The Specific Characteristics of Vitality*

Essential Differences Between the Living and Non-Living State

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THE attempts to identify life with "mechanism" depend chiefly on certain analogies between living beings and man-made machines or engines of some sort.

In a certain sense living beings are mechanisms, as when we choose to regard the body as a means of transmuting the chemical energy of food into the kinetic forms of heat and movement: here we may speak of the body as a heat engine. But to insist on describing a warm-blooded animal as a heat-engine is to concentrate our attention on one phase of its activity and totally to overlook a number of aspects in which it does not at all resemble a man-made machine.

Certain tissues of the living body are so disposed that they perform the functions of valves, levers, pulleys, hinges, all of which contrivances act precisely as metal valves, levers, pulleys, or hinges; but to admit this is not by any means to see no essential difference, physico-chemically, between protoplasm and machines of purely human construction. To say that there is no essential difference between the growth of a crystal and of an infant is to magnify the resemblances out of all proportion to the differences. But this sort of thing is what Prof. Ostwald does when he writes, "Our observations so far have shown the organisms to be extremely specialized individual instances of physico-chemical machines."

He has been comparing a living organism to a flow of water through a pipe; and, by laying great stress on the truth that each is not a stable but a stationary form of matter, that is, the form although not the matter of the jet and of the body respectively is conserved from moment to moment, Prof. Ostwald finally loses sight of any fundamental differences between the non-living and the living forms.

That living matter is able to transform energy and is itself highly unstable, chemically speaking, need not compel us to regard it as precisely in the same category as certain other much more stable forms of matter which also are able to transform energy.

The following enumeration of the properties of protoplasm or living matter would probably be disputed by no philosophical biologist as constituting the characteristics of the highest (mammalian) type of protoplasm.

1. The possession of affectability (irritability);
2. The possession of functional inertia;
3. The power of transmuting the chemical energy of food into the kinetic forms of heat, movement, nerve energy, electric current, and sound.
4. The power of assimilating matter which is chemically unlike the living substance, and of growing thereby.
5. The power of producing, under the influence of foreign substances or poisons, anti-bodies (anti-toxins, or ferments) designed to render the former innocuous.
6. The power of reproduction, that is, to cast off an organism capable of independent existence which shall perpetuate the parental type.
7. The power or propensity to evolve, from a relatively simple microscopic layer of cells, all the highly differentiated tissues and systems of the adult body.

Now it is undeniable that some of these characteristics of livingness are also possessed by matter which is not living and has never lived. For instance, affectability or irritability, found in every text-book of physiology as a property of living matter, is certainly a property of such lifeless matter as gun-powder or dynamite and of many another unstable chemical substance. Gunpowder has affectability toward the stimulus of a spark, and dynamite has affectability toward the stimulus of concussion, for affectability is but the power of responding to a stimulus.

Similarly functional inertia—or the power of non-response to a stimulus—is a property possessed both by living and by non-living matter. In living matter it is the property by which limits are set to its activity, by which it is made insusceptible to certain stimulations, by which rates of response beyond a certain number are made impossible; it is that property which prevents indefinitely long-continued action and unending response.

But clearly this same property is possessed by certain chemical systems. Thus dynamite has inertia toward a spark; it explodes by concussion, not by ignition.

The extreme molecular instability of certain substances, the pierates, fulminate of mercury or of silver, may certainly be called their affectability toward stimuli tending to cause their disruption, but their possession of this high affectability does not entitle these materials to be called living.

Affectability is a property not of living matter exclusively, but of many varieties of non-living matter as well: affectability is correctly classified as one of the fundamental properties of protoplasm, but protoplasm is not living matter because it possesses affectability. Living matter also possesses functional inertia, which is the power to disregard or be oblivious to certain kinds of stimuli; but some kinds of matter that are non-living also possess this property in a high degree. The possession, therefore, of a degree of inertness toward certain forms of stimulation does not distinguish living from non-living substance. Both affectability and functional inertia are vital properties, but they are properties not possessed exclusively by living matter.

When we pass on to the other characteristics of vitality, we find ourselves on very different ground.

Living animal bioplasm has the power of growing, that is, of assimilating matter in most cases chemically quite unlike that of its own constitution. Now this is a remarkable power, not in the least degree shared by non-living matter. Its very familiarity has blinded us to its uniqueness as a chemical phenomenon. The mere fact that a man eating beef, bird, fish, lobster, sugar, fat and innumerable other things can transform these into human bioplasm, something chemically very different even from that of them which most resembles human tissue, is one of the most extraordinary facts in animal physiology. A crystal growing in a solution is not only not analogous to this process, it is in the sharpest possible contrast with it. The crystal grows only in the sense that it increases in bulk by accretions to its exterior, and only does that by being immersed in a solution of the same material as its own substance. It takes up to itself only material which is already similar to itself; this is not assimilation, it is merely incorporation.

Writers of a materialistic bias have, however, striven to regard such growth of crystals as not essentially differing from protoplasmic growth. Except that matter is taken up from outside in both cases, there is no similarity between the two processes at all. Growth of bioplasm, which includes and is the outcome of the incorporation of the dissimilar, the essence of the metabolic phenomena characteristic of living matter, is something *sui generis*.

The term "growth," strictly speaking, can be applied only to metabolism in the immature or convalescent organism. The healthy adult is not "growing" in this sense; when of constant weight he is adding neither to his stature nor his girth, and yet he is assimilating as truly as ever he did. Put more technically: in the adult of stationary weight, anabolism is quantitatively equal to katabolism, whereas in the truly growing organism anabolism is prevailing over katabolism, and reversely in the wasting of an organism or in senile decay, katabolism is prevailing over anabolism. The crystal in its solution offers no analogies with the adult or the senile states—but these are of the very essence of the life of an organism. The crystal, when not incorporating molecules exactly similar to itself, is not in any sense active; but an organism at all stages of its life-history is active—unless indeed it is in the state of latent life.

The fact, of course, familiar to every beginner in biology is that the crystal is only incorporating and not excreting anything, whereas the living matter is always excreting as well as assimilating. This one-sided metabolism—if it can be dignified with that term—is indeed characteristic of the crystal, but it is at no time characteristic of the living organism. The organism, whether truly growing or only in metabolic equilibrium, is constantly taking up material to replace effete material, is replenishing because it has previously dispenised itself or cast off material. The resemblance between a so-called "growing" crystal and a growing organism is verily of the most superficial kind.

It is true that a living organism resembles a wave—the form persisting, the matter changing—but that does not entitle us to lose sight of the inherent differences between the two; it justifies us neither in calling the wave alive nor the living organism "mechanical." Assimilation of matter is, then, a vital characteristic, specific for livingness in a sense in which neither affectability nor functional inertia is specific for it.

But when we pass on to that vital property, the power to produce anti-bodies, we encounter a property whose specificity is absolute. This is a property known only within the last few years; and as it is the basis of immunity from the poisonings due to disease-producing micro-organisms, it is being very carefully studied at the present time by workers in pathological chemistry.

Hardly any subject of biochemistry is so unsuited to

popular presentation, but the principle of it may be stated as follows; if material foreign to the blood or tissues of an animal be introduced into that animal's blood, then the body cells proceed to elaborate a substance (anti-body) designed to counteract or neutralize the foreign substance introduced.

The substance introduced is known as an antigen; the substance produced as a vital response to the foreign stuff is the anti-body. This is evidently a protective chemical procedure, or "mechanism," as it is called for short; it is the expression of the body's power of combating chemical insults by chemical means. As a chemical process it is highly specific, that is to say, the particular anti-body which neutralizes the poison of diphtheria, for instance, will not also antagonize the poison of typhoid fever or of pneumonia. Each toxin is responded to only by its own specific antitoxin. Now this is wholly without parallel or analogy in the world of the non-living. *It is characteristic of life alone, it is specific.* Modern biochemistry has, then, given us a new feature or differentia of living matter, a power of protoplasm not recognized a few years ago, not known to the men who regarded affectability as the chief vital manifestation.

The properties of reproduction and differentiation of tissues, though recognized for a much longer time than the formation of anti-bodies, are none the less confined to life alone. Non-living matter behaves in no wise which could be construed into regarding it as capable of reproduction or of progressive morphological differentiation.

Homogeneous non-living matter makes no spontaneous efforts from within toward heterogeneity.

If anyone cares to regard the breaking off of a portion of a crystal as analogous to the giving birth to an immature organism, capable, in due time, of an independent existence, he may do so as a poetical exercise, but not as any contribution to the philosophy of biology.

The power of sexual reproduction is entirely *sui generis*, and has no analogy in the non-living world. The so-called similarities between sexual phenomena and the attraction of oppositely electrified atoms or ions are really only pretty fancies. Possibly the most mysterious or wonder-rousing property of living matter is its inherent power of progressive cell-differentiation.

Out of the single fertilized ovum (or egg), usually of microscopic size, there arises in due time the perfect animal; the simple ovum having given place to millions of cells, each having its own niche in the living mosaic. And the end-product of the cell evolution is highly characteristic, for the microscopist can tell at a glance a brain-cell from a liver-cell, a bone-cell from a cell of the retina, and so on. Morphological differentiation evidently underlies functional specialization.

Sometimes these self-developing systems are spoken of as "mechanisms," but that is justified only in the interests of brevity of expression; no man-made mechanism ever evolved itself, or, being made, ever became anything else; but this is precisely what the "mechanisms" of protoplasm are continually doing. The single and simple can evolve into the multiform and complicated merely, apparently, by possessing the power of assimilation. The like can evolve into the unlike; the cells of the embryo which at one stage are practically all alike are destined to become something exceedingly different, as different as brain from bone. A mere mass of sperules will shortly become all the complexities of the eye or ear; some lens-cells detached from the lens of the eye can produce a lens outside of and away from the eye altogether; some bone-cells placed on the skin forthwith proceed to develop bone on the outside of the body.

It is customary to make a great deal out of radium being able to disintegrate and become something else as though this interesting transformation could blur the sharp lines of distinction between the living and the non-living.

It is characteristic of vitality to have its youth, its prime, and its decline, but there is nothing of this in the non-living. The hills are everlasting; but neither the sheep nor the shepherds are. "Change and decay" applies only to the living environment: the "birth" and "death" of worlds is poetry.

It is of the essence of living things to have phases or rhythms in their metabolism and phases or stages in their life-history. If the non-living corresponds at all to any phase or stage of the living matter, it is to the phase of latent life.

Latent life is that condition of living matter where there are no signs of life, only the potentialities of life

*Science Progress.

¹Ostwald, "Natural Philosophy," London: William & Norgate, 1911.

in the future. The vital material of the frozen frog, insect, fish, or rotifer, while it remains in latent life, is in the *status quo ante* just as a stone is; but whereas the frozen organism can revive, as we say, or again shows signs of vitality, that is, come out of its latent phase, the stone or crystal cannot, and all attempts to represent it doing so are based on metaphors.

The living thing tends to death; the non-living tends to nothing at all. Death is the natural end of life; physical science as such knows nothing of the endless existence of living things.

In life there is some affectability and some functional inertia; in latent life there is minimal affectability and much functional inertia; in death there is no affectability and maximal functional inertia.

This is, then, a new definition of death, for it is a positive one, all others, such as "death is the cessation of existence," are negative. Whereas in life there are signs and potentialities for future life; in latent life there are no signs but only potentialities; in death there are no signs and no potentialities. This is another new positive definition of death.

These conclusions do not necessarily preclude the belief that living matter has been evolved from non-living as Sir Edward Schäfer and Prof. B. Moore indicate. Possessing the fundamental properties of affectability, functional inertia, and the power to transmute energy, it is conceivable that non-living matter became, physico-chemically, so unstable that it finally acquired the four properties which have just been described as specifically characteristic of it: when it had acquired these it was alive.

Functional endowment, therefore, and not the possession of any "vital force," constitutes livingness. The desire of the chemists to create living out of non-living matter is not hereby ridiculed, neither is it pronounced impossible. But we must be prepared beforehand to recognize this man-made living matter whenever and wherever we may be privileged to see it. Presumably it will be first presented to us in a test-tube. How shall we know that it lives? The biochemist says that protoplasm is an irreversible colloidal hydrosol of emulsoid constitution: excellent, but how may we know that this hydrosol is alive? Not from its conforming to the above description, for matter entirely dead might still be so described. By its "extreme complexity"? No; for again extreme chemical complexity can characterize both non-living and dead matter. By its possessing affectability, functional inertia, and the power of transmuting energy? Once more, no, for all these three are possessed by certain lifeless substances. Matter, whatever its origin, cannot be pronounced alive unless it is capable of assimilating the unlike, of producing anti-bodies, of reproducing itself and of undergoing spontaneously a certain degree of morphological differentiation.

These are the credentials of living matter as we find it in the universe to-day; matter, wherever it has arisen, which possesses these four properties must be called alive.

Some years ago I contended² that affectability and functional inertia were the two fundamental properties of living matter, and such indeed we must regard them. No kind of matter which does not respond to a stimulus can be called alive; all matter which is alive can or may respond to a stimulus, but affectability is shared by non-living matter. Conversely, matter which was the everlasting plaything of stimulation, which could not resist or be oblivious to certain stimuli at certain times, would not be alive. It is of the essence of livingness to disregard some stimuli, to prevent some responses, to set limits to activity, to act rhythmically and not constantly or continually; but insusceptibility to stimulus is a property shared also by non-living matter.

It is theoretically possible that both these fundamental properties of living matter came to be found in it because they were inherent in the pre-existing non-living matter from which the living may be supposed to have been evolved. Similarly for the power of transmuting energy, a property notoriously not confined to livingness.

Nor does anything said here contradict the belief that affectability, functional inertia, and the transmutation of energy are primary or fundamental properties, while the last four are secondary or derived. For instance, if living matter had no affectability, it would be unaffected by the presence of food material, and so would not respond to it in the direction of assimilating it.

Recent physiological work has made us aware of a power in living tissues to offer resistance to the so-called "physical forces." We have been shown that the important function of absorption of food from the intestine is not capable of being explained by the laws of "physical" osmosis alone. The "mechanism" of absorption is not mechanical in the sense that it is the outcome of laws operative entirely in non-living matter. Prof. Waymouth Reid has demonstrated that if the living cells lining the alimentary canal be removed, the food is absorbed less perfectly than before, although now it is of

course actually nearer to the blood which is ultimately to receive it. Similarly, Prof. Gregor Brodie has proved that in the kidney, merely physical forces, blood-pressure, etc., will not account for the formation of the watery secretion of that gland; he is compelled to speak even of the water as being vitally secreted. Dr. J. S. Haldane, of Oxford, asserts that under certain conditions the living lining of the lung acts, as regards the excretion of carbonic acid gas and the intake of oxygen, in direct opposition to purely physical diffusion.

I have purposely not grounded the thesis of this paper on the phenomena of consciousness. The existence of consciousness is the supreme distinguishing feature between the living and the non-living; but our uncertainty as to the existence of self-consciousness in the lower forms of life precludes us from making dogmatic statements about its significance as a differentia of livingness in every one of the types of living matter. It seems safe to assume that consciousness does not arise until the related neuroplasm has attained to a certain degree of functional differentiation.

Certain biologists, for instance Haeckel, have on the contrary, assumed that consciousness does exist in every animal form from amoeba to man; but as this position is absolutely beyond the reach of proof, it cannot be used as a datum for further argument.

The assumption seems extremely improbable; were it true, the *fetus in utero*, for instance, would be a self-conscious existence; but if we are sure of anything, we are sure that it is not. If we could be certain that consciousness is an accompaniment of all living matter, then we could regard it as an additional differentia of protoplasm, for no one holds, save as poetry, that non-living matter is conscious.

In those animals which possess it, consciousness is a characteristic of life *sui generis*, in which respect it resembles the power of producing anti-bodies; but only somewhat highly differentiated protoplasm possesses either of these properties.

Enough has been said to justify us in refusing to see no essential differences between matter in the living and in the non-living state. That living matter had its origin in the non-living is a conceivable evolutionary possibility; but that we may discover in matter which has never lived all the properties whereby we recognize vitality does not seem a correct interpretation of the world of life as we find it.

By magnifying resemblances and by explanations based on analogies, we can endow the non-living with the semblance of life, but we are somehow certain after all that differences are there, and that it is poetry and not science that has been enriched. Between the living and the non-living there is a great gulf fixed, and no efforts of ours, however heroic, have as yet bridged it over.

The Microscope Fine Adjustment

IN the choice of a microscope, the amateur too often neglects to ascertain the efficiency of the fine adjustment when working with really high powers. In some medical schools, where the matter is entrusted to the lecturer, the same holds good, and microscopes of an old and once excellent pattern are still recommended, though entirely out of date and utterly unsuitable.

Two years ago Prof. Minot, of Harvard, called upon me, and together we discussed a few points about the modern microscope. "Do you know the ——— microscopes?" he asked. I told him I did. "And what do you think of them?" he said. I answered, "Excellent, except that the fine adjustment is not good enough for oil-immersions." "You are quite right," he said. "I told them so only a few months ago, and they are altering their pattern." And altered these microscopes are, though even yet not quite perfect, in my own opinion.

The first point to test is whether there is any backlash or loss of time in the movement. As a matter of fact, this is seldom found, as most microscope makers obviate all chance of this by means of a counter spring, which in most cases acts admirably. Only in old and second-hand instruments is this defect sometimes to be detected, and a new spring soon puts it right. Any side movement can also usually be corrected by tightening the screws of the slide, or in some cases by a drop or two of good sperm oil or oil of sweet almonds on the movement, wiping off all superfluous oil with a clean linen cloth. Usually it is only apparent with the highest powers. But it should not exist at all, and indicates soft metal or great age, or both.

Roughly speaking, fine adjustments fall into two classes—those acting directly with a screw and those having in addition a lever or cam, or some intermediate method of diminishing the motion of the screw.

In the first class the threads of the screw are almost invariably half a millimeter (one-fiftieth of an inch) in pitch. Thus one whole revolution of the screw gives a movement of half a millimeter. This acts very well for all objectives up to four millimeters (one-sixth inch) in focus, and up to about .65 in angular aperture. Such a

lens, with the highest eye-piece in common use, gives a magnification of about 600. Most observers will not use it for a magnification of more than 400, but the image is hardly impaired even at the higher figure. Such an objective will work through any thickness of cover within reason, and needs neither collar correction nor any alteration in length of the draw tube for varying thickness of covers.

When, however, we substitute an objective of the same focal length, but with an aperture of .85, we find that this make of fine adjustment breaks down, and is scarcely sensitive enough. One maker at least obviates this difficulty by making his screw one-third of a millimeter in pitch; but even then it breaks down with objectives of three millimeters and still more with a 2.5 millimeter, the highest dry-power objective in common use for bacteriology. For oil-immersions of the usual power and aperture, and still more for microphotography, this form of fine adjustment is utterly out of question.

So far we have spoken only of what experience teaches. It remains for us to deduce conclusions and state results, and apply them to higher powers.

Prof. Abbe long ago demonstrated that the depth of focus (or depth of sharpness or penetration) was in inverse proportion to the product of the numerical aperture and the initial magnification of the objective.

Thus the depth of focus of the four-millimeter objective of N. A. .65 would be

$$\frac{1}{.65 + 40}$$

the latter being the initial magnification of the system with the one-hundred-and-sixty-millimeter tube.

Now let us proceed to the ordinary one-twelfth-inch oil-immersion of N.A. 1.30, which is most commonly used, and costs everywhere £5. It is in reality a one-fourteenth-inch, i. e., 1.8 millimeter objective, and hence

its initial magnification is $\frac{160}{1.8}$, say ninety. Thus its

$$\begin{aligned} \text{depth of focus is } & \frac{1}{1.30 + 90} \\ & .65 \times 40 = 26. \\ & 1.30 \times 90 = 117. \\ & 117 \text{ is to } 26 \text{ as } 4\frac{1}{2} \times 1 \end{aligned}$$

In order, therefore, to be perfectly efficient the fine adjustment for the 1.8 millimeter lens should be four and a half times as slow as one for the four-millimeter objective. In order to embrace oil-immersions of N. A. 1.4, we may change $4\frac{1}{2}$ into 5 with advantage.

The four-millimeter objective requires a movement of .5 millimeter per turn of the fine adjustment; the 1.8

millimetre would therefore require $\frac{.5}{5} = .1$ millimeter per turn.

It is objected that such a slow movement (one-two-hundred-and-fiftieth inch) is not a convenient one with medium powers, as it is difficult to decide which is the best focus. This difficulty, however, completely disappears with experience. The tyro may try the dodge of putting the image just out of focus; then turn the fine adjustment until it is equally out of focus the other way. Then turn the milled head just half the distance back, and the correct place will be found.

One maker gets over the difficulty in a very ingenious and efficient manner. A screw with a coarse thread works *inside* another with a thread five times as fine. The coarse thread moves the body about one-sixtieth inch per turn; the fine one, one-three-hundredth inch. We should have preferred one-half millimeter (one-fiftieth inch) and .1 millimeter (one-two-hundred-and-fiftieth inch), but this is perhaps hypercritical. At any rate, the idea is a good one, and gives excellent results in practice. It shows also how well theory and practice agree.—E. Ardron Hutton, M.A., in *Knowledge*.

Prehistoric Irrigation Ditch Built by Indians

THERE exist in several parts of Arizona the remains of irrigation systems that date back to prehistoric days, when some quite highly civilized Indian tribes inhabited these valleys.

One of the most famous of these ancient irrigation works is on the Arizona state highway from Prescott to the Grand Canyon. Water was taken from what is known as Montezuma's Well, a curious natural well 440 feet in diameter and 93 feet deep, except in one spot, where no bottom was reached at 500 feet.

The water carries a great deal of lime in solution, and the sides of the ditch have been preserved by the petrification of the original earth. One rancher at the present time is using several thousand feet of the old ditches, after merely cleaning them out. F. R. Goodman, State highway division engineer, was once tempted by curiosity to run a line of levels along the bottom of one of these old Indian ditches. He found the grade to be almost perfectly uniform at a rate of 0.01 foot per 100 feet.—*Engineering News*.

² Fraser Harris, "The Functional Intertia of Living Matter," London: Churchill, 1908.