1.3	8.4	6 9	1.2	180.	190.	1.0
9	.3	.28	1.1	.44	.43	1.0	4.3	4.1	1.1	62.	60.	1.0
10	.5	.4	1.2	.25	.8	0.3	13.	3.2	4.0	320.	25.	15.0
11	.55	.48	1.2	.27	.47	0.6	13.	6.2	2.1	300.	80.	3.7
Average.			2.3			0.8			3.2			6.7

(II.) Large Waves. E. W. Component.

No.	Amplitude.			Period.			Max. Vel.			Max. Acc.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
1	2.	1.65	1.2	1.	.8	1.3	13.	13.	1.0	80.	91.	0.9
2	.42	.35	1.2	.5	.5	1.0	5.3	4.4	1.2	66.	55.	1.2
3	.57	.7	0.8	.93	.9	1.0	4.	5.	0.8	26.	34.	0.8
4	.63	.85	.7	1.	1.	1.0	4.	5.3	0.8	25.	33.	0.8
5	.53	.58	.9	1.2	1.1	1.1	2.8	3.3	0.9	15.	19.	0.8
Average.			1.0			1.1			0.9			0.9

(III.) Ripples. N. S. Component.

No.	Amplitude.			Period.			Max. Vel.			Max. Acc.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
1	.27	.18	1.5	.22	.23	1.0	7.7	4.9	1.5	220.	130.	1.7
2	.6	.55	1.1	.32	.43	0.7	12.	8.	1.5	240.	120.	2.0
3	.55	.31	1.8	.3	.35	0.8	12.	5.6	2.1	240.	100.	2.4
4	.37	.2	1.9	.25	.35	0.7	9.3	3.6	2.6	230.	65.	3.9
5	.54	.04	14.	.4	.3	1.3	8.5	0.8	11.	130.	16.	8.0
6	.58	.15	3.9	.24	.3	0.8	15.	3.2	4.9	400.	68.	6.0
Average.			4.0			0.9			3.9			4.0

(IV.) Large Waves. N. S. Component.

No.	Amplitude.			Period.			Max. Vel.			Max. Acc.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
1	.75	.55	1.4	.6	.58	1.0	7.9	6.	1.3	82.	65.	1.2
2	.78	.53	1.5	1.3	1.2	1.1	3.5	2.8	1.2	16.	15.	1.1
3	.8	.6	1.3	1.4	1.2	1.2	3.6	3.1	1.2	16.	16.	1.0
4	1.05	.85	1.2	1.2	1.0	1.2	5.5	5.3	1.0	29.	34.	.9
5	.45	.45	1.0	1.1	1.1	1.0	2.6	2.6	1.0	15.	15.	1.0
6	.75	.75	1.0	1.7	1.6	1.1	2.8	3.	.9	10.	11.	.9
7	.52	.45	1.2	1.1	1.0	1.1	3.0	2.8	1.1	17.	18.	.9
8	.55	.53	1.0	1.3	1.0	1.3	2.6	3.3	.8	12.	21.	.6
9	.75	1.0	.8	2.	2.	1.0	2.3	3.1	.8	7.4	9.6	.8
Average.			1.2			1.1			1.0			0.9

In (I), the ripples numbered 3, 4, 5, 6 which are distinct on the surface have united into one wave in the pit. In taking the ratios of maximum velocities and maximum accelerations, this single wave is compared with the greatest of the corresponding ripples.

(14.)—June 3rd, 1888—An earthquake of moderate amplitude.

N. S. Component.

n			Aver. Period.		
Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
35.	17.	2.	.3	.6	.5

No.	Amplitude.			Period.			Max. Vel.			Max Acc.		
	Surf	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
1	.3	.4	0.8	1.2	1.2	1.0	1.6	2.1	0.8	8.5	11.	0.8
2	.5	.45	1.1	1.5	1.	1.5	2.1	2.8	0.8	8.8	17.	0.5
3	.46	.32	1.4	1.	1.	1.0	2.9	2.0	1.5	18.	13.	1.4
Average.			1.1			1.2			1.0			0.9

E. W. Component.

Max. Ampl.		
Surf.	Pit	Surf./Pit
1.1	.95	1.1

(15.)—October 20th, 1888.—A small earthquake. In this case the amplitude seems to be much greater in the pit than on the surface.

	a			Aver. Period.			Max. Period.		
	Surf.	Pit	Surf./Pit	Surf	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
E. W. Comp.	31.	20.	1.6	.33	.5	0.7	.6	.9	0.7
N. S. Comp.	28.	21.	1.3	.45	.5	0.9	.5	.6	0.8

E. W. Component.

No.	Amplitude.			Period.			Max. Vel.			Max. Acc.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
1	.12	.2	0.6	.7	.9	0.8	1.1	1.4	0.8	10.	10.	10.
2	.1	.2	0.5	.5	.7	0.7	1.3	1.8	0.7	16.	16.	10.
3	.06	.21	0.3	...	...	...	...	...	...	...	...	...
4	.18	.26	0.7	...	...	...	...	...	...	...	...	...
5	.11	.21	0.5	...	...	...	...	...	...	...	...	...
6	.14	.21	0.7	...	...	...	...	...	...	...	...	...
Average.			0.6			0.8			0.8			1.0

N. S. Component.

No.	Amplitude.			Period.			Max. Vel.			Max. Acc.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
1	.16	.15	1.1	.4	.5	0.8	2.5	1.9	1.3	39.	24.	1.6
2	.1	.2	0.5	.4	.6	0.7	1.6	2.1	.8	26.	22.	1.2
3	.1	.2	0.5	.7	.5	1.4	0.9	2.5	0.4	8.	31.	0.3
4	.1	.16	0.6	.4	.5	0.8	1.6	2.0	0.8	25.	25.	1.0
5	.1	.16	0.6	.5	.5	1.0	1.3	2.0	0.7	16.	25.	0.6
6	.1	.21	0.5	.5	.5	1.0	1.3	2.6	0.5	16.	32.	0.5
7	.3	.4	0.8	...	...	...	...	...	...	...	...	...
8	.11	.28	0.4	...	...	...	...	...	...	...	...	...
9	.1	.27	0.4	...	...	...	...	...	...	...	...	...
10	.1	.25	0.4	...	...	...	...	...	...	...	...	...
Average.			0.6			1.0			0.8			0.9

(16.)—November 2nd, 1888.—A small earthquake. The pit diagram is much smoother than the surface one.

	Max Ampl.		
	Surf.	Pit	Surf./Pit
E. W. Comp.	.19	.16	1.2
N. S. Comp.	.15	.14	1.1

(17.)—January 1st, 1889.—A small earthquake.

	Max. Ampl.		
	Surf.	Pit	Surf./Pit
N. S. Comp.	.04	.05	1.

(18.)—February 18th, 1889.—A severe earthquake, in which there was a considerable amount of vertical motion. The earlier portions of the diagrams of the E. W. component are given in Pl. XXXVII, Fig. 7. The glass plates of the surface and pit instruments made revolutions in 108 sec. and 95 sec. respectively. The periods of the vibration are very short and the motion on the surface seems to be much sharper than in the pit.

	E. W. Comp.			N. S. Comp.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
n_1	46.	28.	1.5	50.	30.	1.7
n_2	35.	21.	1.7	49.	23.	2.1
n_3	20.	15.	1.3	39.	14.	2.8
n_4	19.	19.	1.0	26.	20.	1.3
n_5	12.	11.	1.1	15.	16.	.9

In this table n_1 n_2 .... are the number of irregular wavelets in the successive 10 sec. intervals.

(I.) Ripples. E. W. Component.

No.	Amplitude.			Period.			Max. Vel.			Max. Acc.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
1	.24	.23	1.0	.28	.27	1.0	5.4	5.4	1.0	120.	130.	1.0
2	1.05	.8	1.3	.7	.66	1.1	9.4	7.7	1.2	84.	74.	1.1
3	1.35	1.3	1.0	...	...	...	...	...	...	...	...	...
4	2.4	2.17	1.1	...	...	...	...	...	...	...	...	...
5	.73	.4	1.8	...	...	...	...	...	...	...	...	...
6	.95	1.05	0.9	...	...	...	...	...	...	...	...	...
7	.3	.06	5.0	...	...	...	...	...	...	...	...	...
8	.82	.52	1.6	...	...	...	...	...	...	...	...	...
9	.8	.32	2.5	...	...	...	...	...	...	...	...	...
10	1.3	.8	1.6	...	...	...	...	...	...	...	...	...
11	.7	.35	2.0	.24	.25	1.0	18.	9.	2.0	480.	220.	2.2
12	.65	.25	2.6	.32	.23	1.4	13.	7.	1.9	250.	190.	1.3
13	1.05	.8	1.3	.35	.73	.5	19.	7.	2.8	340.	60.	5.7
14	.31	.2	1.6	.27	.29	0.9	7.2	4.4	1.6	170.	100.	1.7
15	1.15	.72	1.6	.55	.54	1.0	13.	8.4	1.6	150.	100.	1.5
16	.8	nul	...	.5	...	...	10.	...	...	130.	...	...
17	1.2	.7	1.7	.33	.3	1.1	23.	15.	1.6	440.	320.	1.4
18	.4	nul	...	.18	...	...	14.	...	...	490.	...	...
19	.85	nul	...	...	...	...	...	...	...	...	...	...
20	1.73	1.5	1.1	...	...	...	...	...	...	...	...	...
21	.78	.6	1.3	.26	.64	0.4	19.	6.	3.2	160.	60.	8.0
22	.75	.45	1.7	.36	.6	0.6	13.	4.7	2.8	230.	50.	4.7
23	.3	.06	5.0	.2	.2	1.0	9.	1.9	4.7	280.	60.	4.4
24	.87	.75	1.2	...	...	...	...	...	...	...	...	...
25	.71	.6	1.2	.3	.7	0.4	15.	5.4	2.8	320.	50.	6.5
26	.95	.79	1.2	.6	.8	0.8	10.	6.2	1.6	100.	50.	2.0
27	.88	.75	1.1	.55	.58	1.0	10.	8.2	1.2	110.	90.	1.3
28	.5	.55	0.9	.3	.58	0.5	11.	6.0	1.8	220.	66.	3.3
29	.47	.3	1.6	.5	.32	1.5	6.	6.	1.0	80.	120.	0.6
30	.84	.56	1.3	.6	.8	0.8	8.8	4.4	2.0	92.	35.	2.6
31	.32	.23	1.4	.4	.5	1.0	5.	3.6	1.4	78.	56.	1.4
Average.			1.7			.9			2.0			2.8

(II.) Large Waves. E. W. Component.

No.	Amplitude.			Period.			Max. Vel.			Max. Acc.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
1	4.1	2.	2.1	...	...	...	...	...	...	...	...	...
2	1.7	1.4	1.2	1.5	1.7	0.9	7.1	5.2	1.4	30.	19.	1.6
3	1.75	1.5	1.2	.72	.79	0.9	15.	12.	1.3	130.	96.	1.3
4	2.	1.6	1.2	2.	2.	1.0	6.3	5.	1.3	20.	16.	1.2
5	1.4	1.	1.4	2.5	2.4	1.0	3.5	2.6	1.3	9.	6.8	1.3
6	.92	.95	1.0	1.0	1.0	1.0	5.8	6.0	1.0	37.	38.	1.0
7	.8	.92	.9	1.4	1.3	1.1	3.6	4.5	0.8	16.	22.	.7
8	1.4	1.1	1.3	1.4	1.3	1.1	6.3	5.3	1.2	28.	26.	1.1
9	1.8	1.35	1.3	2.	1.9	1.0	5.7	4.5	1.3	18.	15.	1.2
10	2.05	1.75	1.2	3.9	3.7	1.0	3.3	3.	1.1	5.3	5.1	1.0
11	1.45	.9	1.6	2.	1.9	1.0	4.6	3.	1.5	15.	10.	1.5
12	1.2	.8	1.5	1.7	1.7	1.0	4.5	3.	1.5	17.	11.	1.5
13	1.4	1.3	1.1	2.7	3.	0.9	3.3	2.7	1.2	8.	5.6	1.4
14	1.65	1.	1.7	3.	3.	1.0	3.7	2.1	1.8	8.3	4.4	1.9
15	2.2	1.25	1.8	2.4	2.6	0.9	5.8	3.2	1.8	15.	8.2	1.8
Average.			1.4			1.0			1.3			1.3

(III.) Ripples. N. S. Component.

No.	Amplitude.			Period			Max. Vel.			Max Acc.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
1	.85	.7	1.2	.43	.52	0.8	12.5	8.5	1.5	180.	100.	1.8
2	1.65	1.2	1.4	.6	.56	1.1	17.	14.	1.3	500.	150.	3.3
3	.4	.09	4.4	.2	.23	0.9	13.	2.5	5.0	400.	70.	5.7
4	.72	.65	1.1	.3	.3	1.0	15.	14.	1.1	320.	290.	1.1
5	.4	nul	...	.15	...	...	17.	...	...	700.	...	...

Ripples. N. S. Component. *(Continued).*

No.	Amplitude.			Period.			Max. Vel.			Max. Acc.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
6	.85	.78	1.1	...	...	...	...	...	...	...	...	...
7	.75	.85	0.9	.33	1.0	.3	14.	5.	2.8	270.	34.	8.0
8	.3	.1	3.	.14	.25	0.6	14.	3.	4.7	600.	60.	10.
9	.4	.6	0.7	.17	.6	0.3	15.	6.3	2.4	550.	66.	8.3
10	.65	.55	1.2	.3	.5	0.6	14.	7.	2.0	290.	87.	3.3
11	.4	.12	3.3	.14	.25	0.6	18.	3.	6.0	800.	80.	10.
12	.5	.56	0.9	.46	.4	1.2	7.	9.	0.8	93.	140.	0.8
13	.6	.4	1.5	.46	.45	1.0	8.	6.	1.3	110.	80.	1.4
14	.6	.5	1.2	.4	.4	1.0	9.	8.	1.1	150.	120.	1.3
15	.5	.3	1.7	.44	.4	1.1	7.	5.	1.4	100.	74.	1.4
16	.65	.45	1.4	.73	.7	1.0	6.	4.	1.5	48.	46.	1.0
17	.94	.74	1.3	...	...	...	...	...	...	...	...	...
18	.66	.33	2.0	...	...	...	...	...	...	...	...	...
19	.28	nul	...	.24	...	...	7.	...	...	190.	...	...
20	.99	.89	1.1	.53	.58	.9	12.	9.7	1.2	140.	110.	1.3
21	.65	.59	1.1	.24	.4	.6	17.	9.	1.9	450.	150.	3.0
22	.67	.42	1.6	.24	.3	.8	18.	8.8	2.0	460.	180.	2.5
Average.			1.6			.8			2.2			3.8

(IV.) Large Waves. N. S. Component.

No.	Amplitude.			Period			Max. Vel.			Max. Acc.		
	Surf.	Pit	Surf./Pit	Surf	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
1	2.75	2.3	1.2	1.6	1.6	1.0	11.	9.	1.2	44.	35.	1.3
2	2.9	3.3	.9	2.0	1.9	1.0	9.1	11.	0.8	29.	37.	0.8
3	.8	7.	1.1	.6	.42	1.4	8.4	11.	0.8	88.	170.	0.5
4	.5	.25	2.0	.6	.7	0.9	5.3	2.3	2.3	56.	21.	2.7

(IV.) Large Waves. N. S. Component. *(Continued.)*

No.	Amplitude.			Period.			Max. Vel.			Max. Acc.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
5	.85	.63	1.4	.74	.66	1.1	7.2	6.	1.2	61.	57.	1.1
6	.85	.8	1.1	.6	.8	0.8	8.9	6.3	1.4	93.	50.	1.9
7	1.4	1.25	1.2	.8	.8	1.0	11.	9.1	1.2	87.	72.	1.2
8	1.4	.7	2.0	1.1	1.2	0.9	8.	3.7	2.2	46.	19.	2.3
9	1.65	1.4	1.2	.77	.8	1.0	14.	11.	1.3	110.	87.	1.3
10	1.45	1.1	1.3	...	...	...	...	...	...	...	...	...
Average.			1.3			1.0			1.2			1.3

The ripples numbered 16, 18, 19 in (I) and those numbered 5, 19 in (III), which are distinct on the surface, do not exist in the pit.

(19)—May 6th, 1889.—A small earthquake, on whose undulations are superposed minute irregularities. Here the motion appears to be rather greater and of longer duration on the surface than in the pit.

	n.			Aver. Period.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
E. W. Comp.	43.	33.	1.3	.23	.3	0.8
N. S. Comp.	50.	22.	2.3	.2	.4	0.5

E. W. Component.

No.	Amplitude.			Period.			Max. Acc.			Max. Acc.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
1	.1	.1	1.0	1.	.7	1.4	.6	.9	0.7	4.	8.	0.5
2	.05	.05	1.0	1.3	1.7	0.8	.2	.2	1.0	1.	.7	1.4
3	.07	.07	1.0	1.6	1.4	1.2	.3	.3	1.0	1.	1.5	0.7
4	.08	.09	0.9	1.3	1.4	0.9	.4	.4	1.0	2.	2.	1.0
5	.05	.07	0.7	1.3	1.4	0.9	.24	.32	0.8	1.	1.5	0.7
6	.05	.06	0.8	1.	1.2	0.8	.3	.3	1.0	2.	2.	1.0
Average.			0.9			1.0			0.9			0.9

N. S. Component.

Max. Ampl.			Period.			Max. Vel.			Max. Acc.		
Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
.13	.09	1.4	.8	.5	1.6	1.	1.1	0.9	8.	14.	0.6

(20.)—May 30th, 1889.—A small earthquake.

	n.			Aver. Period.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
N. S. Comp.	32.	21.	1.5	.3	.5	0.6

	Max. Ampl.			Period.			Max. Vel.			Max. Acc.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
E. W. Comp.	0.8	.1	0.8	.33	.46	0.7	1.5	1.4	1.1	28.	20.	1.4
N. S. Comp.	.3	.15	2.0	.9	.4	2.3	2.1	2.4	0.9	15.	38.	0.4

(21.)—June 1st, 1889.—A very small earthquake.

In the E. W. and N. S. Components of both the surface and pit diagrams, the maximum amplitudes are about .03 mm. and .02 mm respectively.

(22.)—June 3rd, 1889.—A very small earthquake.

In the E. W. Component of the both the surface and pit diagrams, the maximum amplitude is about .03 mm.

N. S. Component.

Max. Ampl.			Period.			Max. Vel.			Max. Acc.		
Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
.1	.05	2.	1.	.7	1.4	.6	.5	1.	4.	4.	1.

(23.)—June 15th, 1889.—A small earthquake.

	Max. Ampl.			Period.			Max. Vel.			Max. Acc.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
E. W. Comp.	.07	.07	1.0	.8	.8	1.0	.55	.55	1.0	4.3	4.3	1.0
N. S. Comp.	.07	.05	1.4	1.0	.6	1.6	.44	.53	0.8	2.8	5.6	0.5

(24.)—June 16th, 1889.—A small earthquake.

E. W. Component. On the surface, the maximum amplitude is not greater than .02 mm., and in the pit it is about .05 mm.

N. S. Component. On the surface, the maximum amplitude is about .07 mm., and in the pit it is about 0.1 mm.

(25.)—June 20th, 1889.—A small earthquake. In this case, the amplitude seems to be rather greater in the pit than on the surface.

	n.			Aver. Period.			Max. Period.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
E. W. Comp.	35.	25.	1.4	.3	.4	.8	...	...	...
N. S. Comp.	48.	21.	2.3	.2	.5	.4	.6	.7	.9

	Max. Ampl.			Period.			Max. Vel.			Max. Acc.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
E. W. Comp.	.08	.14	0.6	.5	.7	.7	1.	1.	1.	13.	12.	1.
N. S. Comp.	.07	.11	0.6	.4	.5	.8	1.1	1.4	.8	17.	18.	1.

(26.)—June 27th, 1889.—A small earthquake.

	Max. Ampl.			Period.			Max. Vel.			Max. Acc.		
	Surf.	Pit	Surf./Pit	Surf	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
E. W. Comp.	.1	.05	2.	1.4	1.2	1.2	.5	.3	1.7	2.	1.3	1.5
N. S. Comp.	.1	.03	3.	1.2	.5	2.4	.5	.4	1.3	2.7	4.8	0.6

(27.)—July 3rd, 1889.—A small earthquake.

In the E. W. Component, the maximum amplitude is .13 mm. on the surface, and .1 mm. in the pit.

(28.)—February 13th, 1890.—A very small earthquake.

E. W. Component. Both on the surface and in the pit the maximum amplitude is not greater than .05 mm.

N. S. Component. Both on the surface and in the pit, the maximum amplitude is about 0.1 mm.

(29.)—April 11th, 1890.—A small earthquake.

	Max. Ampl.		
	Surf.	Pit	Surf./Pit
E. W. Comp.	.13	.15	0.9
N. S. Comp.	.1	.06	1.7

(30.)—April 18th, 1889.—A very small earthquake.

	Max. Ampl.		
	Surf.	Pit	Surf./Pit
E. W. Comp.	.07	.04	2.
N. S. Comp.	.06	very small.	...

Summary of Results.

It is generally believed that the earthquake motion is considerably less in a pit than on the surface. From the foregoing calculations it seems probable that this is true for some earthquakes and not true for others. Among the thirty earthquakes we examined, there are three which were especially severe. These are (1), (13), and (18). The rest are small earthquakes of the kind that daily occur in Japan. The ratios of the amplitudes, periods, maximum velocities and maximum accelerations for some of these latter earthquakes as observed on the free surface ground to those observed in the pit are collected in the following table, average values being used when a number of waves have been calculated for a single earthquake.

(No.)	Ratio of Amplitudes		Ratio of Periods		Ratio of Max. Vel.		Ratio of Max. Acc.	
	E. W.	N. S.	E. W.	N. S.	E. W.	N. S.	E. W.	N. S.
(2)	0.8	0.7	...	.5	...	1.4	...	3.
(3)	...	1.7	...	.8	...	2.0	...	3.
(4)	1.0	1.2	1.5	.7	.6	1.6	.44	2.2
(5)	1.4	1.0	0.9	0.5	1.6	2.3	1.8	5.0
(7)	1.0	1.1	1.0	0.9	1.0	1.2	1.0	1.2
(8)	1.1	0.9	1.0	0.6	1.2	1.5	1.3	2.7
(9)	0.6	0.8	0.9	0.9	0.7	0.9	0.7	1.1
(10)	0.9	2.6	0.8	0.9	1.3	3.0	1.6	3.7
(12)	1.8	1.6	0.8	0.7	2.5	2.3	3.6	3.6
(14)	1.1	1.1	...	1.2	...	1.0	...	0.9
(15)	0.6	0.6	0.8	1.0	0.8	0.8	1.0	0.9
(16)	1.2	1.1	...	...	...	...	...	...
(19)	0.9	1.4	1.0	1.6	0.9	0.9	0.9	0.6
(20)	0.8	2.0	0.7	2.3	1.1	0.9	1.4	0.4
(22)	...	2.0	...	1.4	...	1.0	...	1.0
(23)	1.0	1.4	1.0	1.6	1.0	0.8	1.0	0.5
(25)	0.6	0.6	0.7	0.8	1.0	0.8	1.0	1.0
(26)	2.0	3.0	1.2	2.4	1.7	1.3	1.5	0.6
(27)	1.3	...	...	...	...	...	...	...
(29)	0.9	1.7	...	...	...	...	...	...
Average. ...	1.06	1.4	0.9	1.1	1.2	1.4	1.3	1.9
Average for both Components.	1.2		1.0		1.3		1.6	

This table seems to shew that for small earthquakes the amplitude and the period are on the whole nearly the same on the free surface and in the pit, there being a slightly greater motion on the surface. This confirms the result which Prof. Milne previously obtained. In the above are not included those very small earthquakes, whose measurements are difficult; these however shew that the motion in the pit is also small when the motion observed on the surface ground is small.

It must be noticed that the diagram taken in the pit appears always to be smoother than that obtained on the surface, and n, or the number of irregular wavelets occurring in 10 seconds, is found in every case to be greater for the latter, being often twice as many as for the former. This is very remarkably shown in the three severe earthquakes mentioned above, for which calculations have been made separately as regards large undulations and small superposed ripples. The ratios of the amplitudes, periods, maximum velocities, and maximum accelerations for the surface and pit motion of these three earthquakes are given in the following tables.

(I.) Large undulations.

(No.)	Ratio of Amplitudes		Ratio of Periods		Ratio of Max. Vel.		Ratio of Max. Acc.	
	E. W.	N. S.	E. W.	N. S.	E. W.	N. S.	E. W.	N. S.
(1)	2.3	1.1	1.2	...	2.1	...	2.1	...
(13)	1.0	1.2	1.1	1.1	0.9	1.0	0.9	0.9
(18)	1.4	1.3	1.0	1.0	1.3	1.2	1.3	1.3
Average. ...	1.6	1.2	1.1	1.1	1.4	1.2	1.4	1.1
Average for both Components.	1.4		1.1		1.3		1.3	

(II.) Ripples.

(No.)	Ratio of Amplitudes		Ratio of Periods		Ratio of Max. Vel.		Ratio of Max. Acc.	
	E. W.	N. S.	E. W.	N. S.	E. W.	N. S.	E. W.	N. S.
(1)	1.9	1.3	0.6	0.8	3.7	1.8	7.8	2.7
(13)	2.3	4.0	0.8	0.9	3.2	3.9	6.7	4.0
(18)	1.7	1.6	0.9	0.8	2.0	2.2	2.8	3.8
Average. ...	2.0	2.3	0.8	0.8	3.0	2.6	5.8	3.5
Average for both Components.	2.2		0.8		2.8		4.7	

It will be thus observed that for principal undulations of severe earthquakes the range of motion is somewhat greater on the surface than in the pit, but there is no great difference of maximum velocities and maximum accelerations between the two sets of observations. This seems to be due to the fact that for the larger undulations the period will somewhat increase with the amplitude. In fact, table (I.) would appear to indicate some slight increase of period on the surface. The case is different with ripples, for which the results are more uniform and the difference of surface and underground effects more decided. From Table (II.) the average extent of horizontal motion in the pit is only half that on the surface ground, and the period for the former seems rather greater than for the latter, which arises from the fact that very many of the ripples disappear in the pit. The maximum velocities and maximum accelerations on the surface are respectively about three and five times those in the pit.

Our conclusion then is that for small earthquakes there is no practical difference between the surface and underground observations; for the principal undulations of severe earthquakes this difference may exist, but not to any marked degree; but for the small quick vibrations the difference is considerable. Now, though only approximate the calculation for the ripples may be, their maximum velocities and maximum accelerations are found to be very great, and, in fact, many times greater than those for the principal undulations. And thus, if these ripples are really in great part smoothed away in the pit, it is very likely that in times of such severe earthquakes as discussed above, there might be less destructive action in deep pits than on the free surface.

We shall not venture here to discuss what these ripples may be. They exist only in the early part of the shocks and seem to be the continuation of the tremors which occur at the beginning of earthquakes. The appearance of the diagrams of the severe earthquakes is very much like that of the disturbances in the sea where minute ripples are superposed on large undulations. If the ripples be regarded as waves travelling on the surface, then the whole thing will admit of an easy explanation.

We must state however that these observations were made at Hongo, where the ground is hard, and it is needless to say that the character of the earthquake motion depends in a great measure on the nature of the soil. Hence it is quite possible that observations in different places may lead to somewhat different results than those obtained here. Thus, for instance, at Hitotsubashi, where the soil is soft, the range of motion is two or three times greater than that at Hongo, and yet the earthquake diagrams obtained there seem to be comparatively free of superposed wavelets.

In the above the observations were confined to the horizontal component motion alone. The usual argument for the supposed smallness of the motion at a subterranean point is derived from the behaviour of a row of ivory balls in contact with each other when one at the end is sharply struck. This argument appears to apply rather to the vertical component than to the horizontal. It is our intention to continue these observations we have been making and in addition to investigate the nature of the vertical motion in the pit.

Laboratory Notes.

By

C. G. Knott., D. Sc., F. R. S. E.

Professor of Physics.

1. Electric Resistance of Cobalt.

The manner in which the electric resistance of cobalt varies with high temperatures does not seem to have been studied with any great care. The peculiar behaviour of nickel and iron as regards their change of resistance with temperature is now well known[1]. With a view to see if cobalt presented any similar peculiarity, I set Mr. Ōmori, one of the graduating students in Physics, to investigate the question.

The piece of cobalt used was cut from a sheet of rolled cobalt which had been given me by Professor Tait. Dr. E. Divers, F.R.S., kindly determined its composition by an analysis of a very small quantity (about 20 grains) supplied him. The result of the analysis is as follows:

Carbon found 0·77 % may be as much as 1·00 %

Silicon... ... 0·15

Iron ... ... 0·73

with a minute quantity of manganese and perhaps $\frac{1}{10}$ % of a metal undetermined. Dr. Divers regarded it as of remarkable purity for a furnace product.

1) See my paper *On the Electric Resistance of Nickel at High Temperatures*, *Trans. Royal Soc., Edin.*, Vol. XXXIII (1886)—also abstract in the *Journal of the College of Science, Tokyo*, Vol. I.

The method of experiment was essentially the same as that described in my earlier paper on nickel. Four stout copper rods, 60 cm. long and 0·7 sq. cm. cross section, were fixed in a vertical position some little distance apart. Their lower extremities were joined in pairs by two coiled wires, one of which was a specimen of nearly pure platinum and the other the cobalt strip that was the special object of investigation. The upper extremities of the rods were joined by stout copper strips to a commutator, which was in connection with a Wheatstone Bridge resistance box of ordinary construction.

In one series of experiments the lower ends of the rods with their connecting wires were dipped in a vessel of oil which could be heated up to a temperature of nearly 240° C. A thermometer, centrally placed so that its bulb lay at the mean level of the platinum and cobalt coils, was used for measuring the temperature. The oil was heated very gradually and was kept briskly stirred until a few seconds before a reading was to be taken. One of the wires was meanwhile thrown into the Wheatstone Bridge, and the resistance adjusted slightly in advance. The temperature was then allowed to rise very slowly until reversal of the commutator in the galvanometer branch gave no deflection. When the equilibrium was thus attained the thermometer reading was noted. In this experiment chief attention was given to the cobalt; a few measurements of resistance were made with the platinum, sufficient to give the most important temperature coefficient.

The resistance curves for the cobalt and the platinum are shown in the diagram (p. 293), Curves Nos. 1 and 2. All corrections have been carefully applied and the resistances are in legal ohms.

By interpolation amongst a number of contiguous measurements the resistance for each of the temperatures 100°, 140°, 180°, 220° C. was calculated as shown in Table I.

Table I.

Resistance of a Cobalt Strip in Legal Ohms at different Temperatures.			
Temperature.	Resistance.	First Difference.	Ratio.
100° C.	.12340		
		.01354	1.1097
140	.13694		
		.01516	1.1109
180	.15210		
		.01649	1.1084
220	.16859		

Since the second differences have appreciably different values, it is impossible to represent the law of change by means of a parabolic function. But the remarkable constancy of the ratios of successive pairs of resistances suggests an exponential function of the temperature as the expression for the resistance.

Thus we may put

$$R = R_0 \, e^{kt}$$

from which we find, if t is the temperature in degrees Centigrade,

$$k = \cdot 002605, \; R_0 = \cdot 09519$$

The measured resistance at 7°·5 C. was 0·09604, which does not differ from the value given by the formula by more than 1 per cent.

In my paper already referred to I found that the same form of expression held for the case of one of the nickel wires investigated, the only essential difference being in the value of the coefficient k, which for the nickel was .003.

The resistance of cobalt therefore does not change so quickly with temperature as does the resistance of nickel.

In the second series of experiments the lower ends of the rods with their connecting wires were inserted into a porcelain vessel. Asbestos was wrapped round the wires; and the whole was heated in a charcoal furnace. The observations of resistance were made as the system was cooling, the cobalt and platinum being thrown alternately into the Wheatstone Bridge. The instants at which the balancing was effected were carefully noted, so that it was an easy matter to interpolate between two successive measurements for the one wire that resistance which corresponded to the intermediate measurement for the other.

By this means more than twenty distinct pairs of measurements were obtained, every cobalt resistance having its corresponding platinum resistance. After all corrections were made the platinum resistances were divided by the resistance of the platinum at 7°C.; and similarly all the cobalt resistances were divided by the resistance of the cobalt at this same temperature. The numbers were then classified into groups so as to afford the means of calculating by interpolation the cobalt resistances which corresponded to assumed convenient values of the platinum resistances. These are the numbers given in Table II. which epitomises the results of four distinct experiments. The measurements were all made during cooling, and the higher values are accordingly tabulated first. The first column contains the platinum resistances, taken as convenient multiples of the resistance at 7° C. measured *after* the experiment; and the other columns give in order the corresponding resistances of the cobalt.

Table II.

Platinum Resistances.	Cobalt Resistances			
	Exp. I.	Exp. II.	Exp. III.	Exp. IV.
2.0	5.8047	5.7996	5.9748	6.0361
1.8	4.5101	4.3423	4.4511	4.4580
1.6	3.1822	3.0536	3.0932	3.2216
1.4	2.2029	2.1795	2.1111	2.2602
1.2	1.5329	1.5337	1.5050	
1.0	1.0000	1.0000	1.0000	1.0000

If we assume that the changes in the platinum resistance follow the same law as in the earlier experiment with the oil, the rise of temperature which will just double the resistance is about 680° C.; and the interval from 1 to 1.2 may be taken as corresponding approximately to a rise of temperature of 136° C. According to the experiment in oil, the resistance of the cobalt would have been increased in the ratio 1.4248 to unity by this rise of temperature. It is apparent then that under the influence of the first excessive heating the cobalt has been considerably altered in its properties, so that the average temperature cœfficient for resistance up to 150° C. has been increased by a quarter.

That the successive heatings caused a marked change in the structure of the wire or strip is shown by the variations in the measured resistance at 7° C. These are given in Table III.

Table III.

When Measured.	Resistance of Platinum wire	Resistance of Cobalt Strip.
At the beginning	.8525	.09724
After 1st heating	.85028	.09135
,, 2nd ,,	.85028	.09354
,, 3rd ,,	.85013	.09674
,, 4th ,,	.85232	.09978

The fall in resistance after the first heating is no doubt due to some change in the contact resistances. It characterises both the platinum and cobalt. Subsequent heatings however do not change the platinum to any great extent until the very last experiment; but their effect on the cobalt is very marked. After the experiments were completed the cobalt was found to be much altered by oxidation. It was exceedingly brittle and broke into small pieces when it was being detached from the copper rods. While the observations were being made, it was noticed that the fourth experiment was much inferior in point of regularity and steadiness to the others, a fact sufficiently explained by the final condition of the metal.

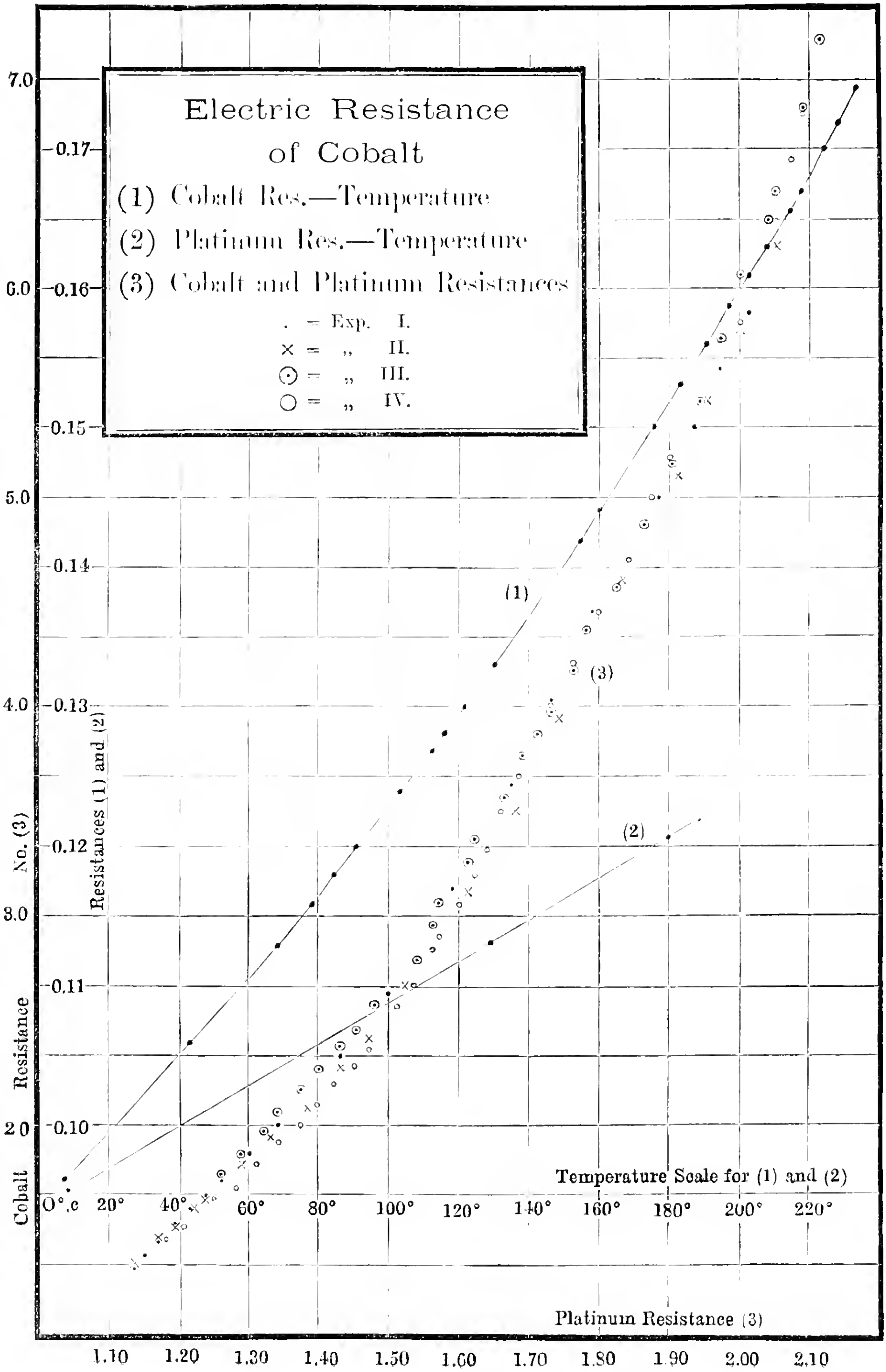
It is not surprising, then, that there is considerable divergence between the values of the temperature cœfficients as obtained from the earlier experiment in oil and the later series in the charcoal furnace.

What is surprising is, that in spite of the great alteration in structure going on in the strip, the general behaviour of the cobalt as shown in the first three experiments is essentially the same. This is well seen from the tabulation of the rates of change themselves. These quantities were calculated by the same general method of interpolation as was used in calculating the resistance. They correspond to the values of dy/dx if y and x are taken to represent respectively the corresponding resistances of cobalt and platinum. They are given in Table IV, the first column containing the values of the platinum resistances to which the tabulated rates of change correspond.

Table IV.

Platinum Resistance (Arbitrary Temp'r scale).	Rates of Change of Cobalt Resistance per unit Change of Platinum Resistance.			
	Exp. I.	Exp. II.	Exp. III.	Exp. IV.
2	7.02	7.30	10.33	9.15
1.8	6.19	7.24	6.74	5.09
1.6	5.45	5.57	6.63	6.10
1.4	3.76	3.58	3.65	3.66
1.2	3.58	3.23	2.78	

I have thought it sufficient to give the condensed numerical results as contained in Tables I, II and IV. The individual observations upon which these results are based are shown graphically in the diagram.


Electric Resistance
of Cobalt
(1) Cobalt Res.—Temperature
(2) Platinum Res.—Temperature
(3) Cobalt and Platinum Resistances
. = Exp. I.
× = „ II.
⊙ = „ III.
○ = „ IV.
(1)
(2)
(3)
7.0
6.0
5.0
4.0
3.0
2.0
0.17
0.16
0.15
0.14
0.13
0.12
0.11
0.10
Cobalt Resistance No. (3)
Resistances (1) and (2)
Temperature Scale for (1) and (2)
0°.c 20° 40° 60° 80° 100° 120° 140° 160° 180° 200° 220°
Platinum Resistance (3)
1.10 1.20 1.30 1.40 1.50 1.60 1.70 1.80 1.90 2.00 2.10

Curves 1 and 2 have already been mentioned. They show the march of resistance with temperature as measured on a mercurial centigrade thermometer. In No. 3, the platinum resistances are virtually used as temperatures, and form the abscissæ. The ordinates are the corresponding cobalt resistances. The points belonging to the various experiments are distinguished by special mark.

It will be seen at a glance that in one particular cobalt behaves very like iron and nickel. There is a rapid increase in the steepness of the curve at the higher temperatures. In iron and nickel this rapid increase is followed at still higher temperatures by a distinct decrease, the curves bending so as to present a concavity toward the temperature (or platinum resistance) axis. Table IV. gives no hint of such a tendency in cobalt. The curves all become steeper with rise of temperature, if we except the distinctly irregular indications of Experiment IV.

It will be seen from Table IV. that Experiments I. and II. are in fair agreement throughout; and that all four experiments point to the existence of a critical temperature, at which the resistance begins to increase rapidly with rise of temperature. This critical temperature is about the stage 1.5, which corresponds approximately to 350° C. The same conclusion may be drawn from Table II. and expressed in these terms. Between the temperatures 400° and 700° C. the resistance of a cobalt strip increases on the average at a rate nearly twice as great as the average rate of increase between 0° and 300° C.

2. The Thermoelectric Positions of Cobalt and Bismuth.

So far as I know, the only satisfactory determination of the position of the Cobalt line on the thermoelectric diagram was made by

Professor Tait's students in the Physical Laboratory of Edinburgh University some fifteen years ago. The position of the Cobalt line, so found, was given along with the positions of certain alloys in a paper by Professor J. Gordon MacGregor and myself published in the Transactions of the Royal Society of Edinburgh, Vol. XXVIII (1878). The particular specimen of Cobalt used in these early experiments was a short rod obtained by electrolytic deposition. The noteworthy facts regarding its thermoelectric line were that it lay below nickel on the diagram, and that its inclination to the lead line was much greater than the inclinations of the iron and nickel lines.

As a Laboratory exercise I gave to Mr. Sawada, one of our students of physics, the task of studying the thermoelectric properties of the sheet cobalt described in the preceding note. The plan adopted was to form a multiple arc of Palladium and Bismuth and by proper adjustment of the resistances in these branches to obtain an intermediate line which should cut through the cobalt line at temperatures within easy reach.

Such an intermediate line passes through the neutral point of the component metals. It divides the region between their lines so that any transversal is cut into portions which are directly as the resistances in the branches of the multiple arc. Thus by varying the ratio of the resistances in these branches we may sweep through the region between the two corresponding diagram lines, interpolating so to speak any intermediate line suitable for our purpose. The extreme accuracy with which we can measure electric resistance enables us to fix the position of this intermediate line as accurately as the positions of the component lines are known.

The low position of cobalt on the diagram very much circumscribed the choice of metals for the multiple arc. Bismuth had to be one of them, as it alone was known to be below cobalt. The other metal fixed upon was Palladium, a substance convenient in every way. Its diagram line is straight up to high temperatures; and its character does not perceptibly change even after severe heatings. Unfortunately, however, the necessity of using bismuth limited the investigation to moderate temperatures.

The bismuth was broken up into small pieces, which were packed tightly into the bore of a siphon shaped glass tube. Gentle heating in a Bunsen flame sufficed to melt the metal, which ran together and solidified on cooling into a fairly uniform rod. The junction wires were fused into the ends of the bismuth rod.

As finally set up, the apparatus consisted of a triple Cobalt-Bismuth-Palladium junction dipping in oil. This formed the "hot junction." Resistance boxes were included in the palladium and bismuth branches. Because of the magnitude of the thermoelectromotive forces between these three metals and copper, great precaution was necessary in keeping the various cold junctions at the same temperature.

The palladium branch always contained 100 ohms resistance. The resistance of the bismuth branch varied from infinity to 200, lower values carrying the intermediate line too far below the cobalt line. For each of the seven selected ratios of resistances, a careful series of thermoelectric observations was made. A delicate high resistance galvanometer was used; and the temperatures were measured by a mercurial thermometer. The electromotive forces between the cobalt and each intermediate "equivalent metal" were in this way measured directly. From these the thermoelectric powers at chosen temperatures could be calculated. But one of these "equivalent metals" was palladium itself, when the resistance in the bismuth branch was made infinite. Subtracting all the other thermoelectric powers from this one, we obtained the thermoelectric powers between palladium and the other equivalent metals. The values of the thermoelectric powers were calculated for 0° C and 100° C and are given in the following Table. The symbol Bi stands for bismuth, Co for cobalt, and Pd for palladium. The various "equivalent metals" are represented by the symbol Pd Bi_n where the number n represents the ratio of the resistance in the bismuth branch to the resistance in the palladium branch. Thus Pd Bi_2 means that, since the palladium always contained 100 ohms resistance, the bismuth contained in this case 200 ohms. The electromotive forces are measured in microvolts.

Thermoelectric Powers referred to Palladium.

Metal.	Thermoelectric Power at 0 C.	at 100 C.	Neutral Point with Cobalt.
Co	7.00	17.31	
Pd Bi_{13}	5.98	6.46	−10°.4 C.
Pd Bi_8	9.38	9.96	+24°.5
Pd Bi_5	14.45	14.69	71.1
Pd Bi_4	17.44	17.44	101.4
Pd Bi_3	21.73	22.13	148.9
Pd Bi_2	29.10	29.55	224.0
Bi	86.0	88.8	

The numbers in the last row have been calculated from the numbers in all the six Pd Bi rows. For if p is the thermoelectric power between Pd and Bi and p_n the same between Pd and Pd Bi_n we know that

$$\frac{p - p_n}{p_n} = \frac{n}{1}$$

or

$$p = (n + 1)\, p_n$$

Thus from the six sets of values corresponding to p_n we obtain the following values for p at 0°C. and 100°C.

$n + 1$	p_0	p_{100}
14	83.7	90.4
9	84.4	89.6
6	86.7	88.1
5	87.2	87.2
4	86.9	88.5
3	87.3	88.7
Means	86.0 ± .8	88.8 ± .7

This table is obviously an indication of the accuracy of the experiment.

And now, referring everything to the Lead line, and expressing the thermoelectric power in the form

$$p = \frac{de}{dt} = A + Bt$$

we obtain for the coefficients A and B the following values.

	A	$B \times 10^2$
Lead	0	0
Palladium	− 6.18	− 3.55
Cobalt...........................	−13.18	−13. 9
Bismuth	−92. 2	− 6. 4

According to the numbers deduced by Fleeming Jenkin from Matthiessen's experiments, bismuth lies four times further from lead than does cobalt. Here we have it seven times. Professor Tait's electrolytically deposited cobalt lies $4\frac{1}{2}$ times further from lead than does palladium. Here we have it a little over two times. According to Becquerel's numbers given at the end of the English translation of Mascart and Joubert's *Electricity and Magnetism*, the ratio at 50° C. of the thermoelectric powers of palladium and bismuth relatively to lead is as 7 : 40. Here we have 1 : 16.

These discrepancies are not surprising. We know how variable are the thermoelectric properties of stable alloys[1] intended to have the same composition, and how a very slight change in composition may be accompanied by a very large change in thermoelectric position. The present experiments must therefore be judged of altogether on their own merits. A simple comparison shows us that Professor Tait's cobalt will fit in to the region between lead and bismuth very much as Matthiessen's cobalt fits in to his own series. Thus the cobalt investigated here seems to differ from these other specimens in much the same way. The new cobalt indeed lies so high in the diagram that its line is higher than the line of Tait's nickel, for which $A = -21.8$.

This unexpected result was at once tested. A rough experiment was made with the couple nickel-cobalt and a neutral point was obtained at a temperature below 100° C. This cobalt line therefore, at ordinary temperatures of the air, is above nickel; but because of its greater downward inclination gets below it at temperatures above 100° C.

As regards the inclination of the cobalt line, the present result agrees as well with the earlier result as could reasonably be expected with two quite different specimens of the metal. Thus, expressed in the same units, the thermoelectric power of Professor Tait's cobalt is given by the formula.

$$p = -26.3 - 0.116\ t$$

whereas for the present specimen

$$p = -13.18 - 0.1386\ t$$

With the exception of the sharp upward bend in nickel, this gives the greatest inclination yet obtained for a thermoelectric line. It would

1) See the paper by MacGregor and myself already referred to, also my paper on *The Electrical Properties of Hydrogenised Palladium* (Trans. R. S. E., Vol. XXXIII., 1886)—abstract in this *Journal*, Vol. I.

be interesting to establish by direct experiment that the Thomson Effect is exceptionally large in cobalt.

The downward trend and comparatively large inclination of the bismuth line are also worthy of note. Because of the position of the line as a whole, lying far below the lines of all other metals, this large inclination does not greatly influence the electromotive forces, so that with bismuth couples the electromotive force is very approximately proportional to the temperature. This fact of course prevents us from making a very accurate determination of the coefficient B, which in the present experiments has a large probable error. Its mean value is a little greater than the value indicated in Battelli's direct measurement of the Thomson Effect in Bismuth[1].

Righi has shown[2] that the electric resistance of Bismuth is altered in a strong magnetic field. To find if any thermoelectric change accompanied magnetisation in nickel, a bismuth palladium couple was set up between the poles of a powerful electromagnet. No effect whatever was obtained, although the arrangement (slightly modified) was sensitive enough to show with great ease the thermomagnetic effect discovered by v. Ettingshausen and Nernst[3].

1) See Wied. Beiblätter, Vol. XI, 1887.

2) See Wied. Beiblätter, Vol. XIII, 1884.

3) See Wied. Annalen, Vol. XXIX, 1886.

Diffraction Phenomena produced by an Aperture on a Curved Surface.

By

H. Nagaoka.

In ordinary problems on diffraction of light produced by apertures of various shapes, the diffracting apertures are supposed to lie on a plane. The more general problem of diffraction produced by apertures on a known geometrical surface has not, so far, been touched. It has been my object to fill in this gap, although the expression for the intensity of diffracted light is integrable only in a few particular cases.

In the following, I give a general expression for the intensity of light diffracted by an aperture on a known surface, both for Fraunhofer's and Fresnel's diffraction phenomena. The expression is then applied to find the distribution of light after its passage through a small slit cut perpendicular to the generating line of a right circular cylinder.

Expression for the Intensity of the Diffracted Light. *

Let L be a source of light, and $A\ B$ an aperture on a known geometrical surface. The ray of light propagated from L is diffracted by the aperture $A\ B$, and the diffraction phenomena thus produced may be seen either projected on a screen at D (Fig. 2), or observed by

* In the deduction of the expression for the intensity, I follow F. Neumann's method.

Fig. 1.

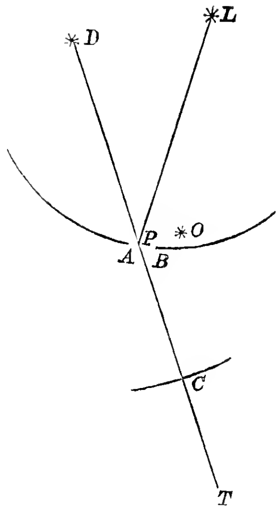
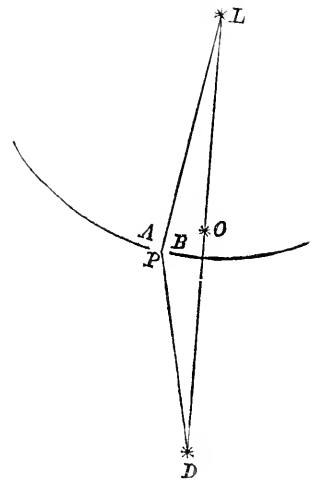


Fig. 2.



means of a telescope placed at T, and so focussed that the observer sees a distant point D (Fig. 1): in other words, D is the so-called diffraction point.

In order to find the general expression for the intensity of light after it is diffracted by an aperture on a curved surface, I shall assume that the diffracting aperture is very small compared with its distance from the source of light, and from the point at which the intensity of diffracted light is considered. Consequently the amplitude of vibration of the light coming from different points of the aperture will not vary at the point considered.

I shall first discuss Fraunhofer's (telescopic) diffraction phenomena. Referring to Fig. 1, let the vibration at L be represented by $\cos 2\pi \frac{t}{T}$; then, at any point P on the diffracting aperture, it will be proportional to

$$\cos \left(\frac{t}{T} - \frac{LP}{\lambda} \right) 2\,\pi.$$

Now considering the ray in the direction DP, the vibration at any point C in the line PT due to the small element $d\sigma$ at P is proportional to

$$d\sigma \cos\left(\frac{t}{T} - \frac{LP}{\lambda} - \frac{PC}{\lambda}\right) 2\pi.$$

Describe a sphere with D as centre, and passing through C; then the time taken by the ray to go from the spherical surface to the eye will be constant, provided D be sufficiently distant. Let this constant time be denoted by τ; the vibration at T is thus proportional to

$$d\sigma \cos\left(\frac{t-\tau}{T} - \frac{LP}{\lambda} - \frac{PC}{\lambda}\right) 2\pi.$$

A similar expression holds for the light propagated from every element of the aperture, so that the total effect at T will be given by the integral

$$(1) \qquad \int d\sigma \cos\left(\frac{t-\tau}{T} - \frac{LP}{\lambda} - \frac{PC}{\lambda}\right) 2\pi,$$

where the integration extends over the whole aperture.

Taking any point O near the aperture, we may write

$$\begin{aligned} PC &= DC - DP, \\ &= DC + (DO - DP) - DO, \\ LP &= LO - (LO - LP). \end{aligned}$$

Denoting the constant distances LO, DO by R and R' respectively, let $LO - LP = \Delta R$, and $DO - DP = \Delta R'$.

Introducing these symbols in the expressions for PC and LP, we find

$$\begin{aligned} PC &= DC - R' + \Delta R', \\ LP &= R - \Delta R. \end{aligned}$$

Substituting these in (1), we get for the vibration at T the integral

$$(2) \qquad \int d\sigma \cos\left(\frac{t-\tau}{T} - \frac{DC}{\lambda} - \frac{R-R'}{\lambda} + \frac{\Delta R - \Delta R'}{\lambda}\right) 2\pi.$$

Since τ, DC, $R - R'$ are all constant, we can put

$$\frac{t-\tau}{T} - \frac{DC}{\lambda} - \frac{R-R'}{\lambda} = \theta,$$

and the above expression for the vibration becomes

$$(3) \qquad \int d\sigma \; cos \left(\vartheta + \frac{\varDelta R - \varDelta R'}{\lambda} \right) 2\pi.$$

The intensity of light at T is, therefore, given by the expression

$$I = \left[\int d\sigma \; cos \left(\frac{\varDelta R - \varDelta R'}{\lambda} \right) 2\pi \right]^2 + \left[\int d\sigma \; cos \left(\frac{\varDelta R - \varDelta R'}{\lambda} \right) 2\pi \right]^2 ;$$

or more simply by

$$(\text{I}) \qquad I = Mod.^2 \int d\sigma \; e^{\, i \frac{2\pi}{\lambda} (\varDelta R - \varDelta R')}$$

When the diffraction point is situated on the other side of the surface from the source of light, and the phenomenon is seen projected on a screen at D, we must slightly modify the expression for the intensity of light.

Proceeding in exactly the same way as before, the vibration at D due to a small element $d\sigma$ at P (Fig. 2), will be proportional to

$$d\sigma \; cos \left(\frac{t}{T} - \frac{LO}{\lambda} - \frac{PD}{\lambda} \right) 2\pi,$$

which can be written

$$d\sigma \; cos \left(\frac{t}{T} - \frac{LP}{\lambda} + \frac{LO - LP}{\lambda} + \frac{OD - PD}{\lambda} \right) 2\pi$$

Putting as before

$$\frac{t}{T} - \frac{LD}{\lambda} = \vartheta,$$

$$LO - LP = \varDelta R,$$

$$OD - CD = \varDelta R',$$

we get

$$cos \left(\frac{t}{T} - \frac{LP}{\lambda} - \frac{PD}{\lambda} \right) 2\pi = cos \left(\vartheta + \frac{\varDelta R + \varDelta R'}{\lambda} \right) 2\pi.$$

Consequently, the total effect at D is given by

$$\int d\sigma \; cos \left(\vartheta + \frac{\varDelta R + \varDelta R'}{\lambda} \right) 2\pi.$$

Thus, the intensity of diffracted light at D is given by

$$I = \left[\int d\sigma \cos\left(\frac{\Delta R+\Delta R'}{\lambda}\right)2\pi\right]^2 + \left[\int d\sigma \sin\left(\frac{\Delta R+\Delta R'}{\lambda}\right)2\pi\right]^2;$$

or more briefly by

$$\text{(II)} \qquad I = Mod^2 \int d\sigma\, e^{\,i\frac{2\pi}{\lambda}(\Delta R+\Delta R')}.$$

The above expression gives the intensity of diffracted light for Fresnel's diffraction phenomena.

To evaluate the integrals given in (I) and (II), assume O as the origin of three rectangular co-ordinate axes x, y, z. Let the coordinates of the points L, D, P referred to these axes be denoted thus:—

$$\begin{aligned} L:&\quad a,\ b,\ c,\\ D:&\quad a',\ b',\ c',\\ P:&\quad x,\ y,\ z, \end{aligned}$$

and let the equation of the surface referred to the same axes be

$$F\,(x,\ y,\ z) = const.$$

Thus, we have

$$\begin{aligned} LO &= \sqrt{a^2+b^2+c^2} = R,\\ OD &= \sqrt{a'^2+b'^2+c'^2} = R',\\ LP &= \sqrt{(a-x)^2+(b-y)^2+(c-z)^2} = R - \Delta R,\\ PD &= \sqrt{(a'-x)^2+(b'-y)^2+(c'-z)^2} = R' - \Delta R'. \end{aligned}$$

Expanding the expressions for LP and PD by means of the binomial theorem, we have

$$LP = R - \frac{ax+by+cz}{R} - \frac{1}{2R^3}(ax+by+cz)^2 + \frac{x^2+y^2+z^2}{2R} + \ldots\ldots,$$

$$PD = R' - \frac{a'x+b'y+c'z}{R'} - \frac{1}{2R'^3}(a'x+b'y+c'z)^3 + \frac{x^2+y^2+z^2}{2R'} + \ldots\ldots,$$

or

$$(4)\quad \begin{cases} \Delta R = \dfrac{ax+by+cz}{R} + \dfrac{1}{2R^3}(ax+by+cz)^2 - \dfrac{x^2+y^2+z^2}{2R}, \\ \Delta R' = \dfrac{a'x+b'y+c'z}{R'} + \dfrac{1}{2R'^3}(a'x+b'y+c'z)^2 - \dfrac{x^2+y^2+z^2}{2R'}, \end{cases}$$

Let the direction cosines of OL be $\varkappa$, μ, ν, and those of OD be $\varkappa'$, μ', ν'; then (4) becomes

$$(4')\quad \begin{cases} \Delta R = (\varkappa x + \mu y + \nu z) + \dfrac{1}{2R}(\varkappa x + \mu y + \nu z)^2 - \dfrac{x^2+y^2+z^2}{2R}, \\ \Delta R' = (\varkappa' x + \mu' y + \nu' z) + \dfrac{1}{2R'}(\varkappa' x + \mu' y + \nu' z)^2 - \dfrac{x^2+y^2+z^2}{2R'}. \end{cases}$$

In Fraunhofer's diffraction phenomena, R and R' are supposed to be very large compared with x, y, z, so that we can neglect the terms containing R or R' in the denominator. Thus

$$\Delta R - \Delta R' = (\varkappa - \varkappa')x + (\mu - \mu')y + (\nu - \nu')z.$$

Writing

$$\frac{2\pi}{\lambda}(\varkappa - \varkappa') = l,$$

$$\frac{2\pi}{\lambda}(\mu - \mu') = m,$$

$$\frac{2\pi}{\lambda}(\nu - \nu') = n,$$

the expression for the intensity of the diffracted light becomes

$$(1')\qquad I = Mod^2. \int d\sigma\, e^{i(lx+my+nz)}$$

where the integration extends over the whole aperture.

In Fresnel's diffraction phenomena, we can no longer neglect the terms $\frac{1}{R}$ and $\frac{1}{R'}$. Thus the expression for $\Delta R + \Delta R'$ becomes very complicated. It is, however, somewhat simplified by taking O in the line LD as shown in Fig. 2. Thereby $\varkappa' = -\varkappa$, $\mu' = -\mu$, $\nu' = -\nu$, because OL and OD are in one line. Thus

$$\Delta R + \Delta R' = \left[(\kappa x + \mu y + \nu z)^2 - (x^2 + y^2 + z^2)\right]\left(\frac{1}{2R} + \frac{1}{2R'}\right).$$

Introducing this value in (II), we get for the intensity of light at D

$$\text{(II')} \qquad I = Mod^2. \int d\sigma\, e^{i\frac{\pi}{\lambda}\left[(\kappa x + \mu y + \nu z)^2 - (x^2 + y^2 + z^2)\right]\left(\frac{1}{R} + \frac{1}{R'}\right)},$$

where the integration extends over the whole aperture.

Thus the problem of the diffraction of light produced by an aperture on a curved surface is reduced to the integration of expressions (I′) and (II′) for Fraunhofer's and Fresnel's diffraction phenomena respectively.

Fraunhofer's Diffraction Phenomena produced by a narrow Slit on a cylindrical Surface.

Let us now discuss Fraunhofer's diffraction phenomena produced by a narrow slit cut on a right circular cylinder and perpendicular to the generating line of the cylinder.

In order to calculate the intensity of light for different positions of the telescope, drop a perpendicular on the axis of the cylinder from the centre of the slit. Assume the centre as the origin of co-ordinate axes. Let the x axis be parallel to the axis of the cylinder, and the z axis perpendicular thereto, both drawn through the centre of the slit.

The axes being thus fixed, we have, by (I′), to find the integral

$$\int d\sigma e^{i(lx + my + nz)},$$

where the integration extends over the whole aperture, and l, m, n are determined by the directions of the incident light and of the observing telescope referred to the rectangular axes above specified.

and by the wave length of light employed in the observation. In addition to this, there is the equation of condition

$$y^2 + z^2 - 2az = 0$$

expressing the fact that the aperture lies on a cylinder of radius a.

In actual calculation, it is more convenient to use polar co-ordinates. In the right circular section of the cylinder, assume polar co-ordinates with the pole on the axis, and take

$$y = a \sin \vartheta, \qquad z = a(1 - \cos \vartheta),$$

Then $$d\sigma = a\, dx\, d\vartheta.$$

Thus $$\int e^{i(lx+my+nz)} d\sigma = a e^{ia} \int_{-b}^{+b} dx\, e^{ilx} \int d\vartheta\, e^{ia(m \sin \vartheta - n \cos \vartheta)},$$

where $2b$ denotes the breadth of the slit.

The integral

$$\int_{-b}^{+b} dx\, e^{ilx} = \frac{e^{ilb} - e^{-ilb}}{il},$$

$$= \frac{2 \sin lb}{l}.$$

It thus remains to find the integral

$$\int d\vartheta\, e^{ia(m \sin \vartheta - n \cos \vartheta)}$$

taken between proper limits.

Introduce an auxiliary angle ϑ', such that

$$a m = \xi \sin \vartheta', \qquad a n = \xi \cos \vartheta'$$

where $$\xi = a\sqrt{m^2 + n^2}.$$

Then $$a\,(m \sin\vartheta - n \cos\vartheta) = \xi \cos(\vartheta + \vartheta') = \xi \cos\varphi,$$

where φ stands for $\vartheta + \vartheta'$.

Thus $$\int d\vartheta\, e^{ia(m\sin\vartheta - n\cos\vartheta)} = \int d\varphi\, e^{i\xi\cos\varphi}.$$

The limits of integration with respect to φ are found from ϑ' and the known limits with respect to ϑ.

The difficulty of the problem lies simply in finding the integral

$$J = \int d\varphi\, e^{i\xi\cos\varphi}.$$

I shall henceforth put $J = K + iL$, where

$$K = \int \cos(\xi\cos\varphi)\, d\varphi,$$

$$L = \int \sin(\xi\cos\varphi)\, d\varphi.$$

Evaluation of the Integral $J = \int d\varphi\, e^{i\xi\cos\varphi}$.

There are various ways of evaluating the above integral. The simplest way would be to find a differential equation which is satisfied by J, and by this means to expand it in a series proceeding according to ascending powers of ξ.

Since every integral of the form $\int d\varphi\, e^{i\xi\cos\varphi}$ between known limits can be decomposed into a sum of two separate integrals of the form $\int_0^{\alpha} d\varphi\, e^{i\xi\cos\varphi}$, I shall only consider

$$J = \int_0^{\alpha} e^{i\xi\cos\varphi}\, d\varphi.$$

Putting $$\cos\varphi = u,\ \cos\alpha = c,$$

$$J = -\int_1^{c} \frac{e^{i\xi u}}{\sqrt{1-u^2}}\, du.$$

Differentiating with respect to ξ, we have

$$\frac{dJ}{d\xi} = -i\int_1^c \frac{u\,e^{i\xi u}}{\sqrt{1-u^2}}\,du,$$

$$\frac{d^2J}{d\xi^2} = \int_1^c \frac{e^{i\xi u}}{\sqrt{1-u^2}}\,du - \frac{1}{i\xi}\Big[(1-c^2)^{\frac{1}{2}} e^{i\xi u}\Big]_1^c - \frac{1}{i\xi}\int_1^c \frac{e^{i\xi u}\,u}{\sqrt{1-u^2}}\,du$$

$$= -J - \frac{1}{\xi}\frac{dJ}{d\xi} + \frac{i\,s\cos(c\xi)}{\xi} - \frac{s\sin(c\xi)}{\xi}$$

where s stands for $\sqrt{1-c^2} = \sin\alpha$.

Thus the differential equations satisfied by K and L are respectively

$$\frac{d^2K}{d\xi^2} + \frac{1}{\xi}\frac{dK}{d\xi} + K = -\frac{s\sin(c\xi)}{\xi},$$

and

$$\frac{d^2L}{d\xi^2} + \frac{1}{\xi}\frac{dL}{d\xi} + L = \frac{s\cos(c\xi)}{\xi}.$$

To find the expression for K and L, assume a series proceeding according to ascending powers of ξ. Differentiating and properly choosing the constants, we easily find that

$$(a)\quad K = \alpha - \frac{s\,p}{2^2}\xi^2 + \frac{s\,\xi^4}{4^2}\left(\frac{c^3}{3!} + \frac{p}{2^2}\right) - \frac{s\,\xi^6}{6^2}\left(\frac{c^5}{5!} + \frac{c^3}{3!\,4^2} + \frac{p}{2^2.\,4^2}\right)$$

$$+ \cdots\cdots + (-1)^{n-1}\frac{s\,\xi^{2n}}{(2n)^2}\left(\frac{c^{2n-1}}{(2n-1)!} + \frac{c^{2n-3}}{(2n-3)!\,(2n-2)^2} + \cdots\cdots\right.$$

$$\left. + \frac{p}{2^2.\,4^2.\,6^2\ldots(2n-2)^2}\right) \pm \cdots\cdots$$

$$(b)\quad L = s\Big[\xi - \frac{\xi^3}{3^2}\left(\frac{c^2}{2!} + 1\right) + \frac{\xi^5}{5^2}\left(\frac{c^4}{4!} + \frac{c^2}{2!\,3^2} + \frac{1}{3^2}\right)$$

$$- \frac{\xi^7}{7^2}\left(\frac{c^6}{6!} + \frac{c^4}{4!\,5^2} + \frac{c^2}{2!\,3^2.\,5^2} + \frac{1}{3^2.\,5^2}\right) + \cdots\cdots$$

$$+ (-1)^n\frac{\xi^{2n+1}}{(2n+1)^2}\left(\frac{c^{2n}}{2n!} + \frac{c^{2n-2}}{(2n-2)!\,(2n-1)^2} + \cdots\cdots\right.$$

$$\left. + \frac{1}{3^2.5^2\ldots(2n-1)^2}\right) \pm \cdots\cdots\Big].$$

where p stands for $\frac{1}{s}(cs+\alpha)$.

It is to be remarked that when $\alpha = \pi$, K becomes equal to $\pi J^{\circ}(\xi)$, where J° denotes Bessel's function of the first kind with index 0. Thus the above expression for K reduces to

$$K = \pi\left(1 - \frac{\xi^2}{2^2} + \frac{\xi^4}{2^2.\,4^2} - \frac{\xi^6}{2^2.\,4^2.\,6^2} + \frac{\xi^8}{2^2.\,4^2.\,6^2.\,8^2} - \cdots\cdots\cdots\right).$$

The expression within the bracket is the well-known form for $J^{\circ}(\xi)$.

It is easily seen that the above two series for K and L converge rapidly so long as ξ is small; but when ξ becomes large, it would be advantageous to employ other expressions for K and L.

The usual process of calculating $\int_0^a e^{i\,\xi\cos\varphi}\,d\varphi$ is to expand $e^{i\xi\cos\varphi}$ in a Fourier series, and integrate each term of the series separately. Thus

$$e^{i\,\xi\cos\varphi} = J^{\circ}(\xi) + 2\sum_1^{\infty} i^n J^n(\xi)\cos n\varphi.$$

$$\therefore \qquad \int_0^a e^{i\,\xi\cos\varphi}\,d\varphi = J^{\circ}(\xi)\,\alpha + 2\sum_1^{\infty} i^n J^n(\xi)\frac{\sin(n\,\alpha)}{n}.$$

Equating the real and imaginary parts to K and L respectively, we have

$$(c) \qquad K = \alpha J^{\circ}(\xi) + 2\sum_1^{\infty}(-1)^n J^{2n}(\xi)\frac{\sin(2n\alpha)}{2n},$$

$$(d) \qquad L = 2\sum_0^{\infty}(-1)^{n-1} J^{2n-1}(\xi)\frac{\sin(2n+1)\alpha}{2n+1}.$$

The form given above is not rapidly convergent. The values of $J^n(\xi)$ can be easily calculated from the values of $J^{\circ}(\xi)$ and $J^1(\xi)$ given in the tables of Hansen and Meissel up to certain values of the argument ξ. But for higher values of ξ, we should have to calculate $J^{\circ}(\xi)$ and $J^1(\xi)$. Moreover, when n exceeds ξ, the value of $J^n(\xi)$ deduced successively from $J^{\circ}(\xi)$ and $J^1(\xi)$ becomes inaccurate, and we are thus compelled to undertake the calculation separately. These considerations make the formulae just given less convenient for calculation than the formulae given below.

As already mentioned, the form of the integral J shows that when the limits lie from o to π, it becomes equal to $\pi J^{\circ}(\xi)$. Thus J includes Bessel's function of the first kind with index 0 as a particular case. By a special transformation, J can be made to depend on $J^{\circ}(n\pi)$ as will now be shown.

Putting $u = \cos\varphi$, we have

$$J = -\int \frac{e^{i\xi u}}{\sqrt{1-u^2}}\, du.$$

Expanding $\dfrac{1}{\sqrt{1-u^2}}$ in a Fourier series,

$$\frac{1}{\sqrt{1-u^2}} = \frac{1}{2} + \sum_{1}^{\infty} J^{\circ}(n\pi)\cos n\pi u.$$

Multiplying this by $e^{i\xi u}$, and integrating

$$\int \frac{e^{i\xi u}}{\sqrt{1-u^2}}\, du = -\frac{i}{2}\left[\frac{e^{i\xi u}}{\xi} + \sum_{1}^{\infty} J^{\circ}(n\pi)\left(\frac{e^{i(\xi+n\pi)u}}{\xi+n\pi} + \frac{e^{i(\xi-n\pi)u}}{\xi-n\pi}\right)\right].$$

After a simple reduction, we have

$$\int \frac{e^{i\xi u}}{\sqrt{1-u^2}}\, du = -\frac{i}{2}\, e^{i\xi u}\left(\frac{1}{\xi} + 2\sum_{1}^{\infty} J^{\circ}(n\pi)\,\frac{\xi\cos n\pi u - i\,n\pi\sin n\pi u}{\xi^2 - n^2\pi^2}\right).$$

Equating the real and imaginary parts of both sides of the equation

$$(e) \qquad \int \frac{\cos(\xi u)}{\sqrt{1-u^2}}\, du = \frac{1}{2}\left[\frac{\sin\xi u}{\xi} + 2\xi\sin\xi u\sum_{1}^{\infty}\frac{J^{\circ}(n\pi)\cos(n\pi u)}{\xi^2 - n^2\pi^2}\right.$$

$$\left. - 2\pi\cos\xi u\sum_{1}^{\infty}\frac{n J^{\circ}(n\pi)\sin(n\pi u)}{\xi^2 - n^2\pi^2}\right],$$

$$(f)\qquad \int \frac{\sin(\xi u)}{\sqrt{1-u^2}}\,du = -\frac{1}{2}\left[\frac{\cos\xi u}{\xi} + 2\xi\cos(\xi u)\sum_1^\infty \frac{J^\circ(n\pi)\cos n\pi u}{\xi^2-n^2\pi^2}\right.$$

$$\left. + 2\pi\sin(\xi u)\sum_1^\infty \frac{n J^\circ(n\pi)\sin(n\pi u)}{\xi^2-n^2\pi^2}\right].$$

These two expressions (e) and (f) are equal to $-K$ and $-L$ respectively.

Thus K and L are made to depend on $J^\circ(n\pi)$, which can be calculated once for all; the rest involving simple arithmetical and trigonometrical calculations.

The expressions (e) and (f) above deduced for K and L require special consideration when ξ is a multiple of π, since both then contain terms of the form $\frac{0}{0}$.

Let us suppose that $\xi = m\pi - \gamma$. Then the expressions for K and L assume following forms.

$$K = -\frac{1}{2}\left[\frac{\sin\xi u}{\xi} + 2\xi\sin\xi u\sum_1^{m-1}\frac{J^\circ(n\pi)\cos(n\pi u)}{\xi^2-n^2\pi^2} + 2\xi\sin\xi u\sum_{m+1}^\infty\frac{J^\circ(n\pi)\cos(n\pi u)}{\xi^2-n^2\pi^2}\right.$$

$$- 2\pi\cos\xi u\sum_1^{m-1}\frac{nJ^\circ(n\pi)\sin(n\pi u)}{\xi^2-n^2\pi^2} - 2\pi\cos(\xi u)\sum_{m+1}^\infty\frac{nJ^\circ(n\pi)\sin(n\pi u)}{\xi^2-n^2\pi^2}$$

$$\left. + 2K'J^\circ(m\pi)\right],$$

where

$$K' = Lt_{\xi=\gamma}\frac{\xi\sin(\xi u)\cos(\gamma u) - \gamma\cos(\xi u)\sin(\gamma u)}{\xi^2-\gamma^2}.$$

$$L = -\frac{1}{2}\left[\frac{\cos\xi u}{\xi} + 2\xi\cos\xi u\sum_1^{m-1}\frac{J^\circ(n\pi)\cos(n\pi u)}{\xi^2-n^2\pi^2} + 2\xi\cos\xi u\sum_{m+1}^\infty\frac{J^\circ(n\pi)\cos n\pi u}{\xi^2-n^2\pi^2}\right.$$

$$+ 2\pi\sin(\xi u)\sum_1^{m-1}\frac{J^\circ(n\pi)\sin(n\pi u)}{\xi^2-n^2\pi^2} + 2\pi\sin(n\pi u)\sum_{m+1}^\infty\frac{J^\circ(n\pi)\sin n\pi u}{\xi^2-n^2\pi^2}$$

$$\left. + 2L'J^\circ(m\pi)\right],$$

where

$$L' = Lt_{\xi=\gamma} \frac{\xi cos(\xi u_2) cos(\gamma u_2) + \gamma sin(\xi u_2) sin(\gamma u_2) - \xi cos(\xi u_1) cos(\gamma u_1) - \gamma sin(\xi u_1) sin(\gamma u_1)}{\xi^2 - \gamma^2}$$

u_1, u_2 denoting the limits of integration with respect to u.

Evaluating these two indeterminate forms K' and L', we find

$$K' = \frac{2\gamma u + sin(2\gamma u)}{4\gamma},$$

$$L' = -\frac{sin\,\gamma(u_1 + u_2)\,sin\,\gamma(u_2 - u_1)}{2}.$$

Thus the expressions above deduced can be employed for calculating K and L for all values of ξ.

I may here remark, though it has nothing to do with the question of diffraction, that a more general integral of the form

$$\int d\varphi\, e^{i\xi\cos\varphi} sin^{2\nu}\varphi,$$

the limits lying between π and $-\pi$ can be made to depend on $J^\nu(n\pi)$, by exactly the same process as above given. In fact, Bessel's function of the first kind with index ν can be expressed by means of the following formula

$$J^\nu(\xi) = \xi^\nu \left(\frac{1.3.5....(2\nu-1)}{2.4.6......2\nu} \frac{\sqrt{\pi}}{2^\nu \Gamma(\nu+\frac{1}{2})} \frac{sin\,\xi}{\xi} + \frac{2\xi\, sin\,\xi}{\pi^\nu} \sum_1^\infty (-1)^{n+1} \frac{J^\nu(n\pi)}{n^\nu(n^2\pi^2 - \xi^2)} \right)$$

For convenience of calculation, the following values of $J^\circ(n\pi)$, for successive values of n, have been calculated and tabulated.

n	$J^\circ(n\pi)$	$log\ J^\circ(n\pi)$	n	$J^\circ(n\pi)$	$log\ J^\circ(n\pi)$
1	−0.304242	(−) $\bar{1}$.483219	26	+0.062329	(+) $\bar{2}$.794694
2	+0.220277	(+) $\bar{1}$.342969	27	−0.061168	(−) $\bar{2}$.786523
3	−0.181212	(−) $\bar{1}$.258186	28	+0.060069	(+) $\bar{2}$.778650
4	+0.157597	(+) $\bar{1}$.197300	29	−0.059027	(−) $\bar{2}$.771051
5	−0.141182	(−) $\bar{1}$.149779	30	+0.058038	(+) $\bar{2}$.763710
6	+0.129064	(+) $\bar{1}$.110804	31	−0.057096	(−) $\bar{2}$.756608
7	−0.119609	(−) $\bar{1}$.077765	32	+0.056199	(+) $\bar{2}$.749732
8	+0.111968	(+) $\bar{1}$.049093	33	−0.055343	(−) $\bar{2}$.743066
9	−0.105625	(−) $\bar{1}$.023768	34	+0.054525	(+) $\bar{2}$.736599
10	+0.100251	(+) $\bar{1}$.001089	35	−0.053743	(−) $\bar{2}$.730320
11	−0.095621	(−) $\bar{2}$.980555	36	+0.052993	(+) $\bar{2}$.724216
12	+0.091579	(+) $\bar{2}$.961796	37	−0.052273	(−) $\bar{2}$.718280
13	−0.088010	(−) $\bar{2}$.944530	38	+0.051582	(+) $\bar{2}$.712501
14	+0.034827	(+) $\bar{2}$.928535	39	−0.050918	(−) $\bar{2}$.706872
15	−0.081967	(−) $\bar{2}$.913638	40	+0.050279	(+) $\bar{2}$.701386
16	+0.079378	(+) $\bar{2}$.899697	41	−0.049653	(−) $\bar{2}$.696035
17	−0.077019	(−) $\bar{2}$.886597	42	+0.049070	(+) $\bar{2}$.690812
18	+0.074859	(+) $\bar{2}$.874213	43	−0.048497	(−) $\bar{2}$.685712
19	−0.072871	(−) $\bar{2}$.862554	44	+0.047944	(+) $\bar{2}$ 680729
20	+0.071033	(+) $\bar{2}$.851462	45	−0.047409	(−) $\bar{2}$.675858
21	−0.069328	(−) $\bar{2}$.840910	46	+0.046892	(+) $\bar{2}$.671094
22	+0.067740	(+) $\bar{2}$.830816	47	−0.046391	(−) $\bar{2}$.666432
23	−0.066257	(−) $\bar{2}$.821228	48	+0.045906	(+) $\bar{2}$.661868
24	+0.064863	(+) $\bar{2}$.812017	49	−0.045436	(−) $\bar{2}$.657398
25	−0.063560	(−) $\bar{2}$.803183	50	+0.044980	(+) $\bar{2}$.653018

Returning to our problem on Fraunhofer's diffraction phenomena, we get for the expression of the intensity

$$I = 4\,a^2 \frac{sin^2\, lb}{l^2} (K^2 + L^2)$$

With a homogeneous source of light, the intensity always vanishes whenever $l\,b$ is a multiple of π. The fringes arising from the term $sin^2\, l\,b$ are exactly the same as those given by the plane slit. When the surface on which the slit is cut is cylindrical, the additional factor $K^2 + L^2$ enters into the expression for the intensity of the diffracted light. This factor has maxima and minima for different positions of the telescope, and moreover depends on the length of the slit. Thus, when the limits of integration lie from 0 to π, $K = \pi\, J^{\circ}(\xi)$ and $L = 0$, and there would be places of darkness for such positions of the telescope as are determined by the values of ξ corresponding to the roots of $J^{\circ}(\xi)$.

For a great number of equidistant slits, the expression for the intensity would be the same as that for ordinary grating, multiplied by the factor $K^2 + L^2$.

The case which calls for special attention is when the ray is normally incident, and the telescope turned so as always to lie in the plane xy. Then $\varkappa = 0$, $\mu = 0$, $\nu = 1$, and $\mu' = 0$. Thus $l = \frac{2\pi}{\lambda} sin\, \omega$, where ω is the angle made by the axis of the telescope with z axis. The places of darkness are given by

$$sin\, \omega = \frac{n}{2} \cdot \frac{\lambda}{b}$$

The maxima and minima arising from the term $K^2 + L^2$ must be separately determined for the particular slit in question.

Fresnel's Diffraction Phenomena produced by a Slit on a Cylindrical Surface.

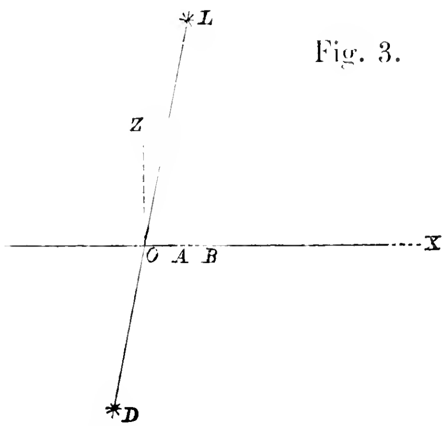


Fig. 3.

Let $A\ B$ be a section of the slit, cut by a plane passing through the source of light L, and the point D at which the illumination is required. I shall suppose that the point D is not very far from the line joining any point on the slit with the source of light. Also, the problem will be still further simplified if the plane $L\ A\ B$ is made to contain the axis of the cylinder.

For calculating the intensity of the diffracted light, assume the point O where $L\ D$ meets the cylindrical surface as the origin of coordinates. Let the x axis be parallel to the axis of the cylinder, and y perpendicular to the plane $L\ A\ B$.

In this case, $\qquad \varkappa = \cos LOA = \vartheta,$

where ϑ is very small,

$$\mu = 0, \qquad \text{and} \qquad \nu = 1 \quad \text{nearly.}$$

Thus

$$(\varkappa x + \mu y + \nu z)^2 = 2\,\vartheta\,x\,z + z^2$$

neglecting ϑ^2 upwards.

Recurring to formula (11),

$$\varDelta R + \varDelta R' = \left[2\,\vartheta\,x\,z - (x^2 + y^2)\right]\left(\frac{1}{2\,R} + \frac{1}{2\,R'}\right).$$

Therefore, by formula (II').

$$(1) \qquad I = Mod.^2 \, a \int d\sigma \, e^{i\frac{\pi}{\lambda}\left[2\vartheta x z - (x^2 + y^2)\right]\left(\frac{1}{R} + \frac{1}{R'}\right)}.$$

Since ϑ, x, and z are all very small, we can write

$$e^{i\frac{\pi}{\lambda}\left(\frac{1}{R} + \frac{1}{R'}\right)2\vartheta x z} = 1 + i\, 2\, \vartheta\, \xi\, x\, z$$

where ξ stands for $\frac{\pi}{\lambda}\left(\frac{1}{R} + \frac{1}{R'}\right)$.

Taking polar coordinates in the right circular section of the cylinder with the pole on the axis, we may write

$$d\sigma = a\, dx\, d\varphi,$$

$$y = a \sin\varphi, \qquad z = a\,(1 - \cos\varphi).$$

Introducing these expressions in (1), we get for the intensity of the diffracted ray

$$(2) \qquad I = Mod.^2 \, a \iint dx\, d\varphi\, e^{i\xi(x^2 + a^2 \sin^2\varphi)}\left[1 + i\, 2\, a\, \vartheta\, \xi\, x\,(1 - \cos\varphi)\right]$$

In integrating the above expression with respect to x, we must distinguish two cases according as D lies within or without the geometrical shadow.

Let $OA = \beta$, and $AB = b$; then the integration with respect to x must extend, when D lies within the geometrical shadow, from

$$\beta \quad \text{to} \quad \beta + b.$$

When D is outside the geometrical shadow, the limits of integration must be from

$$-\beta \quad \text{to} \quad b - \beta.$$

The integration with respect to φ must extend over the whole length of the slit.

I shall first perform the integration with respect to φ.
We can write

$$\int e^{i\,\xi\,a^2\,sin^2\,\varphi}d\varphi = \int e^{i\frac{\xi a^2}{2}(1-cos\,2\,\varphi)}d\,\varphi = \frac{1}{2}\,e^{i\frac{\xi a^2}{2}}\int e^{-i\frac{\xi a^2}{2}cos\,2\,\varphi}\,d\,(2\,\varphi).$$

The integral thus obtained corresponds to J, which was already investigated in connection with Fraunhofer's diffraction phenomena. I shall, therefore, write for simplicity

$$(3) \qquad \int e^{i\,\xi\,a^2\,sin^2\,\varphi}\,d\varphi = K + i\,L.$$

Again

$$\int e^{i\,\xi\,a^2\,sin^2\,\varphi}\,cos\,\varphi\,d\varphi = \frac{1}{a\sqrt{\xi}}\Big[\int cos\,(a\sqrt{\xi}\,sin\,\varphi)^2\,d\,(a\sqrt{\xi}\,sin\,\varphi)$$

$$+\,i\int sin\,(a\sqrt{\xi}\,sin\,\varphi)^2\,d\,(a\sqrt{\xi}\,sin\,\varphi)\Big].$$

But $\int_{sin}^{cos}(a\sqrt{\xi}\,sin\,\varphi)^2 d\,(a\sqrt{\xi}\,sin\,\varphi)$ are derivable in terms of Fresnel's integrals, for which the series obtained by Knochenhauer, Gilbert, Cauchy, or Lommel can be used for calculation. I shall, therefore, put

$$(4) \qquad \int e^{i\,\xi\,a^2\,sin^2\,\varphi}\,cos\,\varphi\,d\varphi = \Gamma + i\,\Sigma$$

Next performing the integration with respect to x, we have to find

$$\int e^{i\,\xi\,x^2}\,dx \text{ and } \int e^{i\,\xi\,x^2}\,x\,dx.$$

The first is an ordinary Fresnel integral; and can, therfore, be written

$$(5) \qquad \int e^{i\,\xi\,x^2}\,dx = C + i\,S,$$

where

$$C = \frac{1}{\sqrt{\xi}} \int cos\,(\sqrt{\xi}\,x)^2\, d\,(\sqrt{\xi}\,x), \quad S = \frac{1}{\sqrt{\xi}} \int sin\,(\sqrt{\xi}\,x)^2\, d\,(\sqrt{\xi}\,x).$$

The second integral is integrable ; thus,

$$(6) \qquad \int e^{i\,\xi\,x^2}\, x\, d\, x = \frac{1}{2\,\xi}\, e^{i\,\xi\,x^2},$$

$$= \gamma + i\,\sigma.$$

Introducing the expressions (3) (4) (5) (6) in (2), we find for the intensity,

$$I = Mod^2\, a \Big[(C + i\,S)(K + i\,L) + i\,2\,a\,\theta\,\xi\,(\gamma + i\,\sigma) \Big\{ (K + i\,L) - (\Gamma + i\,\Sigma) \Big\} \Big].$$

In finding $Mod.^2$, we can neglect the terms involving θ^2.

Thus, we get for the expression of the intensity

$$(7) \quad I = a^2 \Big[(C^2 + S^2)(K^2 + L^2) + 4\,a\,\theta\,\xi \Big\{ C\,(P\,\gamma - Q\,\sigma) + S\,(Q\,\gamma + P\,\sigma) \Big\} \Big].$$

where

$$P = K\,\Sigma - L\,\Gamma.$$

$$Q = K\,(K - \Gamma) + L\,(L - \Sigma).$$

The expression for the intensity of light diffracted by a slit on a circular cylinder differs from that for the plane slit by the introduction of the factor $K^2 + L^2$, and a small additional term multiplied by θ. Both K and L remain constant provided the distances of the slit from the source of light and the point at which the intensity is required do not change. If we observe the fringes in a plane parallel to the axis of the cylinder, K and L will remain sensibly constant. Neglecting the term multiplied by θ, the positions of maxima and minima will be the same as those produced by plane slit of the same breadth.

If the observer approaches or recedes from the slit, the intensity of light at a point directly opposite the slit will differ from that of the plane slit, for the intensity is affected by the factor $K^2 + L^2$, which is no longer constant.

Observation shews that the small additional term is of very small effect. Calculating the minima of C^2+S^2 by means of Knochenhauer's series, I find that the agreement of calculation with observation is quite close, except when the point considered lies outside the geometrical shadow.

In order to test the result of calculation with observation, the following experiments were made with a slit of 90° aperture, cut on a right circular cylinder of 5.0 mm. radius. Sunlight was admitted into a darkened room. After passing through a small vertical slit. and a lens, it was analysed by a prism. The spectrum thus formed was projected on the slit of a spectrometer. The slit, however, was closed by thick paper, and only a small hole was pierced, through which light was passed to the slit under examination. The spectrum was so distinctly formed, that one could easily make the light corresponding to any one of the principal Fraunhofer's line illuminate the slit. The following observations were made for the positions of zero intensity of the fringes formed by the slit.

Width of the slit $2b = 0.5745$ mm.
Wave length of light $\lambda = 0.0004861$ mm.

	Observed Angle of Deviation.	Calculated Angle of Deviation.	Obs.—Calc.
	″	″	″
1st Min.	94.3	93.3	+ 1.0
2nd „	191.9	186.6	+ 5.3
3rd „	283.6	279.9	+ 3.4
4th „	377.8	373.2	+ 4.6
5th „	473.8	466.6	+ 7.2
6th „	566.9	559.8	+ 7.1
7th „	652.7	653.1	− 0.4

In observing Fresnel's diffraction phenomena, the optical bench was used. The intervals between the fringes were measured by means of a micrometer. The following table gives the observed numbers.

$R_c = 324.0$, $R'_c = 285.4$ mm.
$2b = 0.347$; $\lambda = 0.000486$ mm.

	Obs. Distance.	Calcul. Distance.	Obs.—Calc.
1st Min.	1.43 mm.	1.60 mm.	−0.17
2nd ,,	3.18	3.19	−0.01
3rd ,,	4.76	4.80	−0.04
4th ,,	6.39	6.40	−0.01
5th ,,	8.03	8.00	+0.03
6th ,,	9.58	9.59	−0.01
7th ,,	11.22	11.19	+0.03
8th ,,	12.81	12.79	+0.02
9th ,,	14.45	14.39	+0.06
10th ,,	16.06	15.99	+0.07
11th ,,	17.61	17.59	+0.02
12th ,,	19.24	19.19	+0.05

Effect of Magnetization on the Permanent Twist of Nickel Wire.

by

H. Nagaoka.

Pl. XXXVIII.

Professor Wiedemann, in a course of experiments on the mutual relation between torsion and magnetization, found that there was a reciprocal relation between the two. He found that whereas torsion changed the magnetization of iron, magnetization, on the other hand, changed the torsion. To establish the relation between the two, he made a series of experiments, which seemed to indicate many other intimate relations between the two. Experiments relating to the change of twist by longitudinal magnetization have been, so far as I am aware, tried only with iron and steel wires. The curious effect of torsion on the magnetization of nickel has induced me to try experiments in the same line, and find if there also exist similar reciprocal relations between magnetization and torsion in nickel wires. Want of apparatus did not allow me to try experiments on the effect of magnetization on nickel wires under different conditions of twist. The present paper is confined only to the discussion of the effect of magnetization on the permanent twist of nickel wires.

The apparatus used for twisting the wire and measuring the effect due to magnetization was essentially different from that of Professor Wiedemann. I employed an arrangement made on the same plan as that used by Professor F. Kohlrausch* in his experiments on the torsional elastic after-effect of wires. Fig. 1 shows the front view

* Pogg. Ann. 128.

of the apparatus. On a firm stand furnished with three levelling screws (*lll*), two stout pillars (*pp*) were erected. A cross bar of wood (*bb*) was fixed to these pillars. At the middle point of the cross piece, a torsion circle (*t*) was attached, with an arrangement for fixing the wire. Below this stood a magnetizing coil (*c*) on an auxiliary stand. To keep the wire twisted, two stout rods (*rr*) were raised vertically from a thick brass plate of circular shape, which was screwed to the stand (*s*). These rods were fastened to alidades, which were movable

Fig. 1.

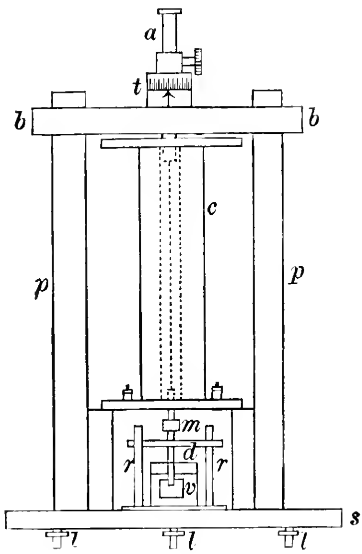


Fig. 2.

about an axis at the centre of the plate. Thus the rods could be fixed in any desired position, and made to catch the cross attached to the lower end of the wire. The cross was made of two rods at right angles to each other. The vertical rod had an arrangement for holding a small plane mirror (*m*). The horizontal rod was capable of sliding in the vertical, and could be clamped firmly to it by means of a screw. A vane (*v*) was attached to the lower end of the vertical rod. It dipped into a vessel filled with water, which served to stop the torsional oscillation of the wire, when the twist was released. The torsion circle had a stout rod (*a*) for vertical axis. This was capable of up and down motion by means of ratch work, and could be clamped by a screw. The lower end of the axis was cut, and made to bite the upper extremity of the wire. The wire is shown in Fig. 2. Two small pieces of thick brass plate were attached to the extremities of the wire. The upper end was placed between the terminal cleft of the axis, and clamped by a screwing nut, while the lower end was similarly caught at the upper end of the cross, and fixed by a screw which went through a hole in the plate, as shown in the figure.

In front of the mirror was placed a circular scale divided into half millimetres. The radius was 85.8 cm., so that one scale division corresponded, when seen by reflection, to one minute of arc. The scale was illuminated by gas jets, and the reflected image was observed by means of a telescope.

The magnetizing coil was 30 cms. long, and gave a field of 36.7 C. G. S. units by passage of a current of one ampere. In addition to the magnetizing coil, a small coil was inserted within the solenoid. Through this coil, a steady current was maintained to compensate the vertical component of the terrestrial magnetic force. The magnetizing current was generally obtained from Bunsen cells, and made to vary continuously by placing a liquid slide in the circuit. It was measured by a Thomson graded galvanometer. The different parts of the apparatus being as described above, the experiment was conducted in the following manner.

A carefully annealed nickel wire was fixed within the solenoid, its upper end being screwed to the axis of the torsion circle, and its lower end to the cross as before mentioned. While the wire was being set in position, the magnetizing force was zero within the solenoid, the vertical component of the terrestrial magnetic field being neutralised by a current in the small coil placed within the main coil. The reading of the torsion circle was then taken, and the two vertical rods (*rr*) were so placed, that they just touched the horizontal rod (*d*) of the cross on its opposite sides. The wire was now twisted by turning the torsion circle, and held in the twisted condition for some time. The reading of the scale was noted. The circle was then turned in the opposite direction so as to make the cross free of the vertical rods. When the residual twist was small, the torsion circle was brought back completely to its original position, and the small amount of residual twist was given by the difference in the initial and final scale readings. For large residual twists, however, turning the torsion circle back to its original position would have thrown the reflected beam off the scale. Accordingly the torsion circle was turned back through a convenient and known angle, so that the wire hung free, and the reflected beam remained on the scale.

In the preliminary course of experiments, after the wire was freed from torsional oscillations, the elastic after-effect was measured by simultaneously noting the successive scale readings and the corresponding times after the release. When the untwisting due to the after-effect had become very slow, the magnetizing force was applied, and the corresponding scale readings noted.

Before entering into the investigation of the effect of magnetization on the permanent twist, it was desirable to have some knowledge of the torsional after-effect of nickel. In every experiment, the wire was twisted and left for some time in this state. On releasing the torsion, torsional oscillations ensued. After its cessation, the wire continued gradually to untwist in virtue of the elastic after-effect. It was then necessary to know when the untwisting due to the after effect should cease, for otherwise the untwistings due to magnetization and to the elastic after-effect would be mixed together.

As a general rule, the after-effect for the same angle of twist is smaller as the wire becomes thicker. For this reason, Professor Wiedemann used tolerably thick iron wires. Although much certainty is gained as to the effect due to magnetization only by using thick wires, yet there is the great disadvantage that the amount of untwisting is very small. With nickel wires, the elastic after-effect is very small, and we can use thin wires without incurring the risk of mixing the effect due to magnetization and that due to elastic after-effect.

A nickel wire 0.51 mm. thick and 27 cms. long was kept twisted through 60° for an hour, the longitudinal pull acting on the wire being the weight of the cross before mentioned. When released from torsion, the wire had a permanent twist of 2° 38′. On the cessation of the torsional oscillations, the following deflections with simultaneous readings of the chronometer were taken.

Time		Torsion	
3h 19m.0	p. m. (11th April 1889)	2° 38′.0	
20.5	,,	37′.6	(Temperature)
22.0	,,	37′.4	9°.5
24.0	,,	37′.2	
36.0	,,	37′.0	
7h 42.0	a. m. (12th)	36′.2	(9°.2)

The readings show that the after-effect in nickel is very small. The wire above tested would have been untwisted through a few minutes more, if we had waited for some weeks or months. Loading the wire, however, increases the after-effect, but when compared with the after-effect in iron under similar circumstances, it is very small. It is unnecessary to give the result of numerous similar experiments. Suffice to say, they all lead to the same conclusion. The precautions which must be taken in discriminating the untwistings due to magnetization and to after-effect in nickel is greatly lessened as compared with the precautions necessary in the case of iron. If sufficient care be taken to wait till the after-effect becomes very small, we may use thin nickel wires in the investigation of the effect of magnetization on torsion. Generally I waited an hour after the cessation of torsional oscillation, but if the wire was loaded, it was left for a night.

The thicknesses of the wires used in the present investigation varied from 0.34 to 0.72 mm. Most of the experiments were tried with the thinnest, for with it the effects were greatest. The wire was always carefully annealed by means of a Bunsen flame. It so happened, that when the twist was very large, the wire once used assumed a spiral aspect as was observed by Himstedt.* Such wires were rejected, and other wires cut from the same specimen were used instead.

The experiment was first tried with the wires above mentioned, when the permanent twist was very small, and the wire was subjected to weak longitudinal stress. The following gives the readings of untwisting due to magnetization when the load was the weight of the cross only.

* Wied. Ann. 17. pg. 712.

$r = 0.17$ Perm. Twist = 1°.6		$r = 0.24$ Perm. Twist = 7°.2		$r = 0.35$ Perm. Twist = 3°.3	
$\mathfrak{H}$	τ	$\mathfrak{H}$	τ	$\mathfrak{H}$	τ
7.1	9′.3	6.0	4′.7	4.4	2′.9
9.8	17′.1	10.3	12′.3	6.3	5′.8
13.2	25′.6	13.2	16′.4	8.2	9′.1
15.9	30′.0	16.7	20′.6	10.3	12′.4
20.7	37′.3	24.1	25′.9	13.4	15′.9
25.2	43′.0	35.4	29′.8	16.0	18′.1
31.3	48′.0	42.2	31′.3	18.5	19′.5
40.7	52′.6	54.1	32′.9	25.8	23′.0
52.0	55′.5	67.2	34′.0	38.4	26′.7
65.0	57′.6	157.8	34′.6	53.2	28′.1
82.9	59′.1	...	...	66.7	28′.8
112.7	60′.1	...	...	103.0	29′.7
184.3	60′.7	...	...	184.3	29′.9

The above table shows how the untwisting proceeds as the strength of the field is increased. With the increase of the magnetizing force, untwisting becomes greater and greater, until at a certain point, the ratio of the untwisting to the corresponding magnetizing force reaches a maximum; in other words, the curve of untwisting has a wendepunkt. After this, the untwisting takes place very slowly, so that ultimately the curve (Fig. I, Pl. XXXVIII) becomes almost straight. Up to $\mathfrak{H}=180$, the curve does not reach a maximum.

In comparing the curves obtained with different wires, we easily see that the untwisting is greater for the thinner wire. For it will be noticed in the experiments first given that the permanent twist is greater for the thicker wire. Nevertheless, even with such handicapping, it is the thinner wire which has the greater untwisting as shown at a glance on the curves.

If after the magnetizing field has attained a certain value, it be gradually decreased, the wire again twists back. The twisting produced by the removal of the magnetizing force is, however, far smaller than the untwisting produced by the increase of the magnetizing force. Consequently, the return curve goes above the other, as is shown by the dotted line in curve (1) Fig. 1. This fact can be briefly expressed by saying that there is magnetic after-effect in the twisting which becomes conspicuous by the removal of the magnetizing force. So long as the amount of permanent twist remains very small, the curve showing the torsional effect of a continuously changing magnetic force resembles the ordinary curve of magnetic hysteresis.

The above remark does not hold when the permanent twist exceeds a certain limit. The decrease of twist with increase of magnetization soon reaches a maximum. After this, the wire begins to twist in spite of the increase of magnetizing force. The amount of twisting of course varies with the permanent set of the wire as well as with the amount of pulling stress. The following table gives the amount of change of twist with the wire of 0.17 mm. radius.

Perm. Twist 6°.7		Perm. Twist 10°.6		Perm. Twist 861°	
$\mathfrak{H}$	τ	$\mathfrak{H}$	τ	$\mathfrak{H}$	τ
4.7	11′.5	2.7	7′.0	6.7	26′.5
7.0	18′.2	5.9	15′.8	10.0	38′.6
10.0	24′.7	8.8	19′.6	12.3	45′.5
13.3	26′.8	12.8	23′.0	15.1	52′.0
17.0	26′.9	17.1	25′.8	17.7	54′.9
18.2	26′.9	20.5	26′.8	23.1	61′.0
27.9	26′.2	32.0	28′.1	31.6	64′.2
42.2	25′.1	47.0	26′.9	50.1	60′.9
62.3	24′.7	72.6	22′.0	62.8	56′.1
125	24′.2	124	11′.5	88	46′.2
...	...	...	...	157	19′.0

These readings are plotted in curves (1) (2) (3) Fig. 2. respectively. Curve (4) is plotted from an experiment made with a wire of the same thickness, with a permanent twist of 1621°. These curves show that the untwisting on the first application of the magnetizing force is very large. When the twist is small the untwisting immediately becomes very small, and the wire begins to twist. But the further increase of the magnetizing force is of very little effect. The curve, shortly after the maximum is attained, becomes nearly parallel to the line of no twisting.

This appearance is confined to those cases where the permanent twist is small. With a residual torsion of 10°.6 in the same wire, the curve acquires quite a different appearance. The rate of increase of untwisting with the increase of magnetizing force becomes less, so that the untwisting gradually approaches the maximum. Thereafter the twisting takes place gradually and steadily. On removing the magnetizing force, there is at first untwisting which reaches a maximum in a magnetizing field less than that corresponding to the maximum untwisting on the first application of the magnetizing force. The wire then again begins to twist, but on the complete removal of the magnetizing force, the wire remains untwisted relatively to its first position. The most striking difference between the curves in Fig. 1 and those of Fig. 2 is that the latter has a maximum point and the former has none. This maximum which seems to be closely connected with the amount of residual torsion occurs in weak magnetizing fields when the twist is small, but as the twist is increased, it occurs in stronger fields.

When the permanent twist is very large, the features of the curve do not change essentially. Curves (3) (4) Fig. 2. show the state of things for the twists of 861° and 1621° respectively. From these it will be seen that the untwisting does not increase proportionally with the permanent twist. On the contrary, the untwisting for the twist of 861° is greater than that for the twist of 1621°. The course of the curve, after passing the maximum becomes steeper with the larger permanent twist as the comparison of (1) (2) with (3) (4) will show. Thus, when the twist is large, and the magnetizing force sufficiently great, the curve may be expected to cut the line of no twisting.

Another difference in the curves of torsion obtained for different permanent twists consists in the course of the curve on the removal of the magnetizing force. In curve (2), we find that the "off" returns below the "on" curve, while in curve (3), it returns above it. In the former there is hysteresis or lagging, in the latter priming or negative hysteresis. This distinctive feature in the curves obtained for different twists also varies with the thickness of the wire.

It is unnecessary to give numerical details for the various experiments made with different wires and with different twists. The characteristics above described are illustrated in the curves of Fig. 3, which gives the results for nickel wires of diameters 0.5, 0.4, 0.7 mm. For these also the untwisting reaches a maximum for a comparatively low field, and a *twisting* begins to set in, and continues to the highest field used.

The following experiment shows that this twisting may proceed so far as to result in a final condition of *twistedness relatively to the original condition of the wire.* The wire, 0.34 mm. thick and 30 cms. long was twisted through eight complete revolutions of the torsion circle, and then released. It thus acquired a permanent twist of 2548°. The magnetizing current was derived from a shunt dynamo. The current strength was adjusted by the liquid slide before described.

Field.	Untwisting.
14.3	+20′.0
36.6	49′.0
68.0	53′.0
89.4	51′.0
152.0	34′.0
200	24′.0
245	12′.3
303	+ 6′.0
361	− 4′.0
432	−10′.0

The application of the magnetizing force showed at first an untwisting, which reached a maximum in a field strength of about 65 C. G. S. units. The wire then began to twist. In a field of about 335 units, it came back to the condition in which it was after release before the magnetizing force was applied. Thereafter the wire continued steadily to twist with the increase of magnetizing force, so that when $\mathfrak{H}=432$, the wire became twisted 10′ from its initial position of equilibrium. Thus a nickel wire with large permanent twist can be twisted by applying sufficiently great magnetizing force. As the course of the curve after passing the maximum is less steep in thick than in thin wires, still stronger magnetizing fields will be necessary to twist the former.

The next set of experiments has to do with nickel wires under longitudinal stress. The only change in the process of experimenting consisted in loading the wire. The vane was detached from the lower end of the cross and a short hook placed in its stead. A pan of weights hung from this hook, and was completely immersed in the water.

Different experiments were tried with wires of various thicknesses, and with different amounts of twist. Some of the results are shown plotted in Figs. (5) and (6). In all of these the untwisting by magnetization becomes greater by loading. When the permanent twist is small, the curve representing change of torsion reaches a maximum quite abruptly. The course of the curve immediately after passing the maximum is quite steep for some time, but after the magnetizing force attains a certain value, the return twist becomes very small. Moreover, there is hysteresis on the gradual removal of the magnetizing force. An inspection of the figures will be of more service than mere verbal description.

With large twists, the features of the curve of torsion do not greatly differ from those obtained with the unloaded wire. The chief change wrought by the loading is that after the maximum untwisting has been passed, the curve goes down more steeply than in the case when there is no load. This evidently suggests the possibility that the curve for the loaded wire will cut the line of no untwisting in magnetizing fields smaller than those needed to effect the same for unloaded wires. And this I found to be the case, as shown by the readings on the following page, which were made on a wire of 0.17 mm. diameter under a load of 342 grm. weight.

The former readings are shown plotted in curve (2) Fig. 4, and the first part of the latter in (4) Fig. 6, and the readings in strong fields in curve (3) Fig. 4. The comparison of these two curves with (1) shows that with the loaded wire the initial position is reached at smaller magnetizing fields than with the unloaded wire. Moreover, there is hysteresis when the permanent twist is moderate, but priming when the twist becomes large.

Finally the effect of transverse magnetization on the permanent twist was investigated. The wire being treated as before described,

Perm. Twist 95°.		Perm. Twist 583°.	
Field	Untwisting	Field	Untwisting
5.8	16′.1	6.1	8′.0
10.8	26′.2	7.5	15′.0
14.6	32′.7	10.9	23′.5
19.4	36′.8	14.1	33′.0
24.6	41′.0	17.4	39′.4
28.6	42′.6	24.5	53′.6
33.5	42′.8	39.4	73′.0
38.8	41′.6	50.3	76′.2
44.1	40′.0	54.4	77′.2
52.2	36′.4	66.7	76′.0
61.5	32′.0	85.6	69′.5
72.6	27′.0	98.6	62′.0
98.1	16′.9	164.2	25′.0
125.7	9′.5	191.9	17′.0
182.1	−1′.3	271	− 4′.0
...	...	328	−12′.2

was placed between two flat coils, through which magnetizing currents of various strength were passed. The wire, however, did not show the least sign of being affected by transverse magnetization, although the apparatus was capable of measuring 0′.1 of deflection.

The next point of inquiry was a comparison of these effects with those produced by twisting magnetized nickel wires. The apparatus used for examining the latter was similar to that used by Professor Wiedemann, in his investigation on the effect of twist on magnetization, and described in his 'Elektricität' Bd. 3. A nickel wire 1 mm. thick and 30 cm. long had two pieces of stout brass wire soldered at the ends. The wire was placed magnetic east and west, and carefully annealed in this position. It was then slid into a magnetizing coil, and its extremities firmly clamped to the twisting apparatus. The magnetizing current was gradually increased by means of the liquid slide, and then slowly removed. Thereupon the deflection of the magnetometer mirror with corresponding angle of twist was read. The following table gives the changes produced on the permanent magnetism in arbitrary scale unit, the amount of permanent magnetism being proportional to the number of scale divisions when the twist is zero.

Twist	(I)	(II)	(III)	(IV)	(V)
0	589	455	183	83	41
5°	549	410	161	74	27
10°	550	385	159	78	20
15°	554	378	173	88	19
20°	558	384	194	102	24
25°	560	393	212	119	33
30°	559	402	224	131	40
35°	554	405	233	141	47
40°	551	405	238	149	52
45°	...	404	238	153	...
50°	540	403	239	155	62
60°	529	397	237	158	68
70°	...	...	235	160	71
80°	...	...	...	160	...
90°	...	...	...	161	74
120°	...	...	...	160	75
180°	...	...	...	...	76
270°	...	...	...	...	74

The examination of the above table shows that the first effect of twist is always to decrease the magnetism of the wire. This decrease soon ceases, and an increase sets in as the twist becomes larger. When the permanent magnetism is large, the increase is small, and the original value of the magnetic moment is not recovered. On the other hand, for small values of permanent magnetism, the increase is considerable; and as the twisting continues the wire acquires a greater magnetic moment than it had originally. When the wire is further twisted, the magnetic moment reaches a maximum, and begins to decrease. The maximum comes earlier for greater values of permanent magnetism. The maximum increase in weakly magnetized wire occurs at tolerably large twists, as an examination of the above table will show. In addition to this, the range of change in permanent magnetism by twisting does not increase, but rather seems to diminish with the amount of permanent magnetism, for moderate angles of twist.

The experiments hitherto described show close relations between the effects produced by twisting the permanently magnetized wire, and those produced by magnetizing the permanently twisted wire. The relation between the two can be most clearly represented by collecting the results in the following parallel statements.

1 The permanent magnetism of nickel wire is at first diminished by twisting.	I. The permanent twist of nickel wire is at first diminished by magnetization.
2. With *large* permanent magnetism, the decrease increases with increased twist.	II. With *small* permanent twist, the untwisting increases with the strength of magnetization.
3. Unless the permanent magnetism is very *large*, the decrease produced by twisting reaches a maximum. Further twisting in-	III. Unless the permanent twist is very *small*, the untwisting produced by magnetization reaches a maximum. The twisting produced

creases the magnetism, so that it becomes greater than its original value.

by further increase of magnetization is so large, that the wire acquires greater twist than it originally had.

It appears from the readings given above for the changes in permanent magnetism, that there is a tendency to a decrease *again* setting in at the higher twists. This suggests that there may be untwisting in very strong fields, after the wire has been for some time twisting under the influence of magnetization. The current at my disposal did not allow me to try experiments with fields much over 400. Up to that limit, the twisting continued. It still remains undecided if further increase of magnetizing force gives a maximum twisting, corresponding to the maximum value of permanent magnetism obtained by twisting.

When the subject is viewed from the theory of rotating molecular magnets, we fall into difficulties which cannot be easily explained. Professor Wiedemann in coordinating the mutual relations between twist and magnetization of iron and steel wires, assumes that the molecules are subject to disturbances in trying to point their poles in the direction of magnetization. Drawing an analogy from the effect of mechanical disturbance applied to the twisted wire, he concludes that the disturbance caused by magnetization must untwist the iron or steel wires. This easily explains the effect of magnetization on the permanently twisted iron wire. It seems quite probable that a similar explanation can be applied to the untwisting observed in nickel wires. The effect of magnetization, however, is not so simple in nickel as in iron. It seems very difficult to explain the maximum untwisting observed in nickel. Moreover the disturbance caused in molecular groupings is not limited to longitudinal magnetization only. Transverse magnetization must likewise produce similar changes among the molecules. Thus the permanent twist would be affected by transversal as well as by longitudinal magnetization. In my experiments, transversal magnetization by flat coil had no sensible effect.

The change of permanent magnetism by twisting is more complex in nickel than in iron. If we have to explain the maximum decrease in permanent magnetism on Wiedemann's theory, we must assume that the nickel molecules rotate only through a certain angle by twisting, but beyond that angle, they move back towards the original position. This we have no right to assume. It seems hopeless to find any explanation of the various relations between twist and magnetization in terms of a really satisfactory theory of rotating molecules.

On Certain Thermoelectric Effects of Stress in Iron.

By

C. G. Knott, D. Sc., F.R.S.E.

Professor of Physics, Imperial University.

And

S. Kimura, *Rigakushi.*

Since the discovery made by Thomson that the thermoelectric properties of wires of certain metals were altered by tension, the subject has been studied experimentally by various scientific men. Of these we may mention more particularly Le Roux, von Tunzelman, Cohn, and Ewing. The work done by Cohn and Ewing is of special importance; and the latter's investigation for iron is the most complete that has been carried out. Reference will be made to their results hereafter. It is sufficient at present to point out one respect in which the work of these experimenters lacks completeness. In all, the method of experiment consisted in studying the effects of stress upon the thermoelectric properties of a wire, whose junctions with the other essential wire of the circuit were kept at steady temperatures. The variations of stress were, in the best experiments, carried through a cycle; and at different successive stages the thermoelectric current was measured on a suitable galvanometer. The observed changes in the electromotive force might be due to either of two quite different effects; and the experimental methods adopted could give no criterion by which to draw the correct conclusion. The nature of the problem is most simply expressed in terms of the language of the thermoelectric diagram. In this diagram the thermoelectric relations of the different metals are represented by lines (usually straight) in such a manner that the electromotive force existing in any circuit of two metals is equal to the area included between the appropriate metal lines and the two lines drawn perpendicular to the temperature axis and through the points representing the temperatures of the two junctions. The question propounded above is then this. What change does stress applied to a given metal produce upon the *position* of the line in the thermoelectric diagram? Does it translate it as a whole up or down; does it rotate it as a whole about some definite point; or does it effect a combination of these so that the line is deformed as well as shifted? In other words does stress change the Thomson Effect in a wire, or does it simply change the Peltier Effect with reference to an unaffected second wire?

Now it is quite clear that the only way to answer this problem is to arrange an apparatus in which the electromotive forces due to *different* differences of temperature can be measured *simultaneously* on a wire under given conditions of stress. This could be accomplished only by having the gradient of temperature along the wire both steady and gradual. Junctions could then be made at several points along the wire; and the electromotive forces due to the several circuits so obtainable could be easily measured and compared, once the temperatures were steady. The simplest way of realizing these conditions seemed to be to stretch the wire inside a metal tube, and then to heat the metal tube as in the Forbes Experiment on the conduction of heat along bars.

For ease in manipulation the tube, which was of iron, was made in two semi-cylindrical parts. The upper part or lid fitted accurately upon the lower part which rested horizontally on sharp edged supports. The lower part was somewhat longer than the upper part, the extra length being a solid cylindrical piece of iron which during the experiment was sustained at a bright red heat in a charcoal furnace. To render the fitting secure a ridge cut out longitudinally on each plane surface of the semi-cylindrical lid fitted into a groove cut out on the opposing surface of the lower part. At suitable intervals along this lower part small radial notches were cut. These became holes when the lid was set in position, and through them wires were led from the interior of the tube. The wire to be used was stretched along the axial line of the tube; and it and all the various junction wires were arranged and adjusted before the lid was laid in position. Each junction was a junction of three wires—(1) the axial wire to be tested, (2) a thin wire of the same material, (3) a thin wire of some other metal. The two last formed what we shall call the Thermometric Circuit. Its indications served to measure the temperature of the junction. The circuit, formed by the axial wire and the thin wire of the same material, was the essential element in the experiment. We shall call it the Thermoelectric Circuit.

The tension was applied by means of a screw at the extremity of the wire, which projected some distance from the open end of the tube; and was measured on a spring dynamometer set in line. To prevent currents of air circulating in the tube, the open cold end was plugged with cotton wool, and the side holes, through which the thin wires came, were filled up with asbestos. The hot end of the tube was closed naturally by the vertical face of the solid cylindrical portion already mentioned. The end of the wire was clamped to this face.

The current were measured on a high resistance double coiled galvanometer, which was carefully gauged after every single day's experiment.

The general plan of experimenting was simple enough. After the tube and contained wire had attained a steady condition as regards temperature, a series of readings of the different thermoelectric and thermometric currents were taken as rapidly as possible, with a sufficient number of repetitions of the same to yield a good mean for each individual circuit. This operation was carried through for a series of ascending and descending values of tension. The small value of the current in the thermoelectric circuit as compared with that in the thermometric required that only a small shunted portion of the latter should be taken through the galvanometer. This necessitated a somewhat complicated arrangement of resistances and commutators, which however it is unnecessary to describe.

In the earlier experiments the thermometric circuits were of copper and iron, and the thermoelectric of iron and iron. By using copper and iron, we expected to be able to get good measurements of the true temperature values of the junctions; and this because of the existence of a neutral point at an easily attainable temperature. It was found, however, that the uncertainties of reduction from the parabolic temperature scale of experiment to the linear scale of accepted use far outweighed the advantages of having an observed neutral point as a guide. Accordingly after many experiments had been made the Copper Iron thermometric junction was abandoned in favour of a German-silver Iron junction. As is well known, the electromotive force of this pair of metals varies in an approximately linear manner with temperature up to a dull red heat. The graphical comparison of the thermoelectric with the thermometric currents will not in this case differ greatly *in appearance* from what would be the case if an accurate absolute scale of temperature were used instead. Ultimately, of course, the thermometric readings were reduced to the ordinary temperature scale by calculation from the results of direct experiment.

It was determined to experiment first with iron wire. Previous workers had all found that the thermoelectric effects of stress were much more pronounced in this metal than in others. It seemed natural therefore to begin with it. Should the experiments prove promising, it was intended to pursue the enquiry in regard to copper, nickel, platinum, etc. A few experiments were indeed tried with copper and nickel wires; but in the latter its viscosity under the influence of sustained stress produced a gradual decay in the value of the stress, applied as it was by a tightened screw. It was obvious that a steady stress could be applied only by means of a load acting by its weight; and for this the apparatus was not readily adjustable.

Several modifications in the mode of experimenting were repeatedly tried before results of a satisfactory character were obtained. In certain experiments with the iron wire, thermoelectric changes of very small amount were obtained by simply varying the *tension* without having established the temperature gradient. This thermoelectric effect increased with the tension. The direction of the current was opposite to the direction of all the currents obtained when the gradient of temperature existed along the wire. In other words, the current was such as might have resulted from a slight heating of the wire where it was gripped by the dynamometer clamp. The probable explanation of this effect is that the part of the stretched wire which lay outside the tube was a little warmer than the part inside the tube. Such a slight gradient of temperature might easily ensue under the influence of the air as it grew warmer with the advance of day, the more massive tube changing more slowly in temperature. If this is the true explanation, the effect will have no existence in the real experiment, in which a steady temperature gradient is to be sustained. In any case, however, these initial currents, as they might be termed, were much smaller than the currents subsequently obtained.

After the best method of experimenting had been by long trial decided upon, the character of the experimental part of the research was in itself very tedious; and since months of preliminary and otherwise futile labour had already been spent it seemed best to postpone a continuation of the experiments till some future date. So far there have been no opportunities for renewing the attack, other work fully engrossing our time.

We are now prepared to discuss the results of the final set of experiments with iron wire.

The dimensions of the tube bar were as follows:

Total length of bar...	102	cm.
,, ,, tubular part	90	,,
External diameter of ,, ,, ...	4.4	,,
Internal ,, ,, ,, ,, ...	2.2	,,

The diameter of the iron wire used was 1.2 mm. It projected about a foot beyond the cold open end of the tube and was attached to a spring dynamometer measuring pounds-weight. The dynamometer was fixed to a screw working in a fixed nut; and by this means the tension could be increased or diminished as desired.

In the final set of experiments each applied stress acted for at least one whole day before the thermoelectric observations were begun. The wire was left for this interval at the ordinary temperature of the air.

The solid end of the cylinder was then heated to bright redness in a charcoal furnace; and after 2 hours' heating the temperature gradient became fairly steady, as indicated by the thermometric currents on the galvanometer.

There were five pairs of junctions, ten in all—five thermoelectric and five thermometric. The positions of these junctions along the iron wire were so arranged that the temperatures of two successive positions differed by 40°–60° C. The pairs of junctions were distinguished by number, No. I. being the hottest and No. V. the coldest.

The observations were made in the following order. First, the five thermometric currents were measured in rapid succession from I. to V., each current being measured first in the one and then in the other direction through the galvanometer. [This was an invariable rule in the measurement of all currents, the total range from the direct to the reverse reading giving twice the true deflection.] Then followed a similar set of readings of the five thermoelectric currents; then a second set of the thermometric; and so on until 4 sets of the thermometric currents with 3 interpolated sets of the thermoelectric currents had been completed. Exactly similar sets of observations were made for the series of tensions representing total loads of 0, 5, 10, 15, 20, 24 and 0 pounds. Reduced to kilogram-weight per square millimetre, these tensions are a little greater than 0, 2, 4, 6, 8, 9·6, and 0 respectively.

In Table I, the observations are given in full for the five pairs of junctions; T standing for the thermometric junctions whose indications form an arbitrary temperature scale, and E for the thermoelectric junctions whose electromotive forces are the real subjects of investigation. The tension, the temperature of the cold junctions, and the factor for reducing the deflections to electromagnetic units of electromotive force, are given in the space to the left of the tabulated numbers.

Table I.

Scale-readings of the Galvanometer-deflections of the E. M. F. of Iron-Copper junctions (T), and of Iron-Iron junctions (E) in the five Places.

	I		II		III		IV		V	
	T	E	T	E	T	E	T	E	T	E
Tension 0	170		134		100.7		75.15		50.55	
Cold temp. 15°.9–17°		140.75		109.5		87.3		69		49.2
Galv. Factor 147.5	174.5		138		104.15		78		53.65	
14th Oct. 1889		141		111		89.75		72.25		52.2
	174		137.7		104.2		78.5		54.25	
		141		111		90		72.75		53.5
	173.5		137.5		104		78.4		54.5	
Tension 5	158.5		123.4		91.5		67.5		44.5	
Cold temp 14°.4–15°.5		136.75		101.3		79		61.7		42.2
Galv. Factor 143	159.9		125.5		94.15		70.5		47.5	
Tension applied		137.25		103.25		81.75		65.3		46.5
11.30 a. m. Oct. 14th	160.7		126.75		95.75		72.25		49.3	
to 1 p. m Oct 15th		139.75		105.25		83.75		68		48.75
	163.75		129.25		97.8		73.7		50.5	
Tension 10	160.9		125.75		94.5		70.5		47.95	
Cold temp. 16°–17°.2		142.2		105.6		84.9		67.95		46.5
Galv. Factor 143.3	161.25		126.75		95.7		72.15		49.65	
Tension applied		140.5		104.5		84.5		68.95		47.8
7 a. m Oct. 17th to	159.2		125.5		94.85		71.5		49.6	
9 a. m Oct. 18th		136.5		101.95		82.6		68.2		47.9
	155.5		122.75		93.25		70.8		49.25	
Tension 15	163.25		126.55		93		68		44	
Cold temp. 13°.8–15°.2		144.1		105		81.5		62.25		39.7
Galv. Factor 143.65	172.2		134.75		100.75		75		50.25	
Tension applied		143.75		107.05		85.3		68.5		44.75
11 a. m. Oct. 18th to	171.5		135.5		102.5		77.15		52.9	
9 a.m. Oct. 19th		145.15		108.3		86.5		70.4		47.2
	174.5		138.5		105.25		79.1		54.5	

Table I. *(Continued.)*

	I		II		III		IV		V	
	T	E	T	E	T	E	T	E	T	E
	170.8		134.5		101.5		76.85		52.8	
Tension 20		150.25		114.5		92.75		76.75		54.5
Cold temp. 17°.3–18°.5	171.75		135.35		102.5		77.45		53.7	
Galv. Factor 143.5		152		116.5		94.75		79.65		56.75
Tension applied	171.2		135		102.5		77.5		53.75	
9 a. m. Oct. 21st to		151.75		116.75		95 25		80.4		57.95
10 a. m. Oct. 22nd	169.25		134		102		77		53.45	
	161.65		126		93.1		69		45.5	
Tension 25–22.5		145.75		107.5		82.95		64		41.7
Cold temp. 14°.8–16°.1	171		133.75		100.15		71.7		50.4	
Galv. Factor ?		148.5		112		89		71		48
Tention applied	173.5		136.75		103		77.25		52.75	
10 a. m. Oct. 23rd to		146.95		111.7		90.5		74.3		51.8
2 p. m. Oct. 24th	168.7		133.3		102		76.65		52.75	
	164.1		127.95		95.3		71.25		46.25	
Tension 0		143		108.7		85.5		63.3		45
Cold temp. 16°3–17°.9	171		134.5		101		76.25		50.7	
Galv. Factor 138.7		144.95		111.75		89		67.55		49.05
Tension released	173.7		137.5		104		79.05		53.15	
11 a. m. Oct. 25th to		145		112.25		90.3		69.5		50.8
10 a. m. Oct. 31st	173		137.25		104.5		79.55		54.5	

It may now be assumed that the mean of any set of four numbers for T will correspond to the mean of the set of three numbers for the E of the same junction-pair. These means are then to be reduced to temperature in the one case, to electromotive force in the other. For the reduction to temperature independent experiments were made to determine the constants of the iron german-silver circuits; and in the final reduction full account was taken of the slight variations in the value of the cold junction temperature. The results of the reduction are embodied in Table II., all the cold junction temperatures being reduced to 13°.5 C.

Table II.

E. M. F. between stretched and unaffected Iron wires, at various Tensions and Temperatures.

Tension	Cold Temp.	Hot Temp.	E. M. F. in Microvolts	Tension	Cold Temp.	Hot Temp.	E. M. F. in Microvolts
0	13°.5	267°.9	562	6	13°.5	269°.4	589
		211°.7	437			211°.0	436
		159°.4	352			157°.5	344
		119°.7	282			160°.6	274
		82°.0	205			77°.5	179
2	13°.5	255°.0	562	8	13°.5	272°.4	617
		199°.8	421			215°.3	473
		149°.6	333			163°.1	385
		111°.5	265			123°.3	322
		74°.7	187			85°.2	230
4	13°.5	254°.2	570	9.6	13°.5	278°.9	624
		199°.8	424			218°.7	468
		150°.9	343			164°.2	366
		113°.4	279			122°.2	296
		78°.1	193			86°.7	200
				0	13°.5	281°.0	605
						221°.3	466
						166°.7	371
						125°.9	281
						84°.3	203

The headings of the columns sufficiently explain themselves. The tensions are expressed in kilogram-weight per square millimetre. The highest tension attained corresponds to a load of 11.3

kilos. acting along the wire. It will be noticed that there is a slight diminution in this highest tension as the experiment progressed, doubtless due to the yielding of the highly heated part of the wire. This yielding occurred at all the tensions if the experiment were begun soon after the tension was applied. For this reason, each new tension was allowed to act at least for a whole day before the thermoelectric experiment was begun. Also just before the taking of the observations the dynamometer was carefully looked to, and the tension was raised to the desired value if any slight fall had occurred. Of course, once the experiment itself was entered upon the wire was not touched until the whole series of observations had been completed. To go to higher tensions than those here recorded was not practicable because of the diminished tenacity of the wire at its hottest parts. Not a few experiments were spoiled by the breaking of the wire at or near the highest tension attempted.

For each tension we have determinations of electromotive forces at five different temperatures. Some of the results are shown in Figure I., Plate XXXIX. To prevent confusion of figure, only three are shown—the initial and final for no tension, and the fifth for tension 8. Of particular interest in the manner in which the initial and final curves cut each other at a temperature of about 150° or 160° C. In interpreting this result, we must know the thermoelectric relation of the two kinds of iron used in forming the junctions. In the language of the thermoelectric diagram, in which the german-silver line lies below the iron line, the iron forming the small wires had its line also below the line of the iron that was or was to be strained. In other words, the current always flowed from the unaffected wire to the strained or to be strained through the hot junction. Now from Fig. I., we see that the effect of the stress is to increase the currents for all temperatures. The wire under the stress 8 has therefore the same relation to the unstrained wire which this latter has to the small unaffected wire. The stress, so to speak, displaces the line upwards on the diagram. The current is accordingly from the unstrained to the strained iron through the hot junction. On the stress being removed, the wire is left permanently strained, or, as we shall for brevity call it, after-strained. And we see that for temperatures below 155°± the current is from the afterstrained to the unstrained through the hot junction; but that above 155° the current passes in the other direction. This would mean that the diagram lines for the unstrained and after-strained wires intersect each other indicating a neutral temperature at a temperature of 85° or thereabouts. The directions of the currents as given above show that the diagram line for the after strained wire is inclined at a less angle to the lead line. Hence the (negative) Thomson Effect in this particular iron wire is numerically decreased after the application and withdrawal of longitudinal tension.

Curves, representative of all the experiments whose results are given in Table II., were carefully drawn by free hand on a large scale; and from these the electromotive forces corresponding to particular temperatures were picked out. A more pretensious process of interpolation could hardly have been more accurate under the circumstances; for the curves, though smooth, have all a distinctly sinuous form, which it would be difficult if not impossible to represent by an equation of degree lower than the fourth. The electromotive forces corresponding to convenient temperatures, picked out as just described by inspection of the curves, will be found tabulated in Table III.; and in Table IV. the result of subtracting each number in the zero tension column from all the others in the same row is shown:

Table III.

E. M. F. between the stretched and unaffected Iron Wires, at chosen Temperatures and at various Tensions.

Hot Temp.	Tension 0	Tension 2	Tension 4	Tension 6	Tension 8	Tension 9.6	Tension 0
100°	242	242	249	240	270	243	231
120°	283	282	294	282	316	294	270
150°	338	333	342	333	366	342	335
180°	387	384	392	381	410	391	396
200°	419	423	425	416	445	424	430
230°	470	494	500	478	506	491	485
250°	515	548	557	531	556	544	529

Table IV.

E. M. F. between the unstretched and stretched Iron Wires at chosen Temperatures and at various Tensions.

Hot Temp.	Tension 0	Tension 2	Tension 4	Tension 6	Tension 8	Tension 9.6	Tension 0
100°	0	0	7	−2	28	1	−11
120°	0	−1	11	−1	33	11	−13
150°	0	−5	4	−5	28	4	−3
180°	0	−3	5	−6	23	4	+9
200°	0	+4	6	−3	26	5	11
230°	0	24	30	+8	36	21	15
250°	0	33	42	16	41	29	14

In the last Table we see, almost at a glance, the progress of things as the tension increased. The graphs of Figure II. are obtained by plotting the electromotive forces corresponding to one temperature in terms of tensions. These should correspond in general features to the curves obtained by Cohn and Ewing. In a very general they do so; but they are much more irregular. This perhaps is not surprising if we bear in mind the fact that each graph is made up out of as many different days' experiments as there are points. If we leave out of consideration the experiment for tension 6, the remaining points on each graph arrange themselves in a fairly regular manner. There does not, however, seem to be any sufficient reason for omitting this experiment. For the peculiar deviations of all the points belonging to it cannot be easily explained as due to any errors in reduction either to temperature or to electromotive force. The same peculiarity appears if we use the unreduced thermometric readings in drawing the curves. On the other hand, the galvanometer constant was almost exactly the same day after day (as may be seen from Table I), excepting for the two last series of experiments at the highest tension and the final zero.

In drawing our conclusions we must however bear in mind the smallness of the quantities tabulated in Table IV. The probable errors of observation are of the order of the smaller quantities given in that Table; so that it would be out of the question to attach any importance to values less than 5.

Nevertheless, we are able to recognize in the graphs figured a certain ordered succession of changes; and there can be no doubt as to the significance of the values for the after-strained wire. Here we have a result apparently new to the subject; we are not aware that the possibility of such an effect has even been hinted at by previous workers. We have already expressed the nature of this result by saying that the Thomson Effect in an iron wire undergoes a permanent change after the longitudinal tension has been applied and removed. If e is the electromotive force between the after-strained and unstrained wire, reckoned positive when the current flows from the after-strained to the unstrained through the hot junction, we may represent the values in the last column of Table IV. by the linear expression

$$e = + 34 - 0.21\ t$$

where t is the temperature in Centigrade degrees, and the unit is 1 microvolt. The deviation of this straight line from the curve drawn through the points is well within the errors of observation. It would be unsafe to sttach any importance to the suggestion of two vertices in the tabulated numbers, indicating two neutral points, one above and one below 160° C. ($e = 0$).

Thomson, Cohn, Ewing, and other investigators have worked with temperatures lower than the highest we used; so that it is not possible to make a thorough comparison between these earlier results and ours. Where a satisfactory comparison can be made there is complete agreement. For example in Ewing's first set of experiments, the after-strained wire came out *positive* to the unstrained wire with the hot junction at 100°C. Our result is $e = + 13$.

In his later series of experiments Professor Ewing was concerned wholly with the thermoelectric behaviour of iron wire under the combined influence of stress and magnetization. He kept his hot junction at a temperature of 160°C; and it will be noticed that the after-strained wire comes out *negative* to the unstrained wire. Since however no observation is recorded for an unmagnetized wire, and since Professor Ewing himself seems disposed to regard this negative character as due to the magnetization, it is impossible to make a satisfactory comparison. The values of the electromotive forces given by him are of the same order of quantity as that just given.

Our experiments indicate a maximum current as occurring about the tension of 8, which corresponds to a load of between 9 and 10 kilos —a result in fair agreement with some of Professor Ewing's.

The general conclusion that may be deduced is that the effect of tension on the thermoelectric position of an iron wire is a complex function of the temperature. Not only does the line on the thermoelectric diagram suffer displacement up or down but it also suffers rotation. In other words the Peltier Effect and Thomson Effect are both changed.

These results can only be regarded as preliminary. They are sufficient to show that the method is workable, and they have a distinct value in themselves. It would be advisable to repeat and extend the experiments with a much more massive iron tube than that here used. A smaller gradient of temperature would be thereby obtained, and it would not be necessary to keep the one end of the wire at a very high temperature. By such a modification, much higher tensions might be applied.

On some Cretaceous Fossils from Shikoku.

By

Matajiro Yokoyama.

With Plate XL.

The Cretaceous Formation in Shikoku occurs in several places. These occurrences, however, are restricted to two zones, lying one on each side of, and parallel to, the central zone of crystalline schists, which traverses the island from ENE to WSW along its longitudinal axis. The Cretaceous strata in the northern zone directly overlie these schists, and form a long narrow belt along the whole northern coast of the island, interrupted only here and there by alluvial flats. Beyond Shikoku, they continue on the east over the southern portion of the island of Awaji to the Katsuragi Mountains in Kii, while on the west, vanishing partly under the sea and partly under the volcanic rocks of Kyūshū, they seem to reappear on the islands of Amakusa. In the southern zone, they are not so continuous. They rather fill up trough-like depressions in the Palæozoic rocks, together with some other members of the Mesozoic Group. These depressions are known as the *Katsuragawa Basin*, the *Monobegawa Basin*, the *Ryōseki Basin*, and the *Sakawa Basin*. But here also the zonal distribution of the Cretaceous rocks is quite evident, as these basins all lie in one straight line parallel to the longitudinal axis of the island.

The northern zone is essentially composed of alternating layers of sandstone and shale, for which complex Dr. Harada[1] proposed the

1) T. Harada. *Die Japanischen Inseln.—Eine topographisch-geologische Uebersicht. I Lief. Published by the Imperial Geological Survey of Japan, 1890.*

name of *Izumi-Sandstone*, from the predominance of a certain greenish-grey hard sandstone, locally known under the name of *Izumi-stone*.

Fossils from this sandstone are very few. Besides a large so-called *Fucoid* which occurs at several places in Sanuki, we know only a *Helicoceras* described below, and some fragments of a large *Hamites-like* Ammonite found by Mr. Suzuki at Ōkuzure in Awaji. Harada,[1] however, mentions also some Foraminifera, bivalves, and conifers as occurring in this sandstone.

The Mesozoic *Basin of the Katsuragawa* occupies the upper part of the river of the same name in Awa. It was geologically investigated in 1883 by Mr. Y. Kikuchi, to whom we owe the first discovery of the Cretaceous formation in Shikoku. Here it consists of sandstones and conglomerates, superposing the Jurassic plant-bearing series. The sandstone is hard, fine-grained, and when fresh greenish-grey in colour, and has nearly the same appearance as the Izumi-stone, while on weathering it assumes a yellowish tint. It contains shells in great profusion, which however belong to a very few species, and are mostly found as casts. They are—

Trigonia pocilliformis,
Trigonia Kikuchiana,
Trigonia rotundata.

Mr. Kikuchi also found a fragment of an evolute as well as of a spirally rolled Ammonite.

The *Monobegawa Basin* is in Tosa. Its geological nature is not well known. We possess only a block of sandstone like that of the Katsuragawa, quite filled with casts of *Trigonia pocilliformis*.

The *Ryōseki Basin* is not far from the above, and occupies the southern portion of Nagaoka-gori, Tosa. Here the Cretaceous forma-

1) Loc. cit., p. 107.

tion seems to consist solely of sandstone which is as usual grey to greyish-green, fine-grained and hard. It contains *Trigonia pocilliformis* and *Tr. Kikuchiana* in tolerable abundance. Besides, it yields remains of many other Lamellibranchs, some Gasteropods and Echinoids, whose preservation, however, is very imperfect. The rock at Okuminodani directly overlies the Upper Jurassic Cidaris-Limestone.

Lastly, the *Sakawa Basin* is situated in Takaoka-gori of the same province, about 40 Km to the west of Ryōseki. What is known of it we owe to the investigations of Messrs Naumann[1] and Nasa,[2] the latter of whom planned the geological map[3] of the district.

The Cretaceous Formation of Sakawa is wholly composed of sandstone, which is quite similar to that of Ryōseki. On the south of the town of Sakawa, it lies partly on the Cidaris-Limestone, and partly on a series of shales and sandstone, which at Yoshida-Yashiki yields some plants.[4] Near Ochi, however, it seems to overlie directly the Triassic sandstone of the district.

Besides Alectryonia, Lucina, Nucula, Solen, Rhynchonella and a Scaphites-like Ammonite, *Trigonia pocilliformis Tr. Kikuchiana*, and *Tr. rotundata* were also obtained from the above sandstone.

From what has been said above, it will be seen that the number of fossil species in the Shikoku Cretaceous is rather small; and these, moreover, are so imperfectly preserved that the majority of them are indeterminable. On this account, I can describe only four species in this paper. These four, however, are very important, as some of them not only show the undoubted Cretaceous age of the strata containing them, but at the same time, they give us the probability that

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1) Naumann u. Neumayr. *Zur Geologie u. Paläontologie von Japan. Denks. d. math.-naturw. Classe d. K. Akad. d. Wissens., Wien, Bd. LVII, 1890.*

2) T. Nasa. *Report. of Geol. Surv. of Sakawamura, Tosa 1885* (MS).

3) Given in Harada's *Japanischen Inseln*, l. c.

4) Nathorst considers these plants as Upper Jurassic. Vide *Beitr. z. Mesoz. Flora Japans. Denks. d. Math.-Nat. Cl. d. K. Akad. d. Wissens. Wien, Bd. LVII, 1890.*

at least the *Trigonia-Sandstone* is to be considered as contemporaneous with the Gaulto-Cenomanian Formation of Hokkaido (Ezo). Already in my paper entitled "Versteinerungen aus der japanischen Kreide,"[1] I have mentioned the occurrence of a scabrous Trigonia, allied to *Tr. aliformis Park.*, in the Cretaceous of Kagahara which I considered as probably belonging to the same epoch as that of Hokkaido. It is this same Trigonia, *Tr. pocilliformis* as I call it, which is so profusely found in the southern zone of Shikoku, playing so to say the rôle of the leading fossil of the Shikoku Cretaceous. The above view is moreover justified by the fact that Mr. Jimbo has recently discovered the same form of Trigonia occurring together with Ammonites in the Cretaceous of Hokkaido. Whether the *Izumi-Sandstone* is also to be referred to the same age is at present unsettled, as it has not yet given any characteristic fossils.

The two species of glabrous Trigoniæ also described below are palæontologically very interesting. They are forms which, like some Liassic species, exhibit a great external resemblance to the Triassic genus *Myophoria*. *Trigonia Kikuchiana*, whose only ally among the Trigoniæ is *Tr. Lingonensis Dum.* of the Lias of England and France, reminds one strongly of some forms of Myophoria glabræ, e.g. *M. lævigata* Alb. The other species, *Tr. rotundata*, has no kindred form among the Trigoniæ hitherto described; on the other hand, it has several corresponding ones among the glabrous Myophoriæ, such as *M. plebeja Gieb.*, *M. orbicularis Goldf.*, *M. rotunda Alb.* In fact, this recurrence of Myophoria-like Trigoniæ in the Japanese Cretaceous seems to confirm the view generally entertained by palæontologists, that there is a close relationship between these two genera.

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1). Palæontographica, Bd. XXXVI, 1890.

Description of the Species.

Trigonia pocilliformis *n. sp.*

Pl. XL, Fig. 1a, 1b, 2, 3.

Trigonia sp. Yokoyama, Versteinerungen aus der Japanischen Kreide, p. 199.

Shell subcrescentic, very inequilateral, inflated anteriorly, attenuated, narrowed, and flattened posteriorly. Beaks antero-mesial, touching, pointed, much incurved and also recurved. The anterior side of the valve is somewhat produced, and its margin is strongly convex, gradually passing into the convex ventral margin which is raised up posteriorly without any marked excavation. The dorsal margin commences at the small ligamental aperture behind the beak, and descends posteriorly with a slight concavity to meet the truncated siphonal margin nearly at a right angle. The escutcheon is lengthened, ovato-lanceolate when the valves are closed, broadest at about $^1/_3$ the distance from the beak, and concave for about $^2/_3$ the length from the same point, beyond which it flattens. It is transversely or somewhat obliquely costellated; the costellæ are simple and smooth, being coarser, more elevated and distant in the posterior than in the anterior portion of the escutcheon. They are also slightly curved out towards the posterior side, and somewhat oblique, with the marginal ends directed anteriorly. The number of these costellæ is probably 15–18, but those situated near the beak are so faint that they are hardly visible. The area begins near the beak as a slight ridge which gradually widens posteriorly and becomes broadest at the siphonal end, where it attains about $^1/_3$ the total height of the shell, and forms at the same time its posterior border. It is for the greater part of its length rendered bipartite by a groove which runs a little above its median line and parallel to it ; each of the two somewhat unequal halves thus formed is moderately convex, and marked by fine transverse plications, some of which can become very coarse. The remaining portion of the valve is ornamented with coarse, elevated, slightly flexuous, crenated ribs whose number exactly corresponds to that of the costellæ of the escutcheon, being, so to speak, the continuations of the same, although interrupted in their course by the intervention of the area between. They arise at the border of the area as narrow crenulated ridges, and diverge in every direction, getting higher and broader as they approach the pallial border, into which they pass over without any marked curvature. The interspaces are smooth. The pallial border is rendered dentate by these ribs.

The internal characters of the shell are not well known.

The younger specimens of this shell are a little shorter, and the ribs more straight and less in number (Fig. 2).

I have already compared this species, in the work above cited, with *Trigonia aliformis Park.* It is nearer to the variety called *attenuata* by Lycett (A Monograph of the British Fossil Trigoniæ,[1] No. 3, p. 117, pl. XXV, Fig. 6) than to its typical form. Still there are marked differences between the two. The most striking lies in the ribs which, in the English form, are not only more numerous, but also describe concentric curves in the anterior portion of the shell, whereas in the Japanese, although somewhat flexuous in themselves, they all pass over straight to the pallial border without making any distinct curvature. Besides, in the former, the marginal ends of the costellæ of the escutcheon are directed posteriorly instead of anteriorly.

A species called *Trigonia Forbesii Lycett* (l. c. p. 122) from Verdachellum in India seems to show similarity in the course

1) *Palæontographical Society, Vol. XXIX, issued for 1875.*

of the ribs to the Japanese. But it differs in having a shorter shell and a broad costellated area.

Trigonia pocilliformis occurs sometimes in great abundance, filling the whole rock. It is, however, mostly preserved as casts, and even when the shell itself is found, this is so firmly attached to the stone that it is impossible to isolate it without breaking it to pieces. Furthermore, these casts are often so deformed that it is difficult to get specimens on which we could found a good diagnosis. The above figures[1] were taken from gypsum pressings of an external cast of a young as well as of a full grown specimen, which was considered as nearly perfect in shape.

This species is one of the characteristic fossils of the Japanese Cretaceous, being met with almost whereever the Cretaceous fossils are found. In Shikoku it is to be found at the following places:

Tanno in the Katsuragawa Basin; Sōyama and Okuminodani in the Ryōseki Basin; Hagino in the Monobegawa Basin (Kamigori, Tosa); Sendachino and Hirano near Ochi, and Yamanokami (Nagano) near Sakawa, both in the Sakawa Basin; Obama, Yokohata-mura, Agawagori, Tosa.

Outside of Shikoku, it occurs in the Sanchū Basin, and in Hokkaidō.

Trigonia Kikuchiana *n. sp.*

Pl. XL, Fig. 4, 5, 6.

Shell ovately trigonal, oblique, very convex. Beaks antero-mesial, prominent, incurved, and very slightly recurved. Anterior margin convex, gradually passing into a less convex ventral margin

1) The teeth which would be more or less visible in the dorsal as well as in the posterior view of this and of the following species are not shown in our figures, as these figures were all drawn after gypsum pressings of external casts.

which posteriorly meets with the nearly straight, obliquely ascending, siphonal margin almost at a right angle, the corner being rounded. Hinge-margin obliquely sloping on the posterior side, and going over to the siphonal margin without forming any marked angle at the point of junction. Area and escutcheon not distinctly separated, forming one, more or less flat, surface which is slightly depressed along its median line. The other portion of the shell, which makes an angle of about 90° with the areal surface, is marked off from the latter by a rounded edge, running from the beak to the postero-ventral corner and slopes to the anterior and ventral margins with a slight convexity. The entire surface of the shell is smooth, except near the beak where a few coarse shallow concentric sulci are mostly found.

The shell seems to have been moderately thick. The median depression of the posterior surface is more marked in the adult than in the younger specimens. The internal casts show two strong, transversely striated, diverging teeth.

Among the Cretaceous Trigoniæ there is none which can be compared to this species. But in the Lias there is one, *Trigonia Lingonensis Dum.* (Lycett, Monogr. of Brit. Foss. Trigonia, No. 3, p. 98, pl. XXII, Fig. 1–4), which shows a close affinity to it. The latter, however, has a little broader shell and the posterior side distinctly separated into area and escutcheon by a sharp ridge.

Trigonia Kikuchiana, like *Tr. Lingonensis*, is one of those forms of Trigonia which externally exhibit a great resemblance to the older genus *Myophoria*.

It occurs almost always as casts, and also often much distorted. The internal mould drawn on the plate has the back accidentally depressed. Fig. 4 is from the largest specimen we got. This was a broken one, but has been restored in our figure. Its shape somewhat differs from that of Fig. 5, especially in its anterior margin. But this difference is probably due to the mode of preservation.

Very frequent at Tanno; also occurs at Sōyama near Ryōseki, and Yamanokami (Nagano) near Sakawa.

Trigonia rotundata *n. sp.*

Pl. XL, Fig. 7, 8, 9.

Shell suborbicular, slightly broader than high, somewhat inequilateral, convex. Beaks approximate, a little pushed anteriorly, prominent, pointed, and incurved. Both the anterior and posterior margins convex, gradually passing into a less convex ventral margin. Hinge-margin also arched. The escutcheon is not clearly separated from the area, there being only a trace of a broad and flat ridge between, running from the beak to the upper end of the posterior margin, which makes the area slightly depressed along its median line. The other portion of the shell is moderately convex, and separated from the area by an obtuse edge, and making with the latter an angle of about 120°. The entire surface of the shell is smooth, if we except a few coarse, shallow concentric sulci near the beak, and coarse, concentric rugæ which sometimes appear on the posterior side near the ventral margin.

In appearance of area and escutcheon this species is very similar to the preceding one.

Among the forms of Trigonia hitherto described, there is none which shows any relation to it. Among the Myophoriæ, however, there are several corresponding forms which have been mentioned before.

Like the two foregoing species, *Trigonia rotundata* occurs mostly as casts, one of which is figured on the plate. It shows two strong, striated, diverging teeth.

Quite as numerous as *Trigonia Kikuchiana* at Tanno; occurs also near Sakawa at Ninomiya, Yamanokami, and Sendachino.

Helicoceras *sp.*

Pl. XL, Fig. 10, 10*a*.

A fragment of the body-whorl of a snail-like Ammonite, elliptical in section, somewhat higher than broad, and with the body-chamber occupying about one half of the entire volution. The external sculpture consists in fine, rounded, transverse ribs, slightly undulatory in their course, and weakest on the umbilical side of the whorl, where some of them even disappear. Their number is about 50 in one circuit. The sutures on the external side of the whorl are indistinct. But as far as they are seen in our specimen, they are deeply and much incised, with saddles and lobes bipartite; the siphuncle seems to lie on the outer side, so that our fragment is that of a Helicoceras which is, at least, closely akin to *Helicoceras indicum Stol.* (Cret. Cephalopoda of Southern India, p. 184, pl. 86, Fig. 1–2). But as the specimen is imperfect, its exact specific determination is not possible.

Helicoceras indicum occurs in the Arrialoor Group of India.

Our specimen was found in a very fine-grained shaly sandstone of Oumi, Ōuchigori, Prov. Sanuki.

Fig. 1.—Comparison Diagrams of the East-West Component Instruments.

Pit Instr.

Surf. Instr.

Pit Instr.

Surf. Instr.

Fig. 2.—Comparison Diagrams of the North-South Component Instruments.

Pit Instr.

Surf. Instr.

Pit Instr.

Surf. Instr.

Fig. 3.—Earthquake of January 15th, 1887.
East-West Component.

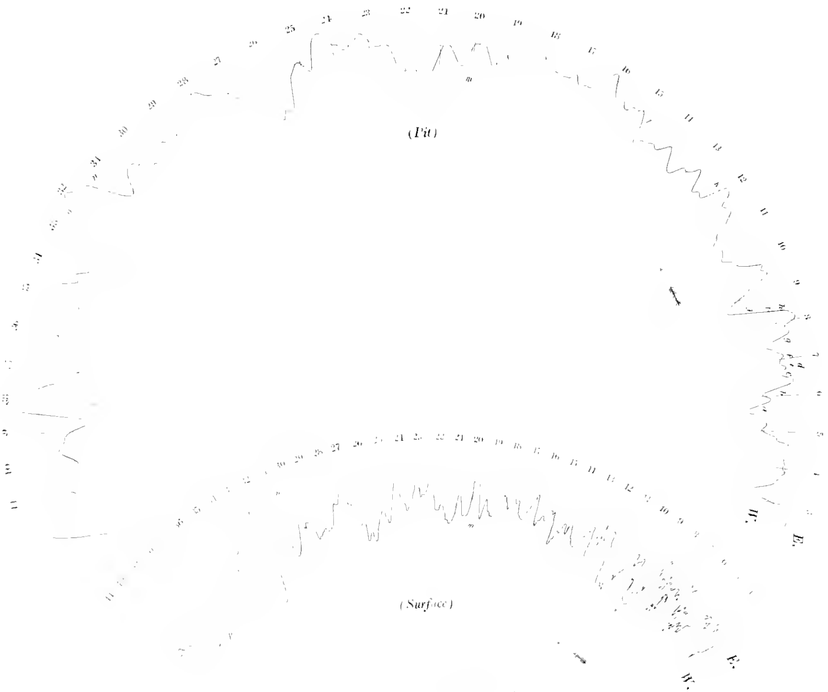


Fig. 4.—North-South Component.

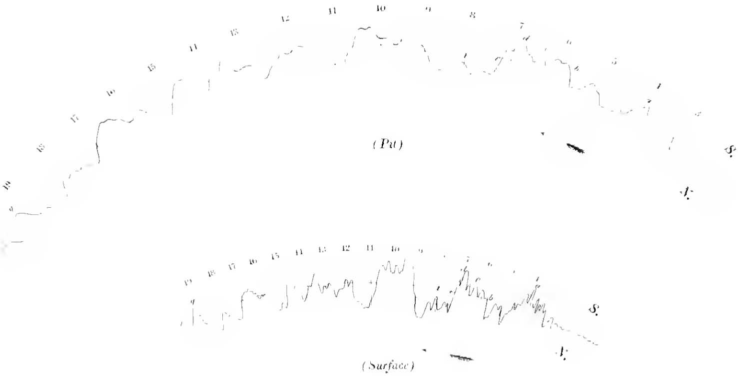


Fig. 5.—Earthquake of April 29th, 1888.
East-West Component.

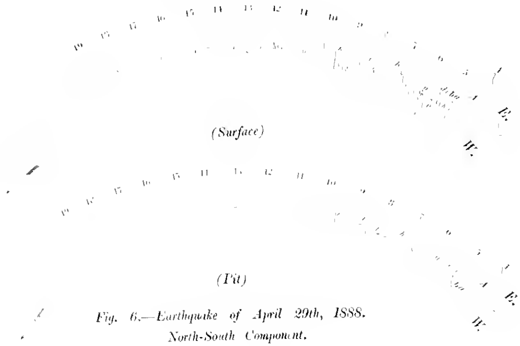


Fig. 6.—Earthquake of April 29th, 1888.
North-South Component.

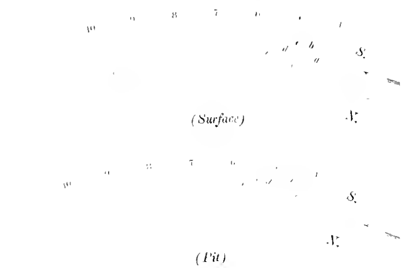


Fig. 7.—Earthquake of February 18th, 1889.
East-West Component.

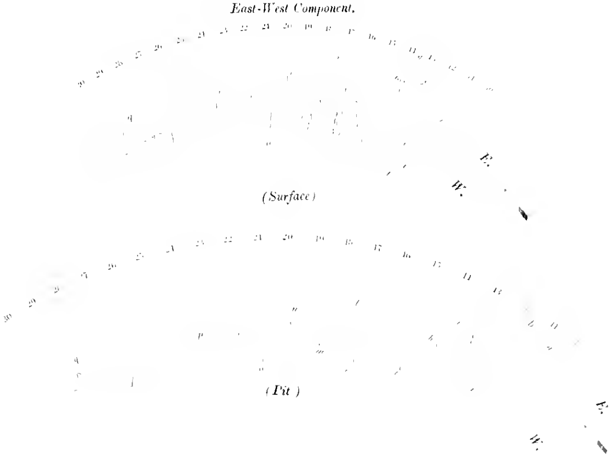


PLATE XXXVIII.

Fig. 1.

(1) $r=0.17$, $T=1^\circ.7$, $w=25$.

(2) $r=0.24$, $T=7^\circ.2$, $w=25$.

(3) $r=0.36$, $T=3^\circ.3$, $w=25$.

Fig. 2.

(1) $r=0.17$, $T=6^\circ.7$, $w=25$.

(2) $r=0.17$, $T=10^\circ.6$, $w=25$.

(3) $r=0.17$, $T=861^\circ$, $w=25$.

(4) $r=0.17$, $T=1621^\circ$, $w=25$.

Fig. 3.

(1) $r=0.25$, $T=626^\circ$, $w=25$.

(2) $r=0.20$, $T=1269^\circ$, $w=25$.

(3) $r=0.35$, $T=1349^\circ$, $w=25$.

Fig. 4.

(1) $r=0.17$, $T=2548^\circ$, $w=25$.

(2) $r=0.17$, $T=95^\circ$, $w=342$.

(3) $r=0.17$, $T=583^\circ$, $w=342$.

Fig. 5.

(1) $r=0.36$, $T=4^\circ.3$, $w=218$.

(2) $r=0.20$, $T=22.^\circ$, $w=218$.

(3) $r=0.20$, $T=16^\circ.7$, $w=411$.

(4) $r=0.20$, $T=968^\circ$, $w=218$.

Fig. 6.

(1) $r=0.17$, $T=18^\circ.5$, $w=156$.

(2) $r=0.17$, $T=584^\circ$, $w=156$.

(3) $r=0.17$, $T=260^\circ$, $w=342$.

(4) $r=0.17$, $T=583^\circ$, $w=342$.

r gives radius in mm.,

T „ permanent twist in degrees,

w „ longitudinal stress in grm. weight.

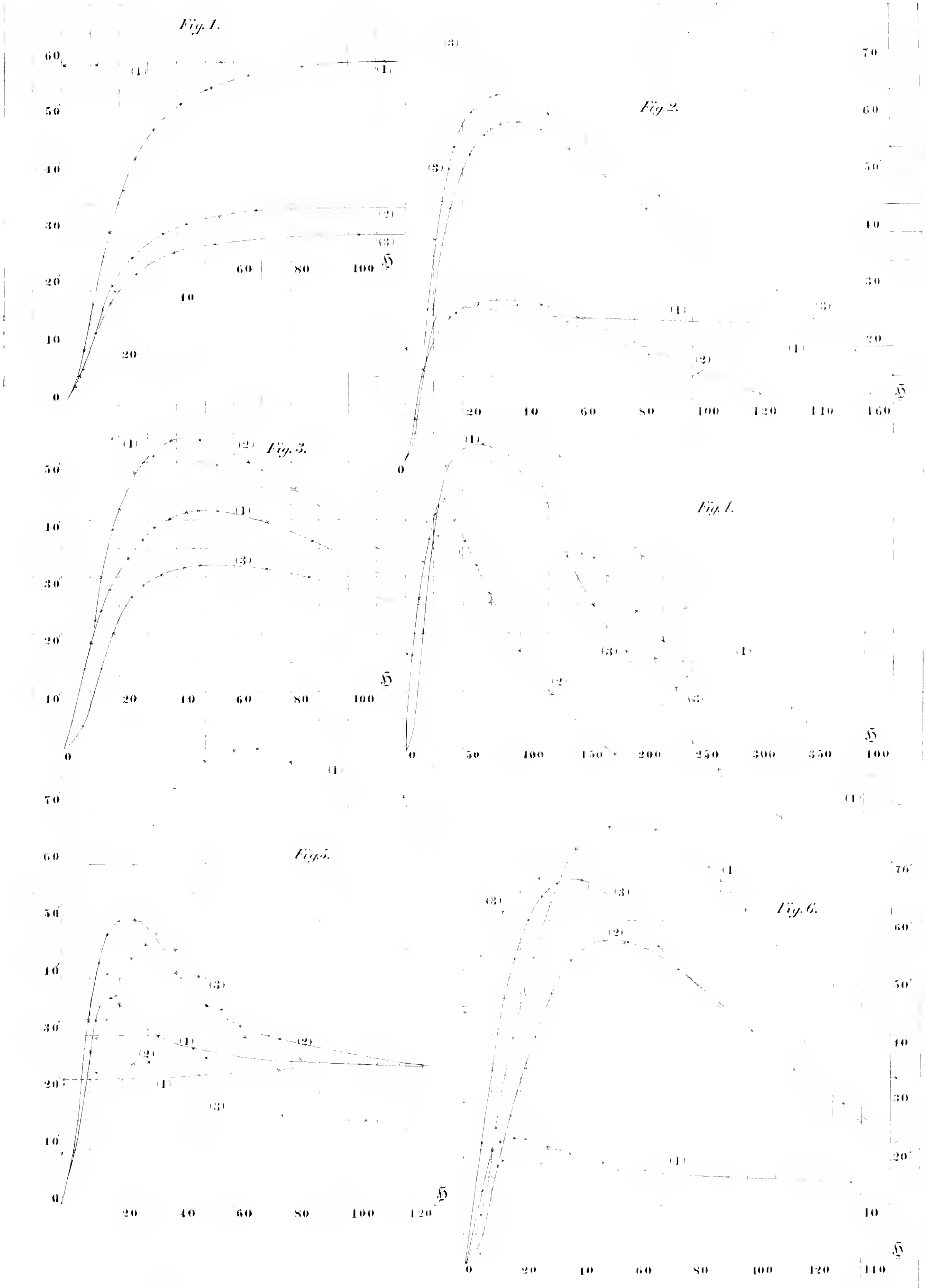
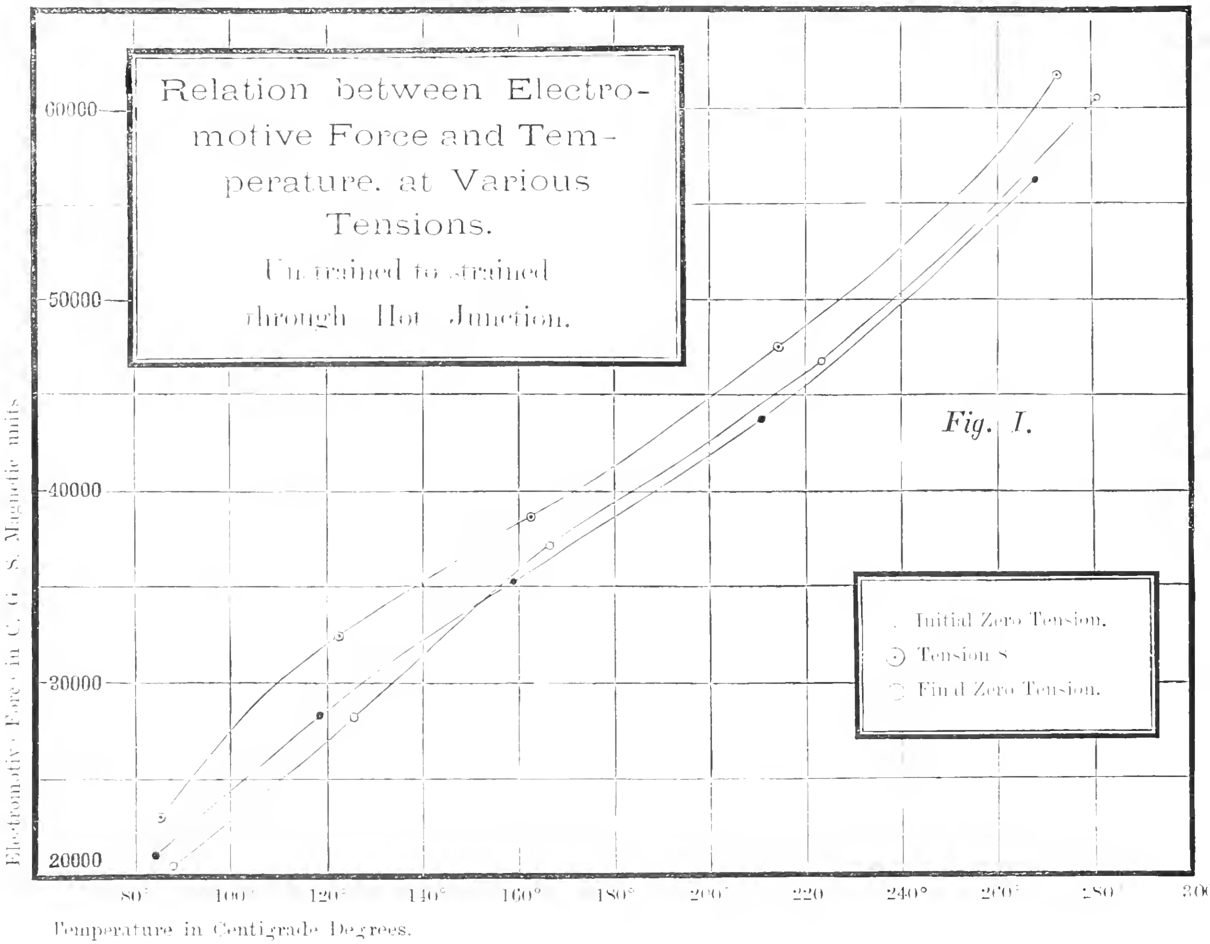


Fig. 1.
Fig. 2.
Fig. 3.
Fig. 5.
Fig. 6.
ℌ


Relation between Electromotive Force and Temperature. at Various Tensions.
Untrained to strained through Hot Junction.
Fig. I.
Initial Zero Tension.
Tension 8
Final Zero Tension.
60000
50000
40000
30000
20000
Electromotive Force in C. G. S. Magnetic units
80°
100°
120°
140°
160°
180°
200°
220
240°
260°
280
300
Temperature in Centigrade Degrees.

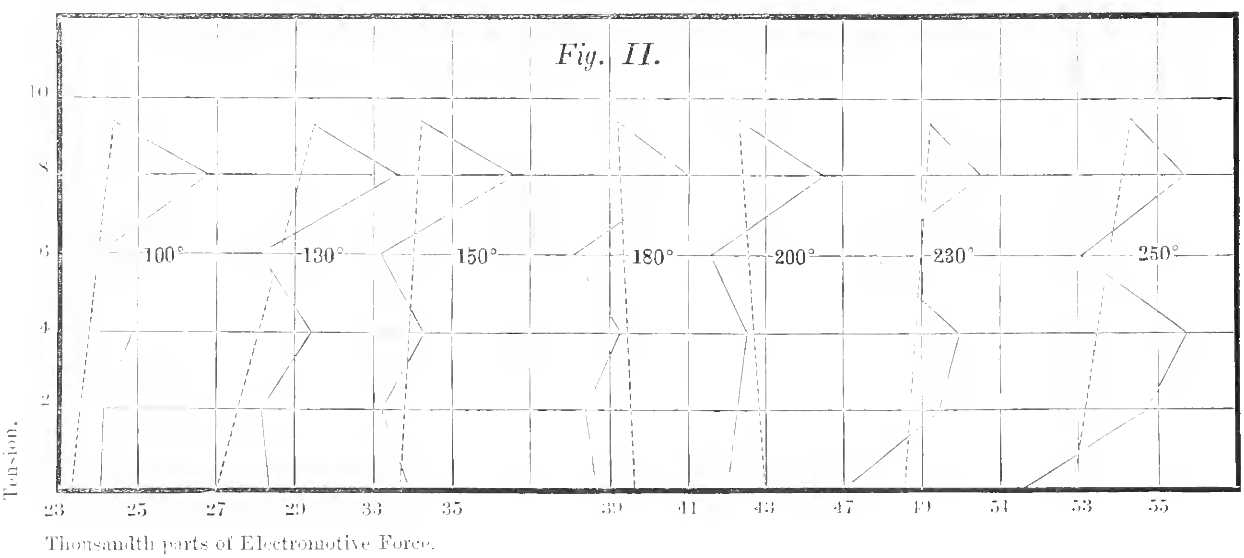


Fig. II.
100°
130°
150°
180°
200°
230°
250°
10
8
6
4
2
Tension.
23
25
27
29
33
35
39
41
43
47
49
51
53
55
Thousandth parts of Electromotive Force.

PLATE XL.

Plate XL.

Fig. 1*a*, 1*b*. Trigonia pocilliformis. A full grown specimen.

,, 2. ,, ,, A young specimen.

,, 3. ,, ,, Cast, somewhat distorted.

,, 4. Trigonia Kikuchiana. A full grown specimen.

,, 5*ab*. ,, ,, A somewhat smaller specimen. 5*b*, seen from the posterior side, showing the indistinct separation of area and escutcheon.

,, 6. Trigonia Kikuchiana. Cast, accidentally depressed on the back.

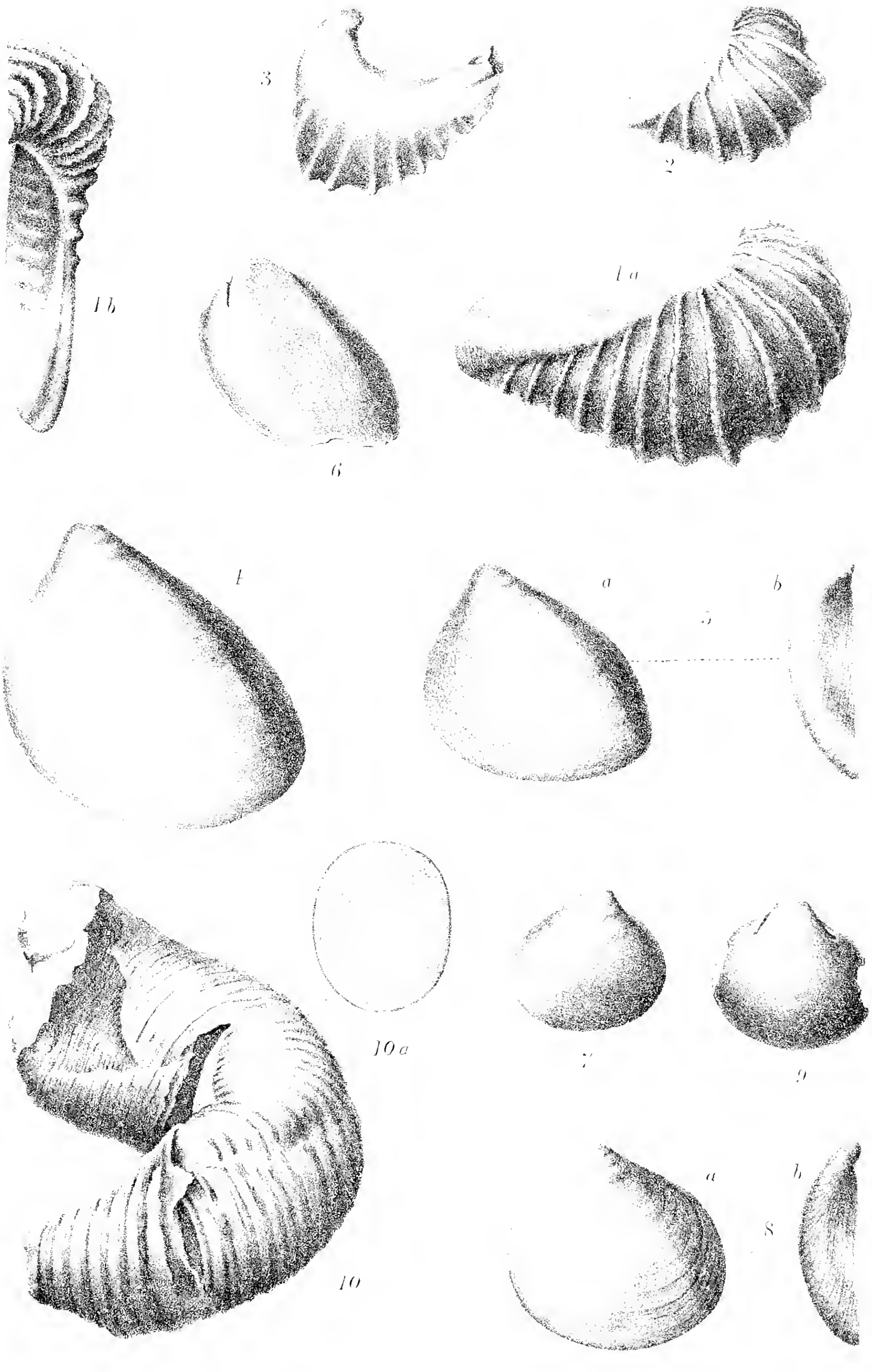
,, 7. Trigonia rotundata. Right valve.

,, 8*ab*. ,, ,, Left valve of a full grown specimen partly restored. *b*, seen from the posterior side.

,, 9. Trigonia rotundata. Cast.

,, 10. Helicoceras sp.

,, 10*a*. ,, ,, Transverse section.


3
2
1 b
1 a
6
4
a
b
5
10 a
7
9
10
a
b
8