The Colonial Diatom *"Bacillaria paradoxa"*: Chaotic Gliding Motility, Lindenmeyer Model of Colonial Morphogenesis, and Bibliography, with Translation of O.F. Müller (1783), "About a peculiar being in the beach-water"

BACKUP #28 August 24, 2003

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Abstract

Bacillaria paradoxa was discovered by O.F. Müller in 1783. We have translated his enchanting description of this organism. It lives up to its name (though it has many others), in providing us with many unsolved problems, including its synchronous motility, apparent cell-cell communication, worldwide distribution, and ability to adapt to many environments. We give an extensive bibliography for this organism, and present a simple L-system model for its clonal growth in terms of cell size reduction. This may have life cycle and ecological implications for all chain diatoms. We also show that its colonial motility may be mathematically chaotic.

Introduction

In the wonderful article by O.F. Müller (1783), he expresses his profound and absolute delight on discovering the "peg-animal", which we now know as the colonial diatom *Bacillaria paradoxa*, a plant, yes, but a most remarkable plant. *Bacillaria* presents us with at least nine paradoxes that have yet to be resolved:

1. The motion of the colony is somewhat synchronized, without any obvious means for cell-cell communication.
2. The cells are apparently attached via the raphe mucilage between them, yet despite continuous motion, the colony stays together.
3. The cells can apparently somehow "detect" their neighbors, since they stack up at rest, and don't come off the end when the colony is fully stretched.
4. The net motion of a colony should be zero, by center of mass considerations, and it appears symmetrical in structure, yet it probably has phototaxis and moves towards regions of appropriate light level.
5. Like all motile diatoms with raphes, each cell moves with no visible moving parts.
6. There appears to be but one species (but maybe two: Schmid, 2001a), worldwide in distribution (Figure 1).
7. *Bacillaria* is euribiontic, as it may be found in both marine and freshwaters, in plankton and in benthos, in brackish waters, soil (K.B.) and in very dirty waters, in the tropics and in North Asia, and so on. ("The most exciting thing to me besides the coupled motility

of *Bacillaria* is its apparent ability to be totally capable of living in both very oligotrophic freshwater with only a few ppm of dissolved solutes and brackish tidal pools. Tough unicell", Ryan W. Drum, personal communication).

8. Since each colony is a clone, sex within the colony would lead to inbreeding, but then how do they have sex with other colonies, or do they?
9. How do daughter cells divide and retain contact while establishing motility between each other? This is an unexplored part of the story of diatom valve morphogenesis.

It is remarkable how many of the features of *Bacillaria* Müller discerned (See our translation from the original, now ancient Danish, to English in Appendix 2). What he missed is that the rectangular colonial morphology (Appendix 2 Figure 3) is a daily resting (sleeping?) stage. Thinking this configuration was dead, he did not look for increase in number of "pegs" (cells) the next night, which double daily under optimal conditions (Kapinga 1989). He might then have concluded that they are, as he wondered, "one mother's children and grandchildren", i.e., a clone.

The *Bacillaria* Shuffle

It was a description of *Bacillaria* that got one of us (R.G.) hooked on diatoms (Bonner 1952), and given the proliferation of web pages and archived e-mail messages showing or discussing this genus, listed amongst the numerous papers and books in our bibliography below, *Bacillaria* continues to fascinate professional and amateur diatomists. This has led to a rather unique behavior of diatomists: "The *Bacillaria* dance began at the IX North American Diatom Symposium [NADS] held at Treehaven Field Station, Tomahawk, WI, October 7-10, 1987. I think that it is more accurate to say that the dance began in response to a video that I made of *Bacillaria* cells moving back and forth" (Margaret Gowdar nee Kapinga, personal communication). Called the "*Bacillaria* Shuffle", this line dance was invented by Edward C. Theriot and P. Roger Sweets:

> "My memory about the whole thing is pretty fuzzy. Actually, getting fuzzy has a lot to do with how the dance got started as you might imagine. I think the dance started at the NADS before the Finland International Diatom Meeting, because we tried it there and it did not

have the same magic. I was the central nodule because I was tall enough to see both ends of the line, if not sober enough.

Choreography was very basic, chant ‘Do the Bacillar -ee - uh. Do the Bacillar - ee - uh.’ Up in tone on the first ‘uh’. Down on the second. During the chant, everyone slid tightly against the next person, front to back, as I recall. Central nodule job was to try to keep both ends moving at approximately the same rate. As we got more practiced at it, we tried to move everyone, but at different rates, much like a real *Bacillaria*. I think groping and falling down occurred but those were not scheduled parts of the dance, but instead were by-products of bad breeding, drunkenness, loutish behavior, genuine affection for the next cell, and general lack of physical coordination of the individual persons and in different combinations depending on the individual.

This went on until we got tired of it. It seemed to take a really, really long time for people to get tired of it. Obviously it should have stopped before it started.

I recall that somewhere around 30 people were involved.” (E.C. Theriot, personal communication, 2002; cf. (Wolin 1988)).

Of course, real *Bacillaria* require no “central nodule”, nor ethanol. “Front” and “back” are the same (or are they?).

***Bacillaria* Motility is Chaotic**

The motion of a single end cell in a *Bacillaria* colony, isolated by laser ablation of its neighbor, moving against a shard of its neighbor, exhibited oscillations in position of constant magnitude but varying frequency, like an FM (frequency modulated) radio signal (Drum *et al.* 1971). The variability in the delay at each end may have been due to cell damage. We interpreted the constant amplitude of the motion as being due to “packets” of fibrous raphe fluid (Gordon *et al.* 1970)(Higgins *et al.* 2002) of fixed volume released in alternate directions. Whether there are fundamental similarities between this motion and the “autonomous reversal rhythm” of noncolonial raphid diatoms (Wenderoth 1984) would be interesting to explore. Phototaxis experiments (Nultsch *et al.* 1973)(Cohn 2001) have yet to be conducted on *Bacillaria*.

In order to analyze the colonial motion, we will idealize the relative position of each cell versus time as successive trapezoids, with the derivative (velocity) as a step function. Thus the velocity is constant in one direction, zero when full extension of cell 2 with respect to cell 1 is reached, zero for a small time (a pause), then constant in the other direction.

Consider a chain of three *Bacillaria* cells, and let's assume for simplicity that there are no pauses in motion. We'll use the first cell to establish a coordinate system, taking the origin ($x_1(t) = 0$ at all times t) to be in the middle of the cell. The length of the cell will be L_1. Let's start from the stretched configuration, and assume all cells are the same length L, so that $x_2(t)$ at time $t = 0$ is $x_2(0) = -L$, and $x_3(0) = -2L$ (Figure 2). We will approximate the motion of the second cell, with respect to the first, as having position $x_2(t)$ versus time given by:

$$x_2(t) - x_1(t) = -L + v_2(t) \mod (t, 3T_2)$$

where $v_2(t)$ is the velocity at time t and T_2 is the time it takes the cell to traverse one length, i.e., $L = v_2 T_2$, and mod is the modulus function. We can let $r_2(t)$ be the dimensionless position of cell #2 relative to cell #1:

$$r_2(t) = (x_2(t) - x_1(t))/L$$

Thus $r_2(t)$ ranges from -1 to $+1$. The period (time to come back where it started) is $6T_2$. The velocity reverses sign (direction) every $3T_2$.

We can write the same equation for cell #3, but it must be relative to cell #2:

$$x_3(t) - x_2(t) = -L + v_3(t) \mod (t, 3T_3)$$

$$r_3(t) = (x_3(t) - x_2(t))/L$$

We can describe the motion in terms of a plot of r_3 versus r_2. For the motion depicted in Figure 2, the result is a loop or trajectory that goes back and forth along a diagonal (Figure 3).

Next, let's start the cells in a different configuration (Figure 4). In this case there is again a cycle, as shown in Figure 5. The important point to note is that, for real cells, we can assume variations in the velocities, lengths of cells, and periodicity of the motion. Thus a real system, even without any communication between the cells, could drift between the cycle in Figures 2-3 and the cycle in Figures 4-5. This is illustrated in Figures 6-7, for which we have taken $|v_3| = 0.9\ |v_2|$, i.e. the third cell moves relative to the second cell at 90% of the speed of cell 2 relative to cell 1. We started from the configuration in Figure 4A and left off in the configuration in Figure 2C, shifting (approximately) from one cycle to the other . This is precisely what we expect in a system that fits the mathematical definition of chaos. Small perturbations break up the precise cycles of Figures 3 and 5, just as they do for a frictionless pool table for billiards (without pockets), a classic case of chaos (Ott 1993).

The implication of all of this is that, to answer the question of cell-cell communication and its possible role in synchronous motility of *Bacillaria paradoxa*, we must take noncommunicating, chaotic motion of the colony as the null hypothesis. Such behavior will generate transiently synchronous colony motion, so the short term observation of synchrony is not proof of cell-cell communication. Statistical methodology needs to be developed to distinguish chaotic, transient synchrony from entrained synchrony. The *Bacillaria* problem is similar to flashing Christmas tree lightbulbs (Gordon 1969b) or Josephson junctions (Hadley *et al.* 1988)(Strogatz 2003) in a series circuit, especially if the raphe mucus surrounding a colony is involved in some form of global synchronization.

A Lindenmeyer Model for Size Reduction of Diatoms in Clonal Chains

The *Bacillaria* Shuffle led us to an interesting question: to what extent are the cells in *Bacillaria* the same? A rough answer may be had by considering the chain as a one dimensional Lindenmeyer model (Lindenmeyer 1968a)(Lindenmeyer 1968b). In L-systems a chain of cells is represented by symbols designating their presumed discrete states (typically a differentiated cell type, such as vegetative cells and heterocysts in cyanobacteria: (de Koster *et al.* 1987)). An approximation is made that all cell divisions occur simultaneously. Then each symbol in the chain gets replaced by two symbols in a parallel computation (Prusinkiewicz *et al.* 1990).

For diatoms in a clonal chain, we can designate a cell with a larger valve on the left as L and a cell with a larger valve on the right as R. Let's suppose we start with a single cell oriented so that it is designated R. To see what is happening, we can draw the cell with brackets of two sizes:

R []

When the cell divides, the cell on the left will be smaller, since the new valves must fit inside the old valves (Kling 1993)(Gensemer *et al.* 1994):

LR [][]

Now we have a chain of two cells of types LR, since the first cell has its larger valve on the left. The brackets of decreasing sizes are difficult to keep straight, so let's shift notation:

R = [1,0]
LR = [1,2][1,0]

Each pair of brackets represents one cell. The higher the number, the smaller the valve represented by the bracket to which it is adjacent. A number represents the "valve generation" of the valve. We can now formulate a simple replacement rule of the Lindenmeyer type:

R^n = [n+1,n] becomes the two cells [n+1,n+2][n+1,n] = $L^{n+1}R^n$
L^n = [n,n+1] becomes the two cells [n,n+1][n+2,n+1] = L^nR^{n+1}

Here, then, are the first few synchronous cell divisions, starting from one cell:

R^0
L^1R^0
$L^1R^2L^1R^0$
$L^1R^2L^3R^2L^1R^2L^1R^0$
$L^1R^2L^3R^2L^3R^4L^3R^2L^1R^2L^3R^2L^1R^2L^1R^0$

Note that the number of cells with a given superscript, which corresponds to the valve generation of its larger valve, is:

0 1 2 3 4 (larger valve generation)
1
1 1
1 2 1
1 3 3 1
1 4 6 4 1

This is Pascal's triangle, so that the distribution of valve sizes follows the binary distribution. In particular, note that there is always one largest cell and one smallest cell. Of course, fragmentation, cell death, lack of synchrony in cell division, and starting from an odd segment rather than a single cell, would alter the proportions.

Many nonmotile diatoms form chains (Migula 1903)(Fryxell 1978)(Dongmann *et al.* 1982)(Fryxell *et al.* 1991)(Pahlow *et al.* 1997)(Buck *et al.* 1998) (raising the suggestion that *Bacillaria* is a motile diatom that "reverted" to chain formation), so our Lindenmeyer model should be applicable to all of them. The flexibility of chains, which affects their entanglement (Karp-Boss *et al.* 1998) might depend on the nonuniformity in size predicted by this model. Smaller cells may also represent weak points in the chain at which it could fragment in a turbulent environment or during predation. So this simple mathematical model may have some life cycle and ecological consequences.

Taxonomy

Like many diatoms, *Bacillaria* has acquired a few names, both common and Latin. *Bacillaria* has been described as "A genus in urgent need of investigation at the species level" (Round *et al.* 1990). As long lists of aliases may be found in (VanLandingham 1967)(VanLandingham 1979), we look forward to a definitive study (Jahn *et al.* 2003). *Bacillaria* is the first diatom identified as to species:

> "Leeuwenhoek (van Leeuwenhoek 1702a) shows a presumable diatom growing on the root of *Lemna* [duckweed]. This has been tentatively identified (e.g. by (Ehrenberg 1838)) as *Synedra ulna*. Remember that Leeuwenhoek's microscopes had a resolving power of somewhat below 1 micron (I've checked this myself) and it is therefore clear that Leeuwenhoek's organism is not reliably separable from a lot of other *Synedras* and *Fragilarias*…. In 1773 Otto Müller (Jones 1939) showed a *Gomphonema*, a *Fragilaria* and a *Melosira*, but none of these is identifiable to species level. Then the 'fire-brigade ladder plant-animal' came onto the stage and although pre-1870 optics do not reveal the structure of its valve, the unique growth form of a bunch of them (but only that!) still permits specific identification" (Chaffey *et al.* 1997).

Most people continue to call this organism *Bacillaria paradoxa*, despite its renaming as *B. paxillifer* (Hendey 1951), perhaps because that name parallels its challenges to us. Its common names are "peg-animal" (Müller 1783) and carpenter's rule (van Egmond 2002). Our bibliography has almost 700 items that mention *Bacillaria*, and confirm its worldwide distribution in many environments.

It has been suggested that *Bacillaria* is at least two species Schmid, 2001a. Frithjof A. S. Sterrenburg (personal communication, 2002) summarizes his experience:

> "Diatoms that broadly conform to the current concept of *Bacillaria paxillifer* (*paradoxa*) - leaving aside the question of whether this concept actually refers to *Vibrio paxillifer* O.F. Müller 1786 and/or *Bacillaria paradoxa* Gmelin 1791 - show marked differences in stria density that could be indicative of different specific status. The more finely striated forms might correspond to what Grunow called the var. *pacifica* and var. *tropica*, which - like *Bacillaria paradoxa* itself - he assigned to the genus *Nitzschia*. The entire taxonomic complex described in the "classic"

literature, including *Nitzschia socialis*, requires revision based on typification."

For those who want defined cultures of *Bacillaria*, see (Andersen & Hargraves 2001) for one strain, or note:

> "I have only one viable strain (as *B. paxillifer*) at the moment, L1041 which was isolated 13IV1994 from Chevelon Creek, Navajo Co., AZ; it is maintained in my CHEV medium which translates to ca. 10% seawater" (David B. Czarnecki, personal communication, 2002, cf: (Czarnecki 1997)).

Acknowledgements

We would like to thank Jorge Alpuche [Spanish], Robert Andersen, Michel Coste, Silvia Cenzano [Spanish], Pierre Compère, David B. Czarnecki, Ryan W. Drum, Mark Edlund, Margaret R.M. Gowdar nee Kapinga, Paul E. Hargraves, Isabelle Harouche [Portuguese], Margaret Harper, Regine Jahn, O.A. Jensen [Latin], Martyn Kelly, Hedy J. Kling, Gina LaLiberte, Susan V. Meschel [Hungarian], Melissa McQuoid, Eduardo A. Morales [Spanish], Madelon Mottet [Japanese], Edna Pacheco-Fernandes [Portuguese], Willem Prud'homme van Reine, Charles W. Reimer, Silvia Sala [Spanish], Annemarie Schmid, Michael Seyfarth [German], Frithjof A.S. Sterrenburg, P. Roger Sweets, Edward C. Theriot and Agata Wojtal [Polish], for assistance with various fine points in the translation, bibliography, and/or these notes. We are greatly indebted to Mr. Bjarne Stavnshøoej of the Danish Royal Academy of Sciences and Letters secretariat for making a scan of the plates of (Müller 1783) available, and for his patient and thorough answers to our questions regarding the Society and its publications.

Figure 1. Worldwide reports of the occurrence of *Bacillaria*, as gleaned for the publications in our bibliography. This map suggests such a widespread distribution that it may actually be a map of the distribution of diatomsists. [TO BE PREPARED BY LUC ECTOR]

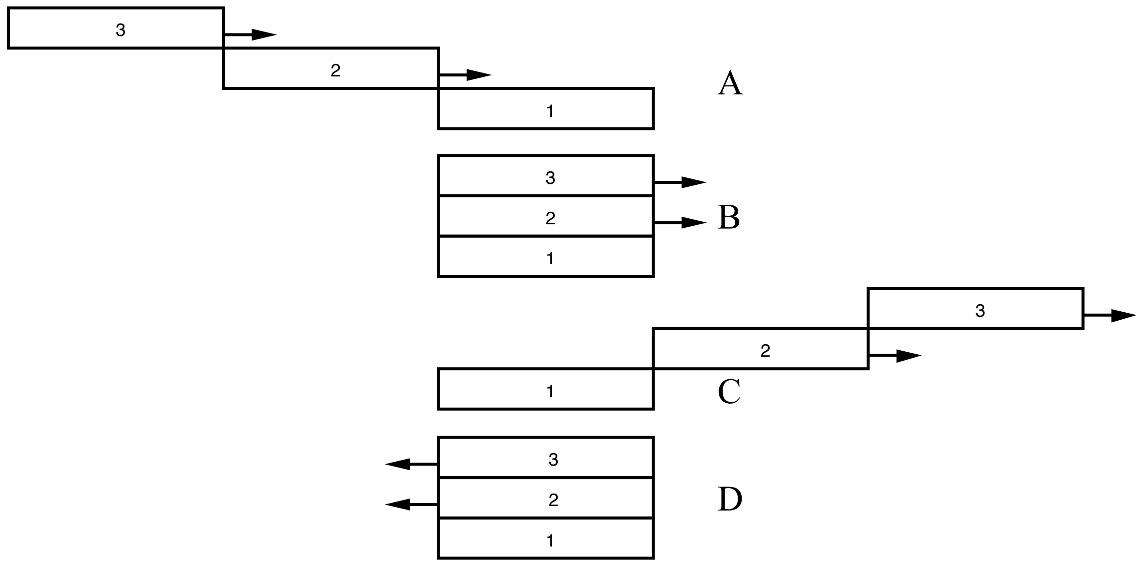

Figure 2. A three cell *Bacillaria paradoxa* colony, moving with "mathematical precision", starting in configuration A, passes through configuration B. At C cells 2 and 3 reverse direction, so the configuration goes through D, then on to A again (after reversing direction once more). Cell 1 is taken as the origin of the coordinate system.

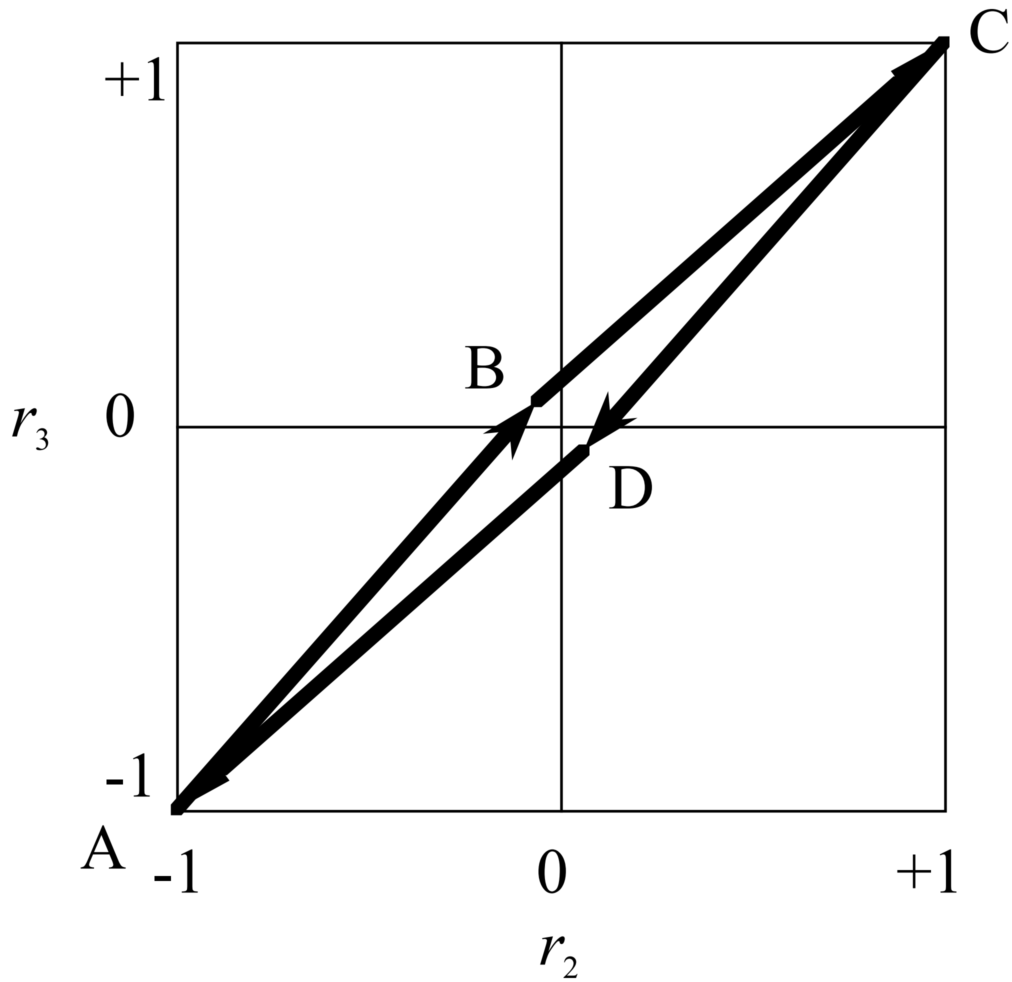

Figure 3. This is a "phase diagram" of the relative positions r_3 of *Bacillaria paradoxa* cell #3 to cell #2 versus r_2 of cell #2 to cell #1, for the changes of configuration shown in Figure 2. While points B and D should coincide at (0,0), we have taken the liberty of separating them slightly so that the cycle can be seen.

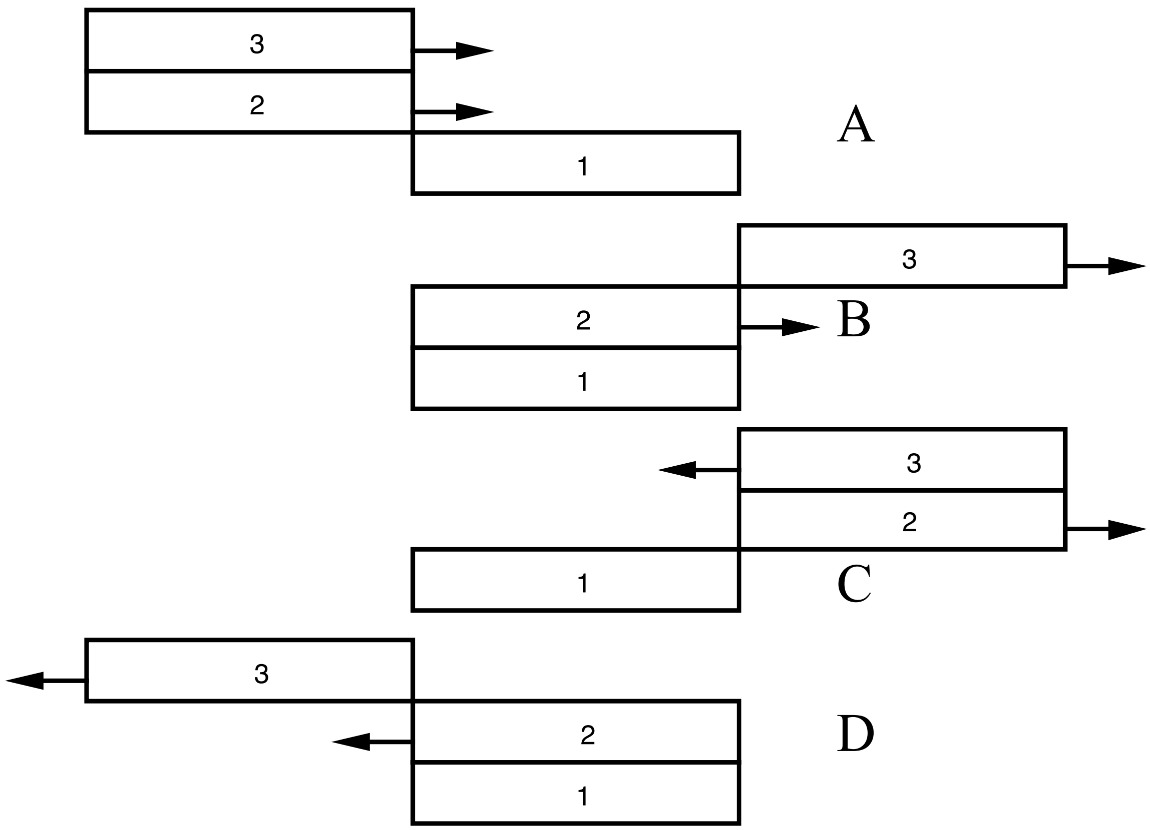

Figure 4. In this cycle, two *Bacillaria paradoxa* cells are stacked to the left in configuration A. When the colony reaches configuration B, cell #3 reverses. Configuration C follows, at which time cell #2 reverses. This carries the colony to configuration D, in which cell #3 reverses. The configuration then becomes A again, since cell #2 reaches the end of its traverse and reverses.

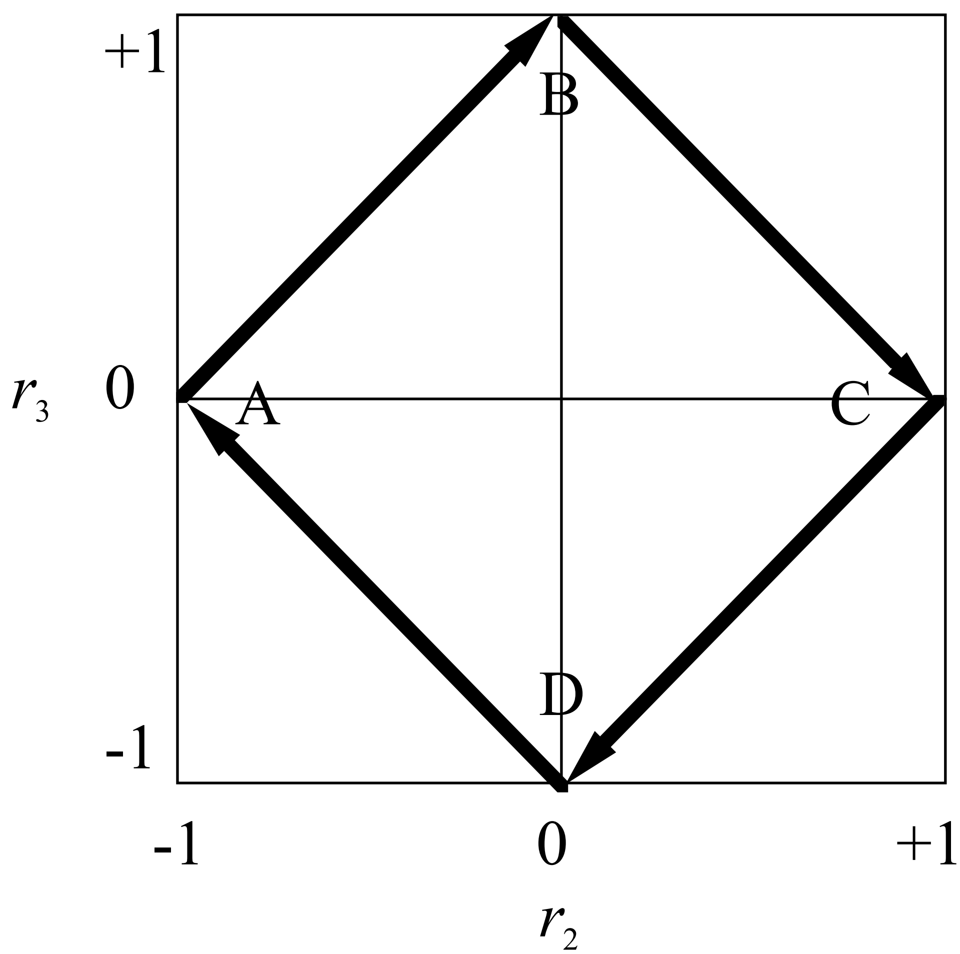

Figure 5. The phase diagram of relative positions corresponding to the colony configurations of *Bacillaria paradoxa* in Figure 4.

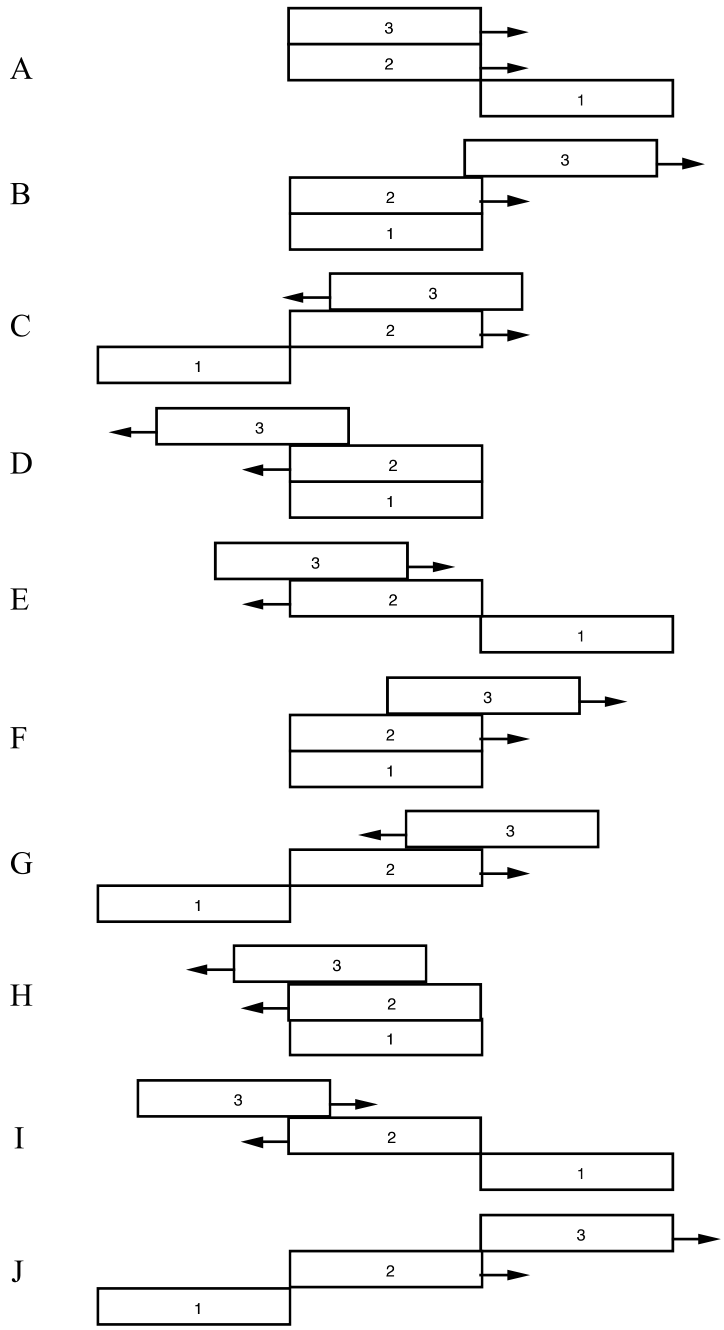

Figure 6. Three *Bacillaria paradoxa* cells start out in the same configuration as that of Figure 4A, and we follow them through until they reach the same configuration as Figure 2C. Cell #3 moves over cell #2 at 90% of the rate as cell #2 over cell #1. In this case we have shown the colony as it would ordinarily be observed in free suspension, with the middle cell, the centre of mass, kept in a fixed position.

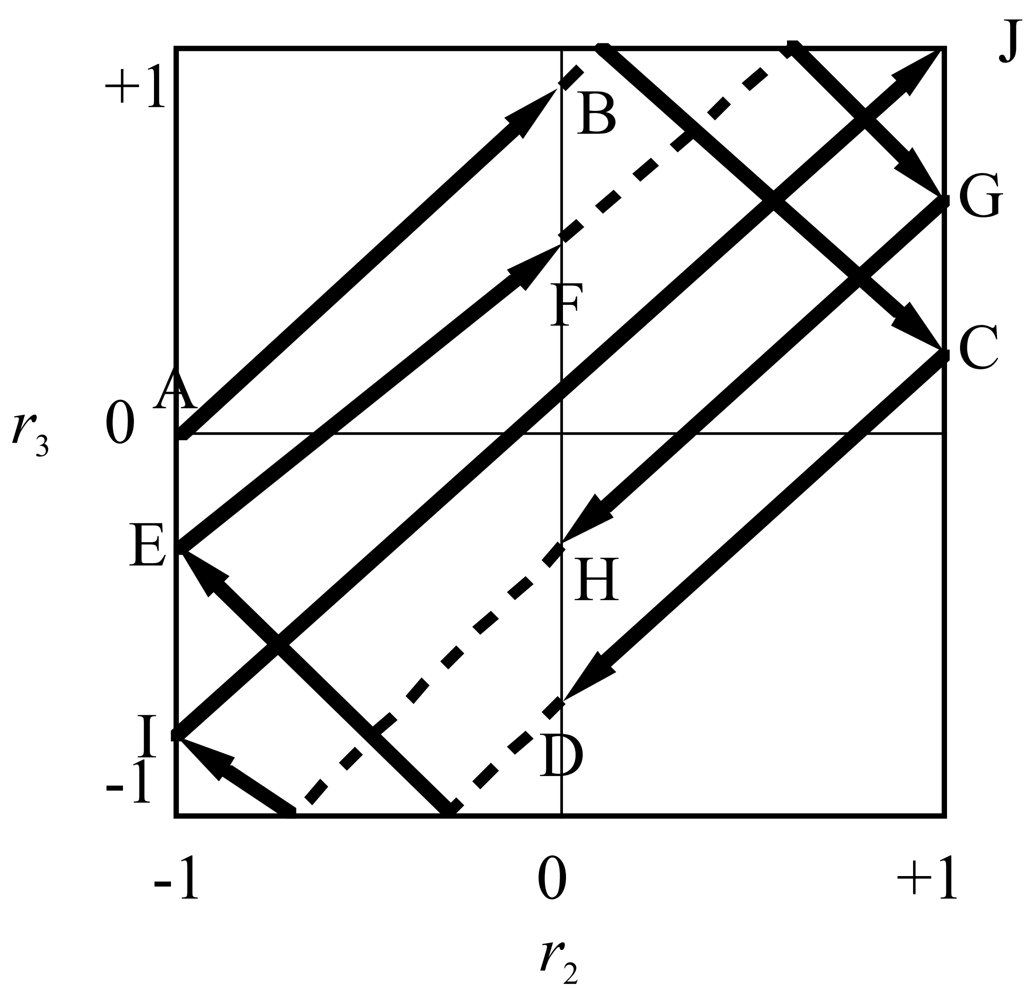

Figure 7. The phase diagram corresponding to the *Bacillaria* colony motions depicted in Figure 6. The nearly closed 'cycle" ABCDE corresponds to cycle ABCDA in Figure 5. GHIJ roughly corresponds to CDABC in Figure 3. Because the speed ratio is a rational number, i.e. $|v3| = (9/10)|v2|$, if we kept working through the configurations, we would eventually end up back at A, i.e., the behavior is cyclic again, but with a much "longer", complex cycle. Were the speed ratio an irrational number, there would be no precise repetition of any cycle.

Appendix I. Reflections on the challenges of translating an 18th century scientific article.

R.G., with whom I (A.P.U.) had corresponded about amphibian haematology, asked me offhandedly whether I had the time to translate an old Danish article into English. Ten pages, he told me, and he had it all scanned and ready.

I agreed, and he mailed me a huge file. The following day, we again corresponded: - “You forgot to tell me it was printed in Gothic letters”. - “I guess I did”.

Well, I read Nordic fairytales, by Asbjørnsen and Moe, in my childhood. A late 19th century book printed in Gothic letters, in the old Norwegian language which is not so different from Danish. I am familiar with the special characters of the Scandinavian languages, and with the ancient way of writing the second “s” out of two so as to resemble an “f” – somewhat like they do in the German “double-s”, which is comparable to the Greek sign beta. (My family name was often pronounced “usfing” by laughing children, unfamiliar with the letters of the olden days used on a brass name plate).

Thus, I thought it could be a funny and relaxing pass-time to work with the translation. Indeed, it turned out to be so. But it was also a far more complicated task than I had realised. For one thing, the handmade types, used for printing, were far from being as neat and sharp and regular as those of my childhood tales. This means that one “e” on a page need not be similar to another “e” on the same page. Different specimens of the same letter might be of different widths, to allow for varying degrees of compression of a line of text (in the days when typography was an art, full justification was a must!). The very elaborate upper case letters also proved to be difficult to decipher. The old, somewhat moldy and otherwise dotted or spotted paper would also make it difficult to clarify whether there were diacritical marks above individual letters.

The largest difficulty turned out to be that of interpreting the intricate and elaborate Danish of an 18th century scholar, an eloquent upper class Danish intermingled with learned expressions in Latin. I learned a lot about my mother tongue in the process, not to speak of the discussions R.G. and I had on the exact interpretations of words like peg, stick, rod, cane and other cylinder-like, shorter or longer, shapes. We have made our best guesses, but have placed the original online for anyone wishing to check our translation, or read the original (Müller 1783).

The handling of the old tome was another challenge. Old books – or large volumes of journals – may not be opened and placed flat on a table. In fact, they may not be placed directly onto the table at all. Acid-free sheets of paper must be spread on the tabletop to begin with, and the book supported by (acid-free) cushions. No living plants, or containers of water, or other items which might contribute to a high humidity, may be present in the room. The handler must wear gloves, to protect the book from harmful substances from the hands, and vice versa. A mask to cover the nose and mouth is recommended, to avoid allergies caused by fungi and other microorganisms, which might inhabit the ancient paper or leather or glue.

The final hurdle was that the folded leaf of plates was missing from the journal belonging to The Danish National Library of Science and Medicine. Stealing artwork out of library books appears to have been a nasty habit through the centuries. Fortunately, the leaf was still present in the volume belonging to the publisher, Det Kongelige Danske Videnskabernes Selskab (The Royal Academy of Sciences and Letters).

Appendix II
References and notes are given at the end verbatim, as in the original footnotes: a), b), etc.

Privy Counsellor **O. F. Müller**

About a Peculiar Being in the Beach-Water.

Quid aluid est philosophum esse, quam ea, quae in nostrum usum terra marique divagantur, naturae artificial ita contemplari, ut ex his non solum utilitatem & voluptatem quondam, sed & multo magis summi illius auctoris ac conditoris nostri longe admirabilem industriam percipiamus. *Steph. in præs. ad Bell. aquat.*

[What else is it to be a philosopher than to observe, as we usually do, the ingenuities of nature on earth and in the sea, so that we can enjoy not alone the usefulness and delight but so much more the so long existent admirable diligence of this the most supreme originator and our founder. *Steph. in the present waterfight*]

The watching of Nature has often awoken in me the thought that the Creator has found pleasure in delighting all possible forms and figures with life and existence, and my rushed observations have not neglected to give it all probability. In the visible world, the gillworms, the flukes, the stalk-animals [*Vorticella*] a) – have shown some pictures of lifeless things elevated to an animal life, but feelingly it is in the microscopical world that such unusual sights most often meet.

That an animal looks like a cornet, another like a jar, a third like an intestine, a moon, a sun, a bladder, a kidney, a purse, a bomb, a peak, a nail, a bracelet et cetera cannot otherwise than cause admiration, for we are not used to thinking animals under such shapes, and our teachers have not told us anything like this, but limited the concept of animals to suckling, flying, swimming and provided with tentacles, and what was nothing of this, four-footed, bird, fish or insect, that the wisest called by the contemptible name worm, indeed did not allow that most creatures belonging here were called animals, but gave them the names animal-plants or plant-animals.

These proud names, like so many others, are founded in vanity and inexactitude. One would astonish with little effort, and even hunted up for weird creatures even more strange names, as they however, without needing such a sign, by their persons' and households' explanation probably would have achieved the quiet admiration, which their presence might claim. As soon as one regards a creature so scrupulously as possible, one will surely become aware whether it has a voluntary movement or not, and this is sufficient to discriminate the animal from the plant. Have I attempted to eradicate animal-plants and plant-animals from the catalogue of Nature's products, then I have also been happy to be able to replace these not sufficiently founded names with the discovery of creatures which by their real and unexpected peculiarities will indemnify the Lovers of Nature of the loss of the for such a long time enjoyed misnomers. Besides what I of this elsewhere have announced, I shall here refer to a recently discovered creature which by all long will be considered a shred of a fine watersilk (conferva) or a vegetable mist, and yet is a real animal, if not a congregation of many animals.

This misunderstanding will, no matter how peculiar, not be what mostly awakens the astonishment; for there is by the peg-animal (thus shall we call this creature) further something which will make the astonishment even greater and more lasting, and which exceeds everything hitherto known about the simpleness in addition to the elaborateness of the Animal Kingdom, or, with other words, about how many changeable contrivances The Creator has manufactured in the simplest animal, for what is simpler than the drawing of a peg, and how many figures is even a little witty person able to do by means of a few pegs, but to give such a creature Life, to let a few pegs by themselves perform the witty person's elaborate combinations; this is its own which said to the globe: "overturn yourself around your sun", and to the person: "calculate its orbit".

But whither does the sight of this creature take me! As I beheld the proteus-whirler's [*Vibrio proteus*] manifold in few moments from within achieved contrivances, I admired the rapid play of many organs in a lively point, and lost the courage to express them b); notwithstanding after some time I dared to anchor some c). Ten years thereafter I discovered the present animals, which by the changeable position of their pegs procure themselves fully as many contrivances from the outside and embarrass me just as much. Often and for some years I had seen it with a passing eye, and assumed it a mist or a shred of an upraked plant. In order to find some unobserved watersilk I had searched many single drops from 6 o'clock till midnight the night between the 6th and the 7th October 1781, along with my brother who was present to draw the appearing peculiarities. Suddenly, I see that a shred raises and stretches throughout the droplet. How! a vegetable shred moves and grows longer before my observing eye! This was [to] me ever so strange that above it I missed another, hitherto unseen, extended body, like the tentacles of the horned beetle (*Cerambyx*), and which in vain I sought the following evenings. Indeed my eye had often met locomoting animal shreds, then such are seen the smallest shreds torn from jellyfish, for some hours still to retain life and movement, and for the ignorant appearing as small worms, and the eel-stretchers [*Vibrio anguilla/anguillulla*] young eels have, even to the most skilled eye, this similarity.

My astonishment increased as I saw that this shred withdrew itself and shortened itself not in one thicker, but in many parallel and by each other attached stiff pegs, which thus created a thin and quadrangular pellicle. Since this locomotion neither came nor could come from the outside, I had to consider it something animal, and the following changes demonstrate that it is not an animal part but rather an entire animal, if not a gathering of several singular (animals), albeit it, except for the random locomotion, does not possess any of the features which otherwise characterise the animals, not even a specific fore or hind end.

It is consequently an animal without head or tail, and consisting of five to more than forty cylindrical pegs; indeed I found some which consisted of fewer, in addition I saw singular ones lying in the droplet, but these uttered no life or locomotion. Each peg is a clear, rigid and cylindrical body, approximately twelve times as long as its width, and within filled with a yellowish creature or pellicle, on which were seen two or three clear dots without any order. In the middle and at the ends the animals appeared whitish and empty.

These pegs are never situated in bundles or on top of each other, but always and during every alteration singular by one another, in a parallel position. During the tranquility of the animal they form by their greater or lesser number a larger or smaller square quadrangle. The locomotion from one place to another occurs as the outermost peg by one of the ends slides forward onto the nearest, and this onto it's neighbour or onto the third, this onto the fourth and so forth. When the progress is continued unabrupted as far as the last peg, the animal is seen such as it first acquired my attention, stretched in a straight line, or, such as I afterwards sometimes saw it, bent in half an ellipse, similar to a fine thread or a microscopic watersilk.

Extraordinary it is, that the pegs in this outstretched gesture loose some of their yellowness, and yet decrease little in their whiteness.

After a few moments of stagnation, the animal stalks back, with the furthermost peg sliding onto the next, both on top of their neighbour, these three on top of the next, and so forth until the outermost at the other side, and by then the animal represents an slanting quadrangle with uneven sides. Immediately thereafter the first manouver is performed, or there is formed a zigzag or a figure likened to a thunderbolt, or two by a middleline united lesser quadrangles; or the forward sliding of the quadrangular figure begins as well as and at the same time in the uppermost and the bottommost peg, and then the closest each follows its leader: the quadrant diminishes and develops two symmetrical or towards the opposite sides equally protruding horns, and in this position the animals remains for a short time. Sometimes a portion or a collection of four or five pegs slide aside from the remaining or the quadrant, so that they not even with the hindmost toppoint touch its angle, and slide slowly back into the previous quadrant position; this is repeated for some times, and has probably, like in many amoebae, its origin in an imminent reproduction by division, although I have not seen it completed.

But, dare we draw any analogous conclusion, since we, as the following will show, not even know whether this tactical being is a single animal or a colony of small animals, and as all its rarities are so new and unfamiliar, that one not otherwise has seen the like in the whole of Nature. Not even in the military evolutions which Mankind has created contrive the commanding by the expansion and compression of perpendicular lengths such sights, as the peg-animal with horizontal lengths, nevertheless the pegs also sometimes stand parallellically upright, and the whole quadrant is seen bent like a chip or a map on sticks. Soon one would believe that Nature here has aimed to imitate the art's military exercises, for this has it not from the unbeknownst peg-animal, or should Mankind not manage to invent any mechanic movement, which indeed is also performed by some organic being?

On some of these animals and really on those which consist of many pegs or segments, are seen on the outermost peg, and on the third or fourth another, standing abeam, immobile. It appears to be without life and disrupted from the others, though it even for some time is attached to and drawn along with the manouvers and movements of the remaining pegs.

Thus, one cannot doubt that this being indeed belongs to the Animal Kingdom, but whether it is a single animal consisting of many similar segments, or an aggregation of many lesser animals which have the means of outstretch and again to gather into indefinite figures, that is difficult to decide. I shall proceed to propose my reasons for and against, and leave the judgement to any one who has courage enough [to pass the sentence].

We know of some insects and worm species, which in their swarming and mating times gather in a mass, and from the same fly or float in different small masses without separating from the original mass, and soon retire into the same.

Such we see with naked eyes in bee and mosquito swarms d), and with the assisted in the swarms of line- and wave-stretchers [*Vibrio liniola* and *Vibrio undula*] e). However, these animals are not each bound to each other, but only gathered partly for a certain time, and partly for a specific purpose; each individual is even less related specifically to its neighbour, but rather changes its position each moment. Differently it is with the above-mentioned peg-animals, where each peg remains the same in the order, no matter how much it changes its appearance. I shall not injure any one's reputation, yet I pray confess, that I, with the prejudice that the peg-animal was a single animal and not a gathering of animals, gave myself the task of recording the most important reasons for both, and these are in my thoughts the following:

It is a single animal, and not a gathering of many.

1) Because one has no example in the whole Nature of such a chain-gathering of several singular animals. Although Mr. Prof. Bluhmenbach has aimed to find the like in the tapeworm, and thence denounced the old ones' [sic] outdated claim that each segment were an animal which stuck to its neighbour; but I expect by my announced observations f) he has been convinced of the opposite. The straw-seafeather g) appears closer to being a gathering of single animals, and yet, if they are not to be considered an animal's many orifices for uptake and outlet, the peg animal differentiates itself from the ordinary in the straw-seafeather in the respect that every segment in the latter is equal-sized and perfect, in the former on the other hand lesser and larger, fully grown and recently established, and thus proving that they are begot by one end, whether it happens as animals or as segments. Though the cave dwellers h) and the sociable whirlers [Rotifera] i) form whole colonies on one stem, yet they are not single animals which

have gathered, but rather one mother's children and grandchildren – which separate themselves from her and from each other, and each become mothers and establish new colonies, like acorns fall off the trees and yield young trees.

2) Because the pegs and the segments not each separate themselves from the remaining, or divert from them and again approach them, which would seem to have to happen if every peg were an animal.

3) Because each peg stays forever at the same sequence and in the same position in relation to the others, no matter how often the animal changes its shapes, which would not likely be the case were each peg an individual animal.

4) Because in the water droplet one is not certain that single pegs move, even less that they aim towards the gathering.

5) Because the peg-animal apparently would reproduce by division, like many other infusion animals.

The answer to the first is that the microscope has discovered many other rarities, of which there is no other example in the household and character of the larger animals.

The second and the third [reason] could be caused by a sticky and indulgent matter, or in an expanding and withdrawing pellicle, which thus keeps the pegs together that they may easily slide upon each other, though not be released, and such a matter or pellicle is challenged to keeping together the pegs, even when they are regarded as mere leitmotif.

For the fourth and fifth reason the observations are yet too rare for any conclusions.

We approach the second sentence, namely: The peg-animal is a gathering of equally shaped small animals, not a single animal with many segments.

1) Because all changes occur from the outside by the spreading or drawing together, as well as the different positions, of the pegs, since the change in shape in other animals is caused by an extension or withdrawal from the inside.

2) Because to my knowledge no animal exists, which has segments standing parallel to the length of the segments; and if one calls the long cross section the width and the short the length, then it is just as unheard of that an animal has been able to send out fine segments in the width.

3) Because both ends are very similar to each other, are utilised in the very same way, and have similar ability to initiate the walk or forward sliding, even initiate it sometimes simultaneously towards opposite directions, or to one side only. I have seen many infusion animals, which with equal ability use whichever end, though one is used more often, and never both at the same time, as in the peg-animal.

4) Because the pegs or segments do not origin from each other, nor do they terminate with the ends by each other, rather they lie beneath each other, even in the most stretched position of one end, and in the shortening phase [they] never withdraw into one another, but alongside each other.

5) Because the outermost peg in some of them is seen to hang without movement across from the second peg, sometimes the fourth and fifth likewise to hang across from the sixth, and yet this and the third are seen in the stretching of the animal with the ends, and in the quadrant position with the whole length, touching each other parallelically.

6) Because the number of the pegs and the segments in each peg-animal differ as much as from five to forty, and yet they are of equal size between the figures. Indeed the segments in individual nereïids, aphrodites, tape worms and others are uneven in number, but not all of similar size.

7) Because the peg-machine's changeable and uneven figures are best explained by the unequal willingness of many animals to follow those, which first move, and by the different journeys taken when the outermost pegs of either end, either simultaneously, or immediately after each other, initiate the movement.

Against the six first reasons I know not of anything definite to say, as they depend on true and hitherto unseen observations; if therefore an animal with by its length parallel segments and with two ends of equal nature could not be created, thereabout is no doubt, but then this animal should be governed by one will, and thus hardly like the peg-animal at the same time proceed towards opposite corners; within [the animal] the movement should initiate from the middle towards both ends, and not from either end simultaneously transmit itself to the centre; should this happen, then it would be governed by two wills, and thence no longer [be] a single animal, or an individual; and should something different from the two ends be distinguished, which were not merely segments, and from whence the random movement of the rest of the organs would assumably originate. Indeed a supple human body can assume many external positions, but besides that its members are quite different, its Sensorium, which command all changes, is evidently felt. That in an animal some segments in one end, or end both ends, are disposed of, either by violence or due to age, and that others in their place are sent out, that we see in the nereïds, the naïds, the starfish and others, but I know of no example where one or two middle segments are disposed of, or that not new but older neighbour segments have united or gathered to replace the disposed, [in order] to complete the broken chain, like the pegs in our peg-animals.

The seventh reason has not fully the strength of the previous, as it is not founded in observations, but in a probable assumption. Indeed one may say of snakes and tape-worms, that they, albeit single animals, can give their bodies different and uneven bends, but alive they never stretch out equally long, even less do their ends at the same time rush towards opposite corners, nor do their rings and segments slide parallel forward with each other, as in the peg-animal.

How willingly indeed I would have dismissed these reasons for the peg-animal's composition of more individual animals, and inasmuch as I still am inclined to believe its individuality, I have yet had to abandon this, which naturally follows from my observations, which in either case contain too many rarities, as well as matter enough for the scrutinizing philosopher.

Some evenings, till late in the night, I have had the pleasure of entertaining myself with this peculiar being; ever since I found all those appearing before me, in a lesser or minor right-angled square, and nothing would anymore utter any movement; probably the unreplaced and stagnant water has caused its death or immobility.

This creature, which equally full deserves the attention of the psychologist and of the researcher of Nature, resides on the dark green broad seaweed (ulva latissima) which is found on our beaches, especially outside Vester Port* by the timberyards.

The explanation to the figures.

1. The peg-animal straight outstretched, similar to a watersilk.
2. The same seen from the side.
3. The peg-animal withdrawn in a oblong square, like a wood-chip, with curved ends and perpendicular standing pegs.
4. The same in a right-angled square, from whence the bottommost piece appears to be separating from the whole.
5. Such as both ends have begun the forward sliding towards one and the same side from the square figure
6. Two small squares, which are connected by middle-pegs, and the outermost peg of which stands in an oblique position.
7. The peg-animal in zigzag shape.
8. The same similar to a thunderbolt.

*) Port is Danish for gate, Vester Port meaning the western gate in the wall once surrounding the city of Copenhagen.

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a) Zool. dan., eller Danmarks og Norges sieldne og ubekiendte Dyrs Historie, I B., s. 63, 116, 129, Tab. XVI, XXX, XXXIII.

b) Verm. terr. & fluv. Vol. I. pars I, p. 98. *Vort. polymorpha*. My eye was so confused, and my mind so full, that it was not in my power to understand the individual figures, but made do with this plain suggestion: oculo punctum agilissimum viride, sub microscopio momentis paucissimis tam multas & varias formas induit, ut nec calamo nec verbid exprimi possint; ex omnibus naturae mirandis, quae videre mihi contigit, hoc sane maxime mirabili, ac summum naturae artificium, quod animus stupet, quo oculus hebescit, inopsque spectator quovis momento roget; *quo teneam vulsus mutantem Protea nodo?* [The green to the eye very movable point, which under the microscope in a few moments adopts so many different forms, which neither pen nor words can express. Of all the wonders in Nature, which move me, this is indeed the greatest and most wonderful of Nature's creations, which astonishes me so much that I almost become a weak and helpless spectator. *How do I understand this ever changing form which Protea adopt?*]

c) Berl. Beschaft, 2 V. p. 20. t. I.

d) The Mosquito swarms usually aim at the mating; besides that one in the quiet summer evenings may watch their matings in swarming dances above brooks and small ponds, once on the tall field I encountered such a swarm on a carriage, and watched myself and my whole equipage suddenly dressed with thousands of copulations.

e) Vibrio Lineola & Undula. Verm hist. I, pars I, p. 39, 43.

f) Vidensk. Saelsk. nye Skrift. I V, p.

g) Danmarks & Norges Dyrhistorie, I V. p. 43 & 150. t. XI.

h) Cellulana. Zool. dan. prodr. p. XXXI.

a) i) Vorticella compositae. Verm. hist. I, pars I, p. 126-129. Vid. Saelsk. nye Skr. 2 B, s. 253.

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