ON THE EXCITATION PROCESSES OF THE CONSCIOUS AND SUBCONSCIOUS MIND.

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Introduction.

Studies of the mind of man and of the heart of the frog, though normally deeply divided, can be bridged when two postulates are granted. The first postulate is that the quality of excitability, on which nerve-cell activity is based, can be studied in any other excitable tissue; the second is that mental activity, as we know it, depends on the presence of excitable nerve-cells in the brain. The postulates being granted, it becomes legitimate to apply the results of experiments on excitability performed with the frog's heart in explanation of the mode of working of the brain and mind.

In accord with the postulates the paper will be found divisible into two parts: in the first part evidence will be presented concerning the dual nature of excitability; in the second this dualism is applied to mental phenomena.

Excitability is generally defined as the capacity of a living tissue to respond to a change in its environment known as the stimulus, and, as every reader already knows, this capacity varies. At one time the response of a tissue to a particular stimulus may be great, at another insignificant. Many agents also, such as drugs, change excitability, the changes being customarily investigated through the muscle and nerve preparation.

The investigators who have used this preparation have realized that it is impossible for a drug solution to penetrate at once to all parts of a muscle in a bath, and so have allowed a reasonable time to elapse for this penetration before applying their tests to ascertain what the drug has done to excitability. They have thus necessarily directed their attention to end-results, and none to the steps, if any, by which those end-results are attained. Finally, those end-results have been expressed as simple variations in the size of the response which is either increased or decreased.

This experimental method has consequently given a definite conception of excitability. From it has arisen a belief that living tissues possess a source of potential termed "excitability" which is

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made dynamic in the response. According also as drugs augment or diminish this supply of energy, so they augment or diminish excitability.

A species of monism, then, is to be regarded as the current general belief concerning excitability. This monism next weaves its pattern into any speculation concerning the functional changes in any living organ, for excitability is the basis of activity.

Inquirers into human conduct, however, have always emerged as dualists, with their dualism so reasonable that the necessary physical basis has next been sought. This search, being conducted on a monistic basis, has led to the conception that there must exist in the brain "higher" and "lower" centres with various inter-relations.

The object of the present paper is to present to those interested in mental phenomena evidence that dualism is a property of every living cell, and to apply the results to the mind. The experiments have been carried out on the perfused hearts of frogs (1–20), and show that living cells possess two independent sources of the potential termed excitability (6, 7, 10), on each of which drugs, etc., may independently act even to opposite ends (6, 9, 13, 16, 17). We find also that an interaction between the two sources gives the excitation process and response (10). Excitation processes and responses thus possess composition as well as size (10).

It should be appreciated that if there be two independent sources of the potential excitability, each contributing its own part to the response, then the customary methods of measuring organic activity in effect measure an alloy in terms of size. Only by accident do they avoid passing base coin into circulation.

It is naturally distressing, even difficult, to any honest man to appreciate the possibility that for many years he has probably been passing base coin into circulation through applying an inadequate test. To have it pointed out that on a particular date a particularly bad coin was passed, I have found received with ill grace. Accordingly, so far as possible, I have cut out actual references to the work of others and made general allusions instead. Also, for simplicity, the paper is illustrated by diagrams rather than records. The diagrams, however, are based on published records, to which reference is given, so that anyone wishing to pursue the matter further may do so.

PART I.

The first diagram shows the manner in which is estimated the contractile capacity of any particular heart on which work is done (2, 3, 11). (See Fig. 1.)

There is a rectangle *AOBD*, and inside it a curved line *PQ*, which is deemed to represent the activity of a heart perfused with the usual Ringer's solution. The distance *OQ* expresses a time of six or eight hours, and a vertical drawn from any intermediate point between *O* and *Q* to meet *PQ* would give the extent of a spontaneous cardiac contraction at the time indicated by the point. Three such points are shown, *viz.*, Q_1, Q_2, Q_3, and three verticals, Q_1P_1, Q_2P_2, Q_3P_3, of heights A_1, A_2, and A_3 respectively. These verticals are continued as dotted lines, P_1D_1, P_2D_2, P_3D_3, to meet the line *AD*, the dotted portions being of lengths K_1, K_2 and K_3 respectively.

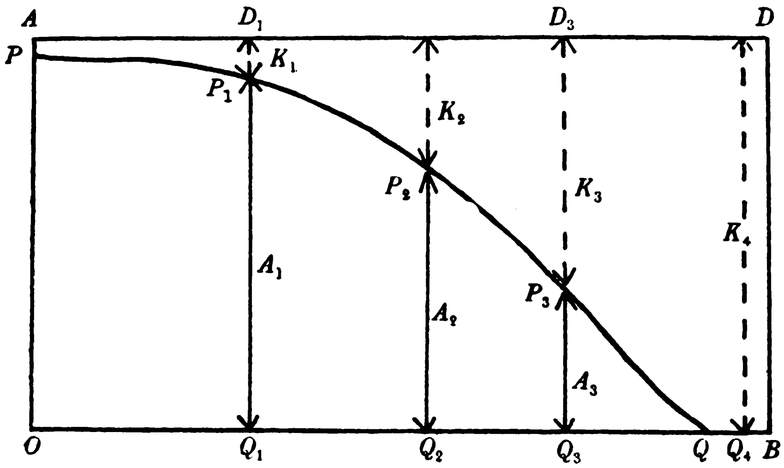

FIG. 1.

Now a 5% KCl solution will make hearts contract, provided contractile material is available, irrespective of their spontaneous activity (1, 4, 11). It is assumed that a 5% KCl solution is applied to the hearts at the points Q_1, Q_2, Q_3 and Q_4, and produces there contractions of heights K_1, K_2, K_3 and K_4.

We then find—

$$(A_1 + K_1) = (A_2 + K_2) = (A_3 + K_3) = K_4 = C.$$

So far as our diagram is concerned, of course, the relations above necessarily follow from the fact that we first drew a rectangle. But in practice we first find the relations which show we can draw the rectangle.

No heart, no matter what augmenting agency or drug has been used, has yet been found to beat higher than the height *OA*. Hence this height represents the maximum cardiac contractile effort.

Any vertical drawn on this diagram between the horizontals and cutting the curved line *PQ* thus records three values. Its whole length measures the maximum possible cardiac effort, the part below the curved line the amount of contractile material in action, and the amount above the curved line the cardiac contractile reserve.

The diagram also shows that the excitation process fails first in perfused hearts. It represents, indeed, a particular case of the general rule that muscles lose irritability before entering into rigor. Later on the heart would have rigored—a process it could not perform unless it were capable of contraction.

It may now be realized that the maximum contractile effort of a heart is a constant, the value of which is readily ascertained under experimental conditions by using a 5% KCl solution. This value I call *C* (3, 10, 11). It may be considered to correspond to the figure denoting the horse-power of a motor in that it indicates possibilities requiring other conditions, or accessories, for their realization (8, 10). The diagram also indicates that the experimenter may determine the value of *C* when he wishes, at the commencement of, during, or at the end of a day's work with a heart. The end is usually the more convenient.

C, as a maximum effort, is also a limiting value which the experimenter with hearts is always liable to meet. If he knows he has met it, he can reasonably account for the results; if, however, he does not know he has run into a stop-block, as it were, his explanation of the resulting phenomena is not likely to be accurate. But only two experimenters, Burridge and Seth (21), have known where the stop-block was, or even that it was there. We know, from their published tracings, that others have run into the stop-block; also, from their explanations, we know they had no inkling before or after that it was there.

In the value *C* we have, then, knowledge of a limiting factor at present outside the ken of other workers. And great attention has been devoted to it at this stage, because it enters into all the work below. When, for example, divers curved lines are placed inside a rectangle to represent cardiac activity, the rectangle is not to be regarded as a mere ornamental border, but as marking out *C*, the limit of the cardiac contractions.

We may now proceed to consider the actions of sodium chloride. They are illustrated in the next diagram (6, 7, 17). (See Fig. 2.)

There is the rectangle *AOBD*, and the curved line *PQ*. Any vertical drawn from the line *OB* to meet *AD* shows what the heart could do, and where the same vertical cuts *PQ* is shown what the heart did do. The heart is presumed to be perfused with a Ringer's solution, and the first level portion of the line *PQ* to indicate regular beating. The first arrow, marked H, indicates that a second perfusing solution differing from the first in added sodium, *i.e.*, a hypertonic Ringer, has been substituted for the first. Following that change in perfusing fluid, the beats fall rapidly away in height, as is indicated by the sudden dip in the line PQ. To this dip we assign the value y.

Next the beats of the heart gradually increase in height again, as is indicated by the rise in the curved line PQ, until at last a steady condition is reached with the beats higher than they were at the start. This slow increase of height is assigned a value z.

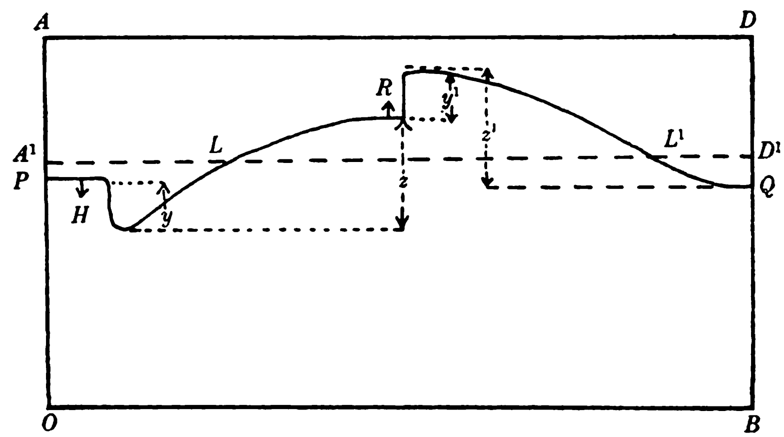

FIG. 2.

After this second steady state had been reached the original isotonic Ringer was perfused again, and following its perfusion the height of the contractions underwent a further increase in height, but this time the increase occurs rapidly. To this rapid increase is assigned a value, y^1.

Succeeding this second and rapid increase of height is a steady decline, which ceases when the height of contraction is the same as that with which we started. This decrease is assigned a value, z^1.

When such an experiment has been done, measurement shows (7, 17):

$$y = y^1 \text{ and } z = z^1.$$

Also it does not matter at what point isotonic Ringer replaces again the hypertonic one; any two differing changes produced by the first solution are reversed by two different, but equal and opposite to the first, changes after perfusion of the second solution. Since, then, the only factor determining the size of a rapidly produced augmentation after R is the size of a previous rapidly produced depression after H, and the only factor influencing the amount of a slowly-effected depression after H is the size of a previous slowly-effected augmentation after H, I deduce that the rapid and slow effects are mediated by independent mechanisms. I have suggested that the rapid changes are mediated by electrolytes, or salts, and the slow changes by alterations in the state of colloidal aggregation (6, 7, 17).

We next note that "slow" does not adequately describe the change due to colloidal aggregation, because it may be developed quite rapidly if the developer be of sufficient strength. Its rate of development is really variable, but, however developed, it subsides slowly in its own time, or shows hysteresis, after removal of its developer. Hence it is preferably termed "hysteresial" (6, 7, 17).

Having thus assigned to electrolytes and state of colloidal aggregation these two independent actions of sodium chloride on excitability, a corollary to the assignment is that in electrolytes and in their state of colloidal aggregation living tissues possess two independent sources of that potential termed "excitability." Next, if there be two such independent sources instead of the one generally assumed, it follows that those investigators, who assumed that there was one only, could only by chance have correctly ascertained the actions of a drug or other agency on excitability. This applies in particular to those who have used muscle-baths and waited for equilibrium, for in such waiting they lost sight of the steps.

Investigators who have used the heart have missed these facts from quite different causes. They have lost their objective through over-caution.

Nothing would seem more reasonable in an experiment than to select first the best balanced Ringer solution you can find, and next to perform your experiments on the heart while it is perfectly fresh. Unfortunately the combined effect of such great care is a heart beating very near its maximum.

The dotted line A^1D^1 in the figure is intended to indicate how near to the maximum such hearts beat, and will be noted to cut the curved line PQ at the points L, L^1. Thus, the man who has taken these precautions automatically loses all parts of the line PQ above the points L, L^1. Moreover, between the points L and L^1 the heart at each beat butts, as it were, into the stop-block which is not known to be there. And that having been done, one cannot reasonably expect under such circumstances a correct explanation of what was happening. Such an expectation is, of course, realized.

These two actions of sodium chloride just described are not actions solely of added sodium chloride, but of any strength of sodium chloride to which a tissue is exposed, so that, when the isotonic solution is made hypotonic, two actions follow, and also when the hypotonic solution is made isotonic (6).

Calcium chloride also exerts two independent actions on excitability the opposite of those exerted by sodium chloride (17, 18).

Now at one time there was much controversy among physiologists concerning the stimulus to the heart-beat. Some said it must be calcium, others that it could only be sodium. The basis of the controversy was an assumption that a particular electrolyte must either depress or stimulate. None had an inkling that a particular substance could at one and the same time be both stimulator and depressor, through acting on two independent mechanisms of the tissue. When that has been realized the controversy assumes a different aspect.

Much heat is still generated over alcohol—a substance which also exerts two independent and opposite actions on the tissue's excitability mechanism (13, 16). This again is a controversy among those who consider the drug must *either* raise *or* depress excitability. The pharmacology of alcohol, like that of sodium chloride, acquires a different aspect when it is realized that it can *both* depress and exalt at the same time. Current statements, for example, that large doses of alcohol are depressor are hopeless half-truths. These large doses are strongly stimulant as well as strongly depressor, though to demonstrate such stimulation is admittedly more difficult than to demonstrate depression. By choosing the experimental conditions so as to make use of the stimulant action of such a large dose of alcohol as 40%, I was enabled to keep a perfused heart beating for three days—a record length of time (13).

The reader by now has, perhaps, realized that in matters of excitability Nature is usually an equivocator, saying *both* Yes and No, but with different voices. Those who have hitherto questioned her have expected *either* Yes *or* No as the answer, and so have only listened to the voice which spoke the louder in answer to their question.

Another aspect of these changes is shown in the two fundamental types of cardiac activity of our next diagram (10). (See Fig. 3.)

This time we start out with a heart which is perfused with such a Ringer's solution as is inadequate to elicit a recordable beat. At the point P the Ca content of this solution is increased and immediately thereafter recordable beats appear. Next, at the arrow N, the added Ca is taken again and the beats rapidly sink back to the threshold level.

At P^1 a weak solution of adrenaline is presumed to be swilled momentarily through the heart, which then begins to beat with

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quickly increasing vigour, and thereafter slowly to fail again. It should be noted that by the swill through only a few seconds' exposure of the heart to the drug is attained. If the drug were made a constituent of the perfusing solution the augmentation produced could be maintained apparently indefinitely (14). Also, if activity be maintained for some time through the drug the beats after drug removal will fail slowly, *i.e.*, with hysteresis, as in the manner shown immediately above, and under sodium chloride (14). Results similar to these of adrenaline may be obtained from testicular, thyroid, or ovarian extract (19).

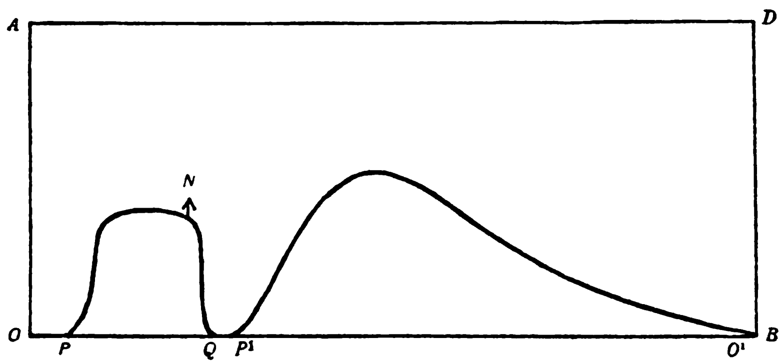

FIG. 3.

Ductless gland extracts produce their effects through alterations in colloidal aggregation (14, 19); it will be appreciated that the effects shown above indicate that above the threshold two different grades of activity may appear, the one coming and going with the utmost speed, *e.g.*, the speed of thought, and the other coming into being at a speed varying with the strength of its producer, and, once produced, fading away in its own time. The isolation shown above, however, is not absolute, for the foundation of the ionic effect was a state of aggregation and the foundations of the aggregation effect were ions (10).

We next observe that these effects can be combined in such a manner that, starting from zero, it is possible to build up a series of beats filling up the whole cardiac field, and to distinguish in those beats a part due to added Ca, a part due to adrenaline, a part due to thyroid, another due to testicular extract, and so on (10). Indeed, for many organs of the body it may well be that ions form the foundations of their activities and ductless glands give the superstructure.

These last points lead us to a consideration of some aspects of salt balance. Once Ringer had discovered that a mixture of inorganic salts was necessary for cardiac activity, attention was next naturally directed to ascertaining what formula gave the best physiological balance between the different salts. Then, the length of time a heart remained active on a mixture being taken as a measure of the salt balance, it was reasonable to believe that the perfect balance existed in blood, because blood kept hearts longest active. But formulæ derived from blood-ash composition being found defective because they give no true guide to ionic concentrations during life, the search for the perfectly balanced Ringer having the same ionic composition still goes on.

Some time ago I tackled this problem from quite a different aspect, *viz.*, to find out which type of solution enabled a perfused heart to show inhibition as readily as did a blood-containing one. The results indicated that blood, regarded as a mixture of inorganic salts, was a hopelessly unbalanced solution (13). Framing solutions along the lines indicated I next found that such unbalanced solutions acquired entirely new recuperative qualities. Recuperation, it should be understood, is entirely foreign to Ringer solutions, for hearts perfused with them just run down, the best Ringer being the one which lets the heart down slowest. Yet, by disregarding balance, it was possible to frame a solution with such definite recuperative properties that, as a matter of course, I could use this solution to put a heart to sleep, as it were, just before going off to lunch, and, on returning later, to wake it up and find it also to be recuperated (18). And adrenaline added in quite small amounts to such a solution renders it capable of maintaining cardiac activity better than any modified Ringer solution that one can devise (14).

It appears probable, then, that the idea of inorganic balance which physiologists have obtained through experimenting with Ringer's solution should be limited to that solution and not applied to blood, because the latter has at its disposal divers ductless gland secretions, any one of which can shift "balance" to an entirely different sphere.

The conception of blood one obtains from such experiments is that, regarded as a mixture of inorganic salts, it is an unbalanced solution incapable of adequately working the machine. Addison's disease measures this inadequacy (14). These salts are, as it were, a slow fire keeping the machine ready to blaze into full activity on admission of the proper draught, or hormone.

Having thus realized that the much-sought-after and respected balance of a Ringer's solution is an entirely artificial conception, one can approach the problem of devising perfusing solutions from quite a different aspect. Accordingly we may next consider the two different methods of perfusion set out in the next diagram (8, 9, 10). (See Fig. 4.)

We have again a rectangle *AOBD*, inside which is a curved line *PQ* and a straight line P^1Q^1. The curved line *PQ*, as in Fig. 1, is intended to represent the activity of a heart perfused with a well-balanced Ringer. The cardiac machine is thereby run for a short time approximately " all out," and then the machine slowly runs down.

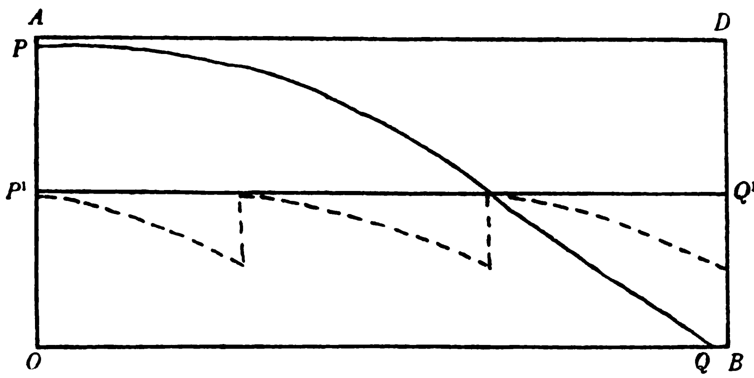

FIG. 4.

The line P^1Q^1 represents a heart beating steadily at approximately half its possible full height. Such steady beating is an ideal only obtainable through using some ductless gland extract (14). We can approximate to it, however, by using a gamut of perfusing solutions which differ only in their Ca content (8, 18). We start out with a Ringer solution of very low Ca content, and subsequently, as the beats fall away with perfusion, their height is restored again by adding Ca to the solution—in practice this addition is made by perfusing another solution of higher Ca content than its predecessor (8, 18). The dotted line beginning at P^1 and ending near Q^1 is intended to represent such fallings away and restorations. The amount of deviation permitted from the line P^1Q^1 is entirely at the discretion of the experimenter.

Now, when the perfusion is begun, the heart possesses a quality which for the present may be called freshness, and, as perfusion proceeds, this " freshness " of course diminishes. With its diminution the beats fall away, such falling away being subsequently compensated by extra Ca.

As the experiments are done, then, two factors are found responsible for the beat—freshness and calcium. The more there is of the former, the less is required of the latter. Hence, calling the former "Y" and the latter "X" and noting that the line P^1Q^1 is at the level $C/2$, we can put our results in the former at a simple indeterminate equation—

$$X + Y = C/2.$$

We next place limiting values to X and Y. The heart will not beat without Ca; also it will not beat if it has lost all freshness and is dead. Hence, in the equation neither X nor Y can be zero.

We may now further define "X" and "Y." The expression of "X" as calcium is merely a convenient method of expressing the effects of Ringer's solution; it really expresses ions (18). "Y" has been shown elsewhere to be a state of colloidal aggregation plus the quantity and quality of their adsorbed potassium salts (18). We have also found above that it represents a ductless gland complex.

The equation also indicates that some form of combination between ions and colloids, the two independent sources of excitability shown above to be possessed by tissues, is responsible for the excitation and response. And, more than this, that behind a response of a particular size there can lie an infinite series of excitation processes, differing only in the proportion of their two constituents.

For the benefit of the non-mathematical we may here digress to point out that the equation above is equivalent to one giving the number of men and women making, say, a thousand. There are 999 possible combinations of the series making that number. So far as number is concerned, also, each combination is equal, but none could expect that the combination of 1 man and 999 women would behave similarly to the combination of 999 men and 1 woman. Quite in accord with this expectation we find by experiment that the behaviour of hearts is altered by the composition of their responses. For as one proceeds along the line P^1Q^1 and tests the reaction of the heart to drugs, one finds it becoming less and less responsive (18, 19, 20, 21). In other words, a tissue framing responses primarily through ions is less responsive to environmental change than a tissue framing its responses primarily through colloidal aggregation change.

This difference of behaviour becomes emphasized when one compares the results obtained according as one works along the first part of PQ or of P^1Q^1 respectively. The comparison may be made through the drugs strychnine (20) and sparteine (21).

These two drugs were long held in repute as cardiac stimulants by clinicians. The laboratory tests, however, made along the first part of *PQ* were believed by those who made them to show definitely that these drugs were cardiac depressants. Accordingly, none suspecting that laboratory tests could mislead, the clinicians were next invited to consider the possible existence of such sources of error in their practice as would lead them to mistake a sedative for a stimulant.

But, on referring to these tests, one found not only that they were made with such huge concentrations of drug as were hopelessly outside clinical realities, but also that even then, if the experimenters had been prepared to consider the possibility that a drug might be at one and the same time both augmentor and depressor, there would have been less enthusiasm about condemning the drugs as being cardiac depressants (20, 21). Monistic interpretation of results, indeed, led investigators to disregard the evidence from the hearts placed before them that these drugs were stimulants (21).

When, however, one worked along the first part of P^1Q^1, it could be observed without equivocation that these drugs both markedly increased cardiac output and improved the beat when used in such concentrations as were within the limits of clinical possibilities, so that they could do under experimental conditions what the clinicians stated they did at the bedside (20, 21).

On comparing results the cause of disagreement was found to lie primarily in the different capacities of hearts working along the first part of *PQ* and P^1Q^1 respectively to react to environmental change. Along the first part of P^1Q^1 the heart is at least one million times more sensitive to these drugs than it is along the first part of *PQ* (20, 21).

These differences in sensitiveness to the drugs would not have mattered if all their concentrations produced similar results, but unfortunately they do not. These drugs chiefly depress at strength and chiefly stimulate at dilution. Along the first part of *PQ* the heart is possibly unable to react to such dilutions of drug as would show chiefly stimulation. Hence experimenters working there have been compelled to use huge drug concentrations to get any result at all, and the results they did get led them to consider the drugs as depressants.

The only difference in the perfusing solutions required to avoid these marked variations in the capacity of the heart to react to drugs is a difference in their Ca content. We have next to observe however that, the heart-beats along the first part of *PQ* being greater than those along the first part of P^1Q^1, the former beats would be considered as those of the more excitable heart. On the other hand, when one considers the capacity to respond to a change in the environment the position is reversed; along the first part of

P^1Q^1 the heart is much more susceptible to environmental change, and so also much more excitable than it is along PQ.

But susceptibility to environmental change is also excitability, so that we have got to the position that the heart with the greater store of excitability, as demonstrated by the size of its beats, is very inexcitable, whereas the heart with a small store of excitability, as demonstrated by its small beats, is highly excitable. Fortunately, however, we know how we got the position, *viz.*, by mixing up the size of the response with susceptibility to change. Our mixing also has been deliberate to indicate how two different investigators of excitability, the one taking size of response as his index and the other taking susceptibility to change, could obtain conflicting results.

We can now appreciate the fact that the excitation process is the formation of an alloy from two ingredients, each ingredient contributing a common factor in size, but of different qualities. This common contribution of size reappears in the response, where it is easily measured. The recording of such changes of size, without reference to a possible dual origin, is in progress wherever experiments are being done. Only by accident can this application of the standard of size to an alloy prevent the passage of base coin into circulation.

PART II.

The gist of these observations on excitability is that a living tissue possesses in its electrolytes and in its state of colloidal aggregation two independent sources of the potential termed excitability. Their interaction gives the excitation process, which in turn evokes the response. Also, any reponse of a particular size can have behind it any one of an infinite series of excitation processes, differing only in the proportions of their two components. This proportion determines behaviour.

Preliminary to applying these results to mental processes, it is to be pointed out that my experimental work on muscle indicates that the excitation processes and the response take place in different structures. For definiteness excitation processes may be taken as sarcoplasmic occurrences, and the responses as the activity of contractile material evoked by the former (1, 2, 3, 4, 7, 8, 18).

A psychic response I take to be a thought, and accordingly, so far as my muscle work goes, this thought represents the activity, or response, of something other than the material in which the excitation processes preceding it take place. I am not going to attempt to define the responding structure, for that is something for which each individual will have a particular taste. All I can do is to point out the necessity of distinguishing the responding organ from that structure which frames excitation processes.

Denoting now the activity of the responding organ as T, we find that activity to result from the interacting of two independent sources of potential possessed by something else. Denoting, next, these two sources of potential as H and L respectively, we express the relations between all three, as in the equation above for the heart, by the simple indeterminate equation,

$$H + L = T.$$

This equation, indicating that thoughts have composition and size, puts us on the track of the moralist's conception of the higher and lower self. But, having found from our experiments above that neither H nor L can be zero, we appreciate that higher and lower selves can no more have separate existences as selves than bronze can exist in either copper or tin. The self is an alloy built up from two components, having no existence as such in either, yet coming into being when the components unite. Myers appreciated such a composite self.

Higher and lower selves thus having no separate existence as such, we have no need to postulate the existence of anatomically separate higher and lower centres mediating them. We appreciate now that they are potentials, and so look to their mediation through the two sources, electrolytes and colloids.

We do not know, however, which mediates the one and which mediates the other. But we can find out through experiments with alcohol.

My experiments with this drug show that it alters the composition of excitation processes in that it diminishes the part played by electrolytes and increases the part played by colloids (10, 13, 16). A response brought under the influence of alcohol may be unchanged, diminished, or increased in size, but, irrespective of such changes in size of responses, the excitation processes evoking them are changed in composition; the part played in them by ions is decreased, and the part played by colloids is increased. Accordingly, admitting alcohol to be inimical to "higher" things and favourable to the "lower," ions must mediate the "higher" and colloids the "lower."

We next draw attention to a parallelism between the production of cardiac excitability change through colloidal aggregation, and the evocation of an emotional response. Just as a cardiac change of colloidal aggregation can be gradually worked up, or produced quickly, according to the strength of the producer (6, 7, 8, 9, 10, 17, 19), so also can one gradually rouse a man's ire, or cause him to fill with wrath explosively. Both changes also, on removal of their producers, subside in their own time, or are carried on indefinitely so long as their original causes still act.

Emotional outbursts, then, are what they are because they must be what they are, since their physical basis is a change of colloidal aggregation. Also, alcohol effects its exaltation of emotional life by increasing the part played by colloids in excitation processes.

Colloidal aggregation thus supplies to thoughts an affective tone. Noting next that the time of subsidence of such change depends on its intensity and not on its rate of development, one can appreciate that the holding power of a thought depends on the degree of colloidal aggregation behind it. Hence, when thought flits light in fancy there cannot be behind each change much of the colloidal element. The chief component must be the ionic complex.

Reverting again to our equation, $H + L = T$, we are now learning that it indicates that a thought of intensity T can be mediated by a wide range of excitation processes differing only in the proportions of two constitutents. We have just learnt that the factor L is a state of colloidal aggregation mediating the thought's affective tone. Correlating this with the fact that a high affective tone cannot go hand in hand with good judging, we note that ions mediate this last. High affective tone and good judging cannot go together because they are mediated by these two constituents of excitation processes, and these processes must be so adjusted that the more you have of the one the less you can have of the other.

Proceeding next from the complex of nerve-cells mediating the activity termed thought, and considering only the individual nerve-cell and its fibres, we appreciate that along a nerve-fibre there can pass an infinite series of nerve impulses of a given strength. Physiologists, by instrumental methods, can only record the strength of these impulses, but the sensorium can also record their quality. These changes of quality, according to our equation, should range from the broadest protopathic to the finest epicritic sensation.

A normally working machine must be presumed to possess some normal balance, whatever that may be, between these two constituents of excitation processes. Each individual probably has his own balance determining his temperament, or whether he shall be hot or cold-blooded. Accordingly, next, we might consider two possible extremes of balance.

An abnormally high state of colloidal aggregation could be maintained either through overwork of the individual's ductless glands (14, 19), or through the circulation of some toxin also capable of enhancing the state of colloidal aggregation. Next, so long as that high state of colloidal aggregation is present, the individual will show a high emotional tone and correspondingly low judging capacity. Also, unless it be assumed that the mischief-maker acts only on nerve-cell colloids, all organs of the body will show high emotional tone. But outside the brain this high emotional tone will not be recognized as such ; a sick mind in a sick body may be recognized, but not that there is similar sickness of mind and body. Such an individual's sick nerves, for example, would convey impulses of abnormally high affective tone; desires normally held in check could acquire too great affective tone to be resisted through the corresponding lack of judging capacity, and so on.

The opposite type to high emotional tone would be based on an excessive ionic element and a deficient colloidal element. His ordinary thoughts would have too little affective tone to give them lingering power, and so they would not linger. So little would they linger that a normal mind would not be able to keep pace with the rate at which they changed from subject to subject. The normal would then call the abnormal rate a "flight of ideas."

Two similar and opposite types are also to be seen in youth and old age. Youth, having at its disposal active ductless glands, can frame excitation processes of high colloidal quality and high affective tone. Old age, on the other hand, with diminishing ductless gland activity, compensates the loss by added calcium, which, additional to intensity, adds resistance to environmental change (6, 12, 13, 14, 15, 17–21). Accordingly youth and old age, having framed excitation processes of equal strength, must yet behave differently because the processes are differently constituted. Youth marvels at the obstinacy of old age; and old age, having lost affective tone with aggregation, can but marvel at the amount of feeling youth displays over matters which, with extra calcium, a riper judgment perceives to be of no concern. A later stage, mental senility, is thus indicated to be a wandering series of over-ripe judgings of too little to judge, for no judgment has then enough of the basis giving staying power.

Youth, on the other hand, depending on its ductless glands for building excitation processes, can but find curtailed the size and affective tone of its thoughts if, for example, the gonads then fail to add their bit.

The obstinacy of old age we thus find to be automatically derived from a process of calcification, for excitation processes framed with a strong calcium component give a machine with difficulty deflected from a set course (8, 17–21). This leads to a consideration of inhibition.

Inhibition, it is to be pointed out, is a specific process not understandable on a monistic basis because in it excitability goes both up and down (7). Accordingly, the man who believes that excitability must go *either* up *or* down is simply lost when he meets excitability going up and down at one and the same time—so lost, indeed, that of recent years there appeared an excellent study of the refractory mistaken for the inhibited state. Monists cannot account for the rebound, but the dualist finds it self-explanatory.

Material for more correctly appreciating the process of inhibition has been given elsewhere (7). Briefly it may be taken to show that when A inhibits B, A sends to B a positive charge, which in B's excitation equation would wipe out X and augment Y. The positive charge simply protects the colloids against calcium combining with them (5, 9). Ions and colloids cannot then interact, and so there is no excitation; when the positive charge is removed they interact once more and with added intensity until the state of aggregation becomes normal again.

In inhibition, then, A attacks B and temporarily puts B out of action. Next, after A leaves B, B, in the rebound based on altered colloidal aggregation, temporarily works better than before (6, 7, 9). But this true inhibition is of a quite different order from the ability of B to deflect A from a set path of activity. For, as we saw from our experiments with drugs, the ability of B to deflect A from a set path depends on the composition and strength of A's excitation processes, as well as on the strength of B. Excess of ions in A's excitation processes thus favours the continuation of A's activity without interruption from B.

A, then, has two possible methods of dealing with B. He may, as it were, raid B's territory and temporarily disarm him, or put up an ionic barrage which B, now the aggressor, is unable to penetrate. The first method is inhibition proper; the second method has not hitherto been recognized, and so must be provided with a name. The name I propose is Exclusion.

Inhibition and exclusion are everywhere mixed up in matters psychological, for the material has not been available to distinguish them, and, as with excitability, concentration has been on the end-result, and not on the means whereby the end has been attained. For example, A, being a normal person attempting to push B out of a room, would have the attainment of the end-result modified by considerations of damage to furniture, damage to B, etc. These considerations are termed inhibitions. If, however, A were sufficiently abnormal to have entire singleness of purpose, then B would be pushed out of the room regardless of furniture or B's person. In this case A is said to have no inhibitions, because nothing is allowed to modify the end-result.

On the other hand, when the psycho-analyst finds that A can keep out of consciousness certain ideas, we have inhibition applied to this excluding process.

We have, then, ideas let into consciousness called inhibitions, and the process of keeping ideas out of consciousness called inhibition, and the man who can keep all other ideas out from the one in hand is declared to possess no inhibitions whatever.

It would be more correct to call ideas let into consciousness, modifiers, and ideas kept out, exclusions. The maniac is not a man of no inhibitions, but one of complete exclusions.

Pavlov applied "inhibition" to a quite different phenomenon altogether, namely, the alterations in excitability produced by bromides (15).

True inhibition between different parts of the cerebral cortex, it is to be suggested, may not exist. For an inhibited part could not be brought to mind, since in it ions are prevented from interacting with colloids, and consciousness depends on their interaction.

The brain being now conceived as a complex of active areas, each competing for possession of the field of consciousness, it is to be appreciated that the idea holding the field holds it either because of its very intensity, or its ionic content, or from both causes. An emotional outburst, for example, holds the field through its intensity, whereas ordinary processes hold it through their ionic content. Evidently also the act of concentration, or attention, must somehow or other raise the ionic content of the processes mediating the idea on which one concentrates.

On the basis just given, the supposed "inhibition" of lower centres by "higher" ones would be an exclusion of certain ideas from the conscious field by the high ionic content of the excitation processes holding it. We test the hypothesis through alcohol.

Alcohol, by reducing the ionic element of the excitation processes (13, 16), enables the machine to be more easily deflected from a set course (10). The drug does not abolish inhibitions, but decreases the capacity to maintain a course set through ions. On the other hand, a course set through intensity of colloidal aggregation, or affective tone, need not be deflected, but, on the contrary, even maintained more steadfastly.

What we term higher conduct is thus based on excitation processes of high ionic content. For the ordinary man alcohol decreases his capacity to keep to the narrow path by altering ionic efficiency. Ideas previously excluded from the field of consciousness can now come in and also appear with added affective tone. Next, helped by environmental stimuli, they could well hold the field by intensity.

Incidentally it is of interest, perhaps, to correlate the action of alcohol on excitation processes with previous remarks on old age and youth. Ageing, we noted, is a gradual process of calcification of excitation processes, and alcohol, we now appreciate, would make them younger. It may not be edifying to see the college " head " behaving like an undergraduate, but it is of interest to appreciate that such may not represent a loss of acquired characters so much as the temporary possession of excitation processes of undergraduate age.

Leaving the brain temporarily, we revert to the heart to point out that in this latter organ an excitation process can be conducted from one part to another without exciting a contractile response, a greater level of ionic efficiency being required to excite a response than to conduct the excitation process from one part to another (4). Accordingly, returning to the brain, we deduce that in this organ a higher level of ionic efficiency is required in its excitation process to evoke the conscious activity of the responding organ than is required to conduct a nerve impulse from one point to another.

Alcohol, thus, may not necessarily be abolishing excitation processes when it produces unconsciousness, but rather may be altering their ionic efficiency. If such be the case, then, since chloroform and ether produce the same alterations of excitation composition as alcohol, the anæsthetized brain during an operation could throughout be capable of receiving impressions. Crile's work on anoci-association shows, I think, that the anæsthetized brain does receive impulses from the operated area. The work above indicates their mode of receipt, also that they would be of too low ionic efficiency to rise to consciousness.

We deduce, then, that in the brain a certain level of ionic efficiency in excitation processes is necessary to enable them to evoke the conscious activity of the responding organ. How that level is reached is a matter for investigation. A likely mechanism seems an increased blood-supply to the conscious area, such increased supply being due to alterations in the calibre, not of the larger vessels, but only of the smaller vessels supplying the conscious area to which the larger vessels act as reservoirs. Consciousness would not, thus, be necessarily accompanied by changes in the total blood-supply to the brain. Yet an adequate total supply would be essential to efficient local variations.

We postulate ions, then, as the constituents of excitation processes, making the responding organ conscious that an excitation has taken place. The responding organ, however, must be made not only conscious, but also conscious of something. This something must obviously be the state of colloidal aggregation. Accordingly all psychic processes should be divided into three parts—the judgment, the judge and the thing judged, or the perception, the perceiver and the perceived. The judgment is the activity of the responding organ which judges through ions the process judged—a state of colloidal aggregation. Also, there are conscious and unconscious judgings depending on the ionic efficiencies of their excitation processes.

The capacity for judging must increase with age, for ageing is calcification, but there must come a time when judging capacity, as ions, has so developed as to leave little to be judged as colloidal aggregation. The second childhood judgments then formed have possibly the same value as those made at the other extreme of life, where there is relatively much for judging, but too little to judge it.

Another possibility of age is that the heightened ionic efficiency of excitation processes can bring into consciousness excitation processes previously outside consciousness. As compared with the more efficient processes, these new arrivals could only be expected to be a dim sort of consciousness, their efficiency being high enough to excite a conscious response, but not high enough in ions to enable the responding organ to judge correctly their significance. Some such process, it is to be suggested, may form the physical basis of hypochondria.

We would next deal with the central nervous system as a storehouse of memories. These we first divide into the conscious and the subconscious, the latter being transformed into the former by added ionic efficiency. Next we divide a conscious memory into three parts. There is the responding organ, which, through ions, the remembrancer, is enabled to appreciate, or remember, a state of colloidal aggregation.

By this method memory traces emerge as altered states of colloidal aggregation. The existence of the faculty of memory next indicates that every impulse which has activated a nerve-cell must leave behind a persisting altered state of aggregation, the degree of alteration depending on the number of activations and their intensity. Macdonald's study of the physical properties of the nerve-cell indicates that such a persistence is inherent in the physical nature of the cell (22).

Nerve-cell activity is thus either the reception of an altered level of colloidal aggregation from some stimulus, or else a reproduction of the activity attending such a reception. The conclusion being accepted, one next may consider whether all cells of the cerebral cortex are always active, or whether only those coming into consciousness are active. The former seems the more likely, for through such continual activity, probably rhythmical, the subconscious part of the machine would be for ever providing the continuous flow of impulses which seem always to be attempting to break in on the conscious field. One must assume that something must happen as each subconscious impulse breaks itself against the ionic barrier of the conscious field, and the probable happening is a disintegration of the ionic barrier. Such gradual disintegration would be termed fatigue of attention.

Incidentally these conceptions of the conscious and unconscious indicate that sleep must be a condition in which excitation processes are inadequate to excite conscious activity of the responding organ, the inadequacy being either in size or in quality. An adequate blood-supply we have already indicated as a necessary factor to build up an adequate ionic complex; an adequate stream of impulses from the environment, or subconscious mind, or both, probably assists.

The dream, it is suggested, has its origin in some local vasomotor disturbance, probably in turn derived from some stimulation arising from environmental change. It represents something below the normal level of consciousness, and as such also possesses a subnormal ionic complex, which in turn determines a subnormal degree of exclusive power. The ionic part of excitation processes being Freud's "censor," we thus get an explanation of the censor's less efficient working in a dream; also why free association, or day-dreaming, should decrease the censor's activities.

Abnormally large ionic complexes, as in old age and mania, would, on the above principles, be a barrier to sleep. The old gentleman's "night-cap," by making his excitation processes younger, would help him in this process.

Also, where ionic complexes are very large, one can conceive the possibility that many different areas, at one and the same time, could frame excitation processes capable of activating the responding organ, which, being only adapted to respond to one, gets accordingly confused.

Reverting to memory again, we noted above that nerve-cell activity was either the reception or the reproduction of a memory; also that the essential difference between an unconscious and conscious act was in the different quality of the excitation processes. Now training involves repeated nerve-cell activity, and the improvement that follows training must imply a better nerve-cell memory, which in turn implies a higher level of colloidal aggregation. Since also in training a conscious act is gradually transformed into an unconscions one, there must be a gradual diminution in the ionic content of the excitation processes mediating the act.

We find, then, that training does not consist in "higher" centres teaching "lower" centres what they should do, but rather is dependent on an alteration in the balance of the excitation processes mediating the act. The grouping of cells mediating the unconscious-trained act is the same as that which mediated the conscious-trained act—a conclusion also reached by Pavlov on different grounds. The conscious act is in fact automatically transformed into an unconscious act by training, yet at any subsequent time the unconscious can be brought back to consciousness by adding ions.

Reverting to the heart again, we find there that the alteration in the composition of excitation processes which we now find to transform a conscious into an unconscious act produces also a cell more readily responsive to environmental change (15–21).

If we now imagine a nerve-fibre making connections with a large number of nerve-cells, and an impulse travelling along that nerve, then, other things being equal, it is obvious that the nerve-cells most readily set into activity by that impulse will be those with the least ionic balance. Also, since a nerve-cell once excited keeps a memory of the stimulus in a higher level of colloidal aggregation and a lower ionic level, cells once made active will be even more readily activated on repetition of the stimulus.

All repeated acts, by developing this alteration in the balance of the excitation components, are automatically transformed from a more conscious to a less conscious type. Also automatically, the chain of nerve-cells mediating the act become more readily excited.

The mechanism just described, however, is a mechanism of *bahnung*, hitherto regarded as a specific property of synapses. It leaves the synapses, then, nothing more to do than to function as passive conductors. And earlier in the paper, in dealing with anæsthesia, sleep and exclusions, which are functions hitherto regarded as dependent on synaptic interference, no necessity was found for assuming the presence of variable synaptic resistances. It would appear, then, that when one realizes that excitation processes have composition as well as size, and that their composition determines behaviour, the synapse will probably have left to it only the function of passive conduction.

The hypotheses of interfering synapses, and of higher and lower centres, were necessary as long as it was believed that nerve-cells possessed only one source of the energy called excitability, which, because it was single, could be measured correctly in terms of the size of the response. The introspective philosopher, however, has for centuries appreciated the existence of two different sources of the energy giving rise to his thoughts, but his results could not be directly filled into a scheme where responses were all or none, and possessed only size. Conceptions of higher and lower centres and the synapses have served to rationalize the hitherto conflicting testimony from muscle and nerve and mind. In the future it seems possible that introspection may be able to teach us much concerning excitability.

SUMMARY.

The maximum contractile effort of a heart is a constant quantity easily capable of measurement. That knowledge being obtained, the experimenter must not only know how a heart under experiment is actually working, but be able to choose the experimental conditions to make the heart work as he thinks fit.

Work performed under such selected conditions, based on knowledge of a heart's capacity, reveals that living tissues have at their disposal, in their electrolytes and in their state of colloidal aggregation, two independent sources of the potential termed excitability.

It is next shown that a response of a given size can be built up by any one of an infinite series of excitation processes which differ only in the proportions of two constituents derived from the independent sources of excitability. The interaction of the two supplies of potential gives the excitation process, which in turn evokes a response. The response and excitation process also take place in different structures.

Excitation processes and responses are thus shown to possess composition as well as size. This composition, in turn, is found to determine the tissue's capacity to react to its environment. These principles derived from the heart are next applied to mental phenomena.

They indicate that every nerve-cell must have at its disposal two independent sources of energy for framing its excitation processes.

Experiments with alcohol next indicate that electrolytes mediate "higher" things and states of colloidal aggregation the "lower."

Excitation processes, however, take place in a different structure from that which responds and do not necessarily evoke the responding organ's activity. Hence in any group of nerve-cells two levels of activity are presumed: the one serves to conduct or frame an ordinary excitation process; the other frames excitation processes which have greater ionic efficiency, to excite conscious activity of the responding organ. Excitation processes of the first level belong to the subconscious, those of the second level to the conscious.

Conscious processes thus require three factors, *viz.*, a responding organ, and an exciting organ possessing two independent sources of the potential termed excitability. The two potentials interact

in the excitation process, which, according to its ionic efficiency, does or does not evoke conscious activity of the responding organ.

Application to mental phenomena is then made of the principle that excitation processes and responses have composition as well as size, and that this composition determines behaviour. This application provides new theories of sleep, anæsthesia, etc., and leaves to synapses the property of passive conduction.

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