

BARRETT

Observations on the Anatomy
of the Circulatory System
and the Course of Blood Flow
In Diplocardia
Communis Garman

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OBSERVATIONS
ON THE
ANATOMY OF THE CIRCULATORY SYSTEM
AND THE
COURSE OF BLOOD FLOW IN DIPLOCARDIA COMMUNIS GARMAN

BY

J. T. BARRETT.

THESIS PRESENTED FOR THE DEGREE OF

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IN

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

J. T. Barrett,

ENTITLED Observations on the Anatomy of the Circulatory System

and course of Blood Flow in Diplocardia communis Garman,

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE

OF Bachelor of Arts.

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HEAD OF DEPARTMENT OF Zoology.

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This paper is based on the results of some investigation work carried on in the laboratories of the Zoological Department of the University of Illinois as a part of the work preliminary to graduation in a specialized course in the College of Science. The subject was chosen at the suggestion of Professor F. Smith who has had immediate supervision of the work and to whom I have been under obligations for suggestions as to methods of procedure and for help in the matter of literature on the subject.

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INTRODUCTION.

Diplocardia communis Garman ('88), is a species of large flesh-colored earth worm common in the black soil of the prairies of Illinois. The body is made up of from 120 to 170 somites, and often reaches a length of a foot. It is cylindrical for the greater part of its length and has its greatest diameter in somite VII. The specimens used in this investigation were collected in abundance on the campus of the University of Illinois. During early morning showers they came to the surface where they remained some little time after the showers had ceased.

In taking up this investigation the aim was to present the anatomy of the circulatory system and the course of blood-flow in this species, since it belongs to a genus concerning whose circulatory system very little is known. Whereas in *Lumbricus terrestris* and in many other species there are seven longitudinal trunks, in *D. communis* there are but four, the subneural and the lateral neurals being lacking in the latter.

A comparison of some of the main trunks of *D. Communis* with those of other worms the circulatory systems of which have been quite carefully worked out will best prepare the way for a more detailed description.

As the name indicates, *Diplocardia communis* has a double dorsal vessel, a condition not entirely lacking in some other worms. As Beddard ('95) states, the most diverse families exhibit this peculiarity. In *Megascolex coeruleus*^{Bourne}_A ('91) the vessel is double only in the anterior part of the body as it also is in *Diplocardia eismichaelsoni*_A ('24); in *Octochaetus multiporus* and in *Acanthodrilus annectens* the vessel is completely double there being two distinctly separate tubes running side by side on the dorsal surface of the alimentary tract. In *D. communis*, as in *Acanthodrilus novae-zelandiae*, there are two such tubes in the middle region of each somite but at the septa the two tubes fuse. From Michaelson's definition of *Diplocardia communis* (typica) in *Das Tierreich* ('00) it is evident that he has the wrong idea concerning this double condition of the dorsal vessel. He says that it is double, for instance, in somites VIII, X, and XII, and single in somites VII, IX, and XI. In *D. communis* the laterals, the paired vessels called by Benham 'lateral longitudinal vessels,' and by Perrier and Bourne 'intestine-tegumentary vessels,' differ, I believe, from all other similar vessels yet described. Whereas the laterals in *Lumbricus* enter the dorsal in somite X and the anterior intestino-tegumentary vessels in *Megascolex coeruleus* end in a network of capillaries in somite XIII, the laterals of *D. communis* extend from their origin at the anterior capillary network posteriorly along the ventral surfaces of the

oesophagus,* leave the same in XIII and pass to the body wall along which they extend as continuous trunks to XVIII giving off branches in each of the somites XIII to XVIII inclusive. They have direct connection with the dorsal by means of the dorso-tegmentaries.

In *D. communis* as in many *Oligochaeta* there is in addition to the dorsal a vessel termed supra-intestinal which extends along the dorsal surface of the oesophageal region where it takes the part in reference to the intestinal circulation that is elsewhere played by the dorsal vessel. This vessel, double in *Megascolex* and entirely absent in *Lumbricus*, is single in *Diplocardia*. There is no relation between the supra-intestinal and the typhlosolar network in *D. communis* as has been assumed by some writers to exist in certain other forms.

METHODS OF OBSERVATION.

The method of working out the anatomy from sections was departed from to a great extent in working out the anatomy of the circularoty system of *D. communis* and instead dissected living specimens were used. A number of points were made out from sections, however, and as means of checking up those worked out on the living speci-

*The term oesophagus as used by Garman in his description of *Diplocardia communis* was applied only to the very narrow region between the pharynx and gizzard, while the narrow part of the alimentary tract following the gizzard and anterior to somite XVII he designated as the first ⁱdivision of the intestine. As has Bourne in his description of *Megascolex coreuleus*, I have used the term oesophagus to apply to any portion of the alimentary canal anterior to the large intestine which is not designated by any special name.

mens they proved quite useful.

The worms used for making the sections were placed in a shallow dish of water under a small bell jar in the presence of a small piece of cloth or cotton saturated with chloroform and allowed to remain there until completely anesthetized. They were killed and fixed in micro-sulphuric acid. The sections were cut 10 to 15 microns thick and stained in Flemming's triple stain. The safranin gave a beautiful red blood stain and enabled one to follow the capillaries into the integument with ease.

The best results were obtained as stated above, by a study of dissected living specimens. It required some little time to become proficient and accurate in the dissections but with proper care very few specimens need be lost in the preliminary work.

The worms were anesthetized by the method stated but were not allowed to become entirely motionless before dissecting. An anesthetized specimen was placed in a shallow petri dish containing a 4/5% salt solution and a strip of cork weighted down by lead. After pinning the anterior end of the worm to the cork it was opened either along the ventral or the dorsal median line care being taken not to sever any of the blood vessels. After pinning down the edges of the worm it was ready for study. If none of the larger vessels were broken the specimen remained alive and in good condition for more than an hour.

I was quite fortunate in having access to a Zeiss binocular dissecting microscope belonging to the State Laboratory of Natural History and made frequent use of it in this investigation. Artificial light from a 32 candle power incandescent light passed through a bulls eye condenser and thrown on the specimen enabled one to see

all vessels with little difficulty.

Very small specimens were examined between slides under a 2/3-inch objective but aside from the valves and a few points concerning the course of flow nothing of importance was made out from them.

ANATOMY.

Dorsal Vessel. (Figs. 1, 2, & 3, D. V.)-- The dorsal vessel is the chief pulsatile organ of the body and extends from the anterior part of the pharynx to the last somite of the body. It lies close to the dorsal wall of the alimentary tract but is not adherent to it in any part of its course. It bifurcates in the fourth somite and each of the two branches into which it divides breaks up into smaller branches on the pharynx and body wall. It is a single tube anterior to septum VI/VII, but posterior to this septum there are two such tubes in the middle region of each somite, while at the septa the two tubes fuse as previously stated.

As a general rule in Oligochaeta the dorsal vessel is of nearly the same diameter throughout its length but in *D. communis* it is quite small anterior to somite VI increasing in size to somite XIV where it reaches its maximum diameter. From somite XIV to XIX it is of nearly a uniform diameter but posterior to somite XIX it is a little smaller and continues with a gradual decrease in size to its termination at the posterior end of the body.

As stated in the introduction some worms are known which have the dorsal represented by two distinctly separate tubes while others are double only at the anterior end as *Megascolex coeruleus* and *Diplocardia eiseni*. Although the double condition as described

above predominates in *D. communis* several specimens were found in which the trunks of the dorsal were separated for as many as seven somites but this condition was never found anterior to XVII. Among nearly a hundred specimens dissected not one was found in which the dorsal vessel was a single tube in any region other than that mentioned above. In *Microchaeta rappi*,^{Boerne} ('86) the dorsal vessel is double but the two halves are closely bound together, and only recognizable as distinct by the presence of two quite separated blood-clots lying side by side in the apparently single tube. In somite VII the dorsal vessel, apparently simple, forms a very wide chamber which is divided by a longitudinal septum reaching nearly to the posterior extremity. One might expect to find in *D. communis*, in some cases at least, that the single tube of the dorsal at the septa was really double as in the case mentioned above, but from sections studied and all small worms in which such facts could be determined no indication of the double condition of the dorsal vessel at this point was found. Posteriorly the dorsal vessel ends abruptly as shown in Fig. 6.

Posterior to somite XIII the dorsal vessel is thickly coated with chlorogogue cells. A few may be found in somite XIII but anterior to it they are lacking.

Ventral Vessel. (Figs. 1, 2, 3 & 4, V.V).-- This is also known as the subintestinal or supraneural vessel. It is a non-contraction single tube supported from the ventral median line of the alimentary tract by a thin mesentery and extends the entire length of the body. Although it is held somewhat firmly by the septa, in the cavities of the somites it lies free and may be seen to fold upon itself. It bifurcates on the pharynx in somite III each branch ending in

the anterior network. Posteriorly it ends abruptly (Fig. 6).

Laterals. (Figs. 1, 2, 3 & 4, LV).-- As stated above, the lateral vessels originate anteriorly in a capillary network on the pharynx and body wall. They are larger than the ventral and lie close to the latero-ventral surface of the alimentary canal. Each bifurcates in somite IV, the anterior end of each branch being connected with a network of capillaries on the pharyngeal wall. This network is connected with the network into which the anterior branches of the dorsal and ventral vessels break up (Fig. 8). In somite V the lateral vessels leave the lateral surface of the gizzard on either side and assume a more ventral position (Fig. 8). The laterals are of a uniform caliber from somite VI to IX; from somite IX to XIII a gradual decrease takes place. In somite XIII they leave the oesophagus and pass slightly ventrad to the body wall along which they extend to XVIII (Figs. 3 & 5).

Supra-intestinal vessel. (Figs. 1 & 3, S.I.).-- As stated above, the supra-intestinal vessel in *D. communis* is a single tube which extends from somite IX to XIV inclusive. It reaches its maximum diameter in somites X to XII where it equals that of a single portion of the dorsal in that region. Anterior and posterior to this region it decreases rather abruptly disappearing in the tissue of the oesophagus. The supra-intestinal vessel is connected with the oesophagus by several short branches in each somite which are called by Bourne supra-intestiro-intestinal vessels. The supra-intestinal also has connection with hearts in somites X, XI and XII.

Dorso-tegumentary Vessels. (Figs. 4 & 5, D.T).-- These vessels are the branches of the dorsal which place it in communication with the

peripheral networks. They are slender, contorted vessels and are given off from the dorsal vessel just anterior to the septa in all somites posterior to XIII. They are entirely free from the intestine but are slightly attached to the septa by a thin mesentery. The pairs in somites XIV and XVIII are quite large and as Garman states, the former without branches reaches the body wall between the outer and inner pairs of setae. But contrary to his statement that they enter the integument, they join the clitellar division of the laterals directly, as do all the dorso-tegmentaries of the somites anterior to somite XIX.

The dorso-tegmentaries pass outward and slightly upward from the dorsal. They then follow along the body wall to which they give three or four branches (Fig. 4, b). Posterior to somite XX each dorso-tegmentary gives off from one to three branches which enter the intestinal wall (Fig. 4, a). As far as I know such a condition has not been described in any species of earthworm. Bourne describes them as branches of the main intestino-tegmentary vessel a vessel not present in *D. communis*. I believe, however, that these vessels in *D. communis* serve a similar function to that of the ones referred to in *Megascolex coeruleus*. Each dorso-tegmentary reaches the body wall between the lateral and ventral rows of setae where it divides into two branches, the larger extending dorsally along the body wall and the smaller ventrally.

Ventro-tegmentary Vessels. (Figs. 4 & 5, V. T).-- There is a pair of these vessels in each somite posterior to somite XIII. They are given off from the ventral just anterior to the septa and place it in communication with the peripheral network. They reach the body wall at about the same point as do the dorso-tegmentaries. The

largest of the ventro-tegmentaries are in somite XIV. They are larger than the dorso-tegmentaries and are quite short.

Ventro-intestinal Vessels. (Fig. 4, V.I).-- These are branches of the ventral placing it in connection with the intestinal capillary networks. In the middle of each somite posterior to somite XIII the ventral gives off one of these branches which enters the ventro-median part of the intestinal wall. In several of the larger specimens two or three of these vessels close together were found in several of the somites near the anterior end of the large intestine. They are not as large as the branches from the dorso-tegmentaries to the intestinal wall and are of such a length as to permit a free movement of the ventral vessel in the somite.

Dorso-intestinal Vessels. (Fig. 4, D.I).-- These vessels place the dorsal vessel in communication with the intestinal capillary network. There are no such vessels in somites I to XIV inclusive. In each of somites XV and XVI the dorsal gives off one pair of dorso-intestinals. There are two pairs of such vessels in each of the somites posterior to somite XVI except in the last twenty or twenty-five in each of which there is but one pair. One pair, the larger, is given off from the dorsal just anterior to the middle of the somite while the second is given off near the posterior septum. Both pairs enter the intestinal wall directly. The course of the anterior pair in the intestinal wall can be traced easily in a live specimen while that of the latter can be seen only in sections. In the intestinal wall they pass as distinct vessels to near the ventral surface where they become ⁰last in the intestinal network.

Lateral Branches. (Figs. 1, 2, 3 & 5).-- The laterals bifurcate in V

and anterior to this somite they give off several branches to the pharynx, gizzard and body wall. In somite V and each succeeding somite to IX inclusive each lateral gives off a branch to the body wall, (latero-tegmentary), one to the oesophagus and one to the septum. The latter which is quite a large branch spreads out over the thick septum sending some of its smaller branches to the body wall. Corresponding branches of the laterals occur also in somites X, XI, and XII. From the septal branches of the laterals in somite XI, branches extend through septum XI/XII to supply blood to the sperm sacs in XII. The sperm sacs of somite IX situated on septum IX/X are supplied by the septal branches of the laterals of that somite. The ventral parts of the septa in somites VI, VII and VIII are supplied with small branches from the latero-tegmentary branches of those somites. In somites V to VIII inclusive each lateral gives off a branch to the oesophagus. These are quite short and break up into smaller branches immediately on reaching the oesophageal wall. In somites IX to XIII inclusive there are in each somite at least two branches from each lateral to the oesophagus. These branches are larger than those of the anterior somites. In somite XIII the laterals give off two or three branches to the integument just before reaching it.

Hearts (Figs. 1, 2 & 3).-- There are eight pairs of contractile hearts connecting the dorsal and ventral vessels. These include all the contractile branches of the dorsal vessel. The five anterior pairs in somites V to IX inclusive are dorsal hearts, i.e. they are connected with the dorsal vessel only, at their dorsal ends; while the three posterior pairs situated in somites X to XII inclu-

sive are intestinal hearts, i.e. they are connected with both supra-intestinal and dorsal vessels.

The dorsal hearts arise from the vessel just anterior to the septa and pass ventrad around the oesophagus to the ventral. In the latero-ventral region (Fig.2, VC), each heart diminishes slightly in diameter and then immediately enlarges forming a chamber which contains valves. Because of the presence of these valves I have designated these chambers as valvular chambers. There are in *Megascolex coeruleus* such enlarged portions of the hearts which he calls muscular bulbs. Each valvular chamber of somite VI in that species gives off two branches neither of which reach the ventral. In somites VII to IX inclusive a branch is given off in each case below the muscular bulb, but in the hearts posterior to IX this bulb is at the juncture of the hearts and the ventral vessel.

In no case in *D. communis* did I find a branch given off from the heart at any other place than at one of these valvular chambers or bulbs.

From each of these valvular chambers a branch is given off to the posterior septum and oesophagus. A short distance from the ventral there is a second valvular chamber from which a branch passes to the body wall and one to the ventral vessel entering it somewhat ventrally. In the most anterior somites the branch joining the ventral and second valvular chamber is smaller than that passing to the body wall, but as we proceed posteriorly the former branch increases in size until in somite IX it is equal in diameter to the latter. The same condition of the dorsal hearts is repeated in each of the somites V to IX inclusive.

The condition of the intestinal hearts is more simple than

that of the dorsal hearts (Fig. 1, I.H.). They are considerably larger than the latter and the moniliform character of these vessels described in other worms is very conspicuous in them. Direct connection with the oesophagus and body wall is wanting but whereas the dorsal hearts take their origin from the dorsal vessel only, the intestinal hearts as the name indicates take their origin from both dorsal and supra-intestinal vessels. An examination of Fig. 1 will show that the connections of the hearts with the supra-intestinal vessel are much larger than those with the dorsal vessel. These intestinal hearts have valvular chambers at the junction of the hearts and the ventral vessel. All three intestinal hearts have relations precisely similar to one another.

Capillary Networks. (Figs. 1, 2, 3, 4, 5, 7, 8 & 9).-- In addition to the vessels described, longitudinal trunks and transverse vessels, there is in *D. communis* as in all Oligochaeta, a system of smaller vessels which form plexuses and may be termed capillaries. These capillary networks may be divided into two series, the peripheral and the intestinal.

Peripheral Networks.-- The network first to be described under this head is the one formed by the anterior branches of the dorsal, ventral and lateral vessels (Fig. 8, A N). From the figure it will be seen that this network is located on the body and pharyngeal walls in the first somite and the anterior part of the second. This network could be made out easily from a small specimen in a compressorium.

The peripheral networks in each of the somites posterior to somite XX are similar to one another. The dorso- and ventro-tegu-

mentaries reach the body wall at about the same point and pass dorsad along it giving off branches which pass into the muscular layers, (Fig. 4, P.N). The ventro-tegmentaries of one somite have direct connection with those of the following somite.

Anterior to somite XX and posterior to XII the peripheral network is more complicated than that just described (Fig. 5). As stated above, the laterals pass to the body wall in XIII and extend posteriorly along it near the ventro-median line to somite XVIII. The dorso-tegmentaries of these somites join these lateral-tegmentary vessels from which branches are given off to the body wall in each somite.

The ventro-tegmentaries of somite XIV supply the body wall in somites XII and XIII and in part in a few somites anterior to these. It will be seen in figure 5 that there are no continuous trunks extending posteriorly along the body wall which the ventro-tegmentaries join, but that each ventro-tegmentary vessel branches on reaching the body wall and supplies parts of two somites, the one in which the ventro-tegmentary is located, and the one posterior to it. In each somite there are branches given off from the two systems which pass to the nephridia and in somites XVIII and XX to the prostate glands. The septal branches of the laterals in X to XII inclusive reach the body wall and send branches along it both dorsally and ventrally.

The anterior branches of the ventro-tegmentaries of somite XIV extend anteriorly and fuse with the posterior branches of the hearts of IX. Branches are given off from these small trunks to the body wall in each somite from X to XIV inclusive (Fig. 5). An-

terior to somite IX the peripheral networks are formed by branches of the latero-tegmentaries and the tegumentary branches of the dorsal hearts. These branches divide on reaching the body wall one large branch extending dorsally and a smaller one ventrally. Anterior to somite V there is no particular segmental arrangement of the network but both the body wall and the pharyngeal wall is supplied with branches from the larger anterior branches of the dorsal, ventral and lateral vessels (Fig.8).

In each specimen in which the clitellum was well developed branches of the peripheral system in this region are much enlarged and distended with blood. In those specimens in which the clitellum was not so well developed the branches of the above system were correspondingly small. Sections showed that the muscular layers and hypodermis were well supplied with capillaries. I have no doubt that the development of the clitellum is correlated with the well developed condition of the peripheral network in somites XIII to XVIII.

Hypodermal Capillaries.- By means of sections capillaries were recognized in the muscular layers and also in the hypodermis of the body wall. The capillaries of the hypodermis in the region of the clitellum in *Lumbricus terrestris* have been figured by Claparède. Beddard ('83) first showed that capillaries also existed in the hypodermis of other parts of *Megascolex coeruleus* and some species of *Perichaeta* while Rosa ('87) showed that a similar condition existed in the epidermis of *Criodrilus*.

From Figure 9 it will be seen that branches of the peripheral system pass into the circular muscle layer and follow along it giving off many small capillaries which pass in among the hypodermal

cells. Corresponding vessels found in the leech by Lankester were termed by him intra-epithelial blood capillaries. Many of the hypodermal capillaries in *Diplocardia communis* form loops between the hypodermal layer and the circular layer of muscles.

Intestinal Networks. (Figs. 1, 7 & 10). - In the region of the oesophagus from somite VI to XVII the epithelial lining is closely longitudinally corrugated and especially so in somites IX to XIII inclusive. This latter region of the oesophagus is enlarged and well supplied with blood sinuses which are situated between the epithelial lining and the muscular layers (Fig. 1, B.P.). Beddard (86) describes a peculiar dilatation in the oesophagus of *Microchaeta rappi* which is quite similar to the region described above in *D. communis*. Where in *M. rappi* the network disappeared at the junction of this dilatation with both the preceding and succeeding parts of the oesophagus, in sections of *D. communis* the longitudinal trunks of the plexus could be traced as far as somite XVI. They were much smaller than those of the dilatation and more regularly arranged. There is also a dilatation at the posterior end of the oesophagus in *Enchytraeus ventriculosus* which seems to be similar to that of *Microchaeta*. Prof. Vejdovsky suggests that this organ functions as a liver but Beddard is of the opinion that the oesophageal dilatation of *Microchaeta rappi* as well as that of *Euchytraeus ventriculosus* probably correspond to the calciferous glands of *Lumbricus*. I believe that this is the correct view and that the dilatation in the oesophagus of *D. communis* carries on a function similar to that of the structures described above.

The intestine which begins at somite XVII is large and well

supplied with vascular networks and especially in the anterior two or three somites. The typhlosole begins in somite XXI and extends to the posterior end of the body. A representation of a cross section of the typhlosole is seen in figure 4. The typhlosole is accompanied by an immense development of blood capillaries which are a part of the intestinal network. This network is so dense and the interstices so small that the typhlosolar network appears to be a continuous sinus.

The internal network of the intestine is continuous from one somite to another and is formed of nearly parallel longitudinal trunks connected by short transverse ones. The meshes are more regular than are those of *Megascolex*. Figure 4 is from ^a cross section of the intestine through a pair of dorso-intestinals showing the meshes near the ventral surface of the intestine.

COURSE OF BLOOD FLOW.

Perrier ('74), according to Harrington ('99) and Bourne ('91), came to the conclusion that in *Lumbricus terrestris* the blood flows anteriorly in the dorsal vessel, downward in the hearts and posteriorly in the ventral vessel, also that the blood flows from the dorsal vessel to the intestine through the dorso-intestinals and into the dorsal from the dorso-tegmentaries. He also believed that the blood flowed through the ventro-intestinals into the ventral vessel and out through the ventro-tegmentaries to the body wall, and further that the blood flowed forward in the laterals.

According to Benham ('91) the course of blood flow in all vessels of *Lumbricus terrestris* agrees with that found by Perrier.

Bourne ('91) from a study of *Megascolex coeruleus*, worked out

a probable course of blood flow which is almost directly apposed to that given by Perrier. He agrees with Perrier that the dorso-tegmentaries and dorso-intestinals play opposite rôles but asserts that in each set of vessels the blood flows in the opposite direction from that asserted by Perrier. Bourne says that the blood flows through the dorso-intestinals into the dorsal and that through the dorso-tegmentaries blood flows away from it; the ventro-tegmentaries supply the body wall and nephridia, and the ventral receives blood through the ventro-intestinals. The blood is carried from the body wall to the intestine by the intestino-tegmentary system. The course of the blood in the laterals is toward the posterior.

Harrington ('99) studied the course of flow in small transparent specimens of *Perichaeta*, *Urochaeta*, *Allolobophora*, and *Lumbricus* held between watch crystals and with the aid of a dissecting lens. He came to the conclusion that the blood flows outward from the dorsal vessel through the dorso-tegmentaries into the sub-neural; into the dorsal from the dorso-intestinals; inward from the body wall through branches of the dorso-tegmentaries into the sub-neural; either anteriorly or posteriorly in the sub-neural; anteriorly in the laterals outward in the ventro-tegmentaries, and into the intestine through the ventro-intestinals.

Johnston ('02) studied the course of blood flow in *Lumbricus terrestris* and arrived at some conclusions different from any given up to that time. He studied the large specimens opened under physiological salt solution. He used three methods in determining the course of flow, viz: clamping the vessels, cutting them, and

watching the pulsations. He also tried injecting the vessels but this served no purpose in determining the direction of the blood flow.

Johnston supports Bourne in his view that the blood flows forward in the ventral vessel anterior to the hearts. He believes that the blood flows into the dorsal vessel through both dorso-intestinals and dorso-tegmentaries although his experiments on the latter were not wholly decisive. He also states that the blood flows posterior in the laterals; the ventro-intestinals supply the intestine, and the blood flows anteriorly throughout the entire length of the dorsal.

The results of my observations on the course of blood flow in *Diplocardia communis* given below are based on the examination of more than fifty living specimens. The animals were anaesthetized and opened as previously described, and by clamping and cutting the vessels, and watching the pulsations the direction of flow was determined. For the study of the course of flow chloretone proved to be a better anaesthetic than chloroform.

Dorsal Vessel.-- As in worms of other species the blood flows anteriorly in the dorsal vessel throughout its entire length. The pulsations can be traced to the anterior end of the body. They can be very readily seen anterior to the hearts in quite small specimens placed in a compressorium.

Ventral Vessel.-- By clamping and cutting the ventral vessel the course of flow posterior to the hearts was found to be backward but anterior to the hearts the blood flows forward. The ventral vessel of one specimen was clamped in VI after the anterior three or four pairs of hearts had ceased to pulsate, and the blood dis-

appeared in that part of the ventral anterior to the clamp. The ventral was cut at the point of the clamp and the blood flowed from the posterior part. In several other specimens the ventral was cut in a similar position with the same result.

Lateral Vessels.-- After clamping one of the laterals in VI the blood collected anterior to the clamp. The same vessel clamped farther back gave a similar result. This experiment was performed repeatedly in different regions of the laterals and in no case did the blood collect posterior to the clamp. Quite a number of experiments were made in which the laterals were cut, usually in somite XIII where they pass from the oesophagus to the body wall and in almost every case the flow of blood was posteriorly. In one specimen one of the laterals was punctured in somite VI and clamped alternately anterior and posterior to the puncture. When it was clamped posterior to the puncture the flow of blood from the opening was increased considerably but on clamping it anterior to the puncture the flow practically ceased. The blood evidently flows posteriorly in the laterals.

Dorso- and Latero-tegmentaries.-- Owing to the dense covering of chlorogogue cells it was quite difficult to see the blood in the dorso-tegmentary vessels of dissected living specimens. It could be seen only in small living specimens placed in a compressorium, and in no case was the least trace of a pulsation detected. The method resorted to for determining the course of flow was that of cutting the vessels and watching the flow of blood. The dorso-tegmentary vessels were cut at different points particularly near the body wall in some and near the dorsal in others. Except in a few

cases the greater amount of blood came from the distal end and in many experiments, especially those in which the dorso-tegmentaries were cut near the body wall there was very little if any flow of blood from both ends of the severed vessel. But while the flow from the distal end was steady and quite pronounced there was at first only a slight flow from the proximal end. In two cases in which the dorso-tegmentaries of the somites lying just posterior to the hearts were cut near the dorsal the slight flow of the dorsal end, mentioned above, was followed by strong pulses of blood produced by the pulsations of the dorsal vessel. Such cases by themselves might seem to indicate that the flow of blood through the dorso-tegmentaries is from the dorsal vessel to the integument but when considered in connection with the large number of cases in which the flow was obviously in the opposite direction, it seems very certain that the normal course of flow is centripetal.

Quite a number of experiments were made on the branches from the dorso-tegmentaries to the intestine (Fig. 4, A II) and in every case in which these vessels were cut the blood flowed only from the (dorso-tegmentary) end.

The latero-tegmentary vessels were cut in several different specimens and in the majority of cases a large flow of blood came from the distal end and only a slight flow from the proximal end. In one or two cases these vessels were clamped but without giving satisfactory evidence as to the course of flow. In all experiments in which there were any results they indicated a flow of blood from the body wall to the laterals. The results of experiments on the septal branches of the laterals which in somites X, XI, and XII

extend to the body wall although not as decisive as in the case of the latero-tegmentaries, indicated the same direction of blood flow.

Ventro- and Heart-tegmentaries.--- No vessels gave more positive results than these. The ventro-tegmentaries were cut in many specimens and the blood always flowed from the ventral only. Experiments were made by cutting a ventro-tegmentary and then clamping the ventral alternately posterior and anterior to the severed vessel. In the former case the blood came from the ventro-tegmentary more forcibly than when there was no clamp on the ventral, and in the latter case the flow of blood almost ceased. Similar experiments of cutting were tried on the heart-tegmentaries with a similar result. The experiments show that the blood flows from the ventral through the ventro-tegmentaries and from the hearts through the heart-tegmentaries to the body wall. In connection with the heart-tegmentaries it may be mentioned that in several specimens dorsal hearts were cut between the ventral vessel and the lower valvular chamber of the heart and in each case there was a flow of blood from both the proximal and distal ends. Since the stronger flow comes from the former it indicates a flow of blood from the ventral outward but under different conditions of pressure in the ventral and in the tegumentary system this may perhaps be reversed.

Dorso- and Ventro-intestinal Vessels.--- The course of flow in the dorso-intestinals was determined by watching the pulsations which in several specimens were easily seen. Several of these vessels were cut and in every case the blood flowed from the intestine.

These two experiments seem to warrant the conclusion that the pulsations were from the intestine to the dorsal. A number of ventro-intestinals were cut in several different specimens and only in a few cases was there any flow of blood. The flow of blood was always from the ventral. The small size of these vessels may perhaps have permitted a rapid coagulation of the blood by the salt solution with which the vessel came in direct contact.

Supra-intestinal Vessel.-- (Fig. 1, S I). This vessel receives all of its blood from that region of the oesophagus over which it lies, by several short connecting vessels in each somite. As has been stated, this blood flows through the intestinal hearts into the ventral. In one specimen in which the pulsations of the dorsal had ceased, it was empty of blood in the anterior region but the intestinal hearts were still pulsating and the blood was coming from the supra-intestinal vessel. The region of the oesophagus supplying the blood to the supra-intestinal receives its supply of blood from the laterals.

CONCLUSIONS.

The course of blood flow in *Diplocardia communis* according to the results of the above experiments is as follows:- The dorsal receives its entire supply of blood from the dorso-intestinals and dorso-tegmentaries. This lends support to Johnston's ('02) conclusion in regard to similar vessels in *Lumbricus terrestris*. The greater part of the blood passes from the dorsal through the hearts toward the ventral while the remainder flows on to the anterior network.

The direction of flow in the ventral vessel was found to agree

with that described by Bourne and Johnston, viz, that the blood flows anteriorly in front of the hearts and posteriorly back of them. That part of the blood which flows anteriorly enters the anterior network (Fig. 8, AN) where it mingles with that from the anterior portion of the dorsal.

From the anterior network the blood flows posteriorly through the laterals supplying the oesophagus in each somite. That part of the blood in the laterals that does not pass into the oesophagus flows into the clitellar part of the peripheral network thence into the dorsal vessel through the dorso-tegmentaries. (Fig. 5).

The body wall is supplied with blood by the ventro- and heart-tegmentaries. This blood after having passed through the peripheral network, supplying the body wall, nephridia and reproductive organs, is in the anterior region, collected and returned to the laterals by the latero-tegmentaries and septal branches of the lateral, and in the posterior region to the dorsal vessel and intestine by the dorso-tegmentaries. (Fig. 4).

From figure 5 it will be seen that the body wall of somites X - XV inclusive are supplied with blood by the ventro-tegmentaries of XIV and the heart tegmentaries of IX. These vessels take the place of the heart tegmentaries of X, XI and XII. The blood supplying the latter somites is returned to the lateral vessels by the septal branches of the laterals mentioned above.

The intestine in somites XV - XX inclusive receives blood only from the ventral through the ventro-intestinals while posterior to XX it receives blood from both the ventro-intestinals and the branches of the dorso-tegmentaries to the intestine. Judging from

the size of the efferent and the afferent vessels of the intestine, the amount of blood carried by each is about equal.

The direction of flow in the blood vessels of *D. communis* in so far as they correspond with those of *Lumbricus terrestris* agrees with that found by Johnston in the latter species.

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EXPLANATION OF PLATES.

A N	Anterior network.
B C	Blood capillaries.
B P	Blood plexus of the oesophagus.
C L	Layer of connective tissue.
C M	Circular muscle layer.
D I	Dorso-intestinal vessels.
D V	Dorsal vessel.

E C	Epithelial cells.
E L	Epithelial layer.
H	Dorsal heart.
I H	Intestinal heart.
Int. Cap.	Intestinal capillary network.
Int.	Intestine.
I N	Intestinal network.
L M	Longitudinal muscle layer.
L I	Latero-tegumentary vessel.
L V	Lateral vessel.
I	Intestino-tegumentaries. (?)
N	Blood vessels of the nephridia.
N C	Nerve cord.
Oe S	Oesophagus.
P G	Blood vessels of the prostate glands.
P N	Peripheral network.
S I	Supra-intestinal vessel.
S'pt. Br.	Septal branch.
Ty	Typhlosole
V	Valves.
V C	Valvular chamber.
V I	Ventro-intestinals.
V V	Ventral vessel.
X	Branch from the heart to the oesophagus and septum.

Fig. 1. - A diagram^matic representation of a cross section through a pair of Intestinal hearts showing the important vessels of

the somite. X 30.

Fig. 2.- A diagrammatic representation of a cross section through a pair of dorsal hearts showing the important vessels of the somite. X 35.

Fig. 3. - A diagrammatic representation of the vessels of somites IX, X and XIII. X about 17.

Fig. 4.- A diagrammatic representation of a cross section of the intestinal region X 35.

Fig. 5 represents the peripheral network of the clitellar region. X about 18.

Fig. 6.- A diagrammatic sketch of the relation of the dorsal and ventral vessels at the posterior end.

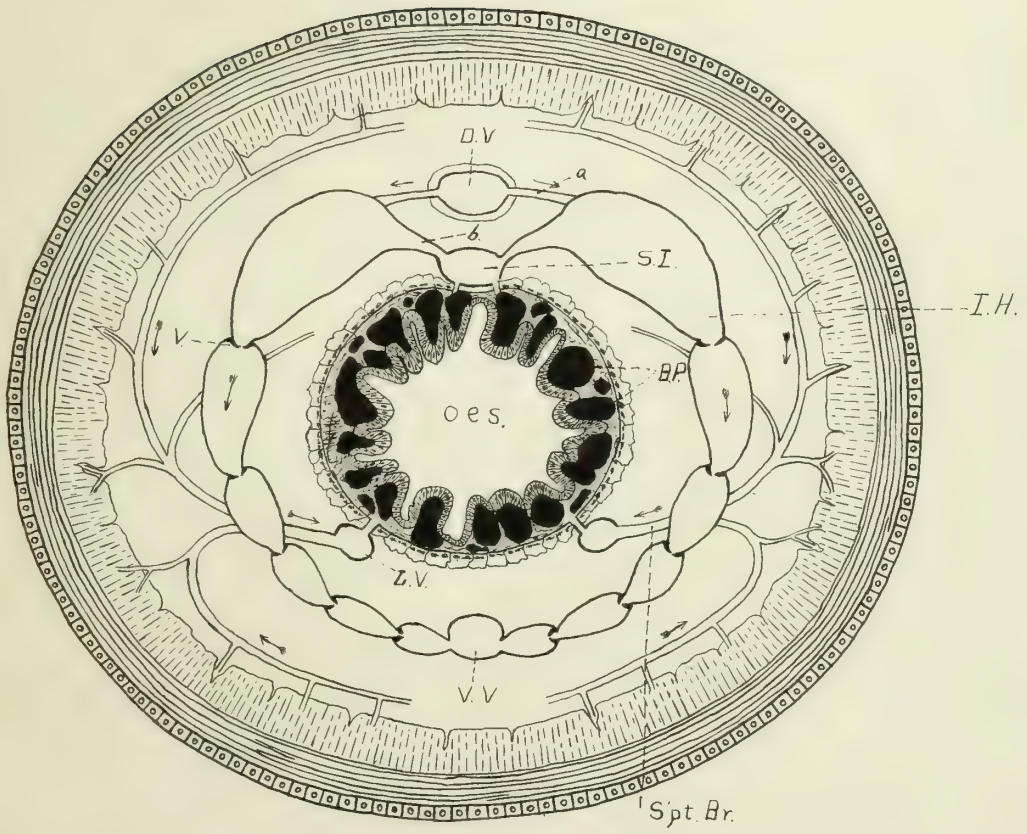
Fig. 7 represents a part of a cross section of the intestinal wall X 500.

Fig. 8.- A diagrammatic representation of the relations of the dorsal, lateral and ventral vessels in the anterior region. X about 8.

Fig. 9.- From a cross section of the body wall, showing the hypodermal capillaries. X 500.

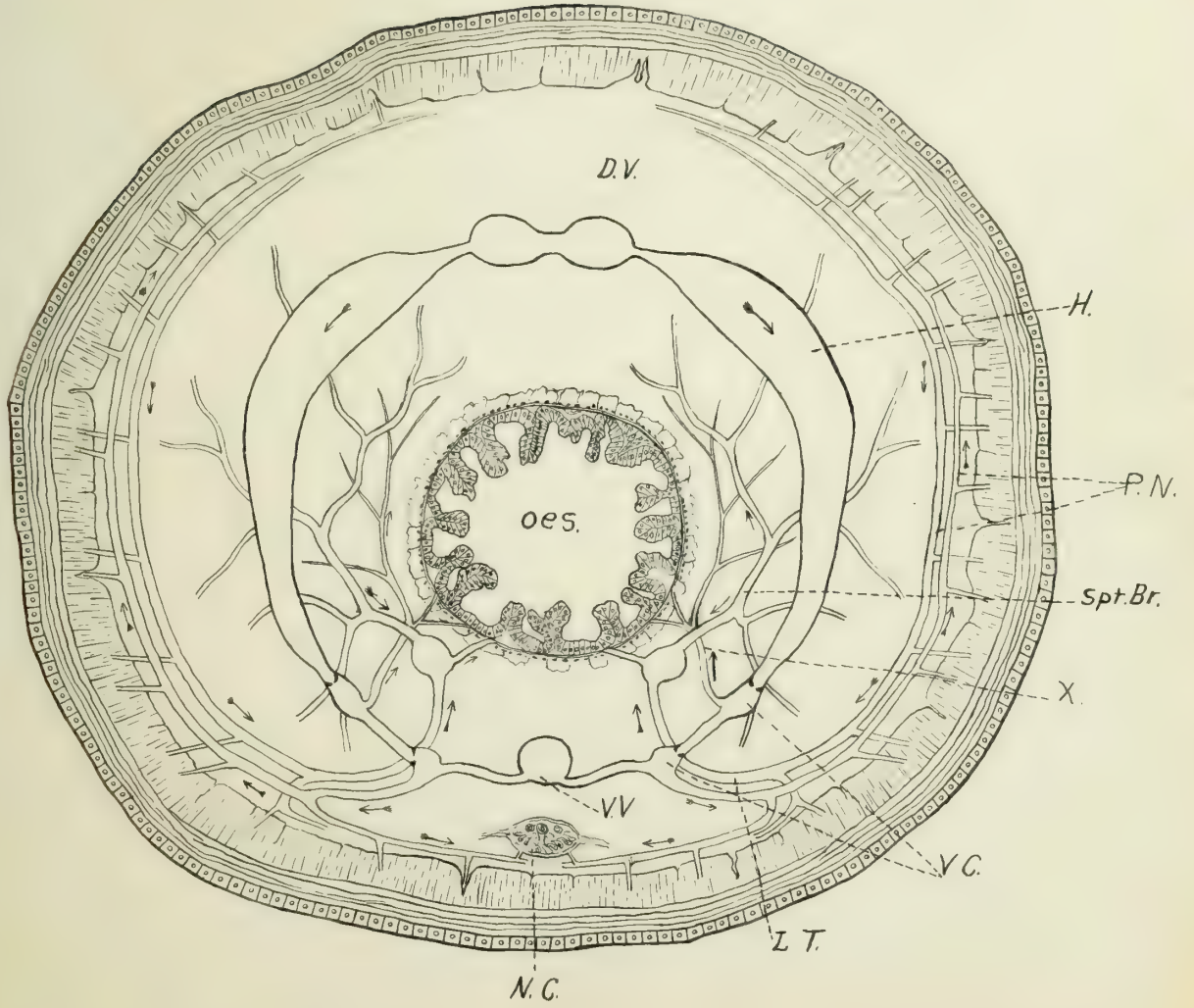
Fig. 10.- From a cross section of the oesophagus of somite XVI. X 40.

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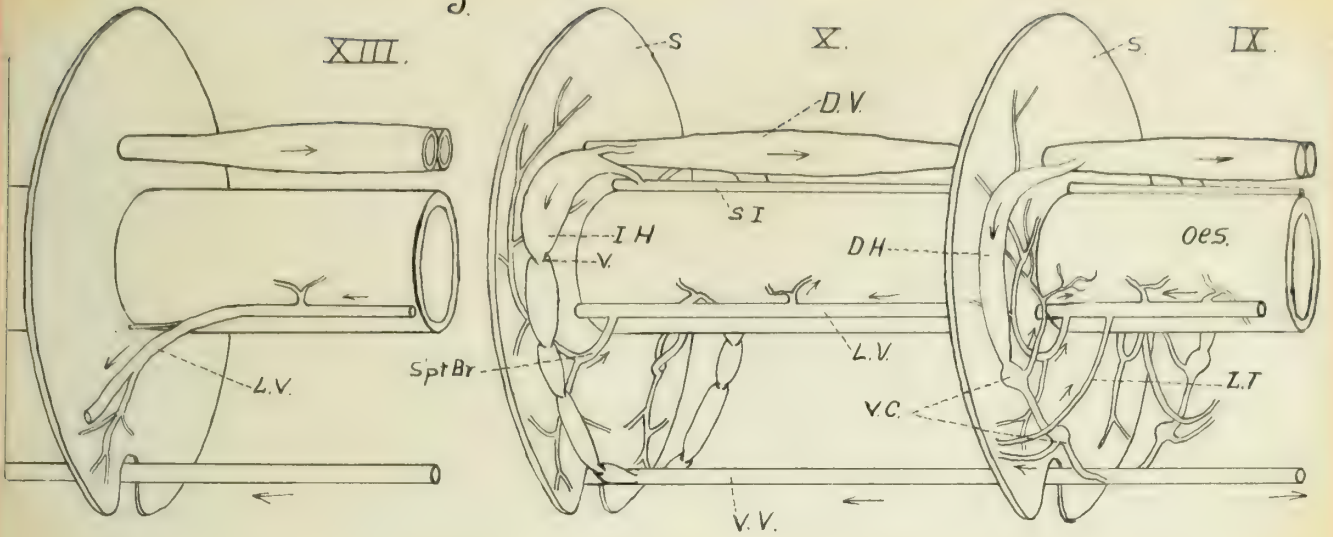
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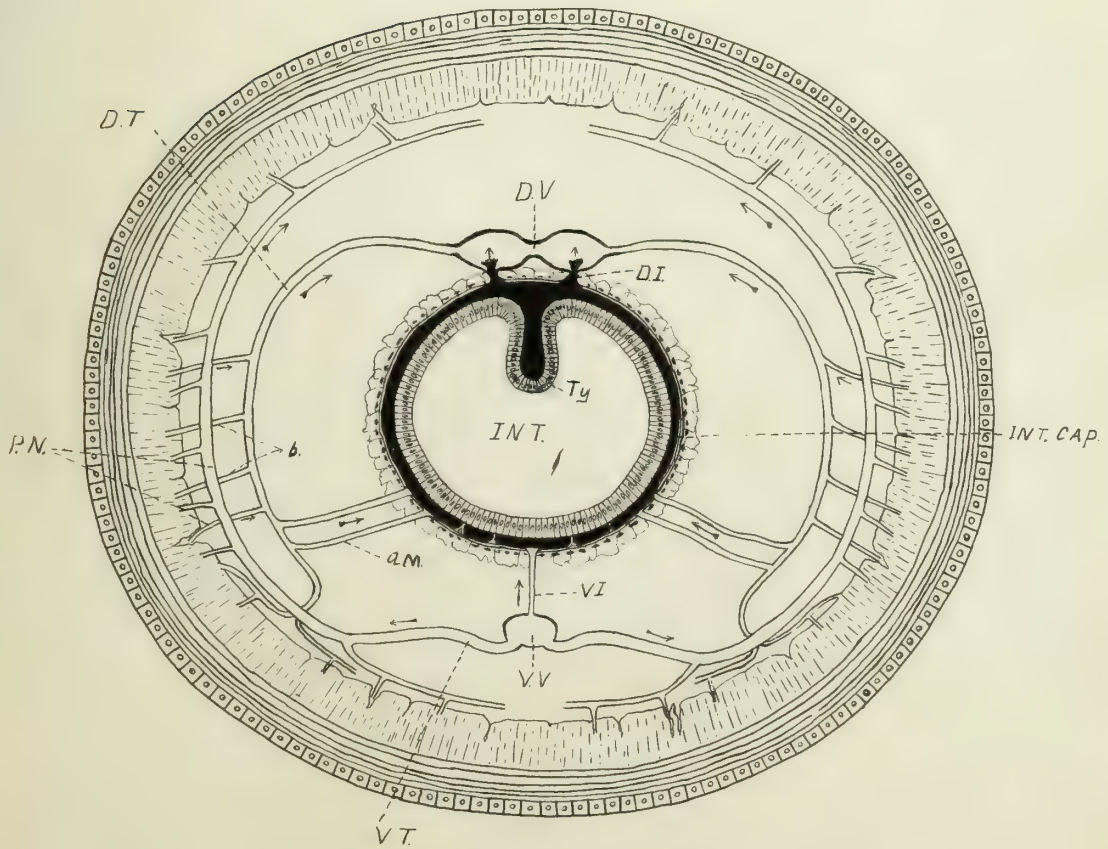




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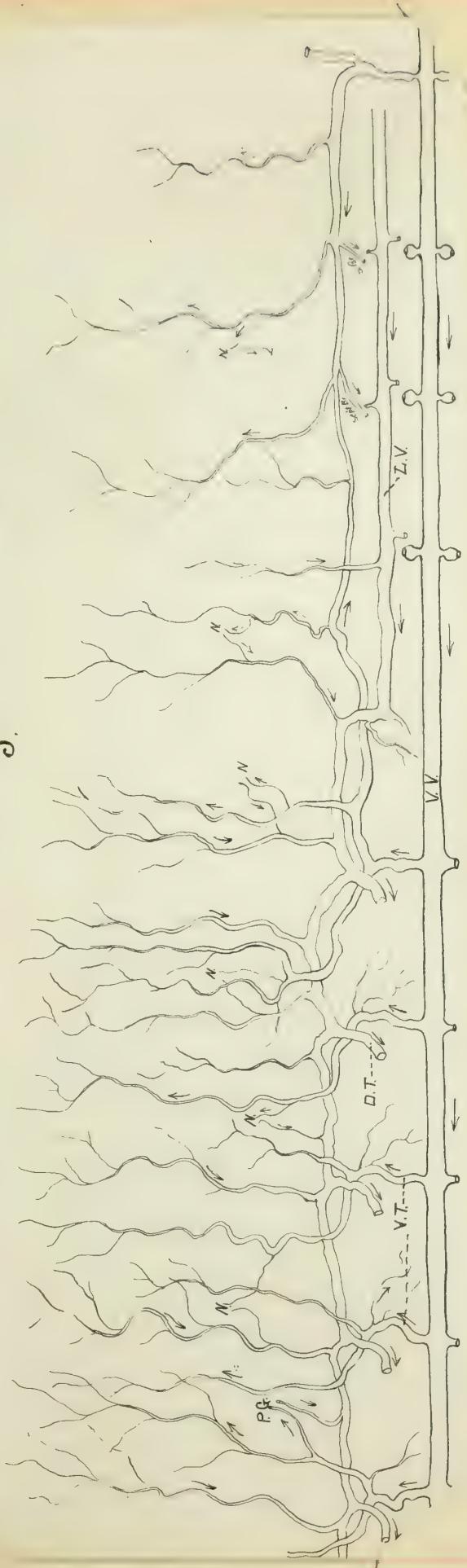


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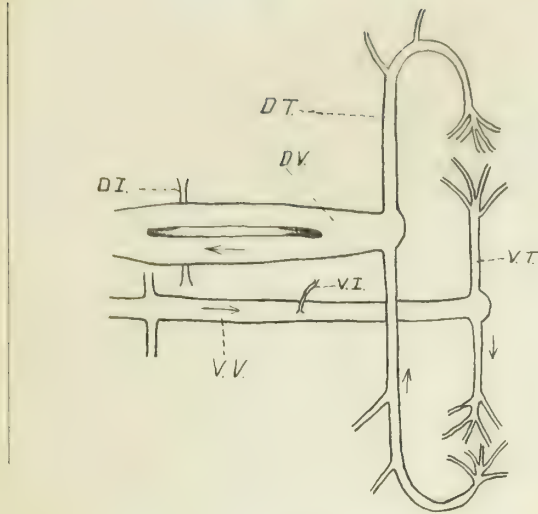
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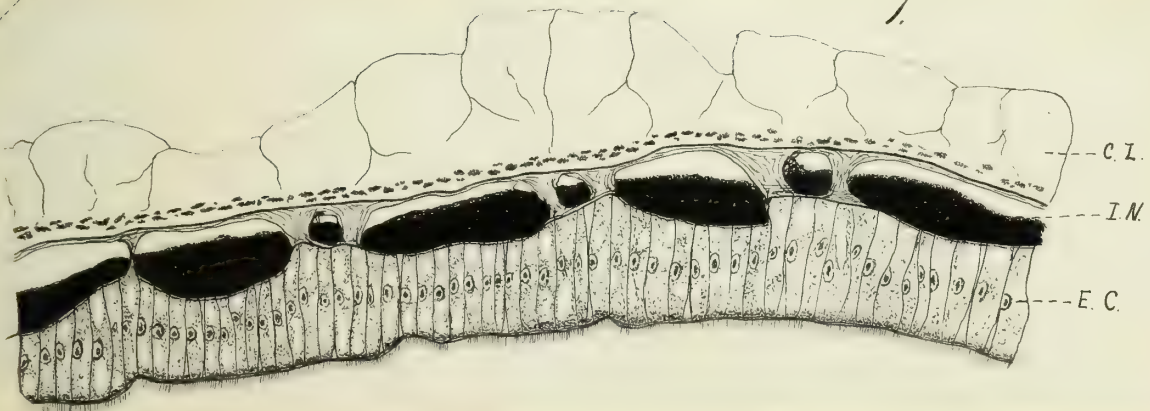




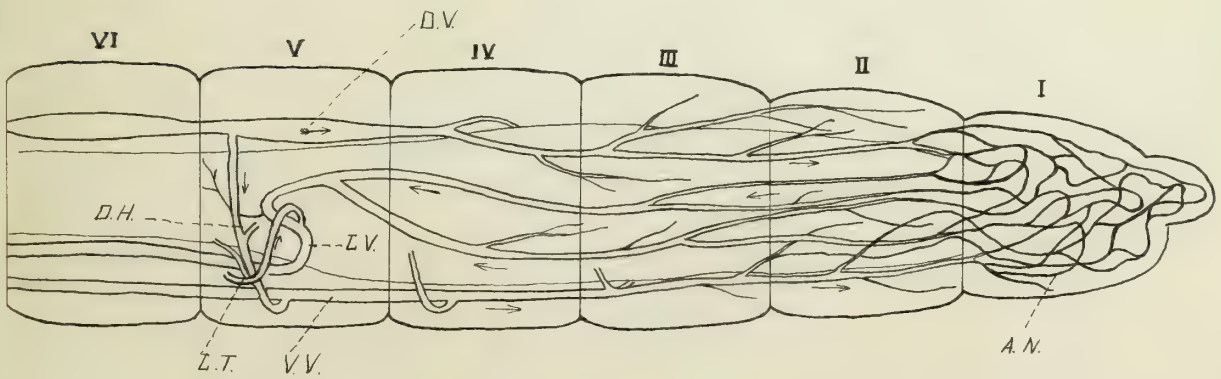
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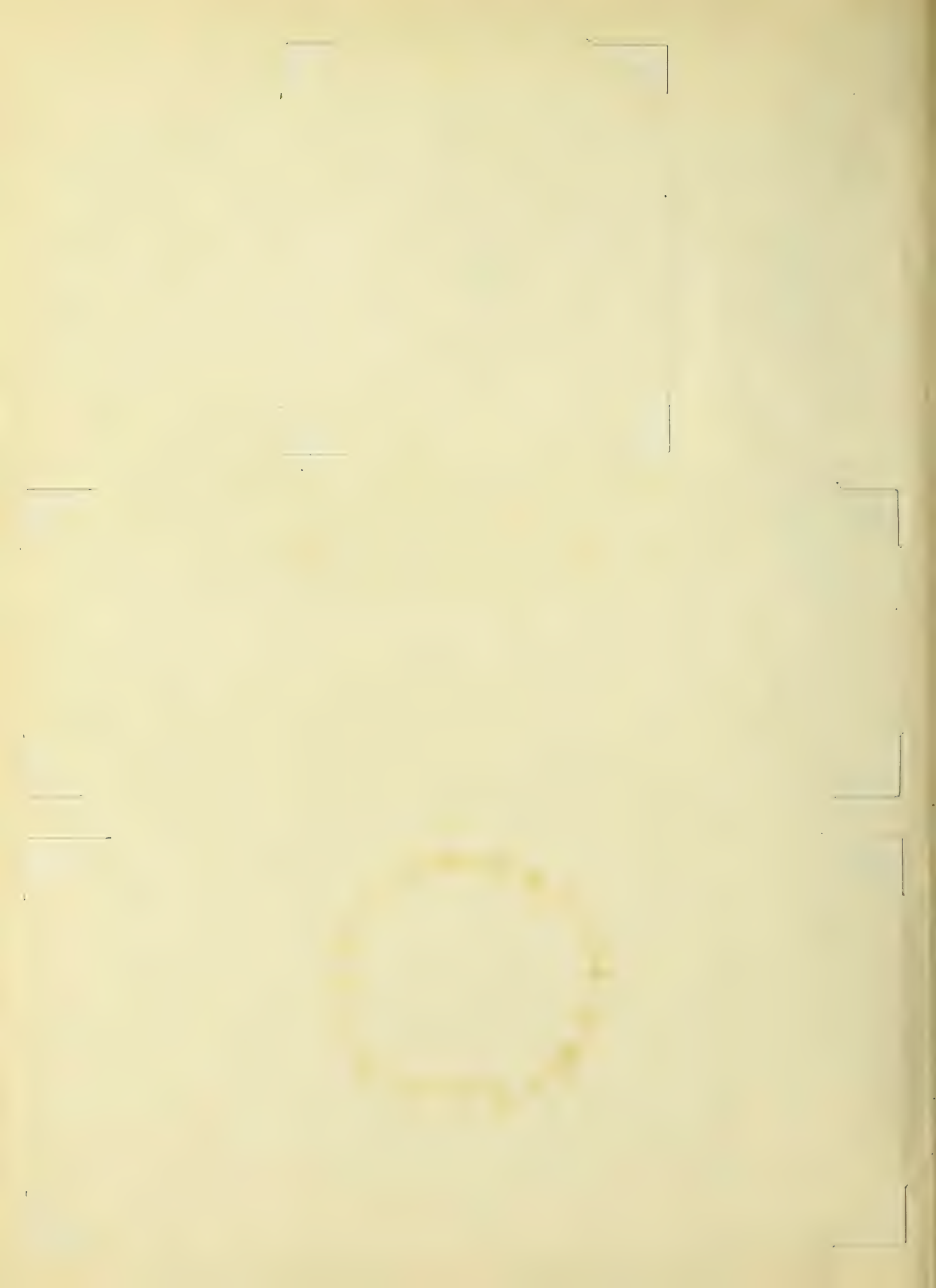


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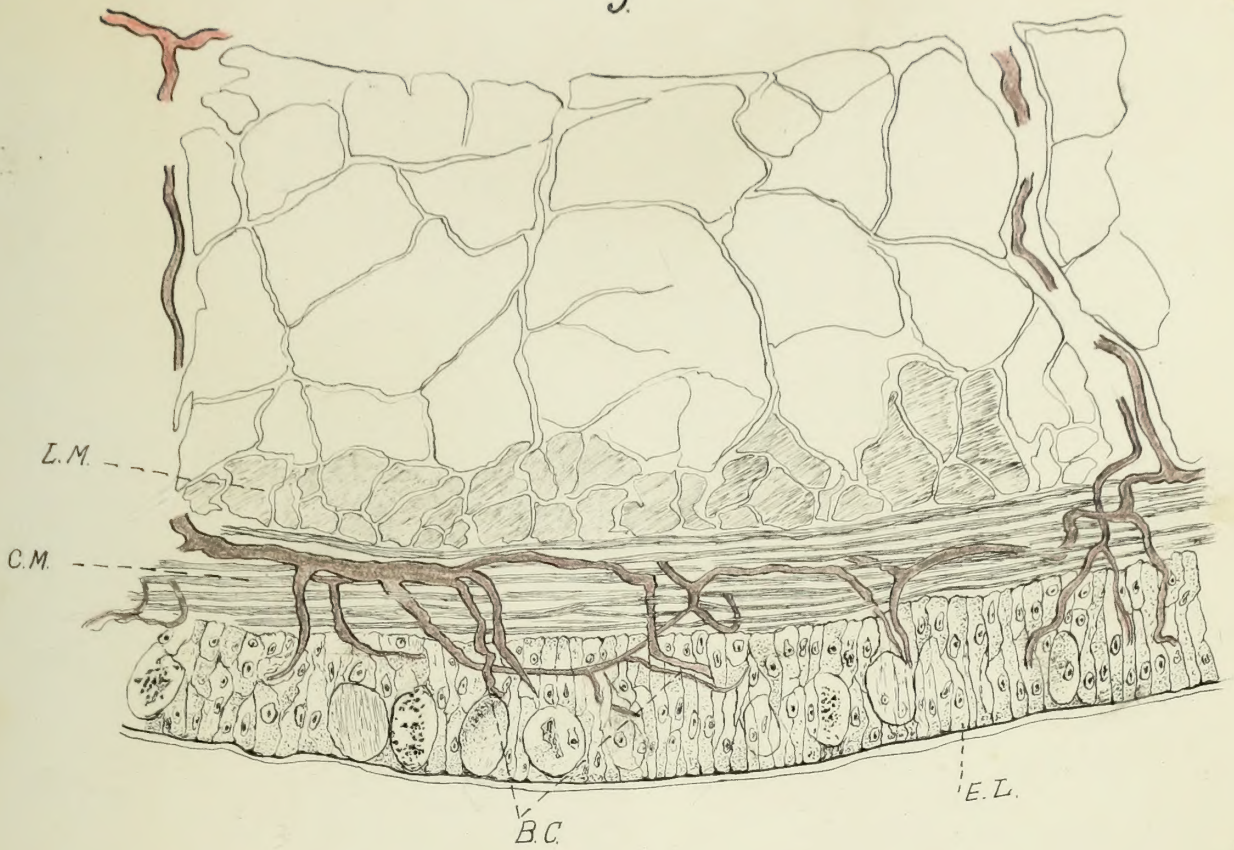


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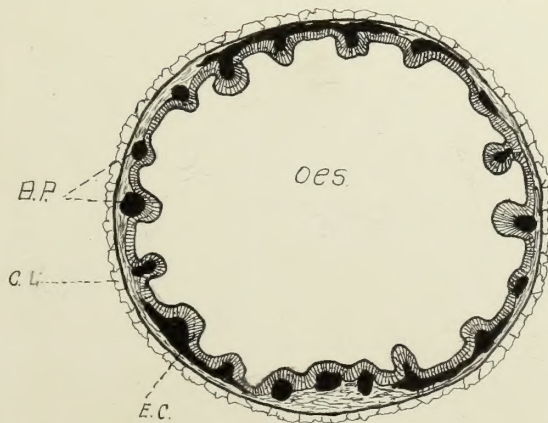


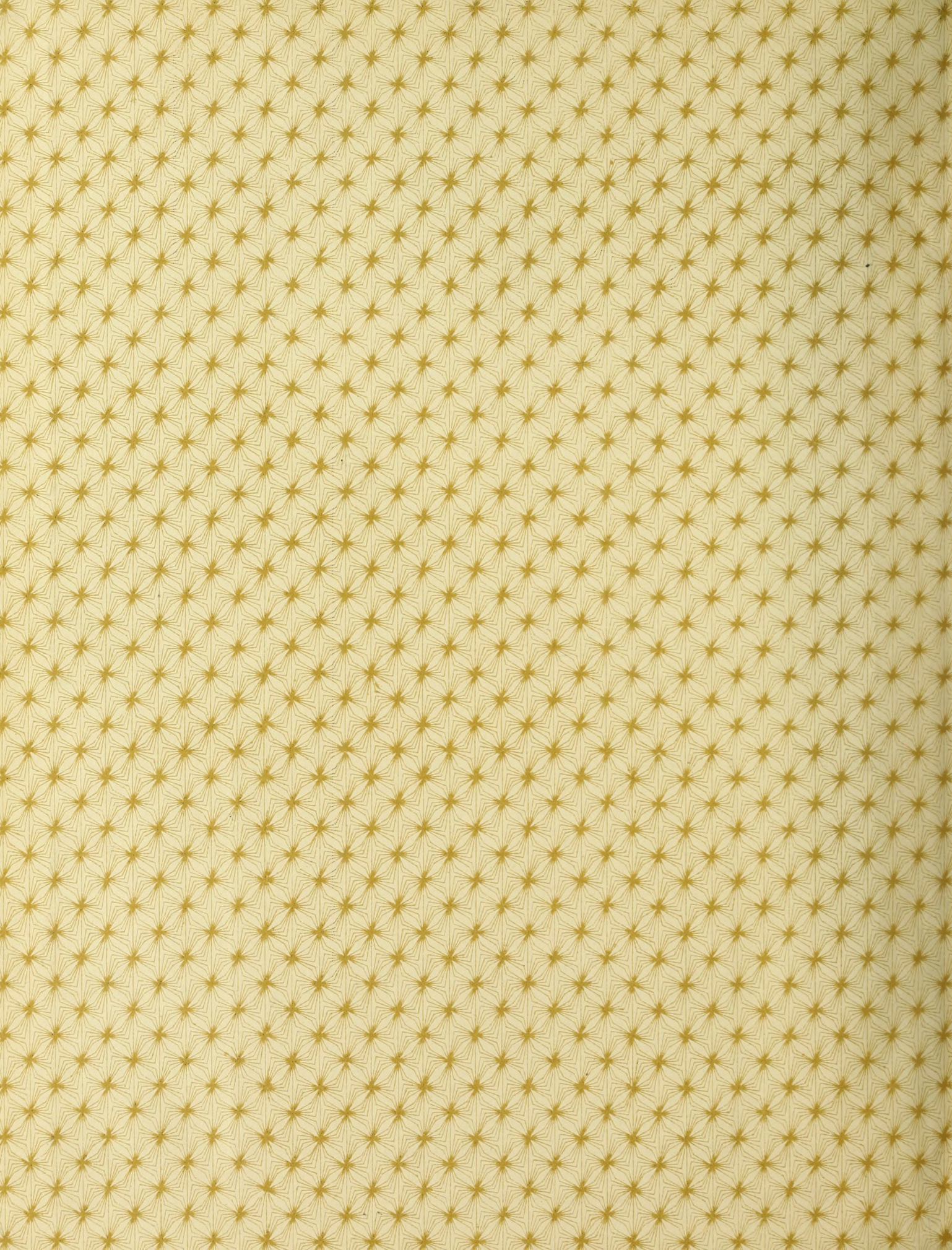


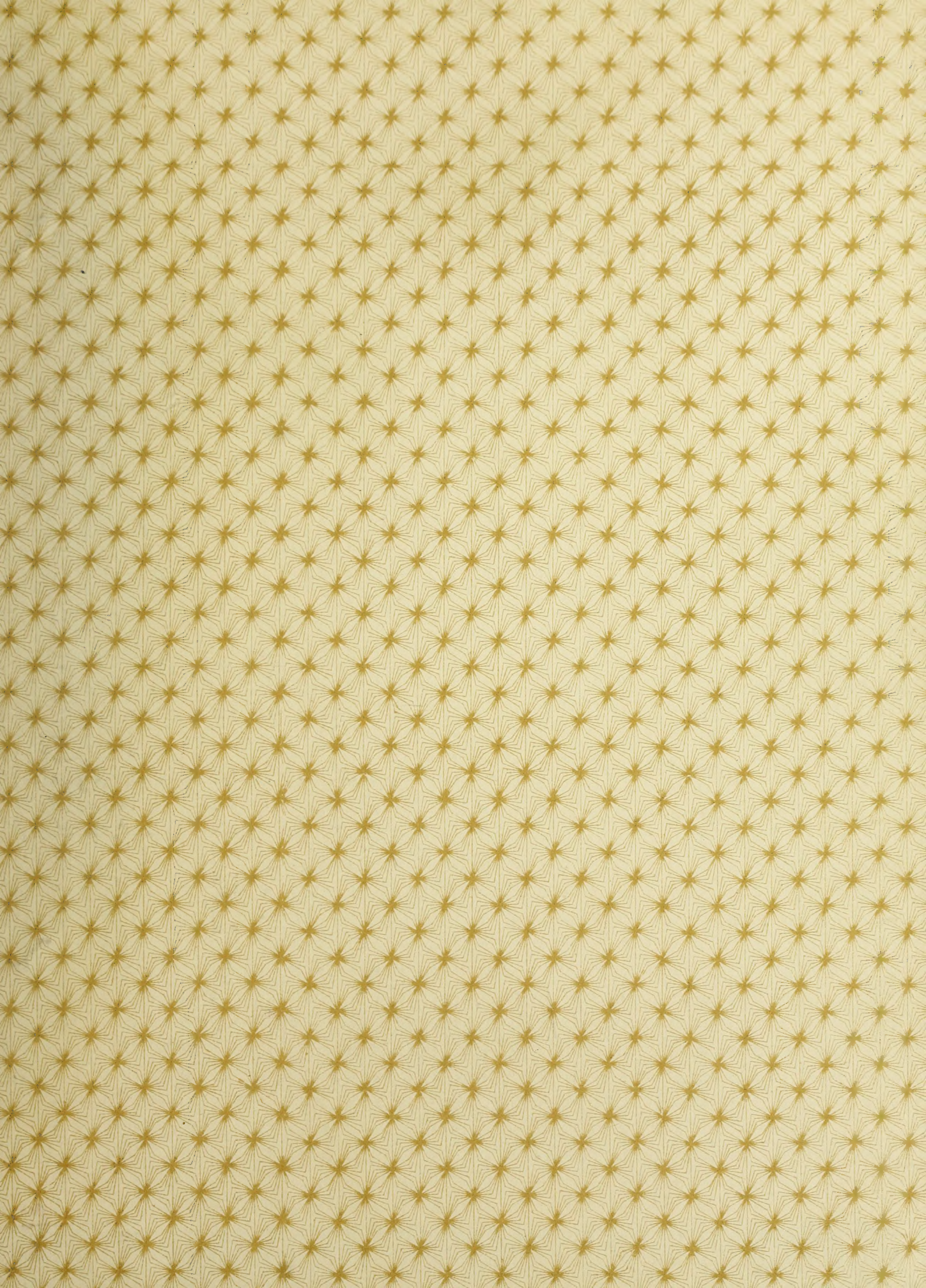
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