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PLANTS AS  
INVENTORS

BY R. H. FRANCÉ



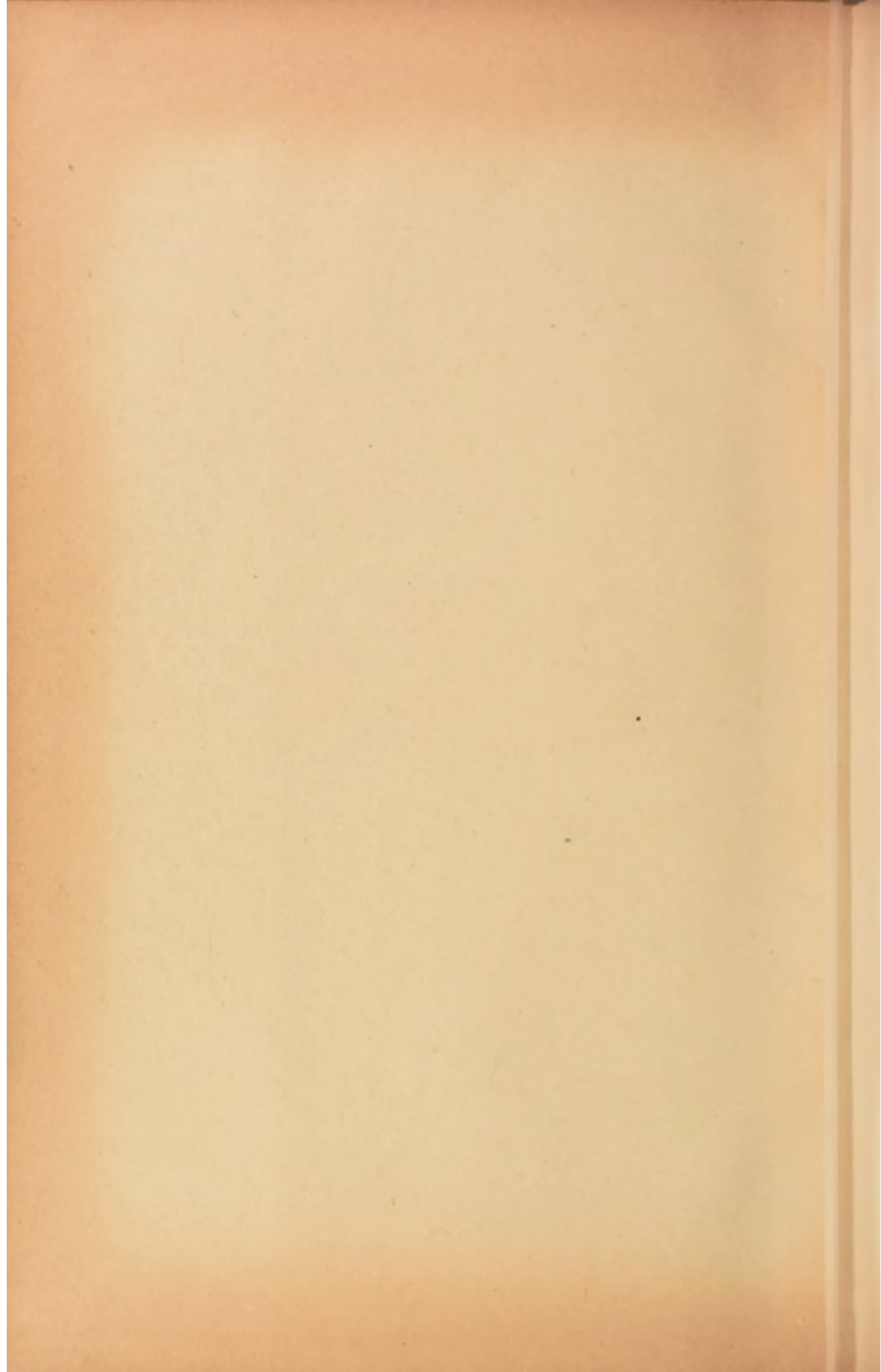
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# PLANTS AS INVENTORS

BY

R. H. FRANCÉ

WITH NUMEROUS ILLUSTRATIONS



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# PLANTS AS INVENTORS

## I.

An honest fellow, who has something to tell, will tell it simply and without digressions. So Schopenhauer declared when he was enraged by the obscurities of Hegel's philosophy. I was always convinced of the truth of this sentence; therefore I intend to tell in the simplest way how I discovered that nature is the greatest inventor and how by that means I became an inventor myself.

One morning I entered my laboratory, thoughtful and ill-humoured, for I had been halted in my studies once more and could not go on. At that time I was studying the life of arable ground. Long ago it had been discovered that the dead black earth was not really dead but filled up with myriads of little beings which all have their own influence upon the abundance of the crop. And it was to be supposed that we could succeed in multiplying our crop if we could succeed in increasing those useful earth-creatures. The simplest way seemed to be to inoculate the soil with them, quite regularly a dozen of the little germs of life sown over each square inch. This was the problem of the day. This I could not solve and therefore I was ill-humoured and thoughtful.

At first I tried different methods. I had already prepared earth which contained myriads of the small desired plants. I mixed it with water and sowed it over my field. Then I investigated the results: All was unevenly distributed.

I tried watering the soil regularly. Still no results! It became evident to me that the inoculating earth had to be spread in a half-dry state. That was the only way to success! So I lived to see in my own house the old tragedy of inventors for whom failure always is a teacher. None of them died in vain: he taught his successors what they must avoid. And to know that is really the most important thing in in-

venting. Invention is always running by compulsion, so that it barricades by degrees one wrong way after the other until at last only the right road remains open.

Or: that day, then, I decided that my right method was dry strewing: The method I had first thought of. For there is also a dark instinct for inventing which most inventors trust exclusively, with so frequent dark and sad a fate.

Next morning I brought several tools with me, whatever I could pick up; a common salt-box such as stands upon every ordinary kitchen-table, a powder-sieve for physicians and little children, and a sprayer. Then I began to experiment. Upon sheets of white and black paper which were covered with numbered squares my material was lightly sifted out, and then I counted how many little grains were lying upon the squares.

I did not succeed at all with the sprayer. Powder-sieve and salt-box distributed unevenly. The lower squares contained double and triple the quantity that the upper ones did; and, there was always less or more than I wished to have.

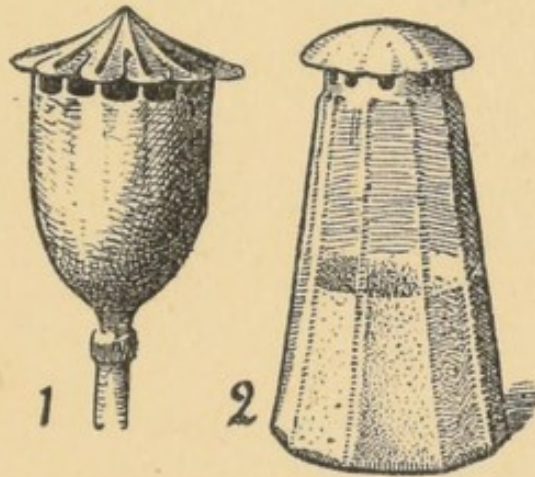
Thus my ship lay becalmed, and remained so for days until I found the right way out.

We used to believe that events of great importance in our life enter solemnly, announced by fore-runners, received with splendour and grandeur, perhaps like princes entering our life. Nothing falser than this opinion! The happiest like the most terrible event always comes with the indifferent face of every day; clad in the dress of insignificance whatever may be hidden beneath it.

So it was with that idea to which I owe so much. A chance idea brought me the question which seemed quite insignificant in the beginning: how does nature accomplish sowing? For the plants have to sow their seeds and, a little bit of thinking tells us at once, that they, too, must obtain the regular distribution for which I was striving. If a fungus is to provide descendants, it has no other way than to trust its young generation, the fungus-spores, to be sown by the wind, for there are only few fungus living in the water and still fewer for which insects or snails manage that service. In the same condition are the mosses. The wind blows their spores from the capsules and sows them. If they are not distributed evenly, two or still more will germinate side by side

and then begin to struggle for life. Instantly I saw<sup>d</sup> that nature must have solved the problem. I only had to imitate it and my problem would be solved.

But such a capsule of spores which I picked from a plant which grows everywhere in humid woods and which I now studied, is a very complicated mechanism. As long as it is young and green, a little cap covers it, with a little lid like a nightcap below it. Not before the capsule is ripe does the lid fall away and show complicated new arrangements. At the border of the capsule there are a great number of delicate little teeth, the tops of which are joined to a tender white skin which again shuts up the capsule. Now these



III. 1. A Biotechnical Invention and its Model.

The new shaker for household and medicinal purpose,  
Patent No. 723730 (2) and a ripe poppyhead (1).

teeth are sensible to the humidity of the air. If the atmosphere is humid, they remain closely pressed together and the sieve is closely shut. But if the air is dry they also dry out, stretch out straight forward, lift the lid and all the tooth-gaps appear on the sides. The capsule of spores moves on its elastic stem and throws out spores.

This invention was too complicated for me. But as I now had found the method I only had to seek further in order to find a model fit for my purpose. And I found it in the capsules of the poppy. Everyone knows them. Everyone knows that the holes arranged in a circle under the lid serve for the dispersal of the little poppy-grains, but no one thought that here was a plant invention which excels man's. I know it because I have examined it. A poppy-capsule filled with

grains of earth distributed much more evenly than I had been able to before.

Astonished, puzzled, filled with an undefined joy I stood on the threshold of a new discovery. With determination, I decided to make certain of my discovery. I drew a shaker for salt, for powder and for medicines according to the model of the poppy-capsule, and applied for a patent on it.

The application was not denied, and my "invention" was given protection under Patent No. 723 730.

Still other inventions of by far greater significance are under way. Some were refused by the patent-office, but not because they were not practicable, but because the same thing had been previously invented, which I could not know as I am not an inventor by profession. However I am not interested in being called an inventor, for I am only a poor imitator of nature. The most important thing for me was the principle; and the patent office, which examines carefully and knows every technical thing, by acknowledging that here are real inventions, has acknowledged my law and the truth of my doctrine, and thus in a manner officially acknowledged the practical use of a philosophy before this philosophy had really entered life.

So a new science is founded: the Biotechnic. This little book will deal with its fundamental thoughts. They are founded on a law of nature. And laws of nature are always true and consequently practical.

What is the origin of this law? How did I find it or, who revealed it to me?

It was a gift of the woods, a practical result of a philosophy which begins with the simplest and with the most natural object: with the poor little, easily fatigued head of man, placed before the great, incomprehensible world. Contemplate the world thoughtfully; as I am accustomed to, when I construct my philosophy: on the top of a mountain, lying alone in the great silence with only the harmonies of the spheres to listen to, and the solemnly resting heads of the rocks, and behind them eternity, to gaze at, not at all dark but glistening in the sun. Then, my mind is quickened with a thousand good thoughts. Or in my firwoods, in a little valley, quiet too, warm, sunny, filled only with the sound of whistling pointed leaves and chirping crickets; where the trees,

the blood-red gilly-flowers, the bell-flowers, the whispering honey-grasses have something to tell me every day in the long hours of watching and thinking. A bud, which yesterday was not stirring, or a leaf withering away, a little ebbing life which is leaving us: these have their meanings to convey; anywhere, the bright procession of the clouds takes my thoughts with it, over and over again, far away, above all men, countries, wishes, cares, above instinct and petty ambition to the quiet ever-resting universe. The little sand-wasps, which fly here and there to their mysterious homes on the pale sand-hills, are my brothers, as are, also, the dark shadowy dragonflies which sit down noiselessly beside me, and the confiding blue butterflies which are like a kind smile looking at the industrious writer and then tumbling away until they too disappear in the universe like myself. From this philosophy of sunny days I brought with me the pale last abstraction of the personality who says: I know nothing. Nothing is anticipated, nothing given; nothing is sure for me except that there is that universe, that immense plurality of my existence.

And upon this thought only, as on a corner-stone, logical thinking can be constructed.

Is existence uniform? My mind asks. No, my experience proves it. It is a construction of different parts. With me, one became two. We may proceed with our thought. We can oppose the whole to its parts and we are sure that there must be a regular proportion between them. What proportion? This, that the whole influences the parts, each part the other, and they all together every part again. If, therefore, the part itself shall endure, it must have its own qualities, must be unlike the other parts and the universe. Or a bit more significantly and therefore more comprehensibly: each part must "be", must have its own nature and qualities, must be an individual. Everything either can dissolve in the universe or "be". But besides this quality of perseverance another quality inheres in things.

The universal is a construction of different parts. That is expressed heavily; you would say more exactly and simply: It is a complex system. Parts of that complex system are removed and they are all endangered, for this threatens to destroy their original qualities. They disturb and influence each other, lose

their position of rest and seek to get it back by their quality of perseverance. By that activity is set on foot. Beside individuality there stands change. Existence stipulates happening. According to a uniform law, for it is true for all things, existence and change preside over our world.

So at once all things have become squint-eyed, as when we look down on town and country from a very high mountain, many thousand men and their works, woods and meadows, nature and culture melt together into one picture. And seen from the height of our contemplation existence and happening, world and processess of the world melt into one, into the notion of the natural. From very high mountains we observe the strange phenomenon that the things of sharpest delineation, — the bank where we rested before climbing up, the great tree, which gave a shadowed seat, the hut of our night's lodging, seen from above, have disappeared, melted into the green or blue dusky table of a meadow or a wood, dissolved into the flat grey identity with which everything is enveloped for the human eye at a great distance. The same process occurs in thinking: notions melt into each other if they are looked upon from a great distance; they are changed into a grey incomprehensible void. So well-known is that to us, that we have given a name to this incomprehensible change: we call it abstraction. We have become accustomed — perhaps the most admirable abstraction of the human mind — to give signs to these abstractions; marks, which we call numbers to calculate with. The hour of that admirable invention was called the birthday of mathematics. The whole world is contained in these numbers, when seen from the highest of all mountains of thought from which all things shrink together to pale, grey, natureless abstractions. The number is perhaps the most interior, the most secret skeleton of all things, and is common to them all. Charming and horrible at the same time is that power of mathematical thinking: Fragrant, manifold and confusing the magic garden of life is spread around us — the mathematician enters and at once the peach-cheeks of the beautiful woman become pale, the flowers fade away, the mountains sink down, all flesh withers away in a terrible dance of death. The apparition of all senses flees like smoke and only the pale last skeleton of every thing remains: its numerable worth. And all happening:

looks of love, hot kisses, silent mourning, dark deeds, proud effects evaporate into their nature: They are only functions of the number. In the place of the moment we lived to see stands there stiffly, ghostly, dead, but full of interior life, clear as crystal and apt to be neatly ruled: The mathematical formula.

Thus at the beginning of our world, stands, as a copy of godlike eternity, with the deep penetration of an eye in which a whole world is reflected, the equation:  $1=1$ . It is the temple-mystery in the most interior cell of God's temple itself. And if you have once conceived what magical significance is hidden in mathematics, then, it is the most charming and most important of all occupations. Upon a sheet of paper with a pencil in your hand you rule over the world by its help.  $1=1$  is the contents of a great book.  $1=1$  tells us that everything is identical with itself; that everything in order to be fulfilled has to return to itself. If you subtract something, if you add something, it cannot be one still, but now begin mathematical, countable and therefore lawful processes; out of existence grows happening which endures till one is one again.

All must have its best form, its "optimum" which is also its nature at the same time. To repeat, because the thesis is so very important: There is for everything, be' it a concrete thing or a thought, only one form which corresponds to the nature of that thing, and which being changed disturbs the state of rest and provokes activity. These processes work by force, that is lawfully by destruction of the old form until the optimal, essential form of rest is reached, in which' form and nature are identical again.

This return is made in the shortest way. We call it the way of the least expenditure of energy, and perceived its operation long ago in daily life in the much quoted' axiom: the shortest way is always the best. This least expenditure of energy is also expressed in the equation,  $1=1$ . For the identity is the shortest way to itself at the same time. The optimal form is also that of the least portion of energy, that of the intensest function. Like wedge-formed writing upon rock, the fundamental knowledge about form and function is engraved in our brain for ever with these lapidarian sentences.

What astonished us so much and was admired boundlessly



two generations ago: the thought of selection, is recognized as a nearly self-evident law of the world, and most simple derivations are so clear that everyone is almost able to examine them in his own mind. Each form changes, none of them is enduring until it is the optimal form which then always corresponds to the nature of things.

Uninterruptedly, by a mechanical world-selection, new forms are selected and an imperfect thing cannot abide, but must develop until it is perfect in accordance with its nature. All changes however take place according to the law of the least expenditure of energy; a process which may be called the law of economy.

It is the law of every function that it seeks by selection to become the shortest process. Translated into a quite simple example, a stone which has lost its position of rest seeks to find it again in the shortest way; and of many stones rolling down a mountain, that one will find its position of rest soonest which is falling perpendicularly. The process itself is natural for us because of its certainty and regularity. We see it take place often and from this experience we abstract the notion of the law of gravitation, a general law of nature.

The shortest way by which a process comes to its conclusion is its law of nature. Things arrive at their eternal position of rest, when they attain their optimal condition of rest, when they exert a minimum of opposition to that condition.

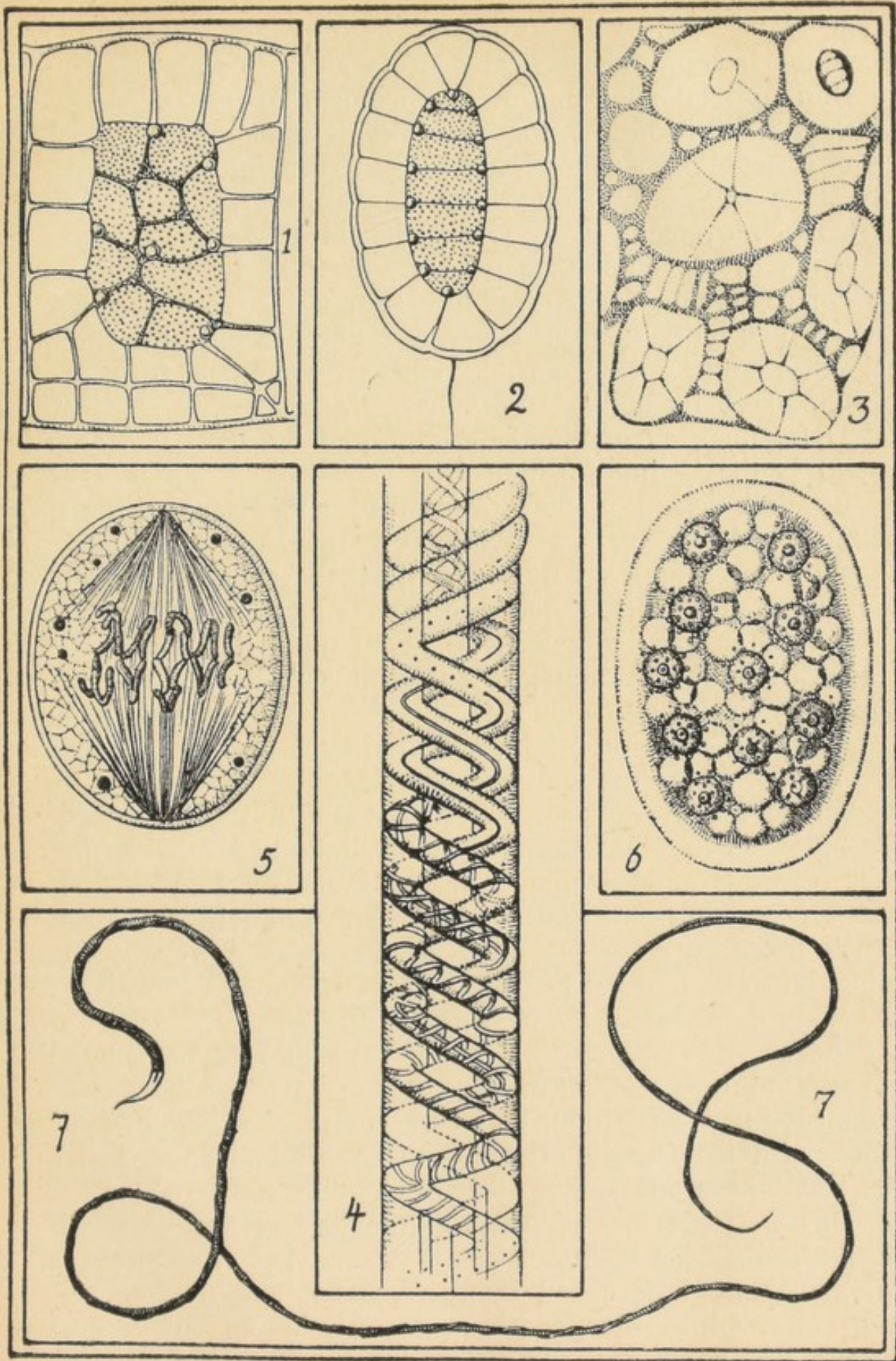
I concede without any objection that I am carrying these thoughts to a tedious, tiresome extreme. But the reader who followed my reasoning will concede that now the top is reached and that he is rewarded by a wider outlook. For now we understand what laws of nature are, and that to every process belong, by necessity, fundamental forms of change. If you descend from the regions of these last abstractions, in the cold atmosphere of which you have tarried so long, you can express the same thing much more intelligibly and much more simply in the thesis now completely motivated for us:

Every event has its necessary technical form. The technical

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### III. 2. The structure of protoplasm.

1. Comb-structure from a swinging-thread-cell.
2. Comb-structure of a bacteria (*b-lineola*).
3. Kernel-structure of an infusorium.
4. Sketch of the structure of protozoic elementary threads according to Fayod and Entz.
5. Thread-building in a dividing cell-kernel.
6. Protoplasm. Sphere-bubbles of a primitive animal (*Colloxooum*).
7. Plasma spiral-threads (seed-thread of a snail, *Reolis*).



Explanation in Foot-Note on page 12

form always arises by processes as functional forms. They obey the law of the shortest process and are always attempts to find optimal solutions of the problem to be solved. Every process thus produces for itself its technical form; cooling requires cooling surfaces, pressure occurs only at points of pressure; pull only along lines of pull. Movement produces forms of movement, every energy its form of energy.

Thus life has its form of life. Each of its functions has its corresponding form. And life as a unity working together has its own individuality. (Everyone who has only the slightest scientific education knows it). It is in its simplest form protoplasm, or in its bodily form, the cell.

Here, then, an excellent definition of the cell is offered to us: It is the bodily form of life.

By that definition the adventurous and strange little grey being which we call a living cell filled with protoplasm becomes intelligible. All its peculiarities are explained if we look upon it as one of the optimal forms of the functions of life. What can a living cell do, what must it do in order to maintain its life. It must be material, substantial, if it is to have any influence upon the things of the world. It must have matter therefore. The cell, before it adopts its special form, must have the faculty of being moulded into every form. Therefore the protoplasm is fluid and elastic, it is amoeboid. Its outer surface has the facility of unlimited movement, for it is formless and capable of taking every form. According to the type of movement, it adopts an optimal form for its functions: a form of feet in order to creep, a waving undulating border in order to propel itself through the water, and the whip in order to swim swiftly.

In the protoplasm itself each of its actions has modelled corresponding parts according to the law of the least resistance: for propagation, the cell-kernel; for secretion, bubbles filled with air and liquid and the secretion, compressed into the least space, the sphere like little grains. (See Ill. 2.)

Down to the lowest visible limits there is no atom which does not obey the law of its bodily form. And it must conform to it, whether it is a cell living for itself and no larger than a grain of dust, or whether it is only a part of a greater system which we can observe, and see every day as a plant or an animal.

The cell has a form for every function. If it remains in complete rest, if all functions have been stopped in it for a while, it returns to the fundamental form, the globe. In the globe the inner and outer pressure are compensated equally and completely; with that a multitude of processes come to rest. The form of a globe realizes the idea of the least expenditure of energy. Therefore, a balance of interior tensions can be attained only when a ball shape has been assumed. This is true for stars and star-systems, for the earth, and for every material to which human hands gave a form, as well as for the smallest egg or the smallest particle hidden in the most remote corner. This law extends to our culture, and to all fancies of the sovereign human spirit. Any system, where everyone is to bear an equal burden, will take the form of a sphere. That is a law of necessity — the real god.

Necessity prescribes certain forms for certain qualities. Therefore it is always possible — and this is the most important thesis of the doctrine of bodily forms, the elements of which we are studying here, — to infer the activity from the shape, the purpose from the form. In nature all forms are crystallized, processes and every delightful figure a creation of necessity.

A system of tensions, changing in a hundred varieties, becomes a crystallized form. Hitherto, we glanced through the collection of minerals with an eye only for beauty, with the idea only of aesthetic enjoyment; now the silent world of the dodecahedrons and klinorhombes, the glittering ores and precious sparkling stones will tell us the history of the powers hidden in them. Where tension and pressure have to perform the same tasks, the same crystal-form grows up; be it deeply hidden in the interior part of an iron-girder, in a stiff dark porphyry rock a thousand yards under the sunny fields, or whether in the cell-form of a glistening green stem, or whether it is in a figure, great or little made by human hands. The wooden block, or the stone, or the piece of glass, lacks the qualities of a cube or a prism until we give it the form of a cube or a prism. By force we reproduce nature in order to give to our work the qualities of nature.

Therefore everything which is designed for pulling must be ribbon-shaped. The muscular fibre; the leaf of the sea-

grass *Najas* exposed to the currents; the fibrile, (scarcely a twenty-thousandth of an inch long) which is deeply embedded in the separating cell and which must draw apart the halves of the cell-kernel; the great muscles and strings in an animal's body or in the human body; the ship's rope; the traces of an equipage; and the driving belts of the transmission. In the great majority of pulling-functions the same form occurs inevitably. The cord, for it is the optimal technical form of draught. If we were living in the age of the Greek philosophers I would be most quickly understood if I said, that form is one of the demiurges which maintain and reproduce the world.

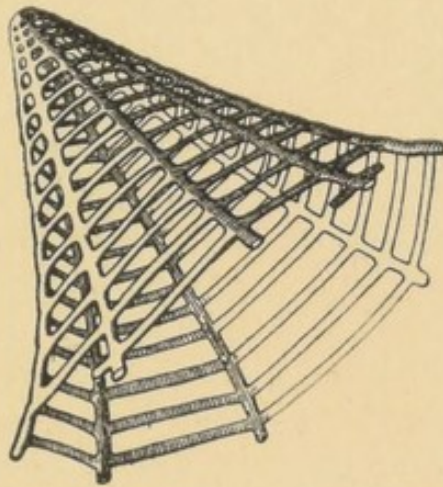
To lean one must have a staff. The old man leans upon his; the roof of a temple upon the row of columns, which are also thick staffs. Trunks, formed like pillars, are built also by the palm-tree in order to support its fan crown; by the beech-tree to support the green burden of its leaves. Every corn-stalk builds a hollow staff to carry its ears; the bone of my own leg is a staff, the smallest unicellular creatures project staffs when supporting functions belong to their necessities of life. When wind and rain models a pyramid from the loam of the earth, with a rock crowning its summit, it also erects a natural-column.

The shape of a screw is adopted by everything which has the function of boring and squeezing through. A tiny bacteria uses it to screw through its world — a drop of water; the terrible spirochaete penetrates, by means of its screw-shape, through all textures, through all the cells of the man suffering with syphilis. The light, screw form of the wings of the maple-seed serves to propel it through the air in the same manner as propellers do an airplane, or the immense wing-screw does an ocean-liner. The gimlet, by virtue of its form, bores into wood more readily than a nail; by virtue of its form, a screw holds more securely than a plug.

We, ourselves, did not invent the screw, the gimlet, and the propellor; nor did the bacteria, the scourging infusoria, or the plants; nor yet the wind which moves most rapidly in spiral windings. The natural law — deeply embedded in the structure of the world — stands behind all these occurrences: spiral movement occurs with less expenditure of energy than movement in a straight line. Therefore, the movement is accomplished much more frequently, if the form is spiral than if

it is not. If something is moving forward, the least inclination towards the spiral makes its passage easier; and the resistance which it encounters models it mechanically. In other words, the type of movement, itself, produces the optimal organ for its accomplishment.

The fundamental technical forms of the world are contained in the crystalline-form, the globe, the plane, the pole, the ribbon, the screw, and the cone. They suffice for every process of the world's occurrences: every process can find its optimal form in them. Everything that exists is a combin-



Ill. 3. Skeleton of Coelestin (mineral-matter), which the Radiolaria uses to support the protoplasm of its single cell. (After Haeckel.)

ation of these seven fundamental forms; but beyond this symbolical number of seven we have no other form. Nature has produced no further form; and the human-mind may devise whatever ingenious shapes it will, they all are combinations and variations of these seven fundamental ones.

It seems incredible to us, and we industriously search our neighbourhood for forms to disprove it. Here stands a fine old house, a many gabled building of the latter Middle Ages. I place my scales upon it, and what do I find? It is a cube, with a prism resting on it as a roof. The walls of the roof are planes; in the volutes of the gable we find the spiral, or screw; the window-frames are built of poles; the entrance hall is supported by columns, i. e. by poles; a globe crowns the turret: from first to last there is nothing in this grand old building which cannot be derived from the seven fundamental bodily forms.

A bunch of fresh field flowers stands on my work-table. Every week there is a different variety, this week: common John's wort, arvensis, blue-bell of the meadow, bird's-foot, and bull's-head. Together a glimpse at random into the life of nature. I make a thoughtful analysis of their forms. Petals and leaves are planes; the crown (corolla) of the blue-bell is composed of ball, cone, and planes. As in a Rococo ornament occur conchoid and spiral-plane — both derived from the spiral; the stalks are poles. Though all forms are recoinced in life with their own purpose, and are recast and complicated in the greatest measure, I could find only the seven fundamental forms; and I had searched and figured for a quarter of an hour before giving up the attempt to discover a new form.

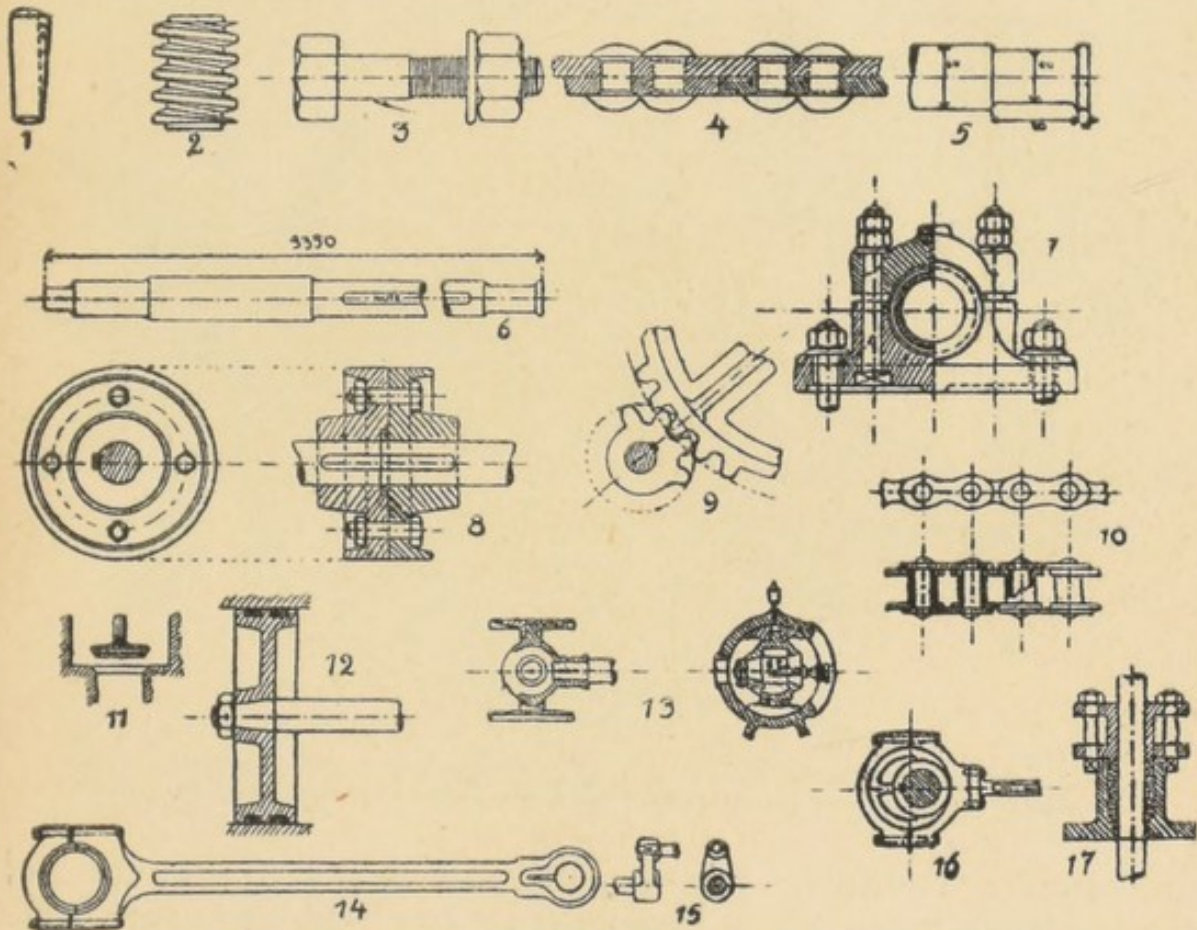
I had pursued my search from the builder's art to the loveliest products of nature, and had found nothing new. Perhaps a masterpiece of human creation may serve to teach me better. I stand before a steam-engine, a locomotive, and seek a refutation of my thesis. I know from the elementary doctrines of mechanics what I can expect. Wedges, taps, screws, rivets, axles, blocks, couplings, gearing, chains, pistons, piston-rods, cross-heads, stuffing-boxes, cranks, eccentrics, connecting-roads, cylinders, tubes, valves — no machine constructed by human hands ever consisted of more (Ill. 4).

I put my measure of the seven forms of nature on each element of an engine and solve all the shapes, of disks, of rods, of screws, of crystalline-forms, of cones, of spherical surfaces. The most unusual parts such as the eccentric wheel employed in our spinning-machines, are composed of screws and planes, which also appear in combination in nature.

No technical form exists which cannot be traced to the forms of nature. Here, like everyone who comprehends this matter, I am astounded by what is uncovered before us. We have in this one law the explanation in one formula of life — all life, mechanics — all mechanics, industry, architecture, all the ideas of the artists from the builders of the pyramids to the expressionists, the experimenters of the present. Eagerly we search on. But everything we touch becomes ashes in the flame of that idea: the forms of minerals—ore and stones, mountains and heavenly bodies, chemical combinations, geography, and even the human body and every artificial structure, all dissolve into the seven elements of the world.

There are only seven fundamental technical forms! They are the basis of architecture, of the parts of an engine, of crystallography and chemistry, geography and astronomy, of art, of industry — of the whole world. And the world teeming with life has produced no other possible forms.

I advanced the weightiest argument for that contention when I showed that the form of the cell is nothing but the



Ill. 4. The elements of which all machines are composed.

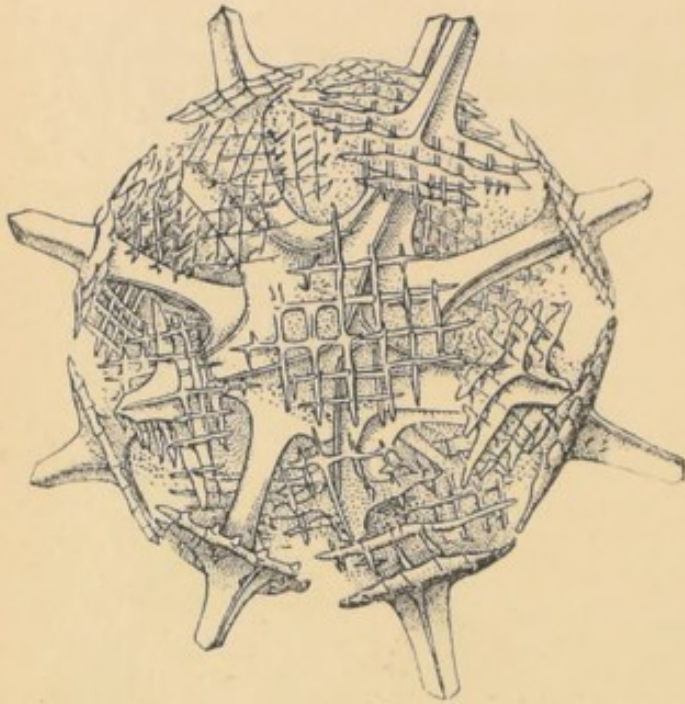
1. Wedge. 2, 3. Screws. 4. Rivet. 5. Tap. 6. Axle. 7. Block. 8. Coupling. 9. Gear. 10. Chain. 11. Valve. 12. Piston. 13. Crosshead. 14. Connecting-rod. 15. Crank. 16. Eccentric. 17. Stuffing-box. (Drawing by Walter Francé.)

bodily form of life. The form of the cell is infinitely manifold, for not only are there 60 cell-forms in animal and human texture and 16 in those of plants, but also about 6 000 one-cell animal-algae, 4 000 plant algae, about 8 000 radiolariae, 3 000 other unicellular animals; altogether about 25 000 cell-forms which differ from each other, although often only slightly nevertheless sufficiently to make it possible to describe them separately. In rich profuseness living matter has realized

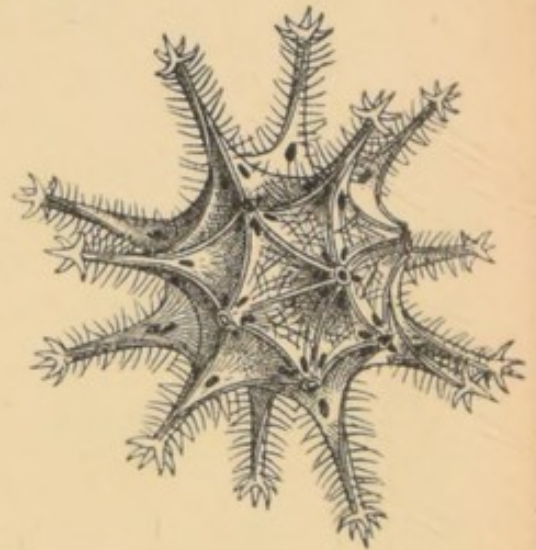


every possibility of formation and the artist's fancy seems a bungling imitator in comparison.

This has been proved by an experiment. Several artists were asked to create as many variations of a decorative form as they could. They could draw only a few dozen, although in the world of unicellular bodies there are hundreds of different models. You may try the same experiment in order



III. 5.



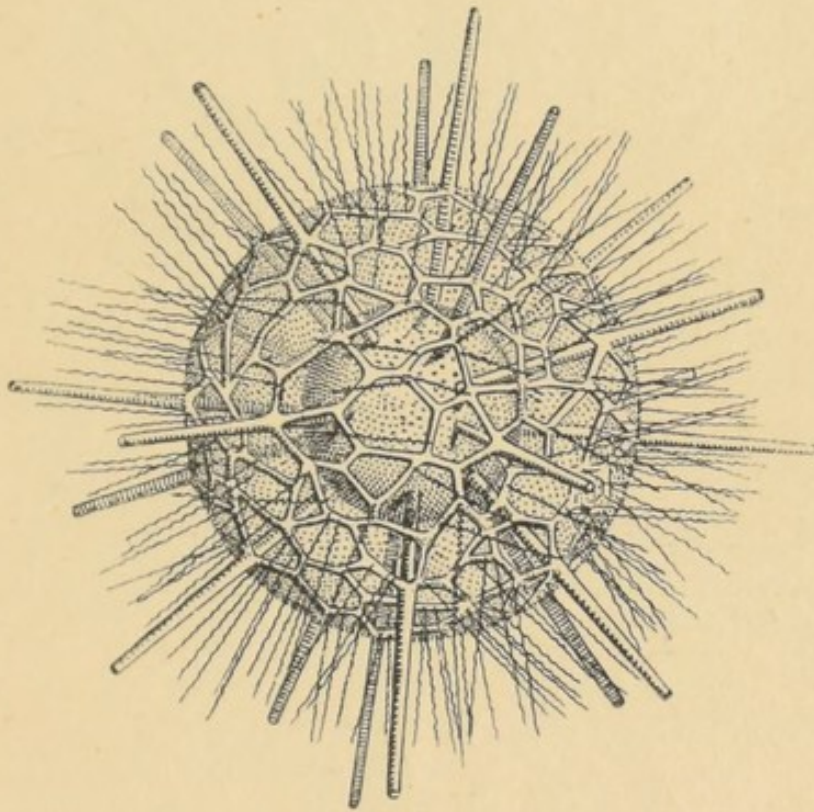
III. 6.

Technical Arrangements of Unicellular Organisms (Radiolariae) which combine solidity of protoplasmic structure with the faculty of swift swimming.

to convince yourself. Try to draw variations of one of the fundamental forms on a sheet of paper. You can start with the ball, carrying it through all the egg-shapes, elliptic, shell, trellis-work ball, star, etc., and see how soon you will stop. Then you may pick up a volume on algaeology, — preferably plant algaeology, — and you will then become forever convinced that living matter as an inventor of forms cannot be matched by man.

But what you can see in the world of cells recurs again in the structures which the cells build together. A long time before science had conceived the idea of the cell, about the time when the first clumsy attempts were made to gaze into the interior magnificence of life through poor microscopes, the fantastic Swede, Swedberg, whom the world knows only

by his name as a nobleman, Swedenborg, conceived the startling idea for his generation that the world is a great unity. He pictured it as an eternal flowing of the same things, a return of similar laws, only in different intensities; at one time concealed in small things, at another returning with a giant's steps to construct rocks and mountains, to write with starry script upon the heavens, or to assume spiritual shape and become feeling in man's brain and heart.

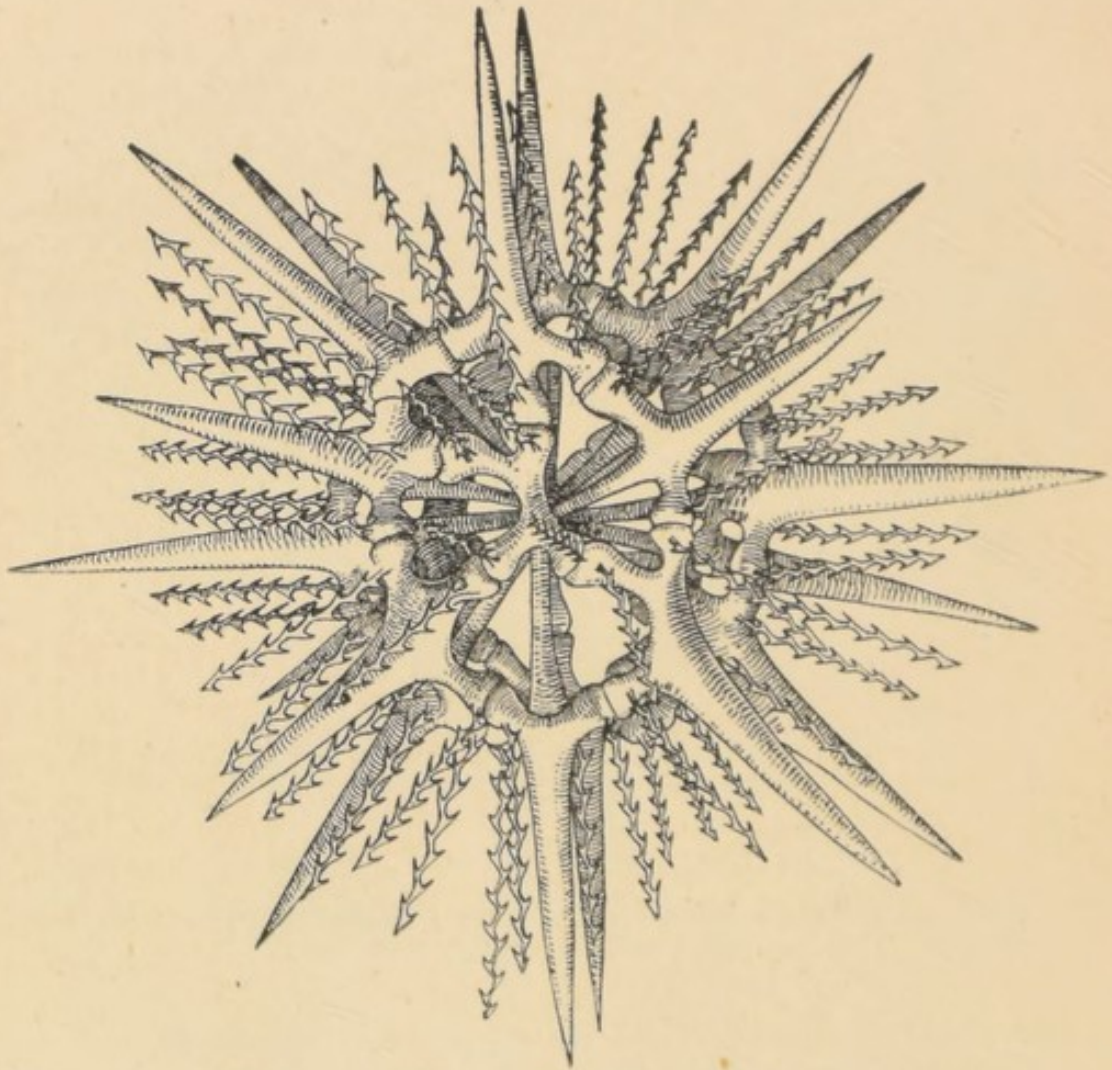


III. 7. An Artistic Form of Nature, really a masterpiece of stability and economic construction.

The fanciful assessor of mines from Stockholm has long been forgotten, and nobody thinks that it is his idea which biology has adopted as the law of degrees of integration — which means that the forms and laws of unicellular life recur in higher stages in higher degrees of intensity. Physics also employs this idea, which is very helpful for it in explaining the theory of electrons by comparison with a solar-system. The movements and relations of the star-filled sky are conceived to recur in the invisible world of electrons.

The technical formations, which in the uni-cellular life confuse and charm our senses, follow precisely the magic

round of the same law in the masterpieces built by cells, leaves, fruit, animals and plants. The same inexhaustible richness and the same structural forms are again found in a higher degree of integration, — and always obeying the law of the seven fundamental forms and their combination, perforce, as instruments of the functional purpose.



III. 8. Celestin Skeleton of a Radiolario from Tropical Waters  
Compare ill. 5 and 6.

Even inside the cell it is not different. The same law recurs within the perception of our eyes, which bring great and small into our mental conception; within the visibility of a microscope which does the same thing for the minute.

Still, that smallest of small worlds, the intracellular world, is not fully opened to man's eye. It is only in the last thirty years that the microscope has been perfected to the point

of spying out the minute and secret structure of the cell: the cell-kernels, the grains of chlorophyll, and the tender scum of living stuff.

It is as exciting as walking along forbidden paths to peep into a world where the thousandth part of a cubic millimeter (approximately one twenty-five thousandth of an inch) is a space which appears to be no less complicated and complete than his corpse is to the young medical student as he gazes at it timidly where it is resting on his anatomical table. (See Ill. 2.)

Within the cell we see another world of cells, the still smaller corner-stones of life, which we call combs and which form cells in the same manner as cells form organisms. On the edges of and within these combs there are still smaller granules, and then again threads, ribbons, spirals and small prisms. Such, for instance, are the muscle-fibres and nerve-cells and a whole star-system of most delicate threads which is developed in every cell when it divides. (Ill. 2, ex. 5).

Again all these parts shape themselves in accordance with the law of the seven fundamental forms, and we recognize that the intracellular organism does not differ from that of the cell or other organisms.

Similarly, in whatever degree of integration, the same mechanical system universally regulates the entire activity of life, and the theory which we hypothesized when we approached the consideration of the cell as a technical form of life, has now become a well-thought out and proved concept.

The laws of the least resistance and economy of action force equal actions to lead to the same forms, and force all processes in the world to develop according to the law of the seven fundamental forms.

The analysis of the fundamental law of bodily formation is now finished, and one of the perhaps most consequential and practical inspections of our life-processes has become completely clear. The technique of nature (cells, plants, and animals, and man) are reduced to a universal fact founded on the structure of the world.

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## II.

If you walk through the world of plants using the knowledge which you have just acquired, field and garden, meadow and wood and rain-drop turn at once into an open-air museum, a model collection of technical miracles, to be used as artists use art-museums to gather ideas from the collected riches of old.

It would require a monumental work in many volumes to explain and make available the models and types of technical culture which our open-air museum contains. In the scope of this work I must limit myself to a few selected masterpieces. But inspection of selected portions of a museum is always more profitable than attempting to see everything and losing its lessons in fatigue.

As an old guide of many years experience in the museum of the bio-technic, I shall show only six halls and contract to convey the right idea of the bio-technical structure of plants. These are the hall of the flagellates, the hall of the plant algae, the great center hall of the plant-cell, and the small rooms of the leaf, the trunk, and the fruit.

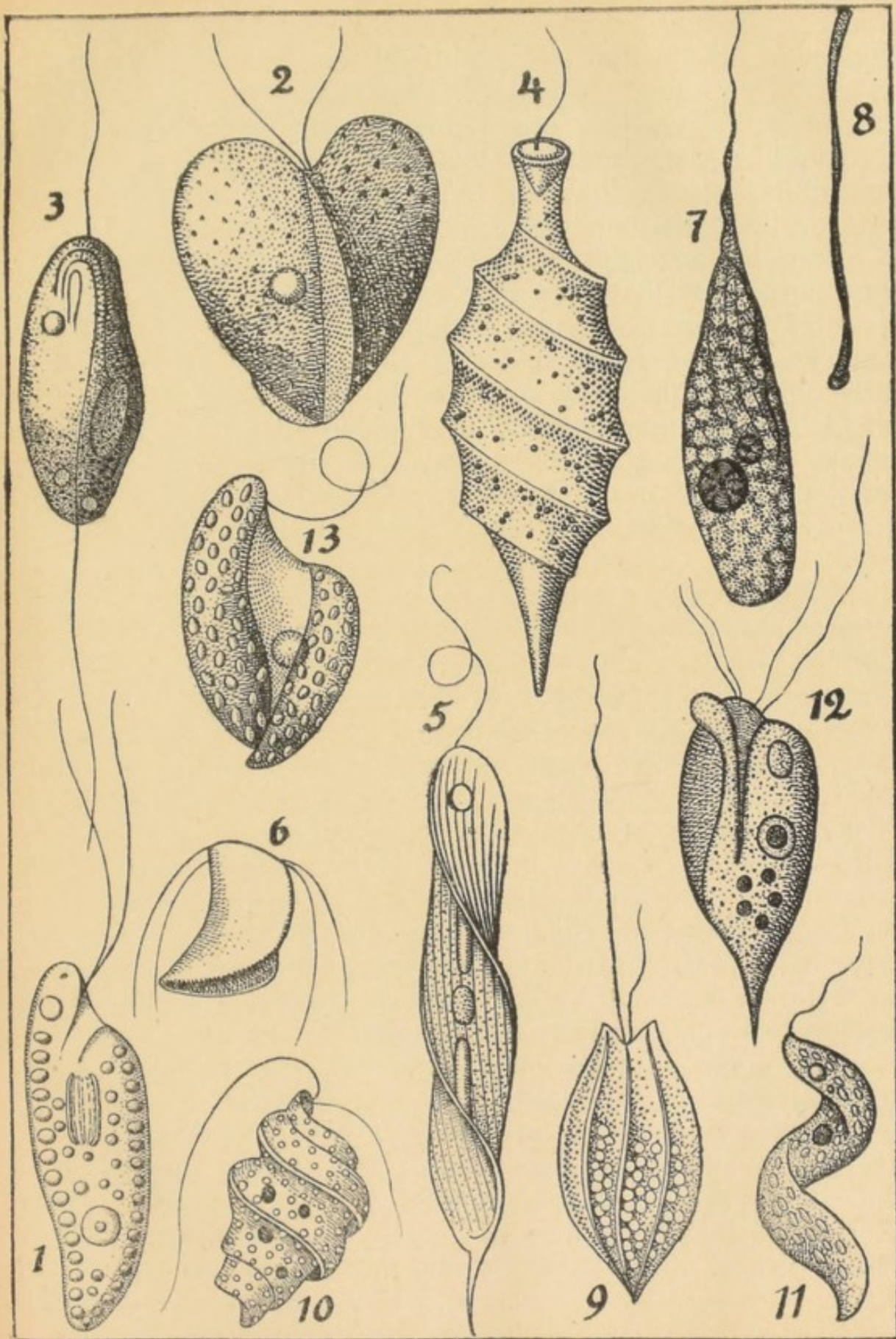
The entrance leads to the little world of the uni-cellular beings of the drop of water, to machines resembling those wonderful clocks made to fit into a pearl, but which are still more marvelous because they would not fill a grain of sand. But we know that the law of integration allows this miracle, and that small and large have significance only for man who measures them in comparison with himself but not for the universe.

Take a little bit of bottom-mud from the gold-brown bottom of any peacefully flowing stream, in an idyllic silent creek surrounded by water-roses and enmeshed in tangles of mouse-ear chickweed, with banks bedecked with the lovely blooms of herbs and umbels of rushes. Let some leaves and stalks rot in a small aquarium and you have enough material for a

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### Ill. 9. Flagellate Forms as Examples of Perfect Swimming Organisms.

1. *Chilomonas paramoecium*, one of the most frequent rapid swimming forms. 2. *Streptomonas cordata*, with a keel. 3. *Anisonema*, with a towing whip. 4. *Urceolus costatus*, a screw form. 5. *Euglena tripteris* a model propeller. 6. *Syromonas ambulans*, a propeller form which has been copied in ship-building. 7. *Trypanosoma*, with its spiral whip. 8. Spiral whip of 7, enlarged. 9. *Tropidoscyphus octocostatus*, an unknown form of screw. 10. *Heteronema spirale*, a model for the torpedo. 11. *Monod*, a modern propeller form. 12. *Tetramitus costatus*, a still unused model for a ship's hull for speed-boats. 13. *Monad*, a new variation of the propeller.



Ill. 9. Flagellate Forms (Explanation opposite).

study of the flagellates, as much as you would need for a whole summer's examination under your microscope. What are flagellates? Unicellular organisms! Sometimes green or golden brown, and then they are harmless plants. Sometimes transparent, like glass, and then they are usually filled with other unicellular plants, for these are as voracious as wolves, and are the tigers of their world.

Both the vegetable and the mineral flagellates must swim as long as they live. The vegetable can also seek the vivifying sun-light under the varying conditions of its life. Industrious and unswerving like a star in its heavenly course, they drive through the drop of water in which you may observe them, and rise or descend like golden dust if the sunlight shines on them. The others rush about rapidly. They are swifter like all beasts of prey, and rush like an arrow on their victims, which very often they catch only after a clever hunt.

Both, therefore, have solved the problem of the swimming form; indeed, the despoilers have become simply a "swimming-body." The law of the least resistance has given to their bodies the slender form of a ship to enable them to part the waters. They all swim submerged: the submarine boat has only repeated their form by force of the same law. Their end is frequently drawn out in a long keel (ill. 9, sec. 12); if they need it for further stability, a real keel may be annexed (ill. 9, sec. 2) so that our boats only embody a principle employed by protoplasm. In place of the keel we very often find a strange invention which airships and not ships of the sea have long used. We should have tried a boat made according to this plan approved by life's models. Section 3 of illustration 9 represents one of these small, common flagellates of marsh-water, to which science has given the high-sounding name of anisonema. It gives itself up to the specialty of swimming-forms, and has another invention in its body. On its under side as it swims, extends a long cord, which floats behind and is useful as a rudder as well as for increased stability. It is astonishing how steadily the little anisonema — it takes twenty-five of them to extend one inch — swims through the water. How quietly it swims and turns, how suddenly it can stop: it certainly controls the element it lives in.

These furrows and incisions occur in surprisingly many

flagellates, especially in the group of monads, which belong to the fleetest and most voracious carnivora of that world of minute organisms. They race through the drop of water like swallows through the air. Often they rush so rapidly through the observer's field of vision that only a glittering wake reveals their existence; and the novice, blinded and puzzled, but also charmed by so swift a ship, has difficulty in seeing it at all. Section 12 of illustration 9 pictures this bird of the water.

Its frame is unknown to the human technique of ship-building. When I applied it to the design of a ship's hull below water, in a practical way without using Norman's formulae, the engineer whom I consulted for the calculations of the model declared his astonishment that a type of ship could be made with so much greater speed and economy of fuel-consumption by the use of this hull-shape. There is no doubt that ship-builders of the future will be forced to study the many strange, peculiarly shaped, skipper flagellates and infusoriae. (See ill. 9, sec. 1 and 7). They drift about before everyone's eyes, marine and aviation models whose usefulness has been tested by millions of years of life and practical application. For each function becomes more vigorous by natural selection, to which all living things are subjected. Every bodily form of a living creature is subjected to the struggle for existence, and is constantly under examination for its usefulness so that we might say that only the "optimal models" are able to maintain and propagate themselves. In nature, also, there is a patent-office which admits only useful inventions, and excludes from practice all those which do not bear the imprint, *probatum est* (it is good).

You must realize that the swimming forms of the water calculate on a different motor from ours. Since antiquity we have had only one method: to screw ourselves through the water. We can do this as well by rowing, which forces water-columns on the side of the boat to whirl in a slow spiral\* by which the hull of the boat is forced forward. It would be driven in a circle; to prevent this we row on both sides, or turn off the water-whirl by a keel, or more conveniently by

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\*) Paddle-wheel steamers, which seem to be based on another principle, really produce a spiral whirl as the flow of water caused by the revolving paddles is thrust by the convex ship's hull to both sides in a spiral.



a rudder. The screw of a ship is only an improvement of that principle, and when fixed, as usual, at the back-board of the steamer, gives a back push to the water.

The hull of the flagellates is screwed forward by a very strange oar; the more delicate structure and purpose of which we have discovered only recently: its real significance coming to light only under the influence of the bio-technical law.

This oar is called a whip, and we believed it to be a simple cord which is swung like a whip, (See ill. 9, sec. 3) a flagellate body has anywhere from one to eight whips, which vary considerably but are generally attached to the front of the body. Some of these whips, as, for instance, the drag-whip of the anisonema pictured in section 3 of illustration 9, are certainly not useful for movement, but only for steering and balancing. They also have a different structure from the organs of movement. They are not threads — I have often examined them, myself — but they are ribbon-shaped like oars (ill. 9, secs 7 and 8). They are slightly twisted in a spiral and produce a screw-like whirl by their motion so that the body is driven forward by it. Frequently two, and occasionally four whips, (ill. 9, secs. 6 and 12) work together in splendid and incomparable unison. Besides there are very complex arrangements which we must be content to merely mention in this general review of the bio-technical science. There is still something to be learned from them which our nautical engineers may wake from their sleep and study from the point of view of the technical man.

This much we can see: the solution of the problem of ship propulsion through the "screw-whip" of the flagellate is an ideal case of economical effectiveness. We have to employ engines of 40 000 to 70 000 horsepower and an immense capacity for consumption of coal to attain 23 sea-miles\* an hour; a little monad attains not the speed of one and a fraction inches\*\* per hour which I calculate is the proportionate speed according to its size in comparison with our swiftest steamers, but a many thousand times better effect. The monad, propelled by its whip-screw, can swim 20 mm a second ( $\frac{4}{5}$  of an inch); and many of these creatures whirl

\*) Approximately 27 ordinary (land) miles.

\*\*\*) The monad is  $\frac{1}{100}$  mm long (less than  $\frac{4}{10\,000}$  of an inch); the steamer 200 m (656 ft.).

only the upper part of their whip, thus utilizing only a small part of their bodily strength.

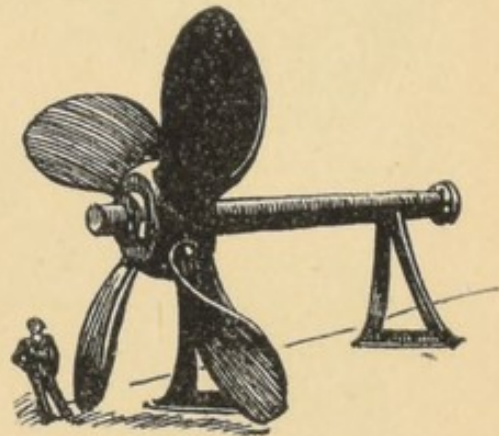
This is the superiority of organic construction to that of human technique.

Great rapidity of motion more than proportionately raises the resistance of the water. This is overcome, as we already know, by the screw form of the body, which cuts the water. It is simple necessity that all rapidly moving flagellates have inherited cutting spiral lines, often entirely screw-shape, as a glimpse at illustration 9, secs. 4 and 9—11, and illustration 13 will make evident. This torsion is general among this group of rapid swimmers, and appears also among the most alert bacteria — vibriones and spiralles. We can see from this how important this technical form is for the attainment of the most effective results in swimming.

Human technique cannot afford to neglect the advantage of this form for torpedo and submarine boats. Man used the same principle in another application without realizing that it was following the best models available, since the beginning of life, in the drop of water. The gun muzzle is rifled to give the advantage of the spiral-flight to the bullet.

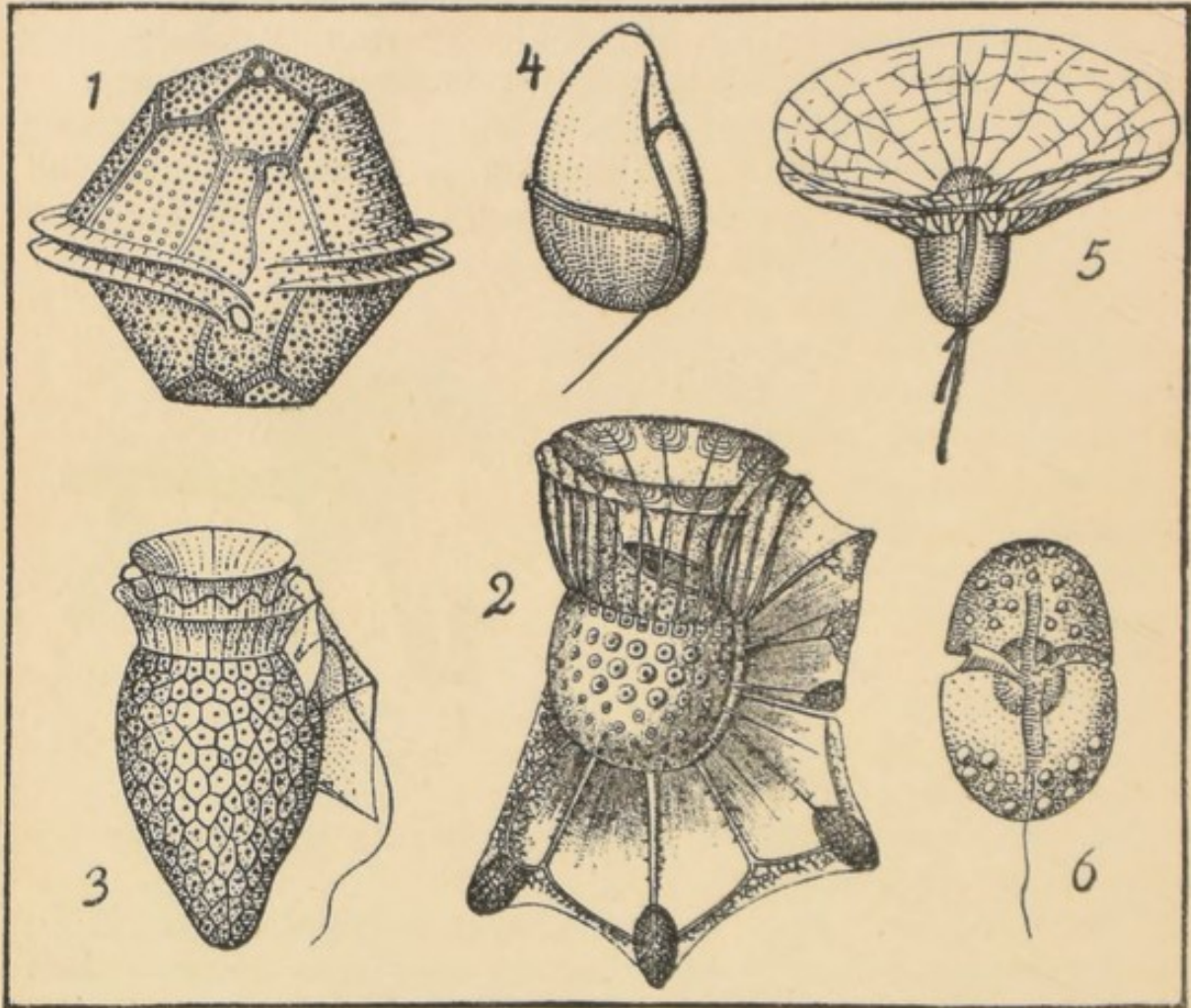
The propeller, also, is nothing but an application of the same principle. Even if ship-builders have also adopted other models again and again; even if the American and English navies, each swears by its own model; the oldest ship-building firm in the world can point to its rich collection of models among which there are a great many which, though tried by Nature, have not yet been tried by man. (C. ill. 9, sec. 6). Experiments would certainly show some of these to have advantages for special applications.

The modern engineer, it is true, has only a superior smile for all these somewhat antiquated questions, since he has made an invention of quite another bearing in the turbine-steamer. But in the bio-technical museum of nature a particularly good collection of turbines and turbine-ships awaits the attention



Ill. 10. One of the Largest Ship-Screws in the World.

and imitation of man. Our home waters contain these models demanded by every-day needs; but if you want to see them in their greatest perfection you must seek them where the best swimming abilities are too. In the ocean, far from the coast, millions of tiny plants, measuring at most a fraction of a



Ill 11. Peridineeae of the Sea as Natural Turbines.

1. *Goniodoma acuminatum*. 2. *Ornithocercus magnificus*. 3. *Dinophysis acuta*. 4. *Gymnodinium spirale*. 5. *Ornithocercus splendidus*. 6. *Gymnodinium rhomboides*.

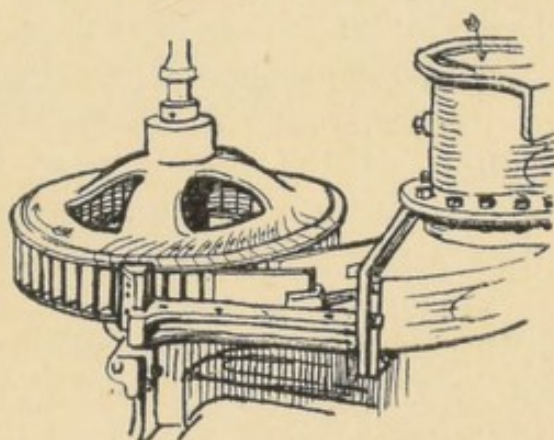
millimeter, rush about. To these glittering, gold-brown plants, tender as glass, botanists gave the family-name of *peridineeae*.

A glance at illustration 11 shows that they have strange, if pretty forms. Observation shows that they have an adventurous sort of life. They drift about freely in the water; the further away from the coast they are the safer they are from the powdering breakers.

They do not swim on the surface; there they would

be exposed to destruction by the waves. Their kingdom is a few feet below the surface of the water, where it is quiet but where an honest plant can still find light enough to live by. In order to maintain themselves at this depth they have developed certain technical activities of a very complicated sort. Their tiny body, a simple cell, cloaks itself in a coat of mail of pure cellulose; only a few of them (ill. 11 sec. 4) are completely unprotected. In this cellulose they have a plastic building material of the very best quality for modelling. Out of it they build a leading apparatus which directs the currents of the surrounding water into special courses. Look at illustration 11, section 1 or 4. Without being an engineer you can see that side currents, averted by this formation into the spiral courses, will force the whole body to rotate like a mill-wheel. The little peridinea screws itself upwards by this resource, since it can easily be seen that this motion must be recurrent. It will not escape the technician that the leading lines become narrower at their ends. Sections 1, 4, and 2 of illustration 11 show this most clearly. By this the instreaming water is retarded slightly in its course, producing a back-pressure, an economical over-pressure which can be observed in the accelerated motion of the cell. Through this construction, it accomplishes more work than would be indicated by the motion performing it.

It is not necessary that I analyse much more. Even the man who is only slightly acquainted with technical theory knows that the turbine is founded on the same principle. Water with over-pressure rushes through a spiral lead (guide-wheel) onto a revolving wheel, the rotation of which unties living energy. It is a question for engineers to determine which of the little peridineae correspond to the Henschel-Jonval-turbine, which to the Francis type; if the curve of the paddles is entirely rational; whether it corresponds to that of our turbine or is perhaps superior by virtue of the use of affecting



Ill. 12. A Modern Turbine.

Compare the leadways for the water with illustration 11.

planes. There are thirty-two species of peridineae with one hundred and sixty variations. Each of them adapts a different form for the application of the turbine principle. Man has scarcely a dozen types of turbine. It is clear that much can be gained by the study of this organism for application to mechanical turbines.

I should like to mention one fact in this place, to make clear the importance of the biotechnical for everyone, not alone for practical engineering.

We have always supposed that it was the power of the waves which drove the little peridinea engine. Our turbines, also, are based on the power of flowing water. But reflect upon these facts:

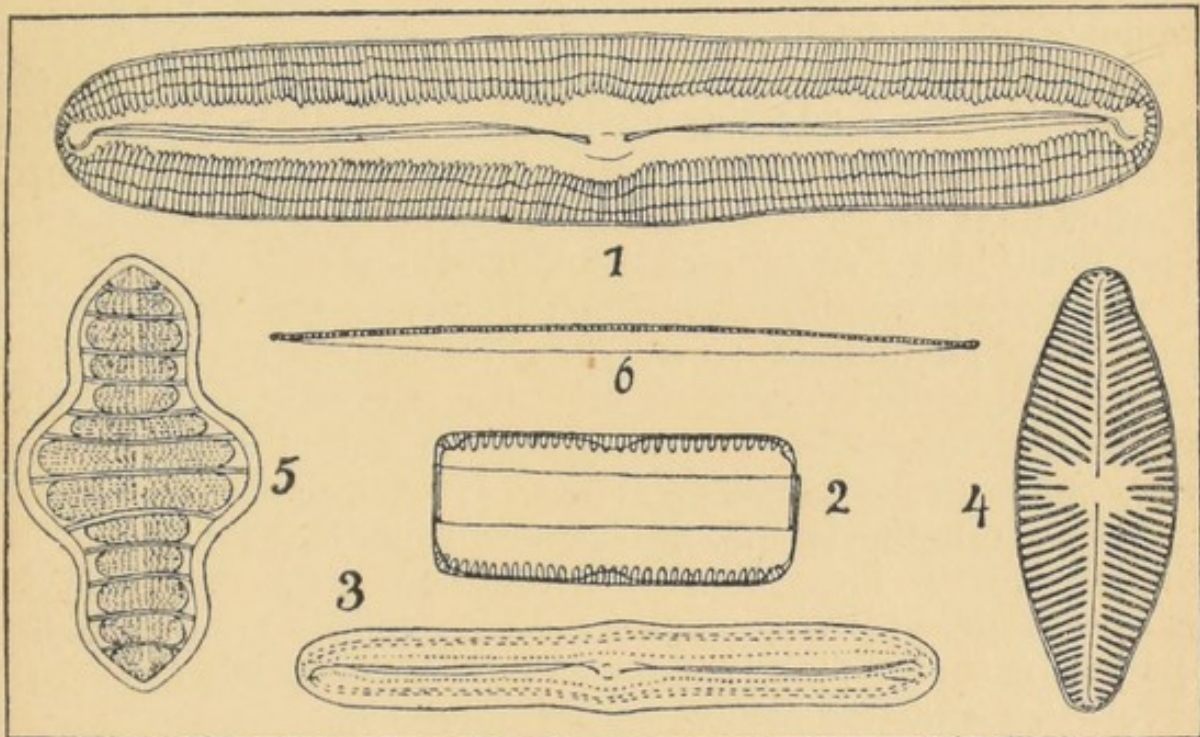
The peridinea cell is heavier than water. It would sink of its own weight to the bottom of the sea if the slightest motion of the water were not converted into a manifoldly swifter motion of the peridinea. The position in which our little plant is pictured in sections 2 and 5 of illustration 11 is preserved when it sinks by balancing, keel, and rudder arrangements — especially noteworthy in the beautiful, so-called, "bird-tails" (ornithocercus). In this position the ascending water-stream produced by the sinking is diverted spirally into the leading apparatus, in which a long channel joined to the cross-furrow works with it. (Section 6). Over-pressure is produced by the tapered-off outlet and, as you can easily calculate, works as a brake; even creates active power and the little apparatus not only stops sinking but even starts to rise until over-pressure is exhausted and the sinking starts again.

In this manner the peridinea-cell rises and sinks in the water like a Cartesian diver, and hovers near the surface, as the needs of its life demand. Both of its whips (one of which lies in the cross-furrow) are used only to compensate for the disturbance of its balance by the waves or to change its position horizontally. In this little, mysterious object, no larger than a grain of sand, we behold an unknown, new construction, a protoplasm machine which has no counterpart in industry.

If the technical world will now make use of the biology of the peridineae in its lectures in schools it cannot omit the study of the silica-algae, as well; for they also have a

device which would give the engineer many a moment of reflection. (See ill. 13).

Silica algae — in heavy scientific language, diatomaceae, or still more heavily, bacillaricaea — have been seen by everybody. You can see them on the bottom of any brook in the late winter or early spring. Spread over the bottom for many yards you will see a soft velvety cloth growth. These are the silica algae. Or you need only look over the water of



Ill. 13. Mechanical Arrangements in Silica Algae

1. *Navicula dactylus*, with shell strainers. 2. Side or "waist" view of *navicula lata*, showing box structure of shell. 3. Raphe course of *navicula major*. 4. Strainer arrangements of *navicula gastrum*. 5. Interior structure of *tetracyclus lacustris*. 6. *Nitzschia gracilis*, a ship form of the silica algae, one hundred times as long as its breadth. (All greatly enlarged.)

the ocean from our coast. You will see so many of these that you could spend the rest of your life and still not count them. They give the green color to our sea in all cold climates. They are a golden yellow and change the natural deep blue of the water, according to the law of the mixture of colours to green. The silica alga is a unicellular organism; the largest is visible only as a grain of dust. Perhaps they are the masters of the earth, for they cover the surface of the sea and the land wherever it is fertile. Together, they

form the greatest "life-mass" that protoplasm has produced on this planet.

I have never shown silica-algae under a microscope to my pupils or friends without arousing startled glances and exclamations of rapture. The bio-technical promises great aesthetic enjoyment to future students. The technical student, also, must not overlook them for they are technical masterpieces of productive life. Unfortunately, up till now they have been observed only for their beauty, by the dilettante, instead of being carefully and systematically studied by the technician.

I select a beloved form out of the great book of models which Nature has laid before us in the silica-algae. It contains 6000 illustrations, and it would, therefore, take more than a generation to draw them correctly and calculate and translate them into living practical understanding.

These plants, like the Chinese, carry their coffins with them through their life; they even live in them: Their coffin remains for millions of years after they are dead and returned to the mass of matter of the universe. It cannot decay because it is made of rock-crystal. It has, as well, unusual solidity.

The bio-technician would be unworthy of his name if he did not draw the conclusion from this fact that solidity is one of the necessary qualities of the silicate armour of the diatomacea, and that it obtains it in the thriftiest way in accordance with the natural law of economy.

If the shell must be firm, it must not, on the other hand, be heavy. For the silica-algae swim, or at least, they creep about freely and briskly. The silica-algae are thus presented with a two-faced problem and their ingenious solution of it entitles them to a special hall in the museum of Nature's technical masterpieces.

Expressed somewhat paradoxically, the first problem is: how to swim if one is forced to travel in one's coffin. The solution, stated in simple modern, human terms, is travel in a self-propelled skiff.

The glass house is a submarine boat of special design. It is built like a box. (Ill. 13. sec. 2). It consists of a lower part and a cover. There is a channel running along both the under part and the lid, which ends in extremely strange spiral curves at both ends of the skiff. (Ill. 13, secs. 1 and 3).

Learned men give that channel a Greek name, "Raphe". They scrutinized, described, and made drawings of thousands of raphes before a clever brain began to concern itself with its functions. When the silica-alga forces water through the screw-like end knots of the raphe it applies something of the principle of reaction conduits as well as the principle of the turbine, to propel itself forward. Indeed, the silica-algae swim rather swiftly, in fits and starts, testifying to the employment of an invention, the exact arrangements of which are new to technical science, and which might, perhaps, be worth imitating.

This invention often propels a glass ship of unusual proportions. There are silica-algae a millimeter long which are only two thousandths of a millimeter wide (Ill. 13, sec. 6). Therefore, this petty engine accomplishes the same work that our engines would if they were in a ship of 50 feet beam and  $2\frac{1}{2}$  miles long. The construction of the reaction conduits of the silica-algae is better than those of our ships. I have made many observations of the speed of the swift little algae living in earth-clefts, and have calculated that they travel a yard in ten seconds. Taking into consideration the size and power of our best ships, this means approximately that the same efficiency would produce a speed of 120 miles in the same time, or 720 miles per hour.

With these dry numbers and calculations, the bio-technical leads us again and again into a fairy-book world of accomplishment. Perhaps they will spur us on to new mighty feats of engineering, for they prove beyond question how wide we are from the ultimate solution of our problems of mechanics compared to the solution Nature has made; though we are on the right road. We travel this road (although we proceed only half-way) because there is only one road, and an invention is not practicable unless it proceeds according to the laws of nature. If we logically follow out the bio-technical, it will indeed show us what improvements can be made in our poor little world, our world of the laws of nature transformed into domesticated animals.

In solving the problem of motion, however, the silica-algae have solved only one of the problems for which they require their house. It is made of rock-crystal substance for solidity; mobility demands light weight. The two requisites contradict each other. How are they acquired in spite of that?



To understand that you must first know why the shell of the silica-algae must be firm. This quality certainly is not demanded by the conditions on a rivulet bottom or on the surface of the sea. Indeed you will be surprised, if you examine the diatomaceae of the ocean, how tender their coat of armour is. It is as thin as a breath of air, or a woven cob-web, and so transparent that you must make an effort to see the shells at all.

For a long time I could not understand this condition, until one day it became clear to me that ocean and pond-bottom are not really the original home of the silica-algae. They live much more in the soil, in little water-clefts of loamy earth, in meadows, fields, and prairies. Their ship-like shape, their brown apparatus for utilizing light (which allows no bright light to enter), their agility (which, in the ocean, has no sense), and their coat of mail are accommodations to that life.

For these water-clefts, which drain into the soil, exist only for a short time after rains. After a week's dry spell they close up, and would crush the little inhabitants if not for their resistant coat of mail.

The circumstances of this sort of life demand unheard of resistance. It has so often been proved technically that insufficient bodies are so constantly destroyed, that those that persist must represent masterpieces of strength against pressure.

Indeed if you will take the trouble to examine the silica-algae — hundreds of thousands exist in every thimble-full of arable earth\* — you will see instantly that this is so. Their shells are firm and strong and have special stiffening supports, cross-beams, chamfers, supports and girders in order to increase their stiffness. In a word, they have all the inventions which man also employs in structures which must sustain great pressures.

We have known these strengthening methods of the silica-armour for a long time; we have used the manifold forms to design thousands of structures. When their form was agreeable to the eye, we spoke of "artistic natural forms", and imagined an aesthetic instinct in the plasm which produced them. The silica-algae were recommended as models for the art-world,

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\*) The water forms have emigrated from the continent to the sea, where they took other shapes, through rivulets and lakes.

and artists directed their attention to them. The technical man, alone, who could have obtained most from their study, neglected them.

From now on, for their own interest, they will study the silica-algae, especially the earth species, and will conceive that a scaffold construction made of such tender material which resists a pressure of many atmospheres must be adaptable to our use, also. Necessity made us unknowingly discover many laws made use of by them; for no other construction had equal resistance. Now we can select from the hundreds of building-types which exist among the silica-algae the optimal solution of pressure-resisting forms. In this form, of course, there must be the greatest economy of material, making for the cheapest construction, also.

The silica-algae cells have attained this optimum, for they were forced to it by the necessity of securing lightness essential to agility. Therefore its shells develop into a skeleton for the necessary points of pressure with cross-beams between; and have omitted filling-in walls wherever possible. In this, it is the model of our steel sky-scrapers, as well as for all architects who must build weight sustaining structures. The architects of the Gothic period, for instance, with their pointed arches, and their perfection of the blending of planes into systems of columns and arches, construed the purest effects of necessity into the most artistic. The vegetable cell of the silica-algae has done the same thing in its construction. In this sense, one of the charming buildings of Venice, or the *Maison du Roi* of Brussels, or the Doges Palace or the *Ca Doro* at Venice, and the artistic and no less charming forms of one of the silica-algae, are equal manifestations of one and the same law.

With this remark, the mind of the reader is prepared for consideration of the faculties of performance in the plant-cells, where they are not exposed singly to the struggle for existence, but have joined with others to effect certain functions as useful members of an organized whole.

A single plant cell is only a building-stone in the society of many similar building-stones in a large many-celled plant. This sentence should be repeated a hundred times daily until it is worn out in thoughtless fluency. It contains the entire interpretation of bio-technical science. Like everything in this

book which seems astonishing and startlingly new, the principles underlying it have been evident under the surface of knowledge for a long time and have been mentioned before in disconnected explanations and sentences.\* But the connection was always missed; and it is this connection which gives sense to it and encourages practical application. We were in the same position in regard to the bio-technical as the children playing in South Africa, who found glittering stones which were only playthings for them, until the first man came and recognized the stones as Kimberley diamonds.

When we erect buildings from bricks and build machines from iron parts, we only follow the road laid out by the laws of the world, which order every complex system to be composed of its parts. The same path is followed by the seed of a plant which fabricates cell building-stones by division, and from them erects its building.

The single cell is here a hollow brick, with walls, with a variety of technically estimable walls.

Human buildings are mostly built of solid bricks of less valuable properties. It is only lately that we have learned the advantages of the hollow brick, and I do not doubt that the bio-technical will influence not only the engineer, but the architect as well, and turn their attention to hollow-brick construction, from which will develop a hitherto undreamt of boom in such buildings.

Hollow bricks are light, warm in winter and cool in summer, and more economical than solid stones. Solid cells are employed by plants only for special purposes to which they are particularly suited.

It is true that we can bake hollow bricks only out of loam and quartz sands (somewhat similar to the silica cells). The plant, however, fabricates them out of cellulose, cork, wood, silicic acid (really glass) and sometimes even out of iron (in certain algae cells). It encloses them sometimes in a coat of wax, varnish, rubber, gelatine, or cement. That ensures for their building a selection of materials not possible for us. Cellulose, itself, is a building-material which excites our envy.

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\*) This is true especially of Part I. Carrier constructions and other mechanical arrangements in stalks and tree-trunks, the wearing arrangements of the plancton-algae, the structure of bones and elbows, were all given individual attention, but never understood as a whole.

What is cellulose?

If we say that it is a carbohydrate which can be changed into starch and sugar, it sounds well but technically means very little. We say more if we state simply that cellulose is paper.

Every wood-pulp mill, turning out mile-long rolls of newsprint paper, works up cellulose. We once had great hopes in the reported discovery of the secret of making linen and cloth from the cellulose product of pine wood.

The plant builds paper-houses. They are warm, light, cheap, and attractive. When it stores wood-stuff in its cells to impregnate their walls, it utilizes a process which surpasses human power. It makes wood from cellulose, and we are unable to imitate it and make cellulose from coal and water in commercial quantities. We cannot procure wood, so essential to our industry and our culture, without despoiling and destroying plants. Man is in the same predicament when it comes to procuring starchy grain foods, upon which his nourishment depends. He gains his daily bread only as a servant of the plant. In its service, he must till the soil by the sweat of his brow; he does not disdain the use of dung, in which he sees a precious fortune. For the good of the plant he has ordered his calling, his thinking, and his feeling. For it he implores the heavens for rain, and works hard and long at harvest-time. All, however, because he is a bungler in the chemical industry, and the plant a master.

I will not repeat things so self-evident as the importance of wood in man's cultural life. But I wish to take three facts from the great book of technical accomplishments by way of illustration, to throw light into the pitch-black darkness surrounding the plant as inventor. These are the elasticity of wood-fibre, its osmotic qualities, and the colloidal qualities of the protoplasm wall.

The best steel-rod has a resistance of about one hundred and thirty pounds to the square millimeter\* cross-section; iron has about one half; and the best copper, though a very tough substance, somewhat less. Similar tests for strength were made with fibres from the inside of living bark, with the following results:

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\*) A millimeter is approximately  $\frac{1}{25}$  of an inch.

A fresh straw thread — the fibre from the inside of the rye outer-wall — has a resistance of thirty-five to fifty pounds, the fibre of lily-stalks, fifty pounds, and New Zealand flax a trifle more. There is no commentary necessary except that drying-out increases their tensile strength.

Wood has the quality of expanding through absorption of water. This is a quality which all vegetable matter has. This expansion makes available an enormous energy. It has been calculated that a cubic yard of expanding vegetable matter can lift more than twenty-five thousand tons. This is the explanation of why trees can split rocks into fragments with their growing roots, and dislodge houses. Since ancient times man has made use of this power. It is used in mining. Wooden pegs are driven into small chinks. It is then only a question of time until the absorption of water will cause them to swell and tear asunder the surrounding rock. Man can, with the help of the technical qualities of the plant, move mountains.

Behind this "expansion" of the plant, lies another quality of the plant, which is the real reason for the immense technical superiority of the plant's building-material. This is the colloidal quality of protoplasm and all its products.

What does that high-sounding scientific phrase mean? Scientific explanations do not throw much light on it when they state that a colloid is a heavy, or uncrystallisable body, which dissolves very slowly. Therefore, we must try to demonstrate the remarkable qualities of colloids in an other way.

Rubber is a colloid solution. The rubber solution which the motorist knows so well is not a liquid, not a gas, and not a solid body. We could quite well say that a colloid is the fourth state which matter can assume. We can change all metals into colloids; we can also change silicic acid and all albumins into this form. Probably, some day, we shall be able to do the same thing with all matter. Now it is very curious that we have found a cell or honey comb structure in all colloids. It is true that we cannot expect to find any special secret in that fact, for we already know that the cell is the technical form of a colloid, the protoplasm. The whole life of plants is a problem of colloids.

Upon this knowledge a special branch of bio-technical science will be founded. The workers in it will seek to pry from the plant its priceless technical secret. Its discovery

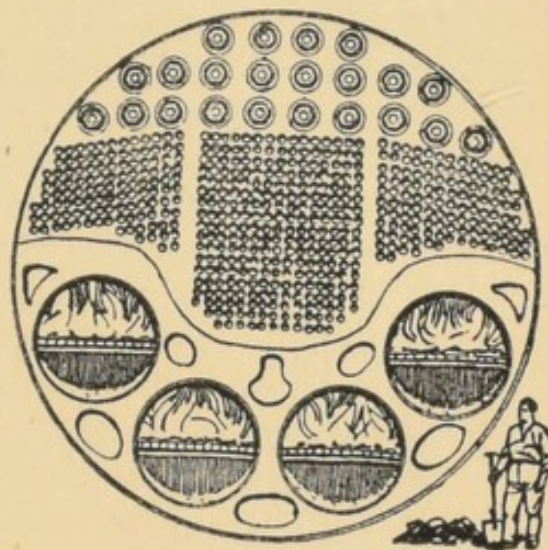
is possible for the plant uses it every hour, though we are still miles from its disclosure. This secret is the colloidal boiler.

If you wish to get a visible picture of Hell, go down into the stoke-hold of an ocean steamer. Half-naked diabolic figures, black with soot, waving brandishing-irons and shovels, receive you. Flames light the dark hole of these kulis of the god of heat. Their prison is vaulted with immense, heavy iron plates, all alike covered with numerous drops of sweat, and all trembling under the enormous pressure on their walls. Fresh coal is shoveled into the boilers amid the wild songs of the demons. They rage and rave around the boiler; and loud clankings as of innumerable gigantic fists pounding on the boiler-walls, arise, threatening to burst them open. But the ship's engineer is not romantic. He coolly explains, "Pressure of Steam" and reads the steam-gauge, "Sixteen Atmospheres".

Ship-boilers are tested up to eighteen to twenty-five atmospheres, that means from 270 to 375 lbs. for each square inch. The thick black iron-plates, solidly held together by rivets, assure this strength. Generally, it is believed that the thickness of the boiler-walls must be one two-hundredth of the diameter of the boiler.

If you look at living plant-cells under the microscope, you will be surprised to see how full they fill their reservoir. But the addition of only a very small quantity of sugar-solution is sufficient to cause the shrinking up of the highly sprung wall. The botanist calls that a debasement of the "osmotic pressure", and in an ingenious way succeeded in measuring that pressure. He arrived at the astonishing result that, in every normal vegetable cell, it amounts to five to ten atmospheres, as much as in a small steam-boiler.

The interesting thing for us in this, is the thinness of the skin which sustains this pressure, and of what substance it



Ill. 14. The Largest Boiler in the World  
Front view of a ship's boiler.

is made. It is of plasmatic nature, that is of colloidal structure. From this simple chain of facts we can conclude that colloidal membranes have an enormous strength which surpasses that of iron.

That is why inner-bark fibres have such great tensile strength. They, also, are of colloidal structure.

But we are not yet finished with our astounding revelations. The cell membrane of the turnip, one twenty-five thousandth of an inch thick, sustains a pressure of 21 atmospheres (315 lbs. per square inch). The wall of this "boiler" is scarcely thicker than one five-hundredth of its diameter.\* It holds this pressure without noise or rumblings, contrary to the ship's boilers. Man must use iron-plate an inch thick, where nature employs a thin membrane. That is the difference between man's technical ability and that of plants.

Here is a new problem for the engineer, a new dream for sleepless nights. How can colloidal boilers be constructed? The task is known; the solution is possible. Surely the human mind will not rest until the steam boilers are all scrapped.

In the light of the thoughts awakened by the plant's mechanical wonders, we clearly see new sign-posts pointing beyond our present-day achievements. We see that the oft repeated "mechanical age" lies ahead and not behind us. Man can gain control of the forces of nature in another sense from what has been meant until now. He can employ all the principles of living organisms, and he will have occupation for all his capital, power, and talents for hundreds of years to come.

Every brush, every tree can teach him; can give him counsel, and give him pointers for numberless inventions, apparatus and technical equipment. A simple leaf contains the arrangements of a great industry, and it is most astonishing that man has been blind to its possibilities for such a long time, and neither saw nor understood that he held its secret in his hands. To prove this statement, I will explain its structure.

The leaf contains a complicated ventilator, a drying-apparatus, a multitude of light, inimitable power-engines, a cooling

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\*) According to Pfeffer, the osmotic pressure in mycoderma can rise to approximately 160 atmosphere (a ton and a quarter pressure per square inch).

apparatus, and a hydraulic press. It is therefore a factory containing an assortment of machinery.

We shall consider first those which are quite unknown in human practice.

Of all the raw materials which are at the disposition of living organisms including man, none are in such available abundance as air and water, or in more exact language, as the gases, oxygen, hydrogen, nitrogen, and carbonic acid. Man utilizes only one of them, and that only in the last few years. We use nitrogen now to make saltpetre; the others remain unused.

The plant-cell employs all four, and therewith has tapped the cheapest raw-material reservoir of the world. But it would take a whole book to explain all its processes, and I must therefore confine myself to one, the capture of carbonic acid and its fabrication, by the addition of water, into sugar.

For thousands of years men busied themselves with speculations on why the world was created. It is only in the last seventy years that they have systematically considered how the world is really arranged. Unfortunately this has not been long enough to learn completely the chemical physiology of the vegetable cell. Therefore, we have only superficial notions of its processes.

We see that almost every plant-cell above ground contains green pigment, and can ascertain by simple experiments that these cells, constantly while they are exposed to sun-light, give off oxygen. They also store a stuff which consists of coal and water (carbonic hydrate), and which, in its liquid state, is called sugar, in its crystalloid form, starch. Closer observation shows that they utilize carbonic acid taken from the air, and cannot work without water.

That is an explanation in simplest form of the most significant invention ever made on this earth. The whole life of plants, as well as that of animals and man, depends upon it. Without it, life would perish. It must, therefore, have been one of the first inventions after the arrival of life on this planet.

Human technique is a long way from being able to imitate this process, which is, in truth quite simple. We do not entirely understand it, yet, because we have not been able to learn the exact composition of the green pigment; for



when we call it the green of the leaves, or in scientific language, Chlorophyll, we do not explain anything. It means very little more to know that it is an albumin combination. The haemoglobin of our blood is a substance very much like it, and also an albumin combination. Its chemical combination is known exactly:  $C_{758} H_{1203} N_{195} Fe S_3$ .

This formula is hopelessly exact, for our chemists can not build such a complicated frame from its elements. Such refined synthetic chemistry is possible only for plants.

Silent and a lovely bright green in the sunlight my small garden greets me. I am ashamed to tread the smallest leaf under foot, having the same feeling of vandalism when I do so that you would have if you walked rough-shod over the delicate mechanisms of costly watches.

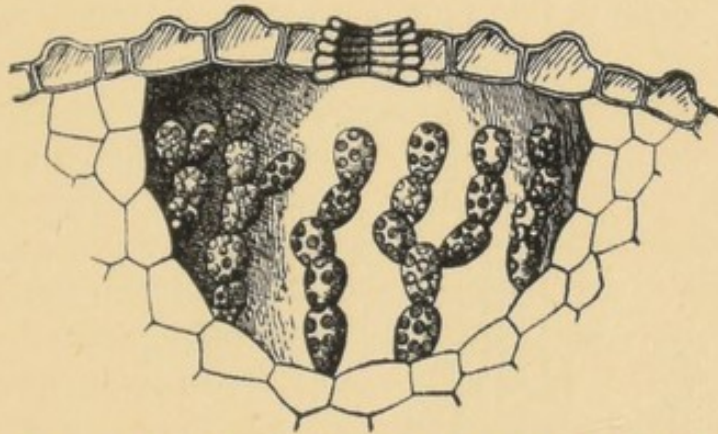
We have much reason to look thoughtfully at the yellow-green spring leaves, in which thousands of sun-power machines work steadily without rest, from morning to evening, to produce for the community the two important foods, sugar and flour.\*

I call them sun-power machines because their specialty is to utilize the energy of the sun's beams. What steam is for the locomotive, the sun's rays are for the green stuff of the leaves. Their productivity is ideal mechanical technique; it is the optimum, itself. An ideally simple apparatus, and the source of power, the sunlight, omnipresent; with these the little leaf-factory turns the cheapest raw material into a precious, irreplaceable product. Matter can not be changed in manufacture more completely than it is here, and you will agree with me that, the biotechnical is the top rung of mechanical technique.

You can observe the simplicity of the apparatus, how well-ordered and humanly familiar it is, in many charming pictures. I advise you to search out a common water liver-wort (marchantia), which you will seldom fail to find in moist, shaded stone-walls or rocks. In its outer form you will see a tendency towards division into diamond shape sections, each of them corresponding to the room of a factory. If you force your way inside — best done by cutting thin cross-sections to be placed under a microscope — you will see that strange, but still again, familiar picture reproduced in illustration 15. There is an arch over the ground, and under it several apparatuses are grouped side by side. The little sun-power engines

usually consist of two or three cylinders in which the precious pigment is exposed to the light in small disk arrangements. The fluid products trickle through the walls of the apparatus and are drawn from the ground through little channels. The light streams in strong and bright through the vaulted, glass-like roof, which even has a large ventilating shaft for the carbonic acid and the water vapour to enter. Everywhere the same principles as in human machinery; everywhere the law of necessity brings similar forms, in nature and in human arts.

The leaves of trees and bushes are generally designed in another style, though the same law governs both. The ventilator is made much more "artistically" with a system of shafts and window-sashes. The diversion of the raw and half-finished



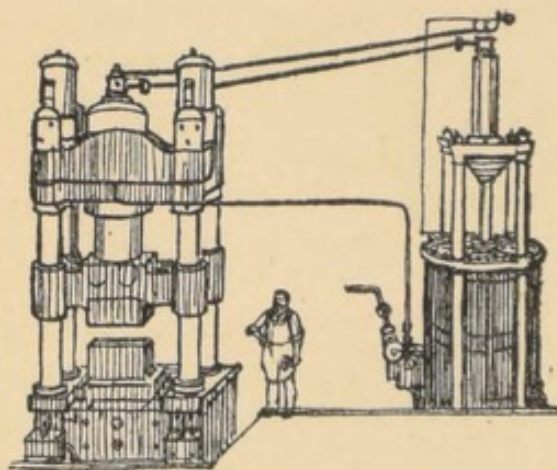
III. 15. A "Factory Interior" in the Plant World  
Longitudinal section of marchantia.

products through a complex net of directing channels everyone has seen if he has seen the veins and stalks of a leaf. The plant unfolds as a real industrial village if it is carefully studied. There are a hundred gradations, ever new forms of accomplishing tasks, which are more perceptible to the mechanic than to the scholar. There are elevators, coolers, condensers, stuffing-boxes, filter and hydraulic presses, electrolytical apparatuses, and evacuating pumps. The more of an expert you are, the more technical forms you will find. I have been able to cite hundreds of technical plant inventions. There are whirligigs, Segner water-wheels, shears, clamps, hollow ball-bearings, automatic doors, springs, diaphragms, balance weights, reflectors, outriggers, couplings, gas-balloons, parachutes, and an endless variety of similar mechanical parts. I have only touched the surface. It is also quite clear that the animal and

human bodies have produced a multitude of other inventions to meet other needs. Inanimate nature — the clouds, mountains, and electrical energy of the air realize still other technical developments. The knowledge of these forms will open the gates to a new world of human achievement.

There are, in this great multitude of strange applications of physico-chemical laws, a number which are unknown to mechanics; others which we can try although we have not as yet been able to analyse the principles on which they work. There are many inventions in plant-life which the botanist failed to recognize owing to his lack of technical knowledge. We can end our visit to the plant's bio-technical museum with a survey of some of these strange phenomena.

A phenomenon, unknown before discovered in a bio-



Ill. 16. A Modern Compressor of more than seven thousand tons pressure. The same principle is used in plant leaves.

technical study of plant-life, is the employment of hydraulic presses in leaves. Man employs the hydraulic press more and more frequently; it belongs to the seven great technical miracles of the age. Steam-forges, so long objects of wonder and admiration, have been replaced in ever increasing numbers for the last decade by the silent compound-press, which is an application of the hydraulic-press.

An entirely new class of tool machines has been developed in the last generation, fulfilling the traditions of the Titan. We turn a lever and cut through a sheet of zinc ten inches thick. Our forges fashion monster ship's screws like the one reproduced on page 29, and houses and bridges are picked up and carried to another locality. When we think of ocean liners we think of immense structures like the Leviathan, of office buildings of towering masses like the Woolworth or Equitable buildings. In their construction, pieces thousands of tons in weight had to be lifted into place.

This was all done by the judicious application of a fundamental law of hydrostatics: the pressure upon water in a

closed cylinder will be transmitted in every direction with equal force. We can, therefore, multiply the pressure to be applied by enlarging the cylinder wall. If we take two vessels, one with a wall-surface a hundred times greater than the other, and join them by a narrow tube, we can exert a pressure in the little vessel which will transmit it multiplied many times to the larger.

This is the theory of all hydraulic presses, of all hydraulic tool-presses.

With this knowledge, you may now consider a leaf of a plant, that of the common garden fuchsia, or of the nasturtium, or strawberry, or dew-mantle (*Alchimilla*), or any that grow in a neighbouring meadow. If you take joy in nature and have only a little knowledge of botany, you know that all these leaves are a sort of weather-signal or prophet. If when you go into the garden on a hot morning you find dew-drops sparkling on the furrowed edges of the leaves, you can know that it will soon rain. Really, the water-drops exuded from the leaves show only that the air is already saturated with moisture and that the normal evaporation from the green parts of the plant cannot take place, whereupon the surplus is pressed out along these crevices.

In the tropical woods, during the rainy season when the air is so humid that every cooler object is immediately covered with little drops of dew, this *guttation* (the scientific name for this phenomenon) occurs with increased vigour compared to that in our climate. Swamp plants drive out (or even throw out) twenty-five to eighty-five drops a minute from every one of their leaves. Sometimes tiny fountains bubble out from these little water crevasses. A *colocasy* has been observed, which one night drove the water out of the top of its leaf with so much force and rapidity that it rose about four inches above it.

To make this possible the water must have pressure behind it, of course. Where does that pressure come from? It is impossible that it can be only the root-pressure, which causes, as everyone knows, trees to bleed in spring. This "fountain", however, requires a much greater force. The solution of the riddle depends upon the following facts: Under the water-crevasses there is a large empty space joined by a tiny channel to the plant's water-conduits, which draw the water

from the soil. In this way the principle of the hydraulic press is applied. The slightest increase of pressure in the roots is multiplied in the open space in the same proportion as its size is greater than the pipes in the root. In other words, there is a pressure ten to one hundred times greater in the reservoir of the leaf, which forces the water to bubble or even spout out of the outlet. If this process had been shown to a physicist of former ages, he would have been able to recognize the principle involved, and the invention of the hydraulic press might have resulted thousands of years earlier.

How important the consequences of this antecedence would have been! But then memories of early historical developments perplex us. Were not all our technical achievements known in antiquity? Were there not steam engines in Serapis in Alexandria? Did not Ktesibios construct a "water-machine"? Did not the Egyptians of the Ptolemaic Dynasty ride in self-propelled carriages? Were not fire-engines a common sight throughout the Roman Empire? Was not the Third Century A.D. a century of technical achievement? And yet all was submerged again in the course of centuries, and man had to recreate his inventions once more from their rudiments with the greatest of effort.

Why this retrogression? How can things, once striven for and attained, be lost again by mankind? Is our culture really not enduring?

The bio-technical gives the answer to this melancholy question. For it teaches us to think biologically, and shows us the root of every invention: necessity. Everything develops, if necessity demands it. In the entanglement of needs you will find the law showing the new form to unravel it. Given the situation requiring the application of the hydrostatic law and the first drops of water bubbled out of the leaves. The plants were relieved by the process, and passed it on to their descendants. When Alexandria became desolate under the assaults of the Monks of Thebes, and when Rome perished in the migration of nations, the new masters of the world had no need of mechanics. What use could the hunter of elk find for the steam propelled hero's carriage? Culture had no place among his needs. We have here a parallel to the ship-building masters of the water-drop, which changed in the course of

the history of their race into other forms no longer requiring the ability to swim, and who, therefore, laid aside the technical culture of their predecessors.

Reality has no tradition; necessity takes its course through the world without sentimentality. Necessity turns the world's wheels; with a turn of its lordly wand it can make the dead rise up, or the living fall from the tree of life.

It is not the plant which invents; nor yet we; but the law of the mechanical form is fulfilled in the icy dark night of necessity.

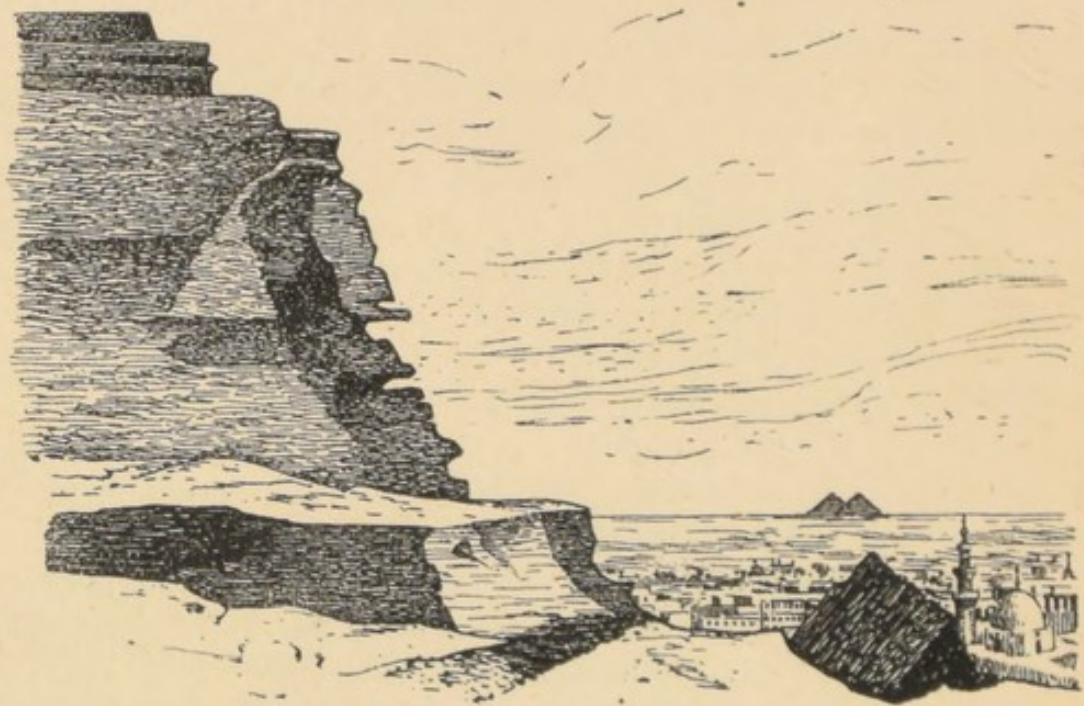
We do not usually like to face such stark truth; but, if, after all, reason has gained the mastery over emotion, we can understand how the mechanical, the mere usefulness of existence, must also have triumphed. Called into being simultaneously with "existence" it controls everything in the world, giving us our one steadfast star in the great sea of change.

If you have followed me so far into the study of the "technique of plants" you will yourself be able to answer the most current objection to the new bio-technical science. There are people, who, in spite of the great array of facts, say that man is not restricted to the inventions of nature, but is himself sovereign in his inventive and technical power. For he has a great number of technical achievements to his credit which could not possibly be copied from nature. Nature, for instance, does not know electric accumulators, nor the locomotive, nor automobiles, nor arc-lamps, nor typewriters.

This objection completely overlooks the fact that no organism anywhere needs to store electricity in large enough quantities to require accumulators. But when an organism needs electricity, as the electric-cell (*gymnotus electricus*) does, then it employs the same doctrines of electricity as man. And the organism uses organs of motion in quite another field of perfection than the locomotive. And one of the most important principles of railroads, the diminution of friction by having the wheels run over rails, can be seen repeated a thousand times in nature, where every continuous regular movement creates a "slide" on the same principle as the rails. Since one evening when I was in the Desert of Arabia, meditating on this question, and noticed the sharp hollow channels and polished borders which the daily desert winds have carved in the hard limestone of the mountains, there

by reducing the friction encountered, since that time I have observed the application of this law a thousand times. The technical form is world-wide; it produces itself from the necessity of the activity, itself.

Swimming, or running on four or six legs, or flying, are all much more perfect solutions of the problem of motion than the steam or electric motor, which put into gainful power only a few percent of the energy derived from the coal. Indeed, this technical weakness of these motors, is a general cause of complaint.



Ill. 17. A View Near Cairo.  
Showing Wind-Current Paths.

Arc-lamps are unnecessary for organisms, which have produced cold light for every colour. Think of the lightning-bugs, glowing fungus, and deep-sea fish.

The typewriter and the bicycle are lever appliances, really very primitive but exceedingly ingenious mechanisms, which have their fore-runners in the lever arrangements of the animal's running parts. And above the typewriter there stands the human hand, which cannot be matched, as you know, by mechanical appliances. That is one reason why handwork is esteemed in works of art high above articles of mass machine production.

But it is of more value in evidence than the citing of single examples to remember that bio-technical accomplishments are the result of the expressions of need: that the final shaping is the direct expression of the want. Only to this end is the creative impulse awakened; and only in daily use is the optimal form selected. Every invention of plant and animal (including man) must be evaluated and compared from this viewpoint. Therefore, before the biotechnical student imitates an arrangement of nature, he must seek to know exactly the need which it fulfills. Only when this need is identical with that for which he is trying to find a solution, will the solution of nature be the optimal form for his purpose, also.

We can see this most clearly if we compare some inventions of man which are also used by organisms but without being developed to the end required by man.

There are, for instance, cooling devices in plants which belong to the same class of machines as our refrigerating machines.

The principle employed in most refrigerating apparatus is that of evaporation. The cooling liquid (ammonia, carbonic acid, etc.) flows through a system of pipes and absorbs the warmth from the surrounding objects through evaporation. In the same way in which the water in a steam-engine is used over and over again, the freezing liquid is also compressed and evaporated over and over again in an endless cycle. The temperature is constantly diminished by the evaporation, so that it is a simple matter to freeze water and make ice.

No plant has any need for ice; it eschews this life-destroying matter wherever possible. It therefore has no reason to develop its cooling apparatus to the extent required by man; if it did, by chance, develop it so far, this useless, nay pernicious, apparatus would be destroyed instantly. In this case, therefore, the perfect form is not reached, but only one sufficient to produce a slight cooling through the condensation of water-vapour.

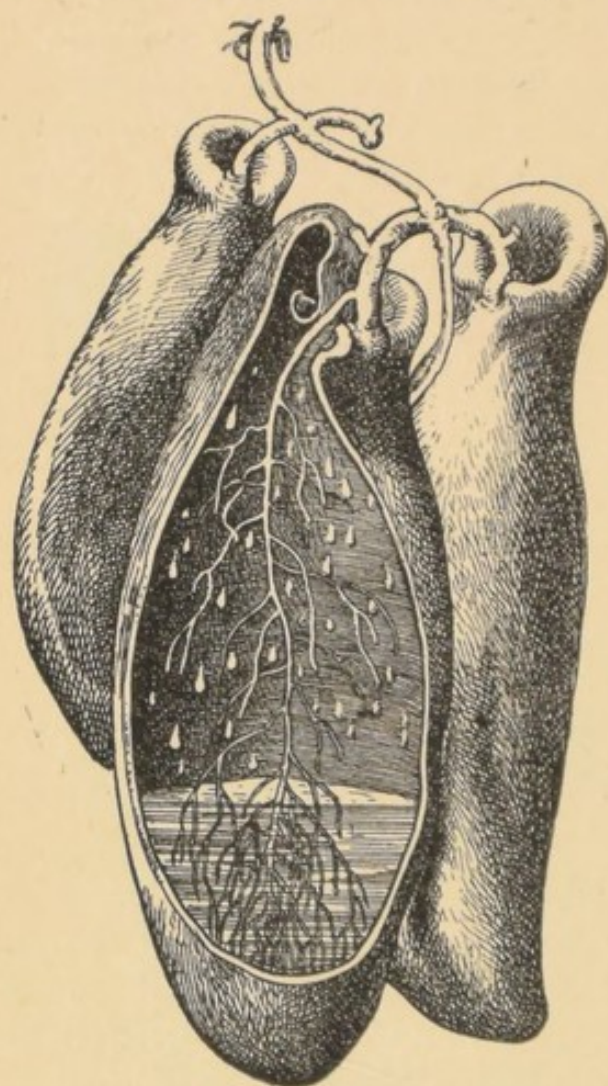
The urn-plant (*Dischidia Rafflesiana*) of India will serve as an example. It is a tree-climber, and often exposed to long droughts. It therefore produces two kinds of leaves. Besides the ordinary leaves it has a variety of strange jug-shaped leaves, which are much contracted at the upper opening. A many-branched air-root with a very small diameter grows



in the leaf at this opening. This air-root connects with the general water-system of the plant.

The inside of the nearly closed urn is covered with a brown wax-coated skin with innumerable fissures.

Let us consider the function of the whole arrangement. The fissures breathe out a great quantity of water-vapour



Ill. 18. The Urn Leaves of the Dischidia, a plant refrigerator. (The leaf in foreground is cut through longitudinally.)

and carbonic acid. Both are the common product of perspiration and breathing. Water-vapour saturated with carbonic acid, however, is a "cold-mixture" in the sense employed in the refrigerating industry. They lower the temperature in the closed urn (which is covered with an insulator, wax) producing considerable condensation. The condensed drops of moisture roll down the smooth wax sides, and form a little pool of water on the bottom of the jug. The air-roots suck in this water, and in this way gather a considerable supply for the use of the plant out of its own leaves.

We can say that this plant waters itself. Indeed it obtains so much water, that it sweats out a great deal of moisture, and thus continues

the endless cycle. The whole arrangement would be a rather high order of condenser, such as we are accustomed to, except for the employment of the "cold-mixture". This makes the urns of Dischidia the biotechnical fore-runners of the ice-machine.

The imperfection of the model is, in this case, a token of its perfection. It serves as an illuminating example of what the biotechnical student must not lose sight of in his research:

the purpose for which the plant employs its apparatus determines its form.

There is one chapter in botany before which the biotechnician as well as the botanist stand silent and cannot explain. Effects are produced before their eyes to which neither experience nor their understanding is equal. They are a perfect example of the importance of judging everything in the plant-organism exclusively with the consideration of its purpose.

This chapter is the chapter of the "waterworks" of trees. It is referred to thousands of times; expounded in school-books; and yet is as dark a secret today as when the first naturalists looked with astonishment into the mysterious interior of a plant. We have learned since that day, nearly two-hundred and fifty years ago, that the inside of every plant, whether it is a simple herb, wheat or corn, or a towering tree, contains a network of hollow piping.

What is a pipe? A hollow-staff! The old technical form which water builds for itself in rushing on its way through gaps and crevasses between firm substances. It is the way of least resistance, which the water digs and smooths until it obtains the optimal form of a straight, smooth pipe.

In the plant, the water does not descend, but rises; for the water-system must supply the entire plant to the uppermost tips of its branches and the highest little leaf with the precious moisture. For without it there can be no life.

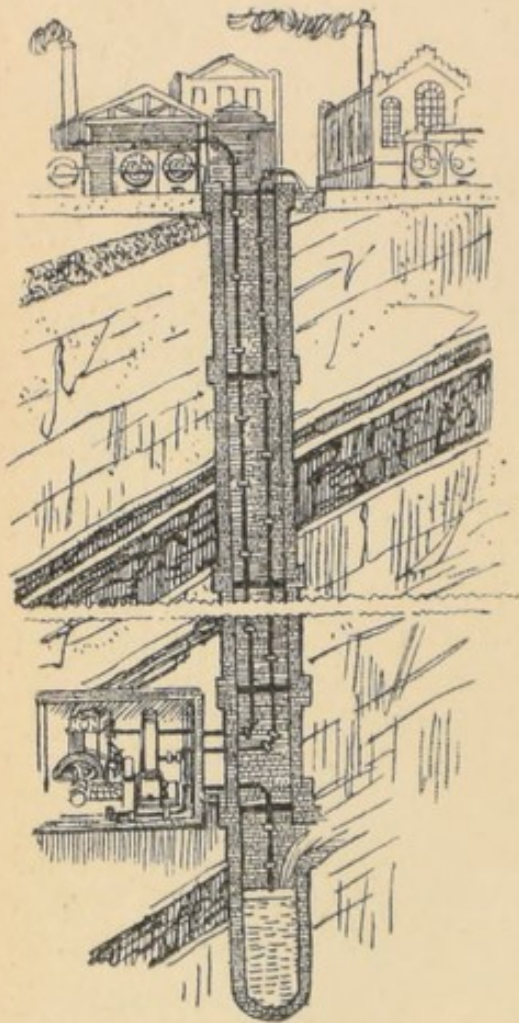
Among human needs a similar requirement has arisen only since the building of modern cities. The many-storied house of the great city is likewise a plant with many cells, in which thirsty inhabitants demand water, even in the top-most room. And my exposition up to this point would be worthless if all of my readers do not at once conclude for themselves that the human solution of the problem paralleled that of the plant. We and the plant must both employ a system of pipes, branching out wherever necessary, and drive the water through it by pressure.

Thus far everything is transparently clear and satisfactory.

The raising of the water can be attained in various ways. We naturally chose the way of least resistance. If there is a source of water in the mountains nearby, the water is brought from there. For then it will ascend by its own pressure, through the system of connecting pipes, to a point as high

as its source. In flat country, however, we must build an artificial mountain out of masonry or other material. That is the water-tower or reservoir, in which the surface of the water must be higher than the highest faucet in the city.

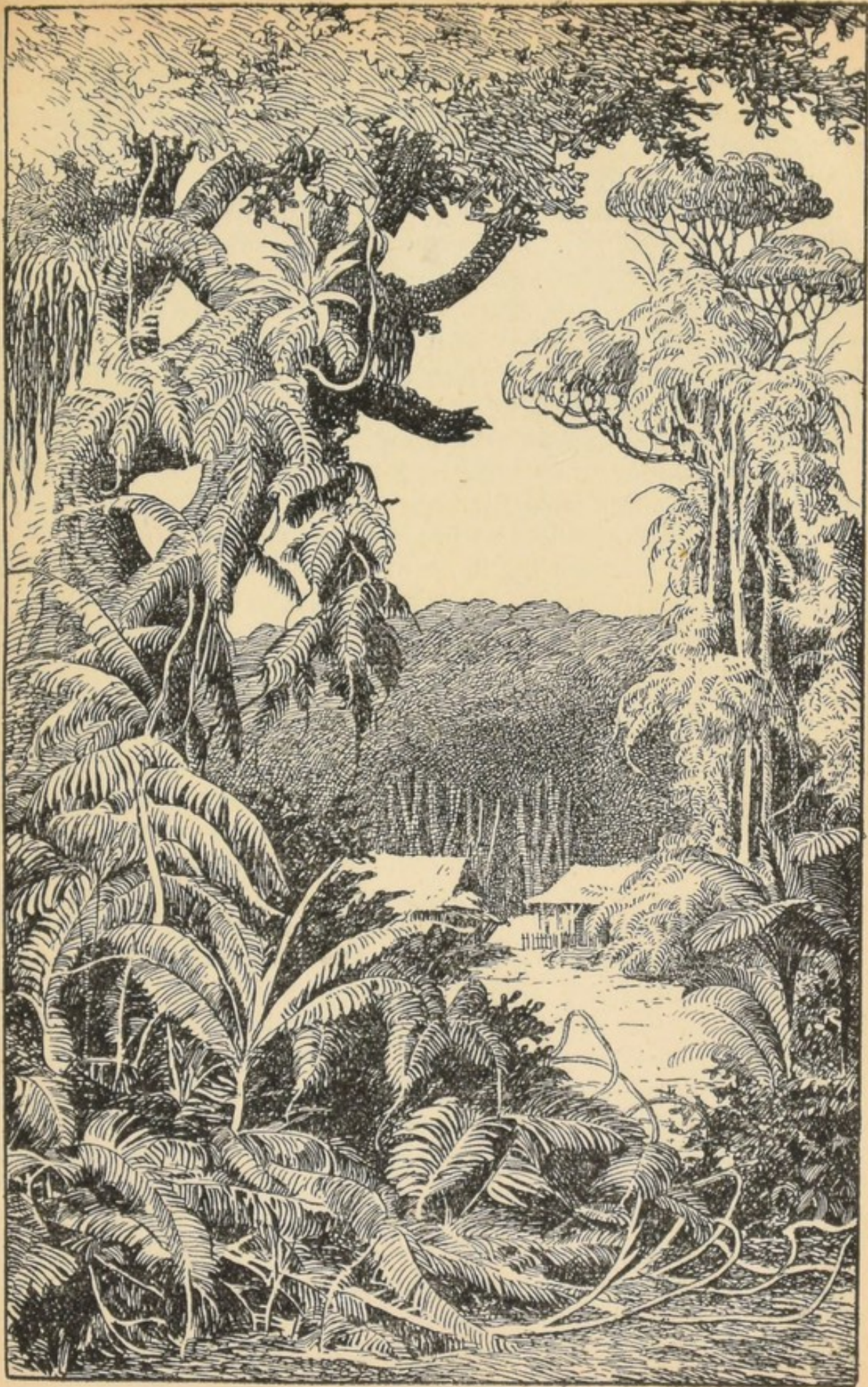
But we must raise the water up to the reservoir. That we do with pumps. A suction-pump is limited in its action to a very small height. We must use pressure-pumps to raise water more than a hundred or so feet; and, naturally, the greater the height the more pressure we must use. Every additional yard of height calls for extra power. Many thousands of horse-power are used to keep the supply of water for a city running. Whoever has seen the great, trembling engines in a pumping-station did not depart with the impression that here was a perfect application of power. Work and effect are here seen in wide disproportion.



Ill. 19. Water Pumping Arrangements in a Mine.

It seems as if Nature were angry at these desecrations of her internal peace and quiet, and is always threatening to destroy the intruders and their work. For protection, they have installed in the interior of their mine, many feet below the light of day, huge engines, which can be heard chugging and groaning deep in the otherwise silent passages. The wheels of the engine spin at lightning speed, always pumping out water, which would rise many feet if they stopped pumping only for one day. It pours in from all sides from underground sources; some rises in springs

We find in the great mines, where Nature has a dark face and everything is enveloped in the breath of tragedy, the most disconcerting picture of the struggle between man's will and the iron resistance of matter.



Ill. 20. Climbing Palms which pump water over six hundred feet.

from below, some seeps in through the earthen ceilings, and some flows in channel courses. The power of steam raises up water from depths of over thirty-five hundred feet, only to let it flow away without any use.

Is this a biotechnical process? No! In the first place because no organism is thirty-five hundred feet high, is the evident, but superficial reply. The more thoughtful man would say that it is not important how many pumping-stations are placed one above the other in a mine in order to drive out the sea which threatens every mine. The important question is if the plant, which often is as tall as a church-steeple, employs pressure to raise the water through the pipe-system from its roots to its upper branches. And if it does employ pressure, where are the engines which produce the power?

Here we find ourselves in the midst of the incomprehensible, facing what is perhaps the most mysterious problem in botany and biotechnical science, a problem which has occupied the human mind again and again during the last hundred years. We have not been able to solve this problem; we are able only to describe its working.

We have been able to tell the story in rather exact formulae, so that we no longer are apt to be led astray in our researches. We are, I believe, standing before the last closed door.

I shall enumerate some of the principal acknowledged facts. First of all the heights which the plants overcome are considerably more than you are accustomed to think. An ordinary church steeple is anywhere from a hundred and twenty-five to two-hundred feet high; the highest in the world, the Munster steeple in Ulm is five hundred feet high; the highest building in the world, the Woolworth tower, is under six hundred feet high. A good-sized white pine tree must force water two-hundred and fifty feet high; the giant red-wood trees of California are four hundred and fifty feet high; and the eucalyptus trees of Australia some thirty or forty feet higher. But there are climbing palms which must drive water through more than six hundred feet of tortuous twistings above ground. When we add the depth of their roots we find that these palms must force water some six-hundred feet, which every engineer will admit requires an immense amount of power. But he has an explanation right at hand; he immediately thinks of capillary power. My non-technical readers will bring to

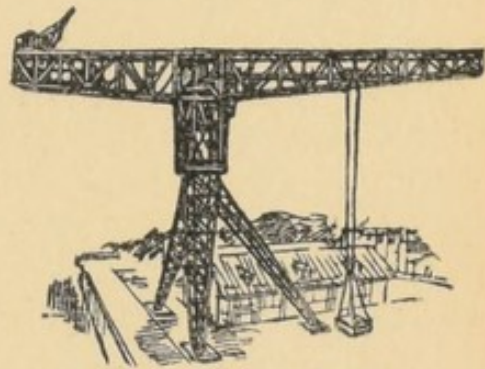
mind their childish delight in dipping a piece of sugar into a cup of coffee and watching the brown fluid rise up in it. This action of the coffee is also the result of capillary attraction.

But capillary attraction fails to explain the cases we have cited. Capillary attraction can raise water only a limited height; and cannot cover the action in plants of over a hundred feet in height.

There is no visible arrangement in plants which gives a clue to this mystery. The system of pipes is there, it is true; without a break it extends from the lowest root to the highest leaf-nerve. Also, it can be stated that there is rarified air above the rising column of water, just as there is in a suction-pump. Hopefully, we immediately jump at a false conclusion: the atmospheric pressure forces the water to rise in the pipes. But our knowledge of physics quickly shatters that solution; for we know that the atmospheric pressure is equal to a column of water only some thirty-four feet high.

We have also discovered a certain root-pressure existent in plants. Country people also know about this pressure, and make use of it in various ways. The peasant-maid steals away into the fresh green May woods, and slashes a criss-cross cut in the birch-tree, counting on the root-pressure to force out the sap, with which she anoints her face in the expectation that it will then become as smooth as velvet for the better attraction of her beloved. The cultivator of wine-grapes knows that the bleeding branches of his vines are natural in spring, for it is merely the rising of the sap, and he thinks no more about it. Scientists, however, have measured root-pressure; in the fox-glove stalk it is sufficient to raise water a little more than twenty one feet; in the trunk of the mulberry-tree, on the other hand, the force is not great enough to raise water more than a few inches. In no plant was this pressure found to be more than enough to lift water more than fifty two feet.

Moreover we have no knowledge of the cause of root-



Ill. 21. Modern Crane.

pressure. We have only observed that it is even active in dead tree-trunks, and therefore does not depend upon living forces. But it is clear that the pipe-system of plants is the forerunner of pressure and suction-pumps, even though it cannot be questioned that the plant employs them in a manner which we cannot imitate, since we do not understand it.

Every tree on the road-side, therefore, hides an invention which man has not been able to realize; its leaves and branches whisper that there are things of which our school knowledge does not dream.

School learning, anyway, is so hide-bound that it often passes by unheeded the important points of knowledge which it already has. The early history of biotechnical science contains a most instructive and clear illustration of this statement.

A generation ago the Swiss scientist, Schwendener, discovered one of the best examples of biotechnical invention, and was convinced that the laws of statics and mechanics are completely exemplified in plant-life. Unconcernedly he observed that "I beams", the fundamental element of all steel construction work, are also utilized in plant stalks and give firmness to them; he also noticed that the principle of the propeller is realized in certain fruits of plants which whirl through the air when they are ripe and ready for seeding (think of the maple tree).

He saw, he measured, was astonished, — but did not dare to draw any conclusions. Before his eyes lay nature's models of the great new inventions which were then occupying everybody's attention. There was the camera obscura of the human eye paralleling the photographic camera; the human ear and the telephone; the corn-stalk and the bony skeleton and the steel structure; flying-seeds and the propeller; and an endless list of similar examples. Writers spoke of resemblances, of analogies, of "organ-projection", of a "philosophy of mechanics"; they indicated, but never dared to follow their thinking to its logical conclusion and say:

"There is only one law. We, natural beings, can only repeat the law of protoplasm and the structure of the world. The laws of mechanics are exemplified before our eyes in the objects of nature".

Instead, scientists quoted these parallels as a curiosity, and straightway forgot them again. Above all, nobody ever drew any practical conclusions from them. Botanists knew

the facts, but made no use of them. The biologist had nothing to give to the mechanic or the engineer. The chemist and the architect believed that biological knowledge lay outside of their sphere, and did not concern them.

But similar oversights occur in all branches of life. Events take place before our eyes; effect their miracles; draw us into the whirl of their activity; but though we perceive them, we fail to realize their importance until we discover their underlying law.

Electricity has played in the atmosphere around man since the first human being looked up into the heavens at a threatening cloud. As a flash of lightning it blinded him; as thunder it sounded its terrible, threatening report in his ears; it demonstrated its power to him by sending giant trees crashing to earth with its discharge. And yet for thousands of years man remained ignorant of the fact that there is such a phenomenon as electricity, and therefore could not harness its power.

The rush of water over a falls crumbled the rocks; raging breakers ground masses of granite sand; every hammered piece of iron became warm; primeval man was still a naked cannibal and just had learned the art of rubbing two sticks together until smoke ascended, and then light and heat for his dark cave. Millions of eyes have observed these events; millions of men had their lives made more comfortable by them, long before anybody thought of the natural laws which governed their occurrence. The law of the conversion of energy was discovered after many generations who had their existence made possible by virtue of its application had passed away. But it was only after its discovery that man could make real use of its possibilities to become lord of its energies.

And this is true also of the biotechnical. Everywhere, biotechnical miracles lie close at hand, in every garden, in every meadow, and every field. Every fleeing beetle is such a miracle; likewise every fly that buzzes around our head; and perhaps the greatest mechanical masterpiece of all is the hand which reaches up to swat it. But man remains blind to it until the underlying law is pointed out, the law which is written in large letters in woods, and fields, and heavens.

But shall we not believe that from this hour on, everybody will see it, as today every educated man knows of electricity and the conservation of energy?



## III.

I have striven to present in as simple words as possible the most instructive examples of biotechnical occurrences in plant-life. I have sought only to make clear the inter-relations between our activities and the ring of nature. I have avoided fanciful wording and brilliant pictures; for the facts themselves are so fantastic and puzzling that imagination must not add one grain nor art one extra daub of colour to the picture.

These matters are so important that one naturally speaks a simple and direct language in referring to them. When the world-spirit speaks, it speaks without furbishes. The biotechnical chapter is really the chapter about the structure of the world.

We studied it in the structure of plants and in the life of unicellular organisms. However we should have found the same facts and come to the same conclusions if we had derived our examples from animals or from the remarkable internal structure of man himself. We have deliberately chosen our examples to show that the simplest technical forms are an impression or mirror of the activity which formed them: the spindle-form in swimming, we have seen, is the impression of the force of the movement of water on the swimming body to bring about the line of least resistance. Then we saw how the activity shapes the tool, how the optimal form for movement through the water (the screw) shapes the various forms of "whips" in spirals. Step by step we followed the same principle through higher forms, and witnessed astonishing and novel applications.

A puzzling abundance of evidence unfolded before us, the turbines of the water-drops and the pools in fissures in the ground. Instead of admiring the artistic forms of nature, we learned to value the complete mechanical forms manifested by the activities of life. The great "mystery-book" opened its pages to us. And in it were pictured the thousands of cell and organ forms, in which we could read the life of the plant. Nature whispered in our ears, every form is only the frozen momentary picture of a process.

This formula opened the great gate to the biotechnical treasure-house. Everything became intelligible, attractive, a fer-

tile source of inspiration, in contrast to the mere description and listing which makes botany so dry a subject for most people, of use only in making small conversation at table about the varieties of vegetables and salads, and neglected for practical use.

But our formula reawakens interest in the subject for the poetical as well as for the practical. The former hear the heart-throb of the world in botany; the latter see visions of the golden stream flowing from the utilization of botanic knowledge.

Botany and biology become essential fields of study for every technical student. Man is shown a new means of profit. The materialists will rejoice. Contentedly they can point to the beautiful world as grist for their mill; the whole world is a machine for them to pattern after.

But the materialists are wrong. Materialism is not a viewpoint; but it is a method of working. The mechanism of the world, on which, in the final analysis, the biotechnical science rests, is as before still the riddle of existence. It is hidden in our own breast; in our brain-cells which construct a world out of their perceptions. It seems mechanical and material because our brain conceives in material aspects, and our thinking proceeds according to the laws of mechanics.

It is certain that the biotechnical will influence the curriculum of our technical schools; perhaps entirely reform it. Without doubt it can cause a new period of inventive prosperity in our industry; perhaps give the impetus to countless new significant inventions. Industry need only stretch out its hand to grasp them. A bright future opens up before our eyes. Blessings will flow upon us from the biotechnical, and we shall be able to live more comfortably and carelessly; the millenium awaits us when we shall have copied the mechanics of the whole world of organisms. Only then will the limits of the mechanical be reached. Until then we shall have to work and explore, to fathom the secrets of the universe. And that will take centuries, for the world is large and every eon harbours its mystery.

But the biotechnical has more to offer us than the material. Mechanics are important. They are beautiful comforting evidence of our sagacity when we are sunk in brooding doubt of our intelligence. They bring man his wealth and endow him with

his might; but they are only the servants of life. I, as an "outsider" looking into the magic circle, have had to devote long study and much reflection to mechanical science; and have therefore been able to form an unbiased opinion of its true position in the great assemblage of powers which make up the world.

It is clear that mechanics are not the basic factors of the world, they are only one link in the chain of processes composing the activity of the universe.

If you turn back, and, with your present knowledge of the laws of technical forms and events, consider our first approach from the new point of view to the "monster world", you will understand fully what I intended to show. What did we mean to convey, then? (Compare page 9). That the world is a unity, each part of which influences all the others. In other words, every part is also a hindrance and obstacle to every other part. Who has not felt that in his own life? The existence of other human beings, the material facts of the world, all stand as obstacles to be overcome in the fulfillment of one's own destiny.

It was my thesis that we can conquer not only by the destruction of disturbing influences, but by compensation and in harmony with the world. Only compensation and harmony can be the optimal solutions; for that end the wheels of the world turn.

To attain its aim, life; to overcome obstacles, the organism — plant, animal, man, or unicellular body — shifts and changes. It swims, flies, defends itself, and invents a thousand new forms and apparatuses.

If you follow my thought, you will see where I am leading, what the deepest meaning of the biotechnical tokens. It portends a deliverance from many obstacles, a redemption, a striving for the solution of our problems in harmony with the forces of the world. On this road lies the optimum of existence; relief from the pressure of difficulties.

Mechanics are not the end of life, I repeat. They are, however, the necessary tools for the poor struggling human being, haunted by a thousand wants, and ever threatened with the snuffing out of his existence if he fails to fill them.

In acquiring the wherewithal to satisfy them, man can do no better than follow the ways discovered by nature. For

millions of years, these forms have been perfecting themselves in the workshop of reality. Buffeted by hostile winds, threatened by countless enemies; in the turmoil of existence only those forms which satisfied most perfectly the object of their aim survived. The others perished by the wayside.

That is why the biotechnical, wherever it parallels man's purposes, is an object lesson of the perfection of the instrument which he must construct.

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## POSTSCRIPT.

That the science which I have endeavoured to expound in this little book is but in its embryonic stage, none will more readily admit than I. Therefore, I have tried only to point out its most significant facts; to draw the reader's attention to the important role which it must play in our civilization.

If from these few citations and commentaries the reader has gained sufficient interest to continue his investigations of the subject, I shall consider that my work has been successful.

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