

Zoology. — "*On the Shape of some Siliceous Spicules of Sponges*";
by Dr. G. C. J. VOSMAER.

The perplexing amount of variety exhibited by sponge spicules has since long made it desirable 1st to designate certain spicules by special terms, and 2nd to divide the spicules into groups. The first attempt to such a classification was made by BOWERBANK in 1858; later, in 1864, modified by the same author. BOWERBANK divided (1864 p. 13) the spicula into "essential skeleton spicula" and "auxiliary spicula". It is obvious that this primary classification is not based on morphological characters. Since KÖLLIKER (1864) has pointed out the morphological value of the axial canal or, more correctly, the axial thread ("Centralfaden"), OSCAR SCHMIDT has rightly based his classification of siliceous spicula on the presence of one or more of such axial threads, which after all represent the axes of the spicula. SCHMIDT distinguishes (1870 p. 2—6) four types of spicules:

1. „Die einaxigen Kieselkörper."
2. Die Kieselkörper, deren Grundform die dreikantige reguläre Pyramide."
3. Die dreiaxigen Kieselkörper."
4. Die Kieselkörper mit unendlich vielen Axen."

Neither GRAY (1873, p. 203—217), nor CARTER (1875, p. 11—15) understood the fundamental value of SCHMIDT's classification. My attempts to draw attention to it (1881 *a* and 1884 p. 146—168) have had but little influence. Thus, in 1887, RIDLEY & DENDY divide the spicula of the Monaxonids in the first place into Megasclera and Microsclera, a classification which practically agrees with those of BOWERBANK and CARTER. The example was followed by SOLLAS in spite of his being well aware of the fact that the distinction is far from "absolute". This author quite correctly remarks (1888, p. LIII): the microscleres and megascleres pass into each other by easy gradations, so that it is not possible to say where one ends and the other begins, indeed there would be a certain convenience in accepting a third division of intermediate or middle-sized spicules, which we might call mesoscleres." Finally, in 1889, SCHULZE & LENDENFELD accept SCHMIDT's primary division into "polyaxone, tetraxone, triaxone, and monaxone Nadeln."

I do not intend to discuss here the triaxons and tetraxons; for the present I only wish to draw attention to some monaxons and some spicules hitherto generally considered as polyaxons.

In the group of the monaxons, i. e. spicula with one single axis, two fundamental divisions may be distinguished, according to the

fact whether the ideal axis lies in a plane or not. In the former case the line may of course be straight, curved, bent, flexuous etc.; in the latter case the line is a screw helix ¹⁾. The spicula belonging to the former case I propose to call *pedinaxons* ²⁾, the others *spiraxons* ³⁾. To the group of the pedinaxons belong e. g. oxea, styles, tylostyles, some of the "amphidisci", some of the "toxa". It is, however, to the spiraxons, that I wish more especially to draw attention.

Again we can distinguish here two cases: α . the screw line is formed on the surface of a circular cylindre or β . on that of an elliptical cylinder. The former group I wish to call α -*spiraxons*; the pitch is here generally large. The latter I call β -*spiraxons*; the pitch is here small.

Let us first examine the α -spiraxons. To this group belong the spicula known as sigmaspires, toxaspire, spirules; further those which are usually called spirasters and which are by the majority of spongiologists erroneously considered as modified asters. This mistake is due, I believe, to OSCAR SCHMIDT. „Eine blosse Modification dieser Kugelsterne," he says, 1870, p. 5, „sind die Spiralsterne oder Walzensterne. Sie werden zwar in manchen Spongien nur allein, d. h. nicht untermischt mit den Kugelsternen angetroffen (*Spiraustrella cunctatrix* Sdt. *Chondrilla phyllodes* N.), häufiger aber, wie wir unten in die Specialbeschreibung (z. B. von *Sphinctrella horrida* N. und *Stelletta hystrix* N.) hervorheben werden, liegen alle Uebergänge von den normal centralen Sternen zu den gezogenen Spiralsternen vor." Unfortunately did SCHMIDT not keep his promise; for in the description of *Sphinctrella horrida* we find nothing more about it, and *Stelletta hystrix* is forgotten altogether. SCHMIDT failed, therefore, to give any proof whatever for his statement that "Spiralsterne" are modified "Kugelsterne". SCHMIDT's suggestion has nevertheless generally been accepted, myself not excluded.

SOLLAS (1888, p. LXI) distinguished two chief series of spicula (microsclera): "the radiate or astral, and the curvilinear or spiral." The former are called "asters," the latter "spires." With some astonishment we further read that the asters are divided into two

¹⁾ These terms are to be taken cum grano salis. No biological formation will ever be absolutely mathematical; thus it may be that the axis of a flexuous or undulating spiculum is not exactly lying in a plane, without, however, being in any way comparable to a screw helix.

²⁾ $\pi\epsilon\delta\iota\upsilon\acute{o}\varsigma$, plane, even.

³⁾ $\sigma\pi\acute{\iota}\zeta\alpha$ (lat. spira), everything which is twisted.

subsections. "the true asters or euasters, and the streptaster or those in which the actines do not proceed from a centre but from a larger or shorter axis, *which is usually spiral*". Evidently one should expect that those "streptasters" were arranged under the "spires." As a matter of fact neither SOLLAS, nor any other author has given very striking arguments to consider the spiraster as a modification of the euaster. We know examples of very young stages of spirasters, they always possess the twisted character. But no instance is known of spirasters originating from or forming transitions to true asters. It is true that such supposed transitions are mentioned by some authors; but probably we have here to do with a mistake due to optical delusion. For instance, SCHMIDT described (1862, p. 45) a *Tethya bistellata*, possessing in addition to ordinary asters, double ones ("Doppelsterne"). But LENDENFELD described (1897, p. 55—58) a *Spirastrella bistellata* (which he considers identical with *Tethya bistellata* O.S.), in which he found that the supposed asters are true "spirasters". Judging from what I saw in a type specimen of SCHMIDT's sponge, I have no doubt that LENDENFELD is right. Quite correctly LENDENFELD believes that SCHMIDT has been misled by an optical delusion, "da diejenigen Spiraster deren Axen im Preparat aufrecht stehen und daher verkürzt gesehen werden, häufig wie Euaster aussehen". . . . I fail to find a single proof that spirasters are modified euasters, either in previous papers, or in my preparations. On the contrary, everything speaks in favour of the view that "spirasters" are a sort of α -spiraxons. The fact that in some cases it is difficult to get certainty about the twisted shape, is no proof against my suggestion in general. For in the great majority of cases the twisted nature is certain, as can be demonstrated by allowing the spiculum to roll in the preparation when observed through the microscope.

Let us proceed now to examine the *different sorts* of α -spiraxons.

1. *Sigmaspira*.

SOLLAS (1888, p. LXII) gives the following definition of the sigmaspira: "a slender rod, twisted about a single revolution of a spiral"; he adds that it appears in the form of the letter C or S, according to the direction in which it is viewed. The definition of the "toxaspire" runs as follows: "a spiral rod in which the twist a little exceeds a single revolution. The pitch of the spiral is usually great and the spicule consequently appears bowshaped when viewed laterally". . . . It seems to me not quite exact when SOLLAS pretends that the bowshaped appearance is in the first place due to the number of revolutions.

Considering the facts that these spicula are generally very small, and that consequently a microscope of very high power is wanted to understand the true shape, it is evidently not easy to determine the number of entire revolutions or parts of it; the same may be said of the pitch of the „spiral” — or rather of the screw helix.

In order to obtain certainty about this I constructed wax models, the axis of which were screw helices of various length and various pitch, of course all drawn on the same circular cylinder. The diameter of the models I made in accordance to the relative size observed in the spicula. Such a set of models ought to be carefully studied *in projection*. This can be done by looking at them with one eye, or, which is far better, by studying the shadows of the models in various positions. These projections are then compared to the camera-drawings or microscopical projections of the spicula themselves. This method most clearly shows 1st that the bow-shape can be obtained with models of less than one revolution; 2nd that the C- or S-shape can be obtained with models of more than 1½ revolution. This depends both on the length and the pitch of the screw helix, as is shown by the following table 1):

Number of revolutions.	Pitch.			
	10°	20°	30°	40°
2/3	C — —	C [S] (Λ)	C [S] Λ	
3/4	C [S] —	C S (Λ)	C S Λ	
5/6	C (S) [Λ]		C S Λ	C, S Λ
1	[C] (S) [Λ]	(C) S Λ	C S Λ	C S Λ
1 1/6	— [S] (Λ)	(C) S Λ	C S Λ	
1 1/4	— (S) Λ	(C) S Λ		C S Λ
1 1/3	— (S) Λ	C S Λ	C S Λ	
1 1/2	— (S) Λ	(C) (S) Λ		C (S) Λ
1 3/4	— [S] (Λ)	— [S] Λ	— — Λ	— [S] Λ
1 5/6			— — Λ	
2	— — —	— — —		— — [Λ]

1) C, S or Λ means. C-shape, S-shape or bow-shape distinct; () means indistinct; [] means very indistinct. A dash — means that the shape cannot be obtained with the wax model.

This result leads us to a dilemma. Either the definitions of sigma-spira and toxaspira will have to be modified, or we have to drop the distinction between the two forms of spicula. I believe that it follows from the above table that the latter way out of the difficulty is preferable. We may maintain the name sigmaspira for smooth, i. e. not spined α -spiraxons of no more than $1\frac{1}{2}$ revolution.

LENDENFELD (1890 p. 425) has another conception of the sigmaspira: "ein einfach spiralig gewundener oder bogenförmiger Stab." Hence he seems to accept two different kinds, instead of considering them as belonging to one sort, the shape of which simply differs according to the direction in which it is viewed. Since he says that his "spirul" has "mehr wie eine Windung", he seems to accept no more than one revolution for the sigmaspire. This is not in accordance with my observations, as laid down in the above table.

2. *Spirula*.

Although CARTER did not give a special definition of the spirula, it is clear enough what he understands by this name. In his paper on the "spinispirula" (1879 α p. 356) he calls the spiculum which he formerly (1875 p. 32) described as "sinuous subspirul", simply "the smooth form of the spirula" and he refers to an illustration of the spicule as it occurs in *Cliona abyssorum* (1874, Pl. XIV, p. 33). Obviously the term spirula used by CARTER is an abbreviation of "spinispirula", not as *terminus technicus*. RIDLEY & DENDY (1887 pp. XXI and 264) introduce the term spirulae as synonym with spinispirulae of CARTER, adding that "these are more or less elongated, spiral or subspirul forms, which may be either smooth or provided with more or less numerous spines." SOLLAS creates (1888 p. LXII) the term polyspire for spirula, stating that it is "a spire of two or more revolutions", adding, however, that he is inclined to adopt the term spirula. In the list given by SCHULZE & LENDENFELD (1889 p. 28) we find a "spirul" described as "spiral gewundene Nadel mit mehr als einer Windung". Consequently we learn that the term spirula by some authors is used both for smooth and for spined forms, whereas others leave the question open. LENDENFELD (1890 p. 426) proposes the name for smooth spicula only: "eine schlanke und glatte, spiralig gewundene Nadel mit mehr wie einer Windung". I herein agree with LENDENFELD and I understand by spirula: a smooth α -spiraxon of at least $1\frac{3}{4}$ revolution.

3. *Spinispira*.

As long as the α -spiraxons are smooth it will as a rule not create any difficulty to distinguish sigmaspirae and spirulae. But there are

a quantity of spined α -spiraxons. Evidently such spined α -spiraxons will exhibit the twisted nature the less distinctly the more the spines are developed. It is, therefore, not practical in this case to make distinctions, based on the number of revolutions. Especially not because there exists a great diversity with many transitions. I prefer, therefore, to propose for spined α -spiraxons the general term spinispirae, to which I bring the spicula called by previous authors spirasters, metastasters, plesiasters, and also (partly) spinispirules, sanidasters etc.

SOLLAS (1888 p. LXIII) has given the following definition of the spiraster: "a spire of one or more turns, produced on the outer side into several spines." SCHULZE & LENDENFELD (1889 p. 28) say that it is a „leicht gewundener gestreckter Aster mit dickem, dornenbesetztem Schaft", a definition which LENDENFELD (1890 p. 426) modified into: „ein kurzer und meist dicker, leicht spiralig gewundener Stab mit starken, meist dicken und kurzen, kegelförmigen Dornen". SOLLAS distinguished "metasters" and "plesiasters" from his spirasters, but he acknowledges himself that: "the three forms present a perfect gradational series, so that it is frequently difficult when they all occur associated in the same sponge, to distinguish in every case one variety from the other". Now it happens very frequently indeed that they all occur associated in the same sponge and that all gradations are met with. One only needs to read SOLLAS' own descriptions and to compare them with his illustrations, e. g. of the many "species" of *Thenea*, *Pocillastra*, *Sphinctrella* i. a. in order to become convinced that it is practically impossible to distinguish spirasters, metastasters and plesiasters. SCHULZE & LENDENFELD, therefore, did not adopt the latter two terms.

I am of opinion that the name spinispira can be likewise applied to the spicula which SOLLAS calls amphiaser; at any rate to such amphiasers as are said to occur in *Styphnus niger* SOLL. ¹⁾ A great confusion exists, with regard to the word amphiaser. The name is first used by RIDLEY & DENDY (1887 pp. XXI and 264), who say that the amphiaser is composed of „a cylindrical shaft bearing a single toothed whorl at each end; occurring for example, in *Axoniderma mirabile*..." The authors give an illustration by fig. 9 on their Pl. XXI, and a further explication saying: "amphiastra = birotulates (Bowerbank); amphidisks (auctorum)." But SOLLAS says (1888 p. LXIV) of his amphiaser "the actines form a whorl at each extremity of the axis, which is straight"; herewith a woodcut on p. LXI.

¹⁾ In his preliminary account on the Challenger-Tetractinellids (1886 p. 193) SOLLAS calls this spiculum "amphiastrella".

SCHULZE & LENDENFELD (1889 p. 8) have about the same conception of the spiculum: "gestreckter Aster; ein Schaft, von dessen beiden Enden Strahlen abgehen." Comparing now the three quoted illustrations, it becomes evident that there are important differences between them. Notwithstanding SCHULZE & LENDENFELD illustrate a spicule with a long "Schaft" and long pointed "Strahlen", we find in the definition of LENDENFELD (1890, p. 419) that the amphiaser is: "ein in die Länge gezogener Stern, die aus einem *kurzen*, geraden Schaft besteht, von dessen Enden mehrere *kurze* Strahlen abgehen". Indeed: tot capita tot sensus. If, therefore, I bring certain amphiasers to the spinispirae, only such are meant as SOLLAS describes e. g. in *Stryplinus niger*.

CARTER (1879 α , p. 354—357) has introduced the term "spinispirula" for spiniferous spirally twisted spicules." Such spicula are, according to CARTER exceedingly polymorph. They may be "long and thin" or "short and thick". The spines may be "long and thin... or long and thick... or obtuse... The spines may be arranged on the spicule in a spiral line, corresponding with that of the shaft... or they may be scattered over the shaft less regularly... Lastly, the shaft may consist of many or be reduced to one spiral bend only..."

Instead of choosing one of the various terms mentioned above, I prefer the new term spinispira, which is then simply: a spined α -spiraxon. If in future it happens become to a desideratum to have more than one name for such spicula, one might distinguish two groups of spinispirae, viz. forms with long spines and such in which the spines are small, in comparison to the total length of the spiculum. In the former group the ratio between the length of the spines and the total length is usually no more than 1:3; very seldom as much as 1:7; the number of revolutions is generally not more than $1\frac{1}{2}$. In the latter group this ratio is usually at least 1:10; the number of revolutions as a rule more than two.

4. *Microspira*.

In some sponges very minute spicula occur, especially in the superficial (dermal) layers and lining the canals, which are either distinct α -spiraxons, or modifications by reduction. For obvious reasons it can only be made out with a microscope of very high power and in favourable situation in the preparation, whether they are smooth or minutely spined. In such small spicula it is not always possible to distinguish with certainty whether they are minute spinispirae, sigmaspirae or spirulae. Moreover they show generally manifold transitions in one and the same sponge specimen. This is e.g. the case in *Placospongia*

carinata. And still, we want to designate them with a name; I propose to use for this the term *microspira*.

5. *Sterrospira*.

In the remarkable genus *Placospongia* the stony cortex and axis are almost entirely composed of spicula, which very strikingly resemble the sterrasters of Geodidae. Keller (1891a, p. 298) was the first to demonstrate that these spicula are of quite a different nature; whereas the sterrasters develop from true asters, the cortical spicula of *Placospongia* take their origin from "Spirastern". This observation is confirmed by LENDENFELD (1894d, p. 115). HANITSCH (1895, p. 214—216) found the same for the corresponding spicula of *Physcaphora* (= *Plancospongia*) *decorticans*; as they possess in this species an elongated, somewhat crescent-shaped appearance HANITSCH called them "selenasters". In 1897 LENDENFELD, not acquainted with the paper of HANITSCH, proposed the name "pseudosterrasters" for the cortical and axial spicula of *Plancospongia graeffei* (= *Physcaphora decorticans* Han.). If one wishes to apply the rules of priority in this case, the spicula under consideration have to be called selenasters. I am, however, of opinion that these rules, excellent as they are for specific nomenclature, need not to be applied in other cases and I propose, therefore, the name *sterrospira*, which at the same time reminds us of the sterrasters (of the Geodidae) and the spiraxons.¹⁾

In the group of the β -*spiraxons* the ideal axis of the spiculum is a line, drawn on an elliptical cylinder. The simplest type of such a spiculum is

1. *Sigma*.

This term is introduced by RIDLEY & DENDY (1887, pp. LXIII and 264) for spicula called by BOWERBANK "bihamate", "contort bihamate" and "reversed bihamate". The authors say that the sigma consists of a "slender, cylindrical shaft, which is curved over so as to form a more or less sharp hook at each end. The two terminal hooks may curve both in the same direction, when the spicule is said to be simple... or they may curve in different directions, when it is said to be contort... There is, however, no real distinction between the two, and, as a matter of fact, the spicules are nearly always contort to some extent". SOLLAS (1888, pp. LXII) modified the definition into "a slender rod-like spicule curved in the form of the letter C. This spicule is not spiral though it probably arises

¹⁾ For details I refer to a paper on *Placospongia* from Dr. VERNHOUT and myself, to appear within a short time (Siboga-Expeditie. Monogr. VI. Porifera).

from a sigmaspire by increase in size and loss of the spiral twist". SCHULZE & LENDENFELD (1889, p. 28) stick to the contorted nature: "gewundene, eine halbe Spiralwindung bildende Nadel". Finally the definition is again somewhat modified by LENDENFELD (1890, pp. 426): "einfach spiralig gekrümmter oder bogenförmiger Stab."

The spicula belonging to this type, appear, like the sigmaspirae in the shape of the letter *C* or *S*, or as a bow. Here too these various appearances depend on the direction in which the spiculum is viewed. According to my conception only such forms belong to this group, which are contorted, not such in which *really* the "hooks curve both in the same direction". The latter are curved pedinaxons, the former are spiraxons. The axis, as a rule, has less than one, but more than half a revolution, which is easily proved by wax models.

As a derivation or modification of the sigma we have

2. *Chela*.

BOWERBANK has already shown (1858, p. 304—305; reprinted 1864 p. 47—48) that the chelae develop from sigmata. This observation is confirmed and enlarged by RIDLEY & DENDY (1887, p. XX), LEVINSSEN (1886 and 1894), H. W. WILSON (1894), PEKKILLARING & VOSMAER (1898, p. 36—38). We remarked (l. c. p. 37): "not only can we confirm this but we can give a new strong argument in favour of it. This lies in the fact that the anisochelae of *Esperella syriaca* are twisted." I can add now that this twisted nature is found in isochelae as well as in anisochelae. Consequently we may regard both as β -spiraxons.

3. *Diancistra*.

According to RIDLEY & DENDY (1886, p. XIX) the spicula, which BOWERBANK called "trenchant contort. bilaminate", and for which they propose the name diancistra are "usually . . . more or less contort, the two hooks lying in two different planes". My own observations confirm this statement and I bring the diancistra, therefore, likewise to the β -spiraxons.

Resuming we may divide the monaxons into the following primary groups:

- I. *Pedinaxons*. Monaxons the axis of which lies in a plane; (oxea, styles, tylostyles, etc.).
- II. *Spiraxons*. Monaxons the axis of which is a screw helix.
 - A. *α -Spiraxons*. The axis is a line drawn on a circular cylinder; the pitch is generally great, to this group belong:

1. *Sigmatospira*; smooth α -spiraxon of no more than $1\frac{1}{2}$ revolution.
 2. *Spirula*; smooth α -spiraxon of at least $1\frac{3}{4}$ revolution.
 3. *Spinispira*; spined α -spiraxon.
 4. *Microspira*; very minute, smooth or spined α -spiraxon; it unites the characters of 1 and 3 diminiutively, and frequently forms transitions and reductions.
 5. *Sterrospira*; the young stages are spinispirae, from which develop by secondary soldering together of the spines the adult forms.
- B. β -Spiraxons. The axis is a line, drawn on an elliptic cylinder; the pitch is always small; always less than one revolution. Hereto belong:
1. *Sigma*; smooth β -spiraxon.
 2. *Chela*; the young stages are sigmata; in course of development very complicated siliceous processes grow out; we distinguish two sorts, viz. isochelae and anisochelae.
 3. *Diancistra*; the young stages are (probably) sigmata from which develop the adult ones by outgrowth of siliceous processes.

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Physics. "*Statistical electro-mechanics.*" II. By Dr. J.-D. VAN DER WAALS Jr. (Communicated by Prof. VAN DER WAALS.)

The distribution of the energy over the different periods in quasi-canonical ensembles.

In equation (8) of my previous communication ¹⁾ a distribution of the energy over the different periods is included. If therefore this equation really represents the condition of a space filled with "black radiation", then a complete spectral formula for black radiation may be derived from it with the aid of the law of WIEN on the shifting of the wave-length with the temperature.

Instead of discussing the rather intricate equation (8) I have taken a simpler equation which I expected to yield the same distribution of the energy over the different periods. This simpler equation, however, proves to include a distribution which does not at all agree with the distribution of the energy which is found in black radiation. Now it is possible that the distribution, determined by the simpler equation does not agree with that, determined by equation (8). But it is also possible and for the present this seems more likely to me, that equation (8) does not represent the condition of a space filled with black radiation, or in other words that the nature of black radiation is not correctly determined by the suppositions that ϵ , φ and χ have a most probable value, and that for the rest the distribution is as irregular as possible. If this second explanation is the true one, the systems are still subjected to other conditions, besides those concerning the most probable values of ϵ , φ and χ , or, what comes to the same, the distribution of the systems of an ensemble in which the conditions for the values of ϵ , φ , and χ are satisfied, are moreover still partially ordered.

The simplification I have applied to equation (8) is the following. In the first place I have omitted $\frac{\omega}{\sigma_2}$; this will no doubt have very

¹⁾ These Proceedings IV, p. 27.