

***C. LLOYD
MORGAN***



***ANIMAL
BEHAVIOUR***

C. Lloyd Morgan

Animal Behaviour

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CHAPTER I

ORGANIC BEHAVIOUR

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I.—BEHAVIOUR IN GENERAL

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We commonly use the word “behaviour” with a wide range of meaning. We speak of the behaviour of troops in the field, of the prisoner at the bar, of a dandy in the ball-room. But the chemist and the physicist often speak of the behaviour of atoms and molecules, or that of a gas under changing conditions of temperature and pressure. The geologist tells us that a glacier behaves in many respects like a river, and discusses how the crust of the earth behaves under the stresses to which it is subjected. Weather-wise people comment on the behaviour of the mercury in a barometer as a storm approaches. Instances of a similar usage need not be multiplied. Frequently employed with a moral significance, the word is at least occasionally used in a wider and more comprehensive sense. When Mary, the nurse, returns with the little Miss Smiths from Master Brown’s birthday party, she is narrowly questioned as to their behaviour; but meanwhile their father, the professor, has been discoursing to his students on the behaviour of iron filings in the magnetic field; and his son Jack, of H.M.S. *Blunderer*, entertains his elder sisters with a graphic description of the behaviour of a first-class battleship in a heavy sea.

The word will be employed in the following pages in a wide and comprehensive sense. We shall have to consider, not only the kind of animal behaviour which implies intelligence, sometimes of a high order; not only such behaviour as animal play and courtship, which suggests emotional attributes; but also forms of behaviour which, if not unconscious, seem to lack conscious guidance and control. We shall deal mainly with the behaviour of the animal as a whole, but also incidentally with that of its constituent particles, or cells; and we shall not hesitate to cite (in a parenthetical section) some episodes of plant life as examples of organic behaviour.

Thus broadly used, the term in all cases indicates and draws attention to the reaction of that which we speak of as behaving, in response to certain surrounding conditions or circumstances which evoke the behaviour. The middy would not talk of the behaviour of his ship as she lay at anchor in Portland harbour; the word is only applicable when there is action and reaction as the vessel ploughs through a heavy sea, or when she answers to the helm. Apart from gravitation the glacier and the river would not "behave in a similar manner." Only under the conditions comprised under the term "magnetic field" do iron filings exhibit certain peculiarities of behaviour. And so, also, in other cases. The behaviour of cells is evoked under given organic or external conditions; instinctive, intelligent, and emotional behaviour are called forth in response to those circumstances which exercise a constraining influence at the moment of action.

It is therefore necessary, in a discussion of animal behaviour, that we should endeavour to realize, as far as

possible, in every case, first, the nature of the animal under consideration; secondly, the conditions under which it is placed; thirdly, the manner in which the response is called forth by the circumstances, and fourthly, how far the behaviour adequately meets the essential conditions of the situation.

II.—BEHAVIOUR OF CELLS

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From what has already been said it may be inferred that our use of the term “behaviour” neither implies nor excludes the presence of consciousness. Few are prepared to contend that the iron filings in a magnetic field consciously group themselves in definite and symmetrical patterns, or that sand grains on a vibrating plate assemble along certain nodal lines because they are conscious of the effects of the bow by which the plate is set in sounding vibration. But where organic response falls under our observation, no matter how simple and direct that response may be, there is a natural tendency to suppose that the behaviour is conscious; and where the response is less simple and more indirect, this tendency is so strengthened as to give rise to a state of mind bordering on, or actually reaching, conviction. Nor is this surprising: for, in the first place, organic responses, even the simplest, are less obviously and directly related to the interplay of surrounding circumstances; and, in the second place, they are more obviously in relation to some purpose in the sense that they directly or indirectly contribute to the maintenance of life or the furtherance of well-being. Now where behaviour is

complex and subserves an end which we can note and name, there arises the supposition that it may well be of the same nature as our own complex and conscious behaviour.

Take for example the behaviour of the Slipper-animalcule, Paramecium, one of the minute creatures known to zoologists as Protozoa. The whole animal is constituted by a single cell, somewhat less than one-hundredth of an inch in length, the form and behaviour of which may be readily studied under the microscope. Thousands may be obtained from water in which some hay has been allowed to rot. The surface of the Paramecium is covered with waving hair-like cilia, by which it is propelled through the water, while stiffer hairs may be shot out from the surface at any point where there is a local source of irritation, as indicated at the top of the accompanying figure. Two little sacs expand and contract, and serve to drain off water and waste products from the substance of the cell. Food is taken in at the end of the funnel, shown in the lower part of the figure. The cilia here work in such manner as to drive the particles into and down the tube, and on reaching its inner end these particles burst through into the semi-fluid substance, and circulate therein. Just above the funnel there are two bean-like bodies, the larger of which is known as the macronucleus, the smaller as the micronucleus.

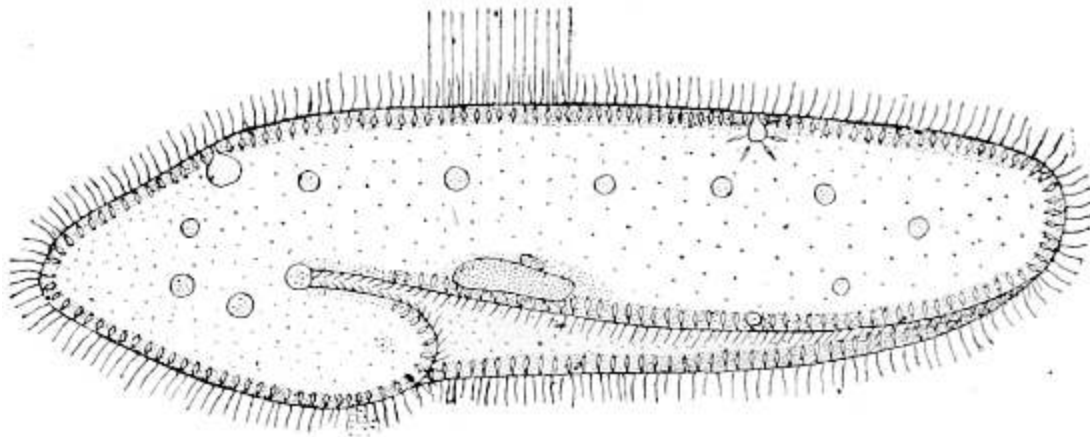


FIG. 1.—Paramecium.

The process of multiplication is by “fission,” or the division of each Paramecium into two similar animalcules. Not infrequently, however, two Paramecia may be seen to approach each other and come together, funnel to funnel; and in each the nuclei undergo curious changes. The macronucleus breaks up, and is scattered. The micronucleus in each divides into four portions, of which three break up and disappear; while the fourth again divides into two parts, one to be retained and the other to be exchanged for the similar micronuclear product of the other Paramecium. The retained portion and that received in exchange then unite to form a new micronucleus. M. Maupas concludes from his careful observations that, in the absence of such “conjugation” in the mid-period of life, Paramecia pass into a state of senility which ends in decrepitude and death. If this be so, conjugation is in them necessary for the continuance of a healthy race.

Here we have what a zoologist would describe as a specialized mode of behaviour of the nuclei; and we have also the behaviour of the minute creatures (which contain the nuclei) as they approach each other and come together

in conjugation. Can one wonder that the latter, at any rate, has been regarded as an example of conscious procedure? In truth we do not know in what manner and by what subtle influences the Paramecia are drawn together in conjugation. But it is scarcely logical to base on such ignorance any positive assertion as to conscious attraction. It is better to confess that here is a piece of organic behaviour, the exact conditions of which are at present unexplained.

We may take from the writings[\[1\]](#) of Dr. H. S. Jennings, of Harvard, some account of other modes of behaviour among Paramecia. They largely feed upon clotted masses of bacteria. If a number are placed upon a glass slip, together with a small bacterial clot, they will be seen to congregate around the clot and to feed upon it. All apparently press in so as to reach it, or get as near it as possible. And if a number be placed on another slide without any clot, they soon collect in groups in one or more regions, as in Fig. 2, III. It appears as if they were actuated by some social impulse leading them to crowd together and shun isolated positions. Nay, more; it seems as if, after thus collecting and crowding in to some centre of interest, the attractive influence gradually waned; the group spreads, and the Paramecia are less densely packed; the assembly scatters more and more, but still seems to be retained by an invisible boundary beyond which the little creatures do not pass.

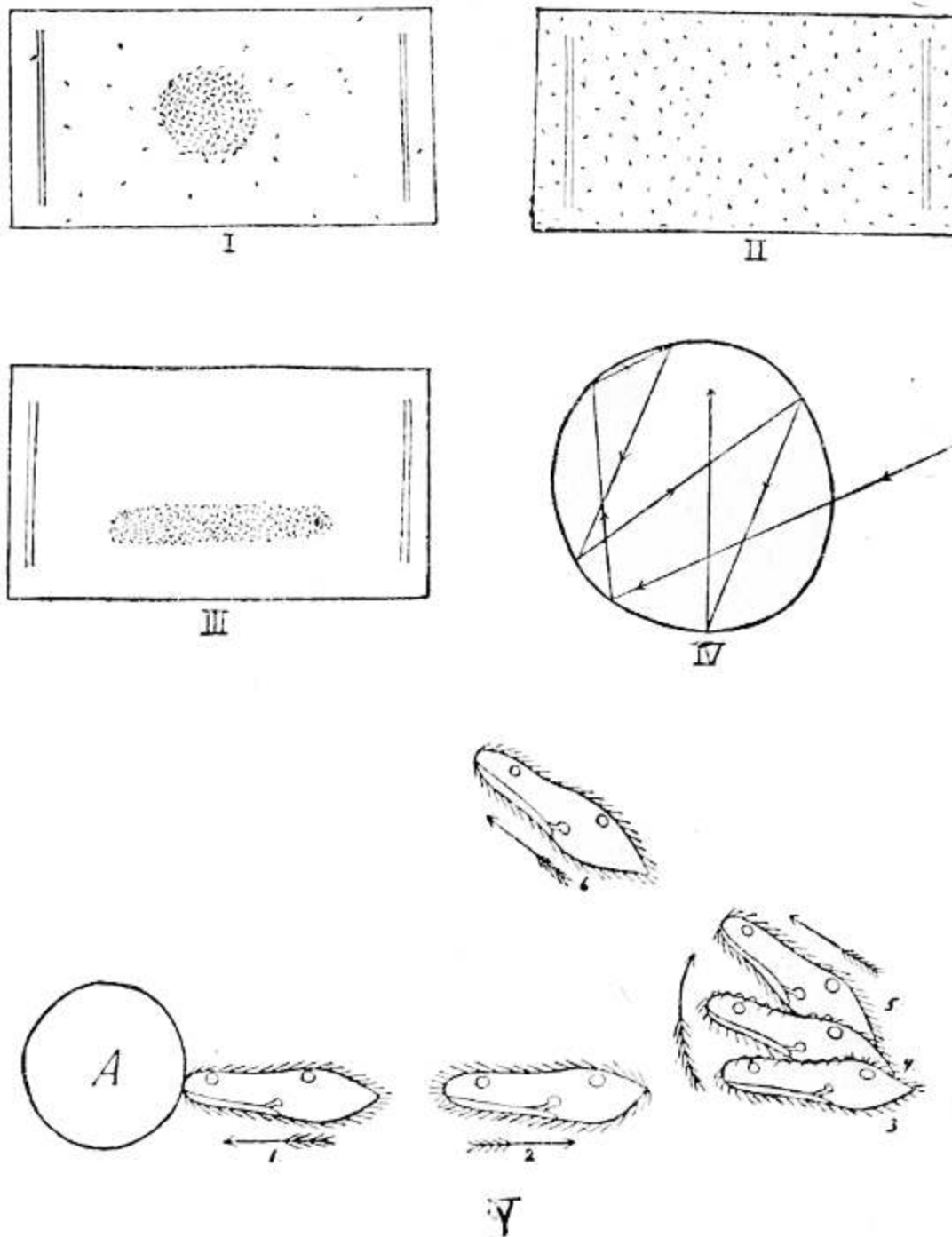


FIG. 2.—Behaviour of Paramecia (after Jennings).

Furthermore, if kept in a jar, the Paramecia crowd up towards the surface where the bacteria clots are floating; and if, beneath the cover glass of a slip on which they are under microscopic examination, a drop of liquid be

introduced through a very fine tube, they will seem either to be attracted to it, as in Fig. 2, I., or repelled from it, as in Fig. 2, II., according to its nature. From alkaline liquids they are repelled; to slightly acid drops they are attracted, unless the acidity be too pungent. Heat and cold are alike repellent, and even a drop of pure distilled water forms an area into which the Paramecia do not enter.

With such facts before him, the incautious observer may be led to the conclusion that Paramecia are not only conscious, but endowed with intelligence and volition. Even M. Binet,[\[2\]](#) who occupies a position which should lead him to exercise more caution, tells us that there is not a single infusorian which cannot be frightened, and does not manifest its fear by rapid flight; he speaks of some of these unicellular animals as “endowed with memory and volition,” and possessed of “instinct of great precision;” and he describes the following stages:—

- “(1) The perception of an external object;
- “(2) The choice made between a number of objects;
- “(3) The perception of their position in space;
- “(4) Movements calculated either to approach the body and seize it, or to flee from it.”

But when we seem to have grasped his point of view, when we have catalogued the memory, fear, instinct, perception, choice and volition, the whole intelligent edifice crumbles; for we are told that “we are not in a position to determine whether these various acts are accompanied by consciousness, or whether they follow as simple physiological processes.” To most of us fear, memory, choice, volition, imply something more than simple

physiological processes; they imply not only consciousness, but highly elaborated consciousness.

Dr. Jennings's researches show that no such implication can be accepted unless we are prepared to cast aside the trammels of reasonable caution. In the first place, the whole matter of feeding appears to be referable to simple organic behaviour not necessarily involving consciousness. The cilia in the mouth-groove and funnel constantly wave in such a manner as to drive a current of water, together with any particles which float therein, towards the interior; and the particles are then engulfed, no matter what their composition may be. Digestible or indigestible, in they go. There is no selection of the one or rejection of the other. But, as we have seen, the *Paramecia* collect around a bacterial clot and feed upon it. Surely here there is selection of the nutritious! Apparently not. They collect in just the same way towards a piece of blotting-paper, cotton-wool, cloth, sponge, or other fibrous body, and remain assembled round such an innutritious centre just as long as round a bacterial clot. There seems to be no choice in the matter; contact with any substance gives rise, as an organic response, to the lessening or cessation of the regular movements in all the cilia except those of the mouth-groove and funnel. As the *Paramecia* swim hither and thither, first one, then another, then more, chance to come in contact with the bacterial clot, the blotting-paper, or other substance, and since the lashing of the cilia is then automatically lessened, there they stay; others find their way to the same spot in the course of their random movements, and they, too, stay; thus many soon collect.

But this does not account for the seemingly social assemblages of Paramecia where there is no such substance to arrest their progress. Dr. Jennings attributes this to the fact that a dilute solution of carbon-dioxide has, what we may call for the present, an attractive influence. If a bubble of air and a bubble of carbon dioxide be introduced into the water in which Paramecia are swimming beneath a cover-glass, the animalcules collect around the carbonic dioxide, but not around the air bubble. At first they press up close to the bubble of carbon dioxide, but gradually form a ring farther and farther from its limiting boundary. This is held to be due to the fact that it is only the dilute solution of carbonic acid that has the peculiar “attraction”—a stronger solution has a different effect. And, as the gas dissolves, the Paramecia collect in a ring just where the solution is sufficiently dilute.

Now carbon dioxide is a product of the organic waste of living substance; it is given off by active Paramecia. Where therefore many are collected together they form a centre of the production of this substance; and when other Paramecia come, in the course of their random movements, into such a centre they remain there and help to swell the numbers in the cluster. If Paramecia be placed in water to which a distinctly reddish tinge is given by mixing it with a small quantity of rosol—a substance which is decolourized by carbon dioxide, and is not injurious to Paramecia—it will be seen that, where the groups are collected, the reddish tinge fades and disappears. As the groups expand, and are less densely packed, the colourless area expands too: and the limits within which the group is circumscribed are also the

limits of decolourization. Dr. Jennings considers it beyond question that the assembling of Paramecia is due to the presence in such assemblages of carbonic acid produced by the animals themselves. The first beginning of the crowd may be some small fragment of bacterial clot or other substance.

It would seem, then, that Paramecia are attracted by faintly acid solutions; and here at least there is, it may be urged, an element of choice. But even here, according to Dr. Jennings, there is not only no real choice, but not even any real attraction. What takes place, according to his observations, is briefly as follows. Suppose a faintly acid drop be inserted beneath the cover-glass. Paramecia may almost graze its boundary without being in any way affected by its presence. But in their random movements some, and eventually many, perhaps most, of the little animals chance to enter the faintly acid region; but there is no sign of reaction or response; they swim on across the drop until they reach its further margin. Here a reaction does take place. Instead of proceeding onwards, slowly revolving on its long axis, a Paramecium thus situated jerks backwards by a reversal of all the cilia, at the same time revolving on its axis in a direction opposite to that in which it was before turning. But the cilia of the mouth-groove resume their normal mode of working sooner than the others, and this causes the Paramecium to turn aside. It then goes ahead until it again reaches the boundary at another point, when the same behaviour is seen. The course of such a Paramecium is shown in Fig. 2, IV.

If, instead of a faintly acid drop, a little alkaline liquid be introduced beneath the cover-glass, the Paramecium similarly jerks backward and turns aside on reaching its outer boundary. The turning may carry it away from the alkali, as shown in Fig. 2, V.; but it just as often brings it again towards the drop, especially a large one. It seems to be a matter of chance which result follows. But eventually the little creature sails off, since each time it comes within the influence of the alkaline fluid it jerks back and turns. It appears, then, that when it is swimming in a normal solution a faintly acid liquid does not much modify its behaviour, but an alkaline fluid evokes a reversal of the cilia; and that when it is a slightly acid solution, not only does stronger acid cause reversal, but normal fluid produces a similar result. A reaction of essentially the same kind is in fact called forth by such different stimuli as chemical substances, water heated above the normal temperature, or cooled considerably below it, and fluids which cause changes of internal pressure within the substance of the cell. Nor does it matter where the stimulus is applied. If it be applied at the hinder end the infusorian still jerks backward, though this may drive it into a destructive solution and thus cause death. There is, however, some evidence of different behaviour in some infusorians according as the stimulus is here or there. In other words, the behaviour is to some extent related to the position of the part stimulated.

Furthermore, it may be gathered from Dr. Jennings's account that there is nothing to lead us to suppose that such free living cells show any indication of what may be regarded as the keynote of intelligent behaviour. They do

not profit by experience. They exhibit organic reactions which may be accompanied by some dim form of consciousness, but which do not seem to be under the guidance of such consciousness, if it exist.

One of the first lessons which the study of animal behaviour, in its organic aspect, should impress upon our minds is, that living cells may react to stimuli in a manner which we perceive to be subservient to a biological end, and yet react without conscious purpose—that is to say, automatically. The living cell assimilates food and absorbs oxygen, it grows and subdivides, it elaborates secretions, produces a skeletal framework or covering, rids itself of waste products, responds to stimuli in a definite fashion, moves hither and thither at random, its functional activities being stimulated or checked by many influences; and yet this varied life may give no evidence of a guiding consciousness: if purpose there be, it lies deeper than its protoplasm, deeper than the dim sentience which may be present or may be absent—we cannot tell which.

And when the cells are incorporated in the body of one of the higher animals, instead of each preserving a free and nomad existence; when they become the multitudinous constituents of an organic republic with unity of plan and unity of biological end, then the behaviour of each is limited in range but perfected within that range, in subservience to the requirements of the more complex unity. The muscle cell contracts, the gland-cell secretes, the rods and cones of the retina respond to the waves of light, and all the normal responses of the special cells go on with such orderly regularity that the term behaviour seems scarcely

applicable to reactions so stereotyped. But the physiologist and the physician know well that such uniformity of response is dependent on uniformity of conditions. A little dose of some drug will profoundly modify and render abnormal the procedure which was before so mechanical in its exactitude; and we are thus led to see how dependent the orderly behaviour really is on the maintenance of certain surrounding conditions.

Moreover, the existence of every cell in the body corporate is the outcome of a process of division involving a special mode of behaviour in the nucleus, of which we are only beginning to guess the meaning and significance, and of which we seek in vain to find an explanation in mechanical terms. And when we trace these divisions back to their primary source in the fertilized ovum, we find changes and evolutions in the nuclear matter of which it can only be said that the more they are studied the more complex and varied do they appear.

The egg, or ovum, is a single cell produced by the female, and varying much in size, according to the amount of food-yolk with which it is supplied. Like other cells, it has a nucleus, and this undergoes changes which are definitely related to the fertilization of the ovum, which we describe as the biological end. Such preparatory changes for a future contingency are especially characteristic of organic behaviour. There is nothing like it in the mineral kingdom. The nucleus divides into two parts, one of which passes out of the ovum and is lost. The nucleus again divides, and again one part passes out and is lost. Thus only one quarter of the original amount of nuclear matter remains. Now,

division of the nucleus occurs whenever an animal cell divides; but in this case (apart from details which would here be out of place) there is this difference. During the ordinary division of cells there are found in the nucleus a definite number of curved rods, and this number is constant for any given species; but in the nucleus which remains in the ovum after three parts of its substance are lost, the number of rods has been reduced to half that which is common to the species. The egg is now ready for fertilization. A minute active cell, which is produced by the male, and which also has only half the normal number of rods, enters the ovum. The two nuclei approach each other, and give rise to the single nucleus of the fertilized ovum, which thus has the full number of rods—half of them derived from one parent, half from the other parent. The sperm cell of the male adds little to the store of protoplasm in the ovum; but it introduces a minute body, which seems to initiate subsequent divisions of the cell. The nature of these divisions may be seen in the accompanying diagrammatic figure. In A the cell is just preparing to divide. Above the nucleus is the minute body (centrosome) just spoken of, which has already divided. In the nucleus the matter of which the rods will be constituted is net-like. In B this network has taken on the new form of a coiled thread, while the divided body above is associated with a spindle of delicate fibres. In C the membrane round the nucleus has disappeared, and the coiled thread has broken up into curved rods (chromosomes), four of which are shown. The two halves of the minute body form the centres of radiating stars. In D each curved rod has split along its length, and

the two parts are being drawn asunder towards the centres of the two stars; the cell itself is beginning to divide. In E the process is carried a step further, while in F the cell has completely divided into two: the rods have disappeared as such, and are replaced by a net-work; a new nuclear membrane has been formed, and the minute body has again divided preparatory to the further division of the cell.

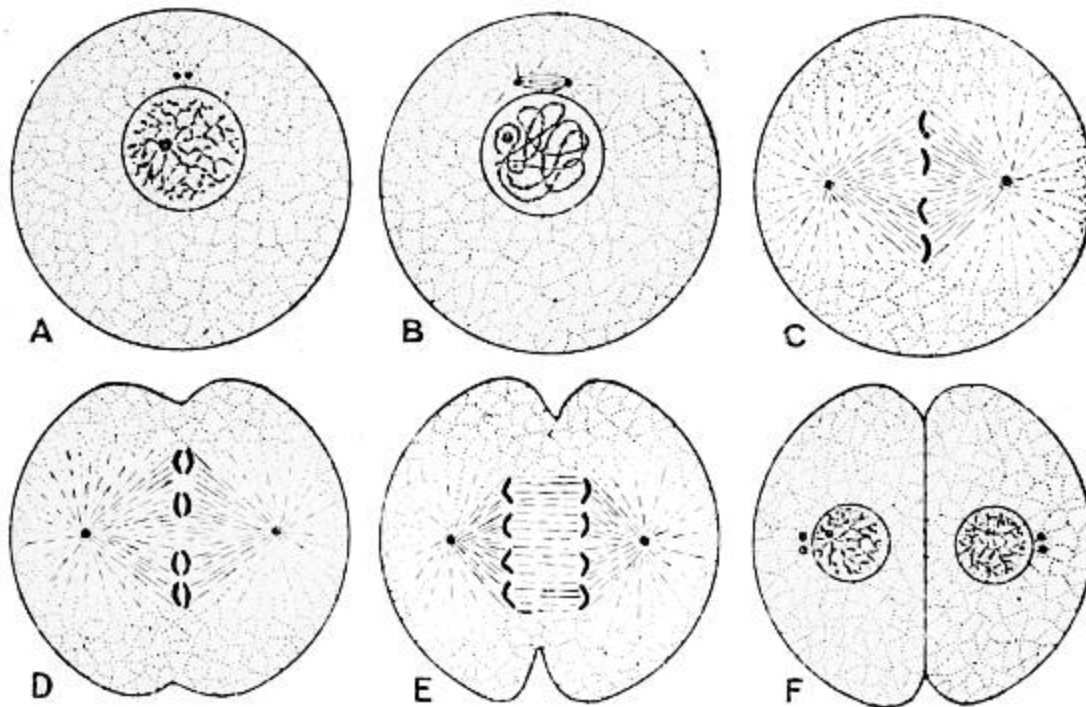


FIG. 3.—Cell-division.

Such, stripped as far as possible of technicalities, are some of the facts concerning the behaviour of cells and their nuclei during the process of cell-multiplication. No good purpose would be subserved by pretending that we fully understand them. The splitting of the rods does indeed seem an efficient means to the end of securing a fair division of the nuclear substance, which, according to many biologists, is the organic bearer of hereditary qualities in the cells. But that is nearly all that we can say. Is the process accompanied by some form of sentience? We do not know.

That it is controlled and guided by any consciousness in the cell is most improbable. But if it be a purely organic and unconscious process it should at least impress on our minds the fact that such organic behaviour may reach a high degree of delicacy and complexity.

III. CORPORATE BEHAVIOUR

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The word “corporate” is here applied to the organic behaviour of cells when they are not independent and free, but are incorporated in the animal body, and act in relation to each other. If the behaviour of the individual cell during division impresses us with the subtle intricacy of organic processes, the behaviour of the growing cell-republic during the early stages of organic development must impress us no less forcibly. We place the fertilized egg of a hen in an incubator, and supply the requisite conditions of warmth, moisture, and fresh air. Before the egg is laid cell-division has begun. A small patch of closely similar cells has formed on the surface of the yolk. Further subdivision is then arrested until the warmth of incubation quickens again the patch into life. But when once thus quickened no subsequent temporary arrest is possible—life will not again lie dormant. If arrest there be it is that of death. And from that little patch of cells, which spreads further and further over the yolk, a chick is developed. Into the intricate technicalities of embryology this is not the place to enter. But it is a matter of common knowledge that, whereas we have to-day an egg such as we eat for breakfast, three weeks hence we shall have a bright active bird, a cunningly

wrought piece of mechanism, and, more than that, a going machine. During this wonderful process the cellular constituents take on new forms and perform new functions, all in relationship to each other, all as part of one organic whole. Here bones are developed to form a skeletal framework, there muscles are constituted which shall render orderly movements possible; feathers, beak, and claws take shape as products of the skin; gut and glands prepare for future modes of nutrition; heart and blood-vessels undergo many changes, some reminiscent of bygone and ancestral gill-respiration, some in relation to the provisional respiration of the embryo by means of a temporary organ that spreads out beneath the shell, some preparatory to the future use of the lungs,—some, again, related to the absorption of food from the yolk, others to subsequent means of digestion; nerve, brain, and sense-organs differentiate. A going machine in the egg, the chick is hatched, and forthwith enters on a wider field of behaviour. Few would think of attributing to the consciousness of the embryo chick any guiding influence on the development of its bodily structure, any control over the subtle changes and dispositions of its constituent cells. But no sooner does the chick, when it is hatched, begin to show wider modes of instinctive behaviour, than we invoke conscious intelligence for their explanation, seemingly forgetful of the fact that there is no logical ground for affirming that, while the marvellous delicacies of structure are of unconscious organic origin, the early modes of instinctive behaviour are due to the guidance of consciousness. Such modes of behaviour will, however, be considered in another chapter.

Here we have to notice that the unquestionably organic behaviour of the incorporated republic of cells may attain to a high degree of complexity, and may serve a distinctly biological end.



FIG. 4.—Wapiti with antlers in velvet.

There is, perhaps, no more striking instance of rapid and vigorous growth than is afforded by the antlers of deer,[\[3\]](#) which are shed and renewed every year. In the early summer, when growing, they are covered over with a dark

hairy skin, and are said to be "in velvet." If you lay your hand on the growing antler, you will feel that it is hot with the nutrient blood that is coursing beneath it. It is, too, exceedingly sensitive and tender. An army of tens of thousands of busy living cells is at work beneath that velvet surface, building the bony antlers, preparing for the battles of autumn. Each minute cell, working for the general good, takes up from the nutrient blood the special materials it requires; elaborates the crude bone-stuff, at first soft as wax, but ere long to become hard as stone; and then, having done its work, having added its special morsel to the fabric of the antler, remains embedded and immured, buried beneath the bone-products of its successors or descendants. No hive of bees is busier or more replete with active life than the antler of a stag as it grows beneath the soft, warm velvet. And thus are built up in the course of a few weeks those splendid "beams," with their "tynes" and "snags," which, in the case of the wapiti, even in the confinement of our Zoological Gardens, may reach a weight of thirty-two pounds, and which, in the freedom of the Rocky Mountains, may reach such a size that a man may walk, without stooping, beneath the archway made by setting up upon their points the shed antlers. When the antler has reached its full size, a circular ridge makes its appearance at a short distance from the base. This is the "burr," which divides the antler into a short "pedicel" next the skull, and the "beam" with its branches above. The circulation in the blood-vessels of the beam now begins to languish, and the velvet dies and peels off, leaving the hard, bony substance exposed. Then is the time for fighting, when the stags

challenge each other to single combat, while the hinds stand timidly by. But when the period of battle is over, and the wars and loves of the year are past, the bone beneath the burr begins to be eaten away, through the activity of certain large bone-absorbing cells, and, the base of attachment being thus weakened, the antlers are shed; the scarred surface skins over and heals, and only the hair-covered pedicel of the antler is left.



FIG. 5.—Wapiti with velvet shredding off.

We have no reason to suppose that this corporate cellular behaviour, involving the nicely adjusted co-operation of so vast an army of organic units, is under the conscious guidance of the stag. And yet how orderly the procedure! how admirable the result! Nor is there an organ or structural part of the stag or any other animal that does not tell the same tale. This is but one paragraph of the volume in which is inscribed the varied and wonderful history of organic behaviour in its corporate aspect. Is it a matter for wonder that the cause of such phenomena has been regarded as “a mystery transcending naturalistic conception; as an alien influx into nature, baffling scientific interpretation”? And yet, though not surprising, this attitude of mind, in face of organic phenomena, is illogical, and is due partly to a misconception of the function of scientific interpretation, partly to influences arising from the course pursued by the historical development of scientific knowledge. The function of biological science is to formulate and to express in generalized terms the related antecedences and sequences which are observed to occur in animals and plants. This can already be done with some approach to precision. But the underlying cause of the observed phenomena does not fall within the purview of natural science; it involves metaphysical conceptions. It is no more (and no less) a “mystery” than all causation in its last resort—as the *raison d’être* of observed phenomena—is a mystery. Gravitation, chemical affinity, crystalline force,—these are all “mysteries.”

If the mystery of life, lying beneath and behind organic behaviour, be said to baffle scientific interpretation, this is

because it suggests ultimate problems with which science as such should not attempt to deal. The final causes of vital phenomena (as of other phenomena) lie deeper than the probe of science can reach. But why is this sense of mystery especially evoked in some minds by the contemplation of organic behaviour, by the study of life? Partly, no doubt, because the scientific interpretation of organic processes is but recent, and in many respects incomplete. People have grown so accustomed to the metaphysical assumptions employed by physicists and chemists when they speak of the play of crystalline forces and the selective affinities of atoms, they have been wont for so long to accept the "mysteries" of crystallization and of chemical union, that these assumptions have coalesced with the descriptions and explanations of science; and the joint products are now, through custom, cheerfully accepted as natural. Where the phenomena of organic behaviour are in question, this coalescence has not yet taken place; the metaphysical element is on the one hand proclaimed as inexplicable by natural science, and on the other hand denied even by those who talk glibly of physical forces as the final cause of the phenomena of the inorganic world.

So much reference to the problems which underlie the problems of science seems necessary. It is here assumed that the phenomena of organic behaviour are susceptible of scientific discussion and elucidation. But even assuming that an adequate explanation in terms of antecedence and sequence shall be thus attained by the science of the future, this will not then satisfy, any more than our inadequate explanations now satisfy, those who seek to know the

ultimate meaning and reason of it all: What makes organic matter behave as we see it behave? what drives the wheels of life, as it drives the planets in their courses? what impels the egg to go through its series of developmental changes? what guides the cells along the divergent course of their life-history? These are questions the ultimate answers to which lie beyond the sphere of science—questions which man (who is a metaphysical being) always does and always will ask, even if he rests content with the answer of agnosticism; but questions to which natural science never will be able, and should never so much as attempt, to give an answer.

Enough has now been said to show that organic behaviour is a thing *sui generis*, carrying its own peculiar marks of distinction: and further, that, for science, this is just part of the constitution of nature, neither more nor less mysterious than, let us say, crystallization or chemical combination. But associated and closely interwoven with all that is distinctively organic there is much which can to some extent be interpreted in terms of physics and chemistry.

The animal^[4] has sometimes been likened to a steam-engine, in which the food is the fuel which enters into combustion with the oxygen taken in through the lungs. It may be worth while to modify and modernize this analogy—always remembering, however, that such an analogy must not be pushed too far.

In the ordinary steam-engine the fuel is placed in the fire-box, to which the oxygen of the air gains access; the heat produced by the combustion converts the water in the boiler into steam, which is made to act upon the piston, and thus

set the machinery in motion. But there is another kind of engine, now extensively used, which works on a different principle. In the gas-engine the fuel is gaseous, and it can thus be introduced in a state of intimate mixture with the oxygen with which it is to unite in combustion. This is a great advantage. The two can unite rapidly and explosively. In gunpowder the same end is effected by mixing the carbon and sulphur with nitre, which contains the oxygen necessary for their explosive combustion. And this is carried still further in dynamite and gun-cotton, where the elements necessary for explosive combustion are not merely mechanically mixed, but are chemically combined in a highly unstable compound.

But in the gas-engine, not only are the fuel and the oxygen thus intimately mixed, but the controlled explosions are caused to act directly on the piston, and not through the intervention of water in a boiler. Whereas, therefore, in the steam-engine the combustion is to some extent external to the working of the machine, in the gas-engine it is to a large extent internal and direct.

Now, instead of likening the animal as a whole to a steam-engine, it is more satisfactory to liken each cell to an automatic gas-engine which manufactures its own explosive. During the period of repose which intervenes between periods of activity, its protoplasm is busy in construction, taking from the blood-discs oxygen, and from the blood-fluid carbonaceous and nitrogenous materials, and knitting these together into relatively unstable explosive compounds, which play the part of the mixed air and gas of the gas-engine. A resting muscle may be likened

to a complex and well-organized battery of gas-engines. On the stimulus supplied through a nerve-channel a series of co-ordinated explosions takes place: the gas-engines are set to work; the muscular fibres contract; the products of the silent explosions are taken up and hurried away by the blood-stream; and the protoplasm prepares a fresh supply of explosive material. Long before the invention of the gas-engine, long before gun-cotton or dynamite were dreamt of, long before some Chinese or other inventor first mixed the ingredients of gunpowder, organic nature had utilized the principle of controlled explosions in the protoplasmic cell, and thus rendered animal behaviour possible.

Certain cells are, however, more delicately explosive than others. Those, for example, on or near the external surface of the body—those, that is to say, which constitute the end-organs of the special senses—contain explosive material which may be fired by a touch, a sound, an odour, the contact with a sapid fluid or a ray of light. The effects of the explosions in these delicate cells, reinforced in certain neighbouring nerve-batteries, are transmitted down the nerves as waves of subtle chemical or electrolytic change, and thus reach that wonderful aggregation of organized and co-ordinated explosive cells, the brain. Here it is again reinforced and directed (who, at present, can say how?) along fresh nerve-channels to muscles, or glands, or other organized groups of explosives. And in the brain, somehow associated with the explosion of its cells, consciousness, the mind-element, emerges; of which we need only notice here that it belongs to a *wholly different order of being* from the