

"On Electromotive Wave accompanying Mechanical Disturbance in Metals in Contact with Electrolyte."\* By JAGADIS CHUNDER BOSE, M.A., D.Sc., Prof. Presidency College, Calcutta. Communicated by Professor REINOLD, F.R.S. Received March 14,—Read May 15,—Revised May 21, 1902.

Take a rod of metal, and connect the two points A and B with a galvanometer by means of non-polarisable electrodes. (Fig 1, *a*.) If the point O is struck, a wave of molecular disturbance will reach A and B. It will be shown that this is attended by a wave of electric disturbance. The mechanical and the attendant electrical disturbance will reach a maximum and then gradually subside. The resultant effect on the galvanometer will be due to  $E_A - E_B$  where  $E_A$  and  $E_B$  are the electric variations produced at A and B. The electric changes at

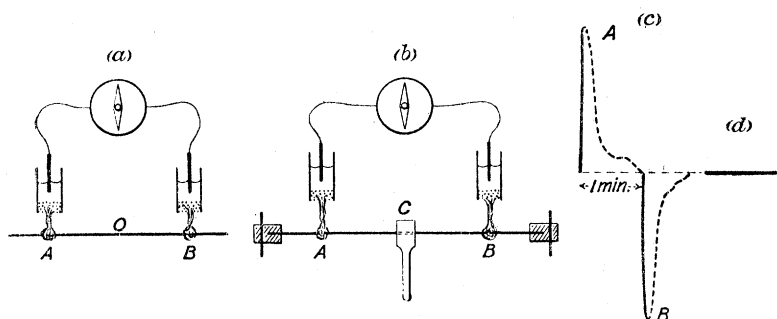


FIG. 1.—In (*a*) mechanical disturbance applied at O produces similar electrical disturbances at A and B; there is no resultant effect. In (*b*) owing to a clamp, disturbance applied at A cannot reach B. A tap or vibration imparted to the end A produces responsive current which flows in the wire from the unexcited B to the excited end A. Disturbance of B gives rise to a current in the opposite direction. (*c*) gives the record of the response to equal stimuli applied to A and B. The ascending part of the curve shows the effect of stimulus, the falling part shows recovery. (*d*) Simultaneous stimulation of A and B gives no resultant response. (In the records dotted lines represent recovery.)

A and B will continuously balance each other, and the resultant effect on the galvanometer will be zero, (1) if the mechanical disturbance reaches A and B at the same time and with the same intensity, (2) when the molecular condition is similar at the two points, and (3) when the rate of rise and subsidence of disturbance is the same at the two

\* A preliminary account of this investigation was given in a paper "On Response in Inorganic Substances," read before the Society, June 6, 1901.

points. In order that a resultant effect may be exhibited in the galvanometer, matters have to be so arranged that (1) the disturbance may reach one point, say A and not B, and *vice versa*. This may be accomplished by the method of block. Again, a resultant differential action may be obtained even when the disturbance reaches both A and B, if the electrical excitability of one point is relatively exalted or depressed by physical or chemical means: we thus have two other means of obtaining a resultant effect, (2) by the method of relative exaltation, (3) by the method of relative depression.

### *Method of Block.*

The electromotive effect described below may be obtained with all metals. A piece of "tin" wire (an alloy of tin and lead used as electric fuse) will be found to give very good results. A specimen of wire 1 mm. in diameter, 10 cm. in length, is mounted in the apparatus. (Fig. 1, *b*.) Two strips of cloth moistened with water or dilute salt solution are securely tied round two points A and B. They hang loose from EE' (non-polarising electrodes—Zn in  $\text{ZnSO}_4$  solution), so that there is no pull on the wire. Special precautions are taken so that there is no variation of contact. If a sharp tap be given to the side A, a transitory electrical current in response to the disturbance will flow round the circuit, which under normal conditions will be found to flow *in the wire* towards the more excited end A. Disturbance of B will give rise to a reverse current. For quantitative measurement it is necessary to have the intensity of stimulus maintained uniform or increased or decreased in a definite manner. Instead of a tap, the stimulus of torsional vibration is more satisfactory. By maintaining the amplitude of vibration constant or increasing or decreasing the amplitude, we may either keep the stimulus constant or increase or decrease it in a definite manner. I shall first describe some of the typical results which may be obtained with the simple "straight wire form" of the apparatus. If worked with care it will give consistent and satisfactory results. For quantitative measurements requiring the greatest exactitude the "cell form," to be presently described, will be found preferable.

*Recording Apparatus.*—The galvanometer used is a sensitive dead-beat D'Arsonval; the period of complete vibration of suspended coil under experimental conditions is 11 seconds. The records are taken by means of a cylindrical modification of the response recorder described in my previous paper,\* or by means of photography. In the latter method, a clockwork moves the photographic plate at a uniform rate and a curve is traced on the plate by the moving galvanometer spot

\* "On the Continuity of Effect of Light and Electric Radiation on Matter," Roy. Soc. Proc., vol. 70, p. 159.

of light. The disturbance of molecular equilibrium caused by the stimulus is attended by an electromotive variation, which gradually disappears on the restoration of the molecules to equilibrium. The rising portion of the response curve shows the electromotive effect, due to stimulus, and the falling portion the recovery. The ordinate represents the electromotive variation, and the abscissa the time.

*Experiments to Exhibit the Balancing Effect.*

If the wire has been carefully annealed, the molecular conditions of different portions are approximately the same. Every portion of the surface will be found nearly iso-electric. If the wire be held near the middle by the clamp, and a vibration through an amplitude of, say,  $90^\circ$  be given to the end A, an upward deflection will be produced; if a vibration of  $90^\circ$  be given to B, there will be produced an equal downward deflection. (Fig. 1, *c*.) If both the ends are simultaneously vibrated, the electromotive variation at the two ends will continuously balance each other, and the galvanometer spot will remain quiescent. (Fig. 1, *d*.) The clamp may even be removed, and the wire vibrated as a whole; the stimulation of A and B being the same, there will be no resultant deflection. Having found the balancing point for the clamp (which is at or near the middle), if the clamp be now shifted to the left, on simultaneous vibration of A and B, the A effect will be relatively stronger (inasmuch as the angular vibration of A is increased and that of B decreased), and there will be produced a resultant upward deflection. Thus keeping the rest of the circuit untouched, by merely moving the clamp from the left, past the balancing position to the right we get either a positive or zero or a negative resultant effect. This can be repeated any number of times. The experiment shows further that when the amplitude of vibration is kept constant, the intensity of electromotive effect is increased by shortening the wire. A thick wire produces a stronger response. The direction of the current of response in the wire is in the majority of metals under normal condition, from the relatively less to the relatively more excited point.

The form of the response curve, stimulus remaining constant, is modified by the molecular condition of the wire. A wire in a sluggish condition shows feeble response, the recovery is also slow. The same wire after it has been vibrated for a time exhibits stronger response. The period of recovery may also then be hastened. Longer time is required for recovery from the effects of a stronger stimulus.

*Comparison of Electric Excitability of Two Points by the Method of Balance.*

As has already been said, when the clamp is put at the balancing

position, alternate equal stimulations of A and B produce equal and opposite electromotive effects, and when the two ends are stimulated simultaneously there is no resultant effect.

*Increased Excitability produced by Preliminary Vibration.*—If now one-half of the wire, say the A half, be vibrated for a time, the electric excitability of that half will be found to be more or less permanently augmented, presumably by increased molecular mobility conferred by vibration. The response of A would now be found to be very much enhanced, as compared with its previous response, the response of B remaining the same as before. If now both the ends are simultaneously vibrated, the balance which previously existed will be found to be disturbed, the resultant showing that A has been rendered the more excitable.

If B be now vibrated for a time, the former approximate balance will be re-established by the enhanced responsiveness of B. Thus in the following experiment with the clamp at the approximate balancing point—

	Response of A.	Response of B.	Resultant response.
Approximate balance .....	+ 5 divisions	− 4·5 divisions	+ 0·5 divisions
After the end A has been vibrated .....	+ 10·5 „	− 4·5 „	+ 6·0 „
After the end B has been vibrated for an equal length of time .....	+ 10·5 „	− 9·5 „	+ 1·0 „

*Effect of Chemical Reagents.*—It will be shown that keeping the electrolyte by which contact is made constant, the electric excitability of the wire depends on the molecular condition of the wire. Certain electrolytes, such as dilute solution of NaCl, dilute solution of bichromate of potash, &c., are normal in their action, that is to say, with such contacts the response to stimulation is practically the same as with distilled water contact.

Contact made with dilute NaCl solution may therefore be regarded as the normal contact. There are again certain chemical reagents which enhance the electrical excitability; others on the contrary produce great depression, or abolition of excitability.

#### *Electric Comparator.*

We may compare the relative electric excitability conferred by chemical reagents by the method of balance. Having previously obtained a balance (with water or dilute NaCl solution contacts

at A and B), one contact, say A, is touched with a few drops of  $\text{Na}_2\text{CO}_3$ , which is an exciting agent. The electric excitability of A will now be found to be greater than that of B; on simultaneous vibration of A and B there will be a disturbance of balance, giving rise to an upward deflection (current of response towards the more excitable A).

	Response of A.	Response of B.	Resultant response.
Both contacts of normal saline .....	+ 12	- 12	0
Contact A touched with $\text{Na}_2\text{CO}_3$ solution.....	+ 32	- 12	+ 20

Similarly, when A is depressed by a trace of oxalic acid the electric excitability of A is less than that of B, the resultant deflection being now downwards (current of response towards the relatively more responsive B). It is to be remembered that in all cases *the resultant current of response in the wire is towards the more excitable point.*

An interesting line of investigation rendered possible by a modification of method of balance described above is to compare the relative excitability induced by various chemical reagents, the influence of the same reagent of different strengths, and the modification of the effect caused by the duration of application. We may thus compare the effect of the reagent in relation to the normal effect of water or dilute  $\text{NaCl}$  solution. There is again an extremely delicate method of comparison of the relative effects of a series of compounds like  $\text{Na}_2\text{CO}_3$ ,  $\text{K}_2\text{CO}_3$ , &c. Balance having been previously obtained between the normal sensitiveness of A and B, the two different solutions are now applied at the two points; the slightest difference in their relative action is at once exhibited by the upsetting of the balance during stimulation, the direction of the resultant deflection indicating the more exciting reagent.

*Resultant Response by Method of Relative Depression or Exaltation.*

From what has been said, it will be seen that by rendering A and B unequally excitable, a resultant response may be obtained. The block may be abolished, and the wire may be vibrated as a whole; the response will now be due to the differential effect at A and B. To produce difference in excitability we may subject one point, say A, to a preliminary vibration, or apply at the point a suitable chemical reagent. By the application of the latter there will be a small P.D. between A and B: this will simply produce a displacement of the zero. (By means of

a potentiometer the galvanometer spot may be brought back to the original position.) The shifting of the zero will not affect the general result. The direction of this more or less permanent current, due to the small P.D., gives no indication of the direction of current of response; the direction of the latter is determined by the rule that the responsive current flows towards the more excitable point. The effect of the mechanical stimulus is to produce a transient electromotive force which is algebraically superposed on the existing P.D. The deflection will take place from the modified zero, to which the spot returns during recovery. I give four records (fig. 2): in (a) A is touched with  $\text{Na}_2\text{CO}_3$  (which is an excitant): a permanent current flows from B to A: response to stimulus is in the same direction as the permanent current (positive variation); in (b) A is touched with a trace of oxalic acid (which depresses the excitability), the permanent current is in the same direction as before, but the current of response is in the opposite direction (negative variation); in (c) A is touched with dilute KHO (3 parts in 1000), the response is exhibited by a positive variation; in (d) A is touched with stronger KHO (3 parts in 100), the response is now exhibited by a negative variation. The last two apparently anomalous results are due to the fact (which will be demonstrated later) that KHO in minute quantities is an excitant, while in larger quantities it is a depressant.

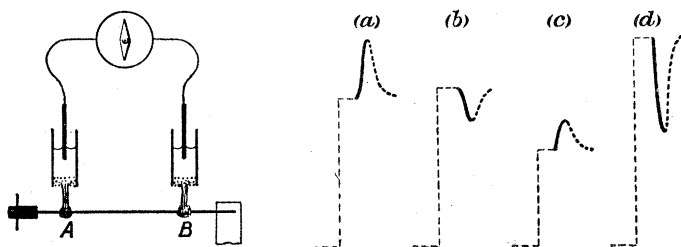


FIG. 2.

- (a) Response when A is treated with sodium carbonate—an apparent positive variation  
 (b)     "     "     "     "     "     oxalic acid—an apparent negative variation  
 (c)     "     "     "     "     "     very dilute potash—positive variation.  
 (d)     "     "     "     "     "     strong potash—negative variation.

This response is up when A is more excitable and down when B is more excitable.

Lines thus — — — indicate direction of permanent current.

	Permanent current.	Current of response.
A treated with sodium carbonate .....	←	←
" " " oxalic acid .....	←	→
" " " very dilute potash... ..	←	←
" " " strong potash .....	←	→

Current of response is always towards the more excitable point.

*Detection of Traces of Physico-chemical Change.*

I will now describe an experiment which will show in a striking manner how exceedingly delicate is the method of electric response to stimulation, and how by its means we can detect and measure traces of physico-chemical changes in different parts of the same solid. Take a wire and touch two points, one with  $\text{Na}_2\text{CO}_3$  solution the other with oxalic acid. Wash the wire. There is no trace left of the previous treatment. Let one contact be permanently made at a normal or previously unacted point N. Let the other exploring contact be moved

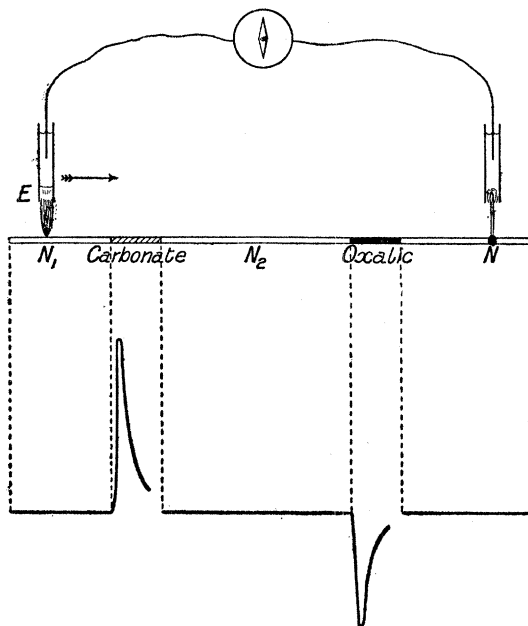


FIG. 3.—Electro-molecular Explorer.

along from the other end towards N, the wire being mechanically stimulated during the test. The galvanometer spot remains quiescent as long as the exploring contact is over normal areas. But as soon as it touches the zone on which is impressed the invisible image of physico-chemical change, the differential effect of stimulus at once reveals it by producing a vigorous movement of the galvanometer spot. At  $N_1$  there was no movement, but there was an upward movement of response when the explorer came over "Carbonate." As the explorer passed on to  $N_2$  there was a cessation of movement, but when it reached the area marked "Oxalic" there was a vigorous movement downwards (fig. 3).

### *Interference Effects.*

I have already described a case of interference in the galvanometric effect when the two points A and B in similar molecular conditions are simultaneously acted on by the same mechanical stimulus. Under these conditions the electric variation at the two points *continuously* balance each other, and there is no resultant effect.

When one point is acted on by a chemical reagent, not only is its electric excitability changed, but its time relations—its latent period, the time-rate of its acquiring the maximum electric variation, and the recovery from the effect of stimulus—will also be modified. Using the block method, we may place a drop of excitant  $\text{Na}_2\text{CO}_3$  on A and depressant KBr on B. On simultaneous vibration of A and B, the A effect being relatively much stronger than B effect, the resultant would be an upward deflection. But on shifting the balancing clamp away from A (thus decreasing the stimulation intensity of A and increasing that of B) we may find a point where the A effect is equal and opposite to the B effect. But owing to change of time relations, simultaneous vibration of A and B will no longer give a continuous balance; instead we obtain a diphasic variation. The diphasic curve thus obtained is exactly the same as the resultant curve deduced from the algebraic summation of the A and B curves obtained separately.

*Continuous Transformation from Positive to Negative through an Intermediate Diphasic Response.*—In the following record, fig. 4, I succeeded in obtaining a continuous transformation from positive to negative phase by continuous change in the relative sensitiveness of the two contacts. I found that traces of after effect due to application of  $\text{Na}_2\text{CO}_3$ , even after it is washed off, remain for a time, the increased sensitiveness conferred disappearing gradually. Again, if we apply  $\text{Na}_2\text{CO}_3$  solution to a fresh point, the sensitiveness *gradually* increases. There is another interesting point, viz., that the beginning of response is earlier when the application of  $\text{Na}_2\text{CO}_3$  is fresh. In the experiment whose record is given, the wire is held at one end, and successive uniform vibrations imparted to the wire as a whole at inter-



vals of one minute by means of a torsion head at the other end. (See fig. 2.) Owing to after effects of previous applications of  $\text{Na}_2\text{CO}_3$ , the sensitiveness of A is at the beginning great, hence the resultant response is at the beginning positive or upward. Dilute solution of  $\text{Na}_2\text{CO}_3$  is next applied to B. The response of B (down) begins earlier, and con-

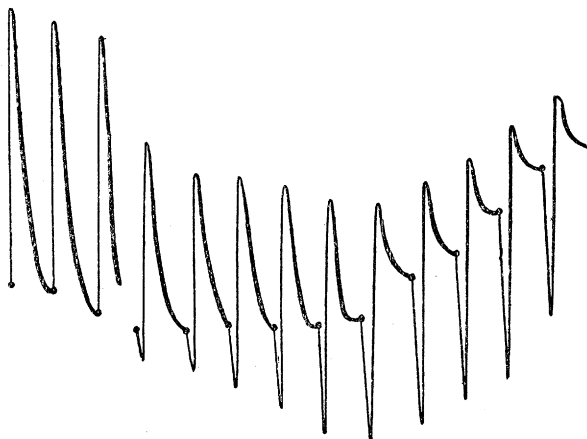


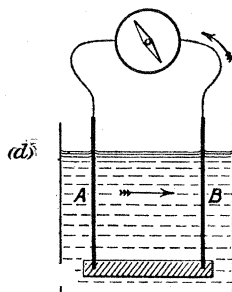
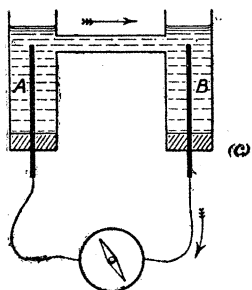
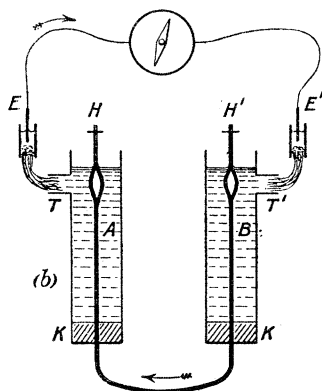
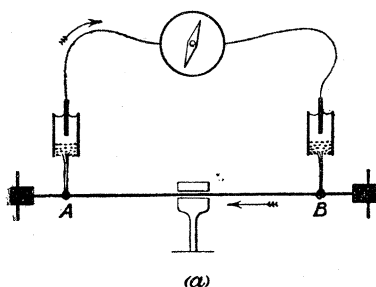
FIG. 4.—Transformation from positive to negative through intermediate diphasic variation. Thick dots represent times of application of stimulus.

tinues to grow stronger and stronger. Hence, after this application, the response shows a preliminary negative twitch of B followed by positive variation of A. The negative grows continuously. At the fifth response, the two phases, negative and positive, of the double response become equal; after that, the negative becomes very prominent, the positive dwindling into a feeble after vibration.

#### *Modification of the Apparatus into "Cell Form."*

The series in fig. 5 explains the transformation from the "straight wire" to "cell" form. The wires A and B, cut from the same piece, are clamped separately below; vibration of A (the amplitude of which is measured by a graduated circle) gives rise to a responsive current in one direction, vibration of B gives rise to a current in an opposite direction. Every experiment may thus be verified by corroborative and reversal effects. The electromotive effect varies with the substance, and is sometimes considerable, for example, with "tin," a single vibration may give rise to as high a value as 0.4 volt or more. The intensity of response does not depend on the chemical activity of the substance, for the electromotive variation in the relatively inactive tin is greater than in zinc. Again, the sign of response, positive or

negative, is sometimes modified by the molecular condition of the wire (see below). In the modified form of apparatus the wires in the cell are immersed to a definite depth in the electrolyte; there is thus a perfect and invariable contact between the wire and the electrolyte. The wire in the cell is clamped below, and torsional vibration gives rise to a strong electrical response. If the wire be now carefully unclamped, and the vibration repeated as before, there will now be found no electrical effect. As all the rest of the circuit was kept absolutely the same in the two different sets of experiments, these results conclusively prove that the responsive electromotive variation is solely due to the mechanical stimulation of the acted wire. The excitatory effect due to the disturbance persists for a time. This may be shown by keeping the galvanometer circuit open during the application of vibration, and completing it at various short intervals after the cessation, when a persisting electrical effect diminishing rapidly with time will be observed. When the wire is brought to the normal condition, successive responses to uniform stimuli are, in the case of metals which, like tin, show no fatigue, exactly the same. I usually interpose a high external resistance, varying from 1 to 5 megohms, so that the galvanometer deflections may be proportional to the electromotive variations;



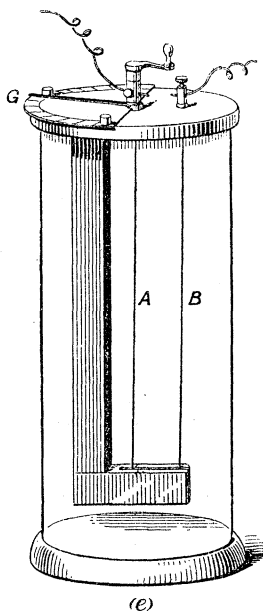


FIG. 5.—Successive modifications of the “straight wire” ending in “cell form.”  
 (b) shows how the ends of A and B of the wire may be vibrated by ebonite clip-holders, H and H'. When A is excited, current of response *in the wire*, normally speaking, is from the unexcited B to the excited A. The stimulated wire becomes zincoid. Note that though the current of response is constant in direction, the galvanometer deflection in (d) will be opposite in direction to (b). In (e) is shown one of the two graduated circles by which the amplitude of vibration is measured.

the internal resistance of the cell and the variation of that resistance by the addition of chemical reagents being thereby rendered quite negligible. Ordinarily I use tap-water as the electrolyte. The responses obtained with tap-water are practically the same as those obtained with distilled water. Zinc wires in  $\text{ZnSO}_4$  solution give responses similar in character to those given by, for example, Pt or Sn in water.

*Character and Intensity of Response dependent on Molecular Condition.*

The following experiments show how intimately the response phenomena is connected with the molecular condition of the acted wire:—

*Effect of Annealing.*—The following photographic record, fig. 6, shows the equal and opposite responses in A and B wires to a succession of uniform stimuli. Hot water was now substituted for the cold water (too high a temperature temporarily reduces the response); the cell

was then allowed to cool to its old temperature, when a second series of responses were taken, the stimulus intensity being the same as before. It will be seen how the responses are enhanced by annealing.

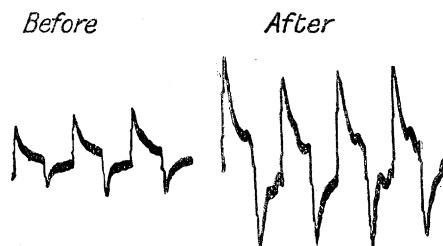


FIG. 6.—Series of responses, to uniform stimuli, of both A and B wires, before and after annealing.

*Effect of Previous Vibration.*—The increased sensitiveness conferred by previous vibration has already been referred to before. I give below a record (fig. 7) obtained with platinum (I have obtained similar

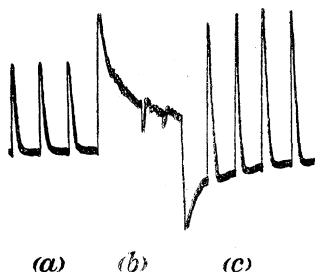


FIG. 7.—Photographic record showing the effect of continuous stimulation in enhancing response (Pt). Each curve shows response (followed by recovery), the stimulus being kept constant throughout. The series of responses (a), enhanced to series (c) after continuous vibration (b).

records with other metals), which clearly shows how the response is enhanced after preliminary vibration.

Sometimes the wire gets into a very sluggish condition, when the response almost disappears; in other words, owing to some molecular modification, responsiveness is reduced from the normal positive value (by positive is meant that the acted wire becomes zinc-like or is zincoid) to zero. In these cases annealing or preliminary vibration are usually effective in transforming the sensitiveness from zero to a positive value.

*Abnormal Response.*

But the modification of which I have spoken does not stop short of mere abolition of responsive power, but sometimes proceeds further, and actually reverses the sign of response—the excited wire becoming cuproid. This abnormal effect is sometimes found even in fresh un-annealed wires, when feeble vibrations (of amplitude of  $5^\circ$  or less) may give rise to a negative response, but vibration of stronger intensity gives rise to the usual positive response. At other times the molecular modification is more pronounced, and there is a persistent reversal of response.

But even in such cases long-continued vibration transforms the abnormal negative to the normal positive. I give below photographic records which exhibit this. In fig. 8,  $\alpha$ , the transformation took place during continued vibration. To detect the point of transformation, I experimented with a platinum cell which exhibited the abnormal effect, and took a long series of records of responses to uniform vibrations acting at intervals of a minute. In the record (fig. 8,  $\beta$ ) I have been able to catch the point or rather points of transition.

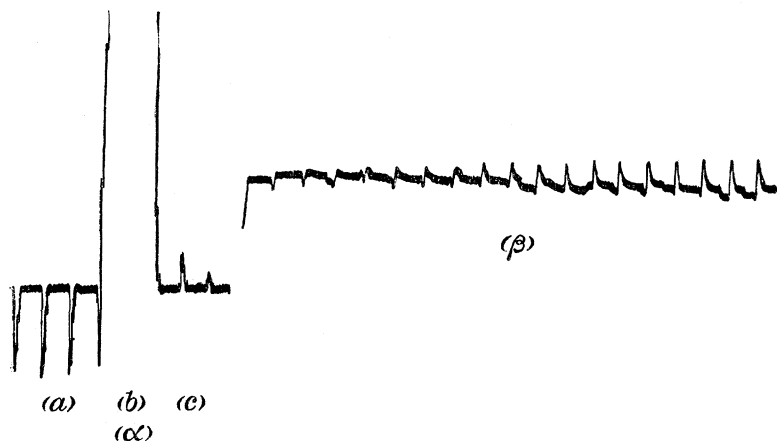


FIG. 8.—(a) Abnormal negative (downward) response (a) converted into normal positive (upward) response (c) after continued vibration (b) (tin).

( $\beta$ ) Shows points of transition from the abnormal negative to the normal positive (platinum).

Thus we may distinguish the following typical cases. Beginning with the case of extreme molecular modification, we have (1) a condition which gives rise to negative response; after continued vibration the negative becomes less negative, and ultimately becomes converted into positive: (2) an irresponsive or neutral condition; vibration or annealing transforms it into positive: (3) a sluggish, feebly positive, becoming more and more positive after continued vibration: (4) a

steady and permanent condition, when the responses are uniform : and lastly (5) when vibration is continued for too long a time, the positive tends to become less positive, the responses decline—a state of things which we designate as fatigue.

*Increased Electromotive Variation with increased Intensity of Stimulus.*

When the intensity of stimulus is increased by increasing the amplitude of vibration, the electric response is enhanced. The following is a pair of records (fig. 9) for increasing amplitudes from  $5^{\circ}$  to  $40^{\circ}$ , and decreasing amplitudes from  $40^{\circ}$  to  $5^{\circ}$ . The vibrations are imparted at intervals of 1 minute. It will be noticed how the response is enhanced with increasing stimulus.

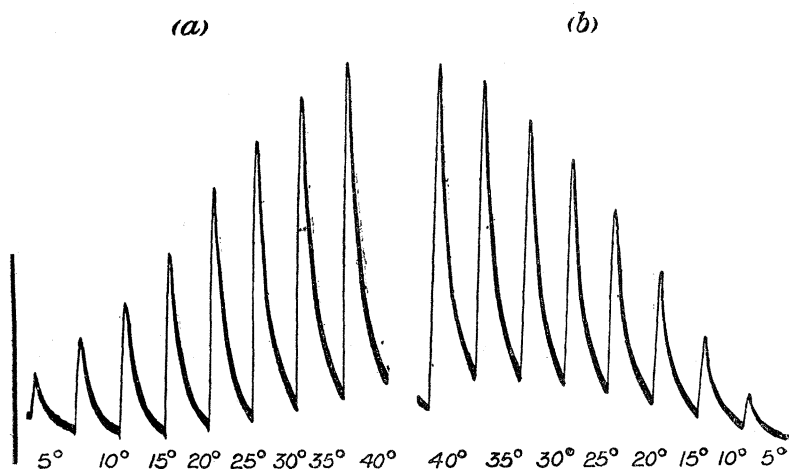


FIG. 9.—Photographic records of response curves. (a) from  $5^{\circ}$  to  $40^{\circ}$ , (b) from  $40^{\circ}$  to  $5^{\circ}$ . The vertical line = 0.1 volt.

Table I.—Showing the Increasing Electromotive Effect due to Increasing Amplitude of Vibration.

Vibration, amplitude.	Deflection. 23 dns. = 0.1 volt.	
	Ascending.	Descending.
$5^{\circ}$	5.5	5
10	13	12
20	25.5	26
25	33	32
30	39	39
35	43	43
40	47	48

It will also be noticed that whereas recovery is complete in 1 minute when the vibration amplitude is small, it is not quite complete within that time when the vibration amplitude is large. Greater strain prolongs the period of recovery. Owing to want of complete recovery, the base line is tilted slightly upwards. This slight displacement does not materially affect the results, provided the shifting is slight. From other records taken through a greater range of stimulation, it appears that in a curve obtained with electromotive variations as ordinates and amplitudes of vibrations as abscissæ, the first part of the curve is, generally speaking, slightly convex to the abscissa (the convexity is pronounced when feeble stimulation gives negative response), it is then straight in the middle and concave in the last part. A limiting deflection is approached with high amplitude of vibration. The shape of the curve is modified by the molecular condition of the wire.

### *Maximum Effect.*

If instead of a single vibration of a given amplitude we superpose a rapidly succeeding series, the individual effects are added up and a maximum deflection is produced which remains practically constant as long as the vibration is maintained. (A single ineffective stimulus may thus become effective by the additive effect of several.) Too long-continued vibration may cause fatigue, but during half a minute or so, the maximum effect is very definite (in tin). For a definite amplitude of vibration there is a definite maximum, which increases with the amplitude. For example, a single vibration of  $5^\circ$  gave a deflection of 3.5 divisions, the same when continued at the rate of four times per second gave a maximum deflection of eighteen divisions.

Again, with the same wire, a single vibration of  $10^\circ$  gave a deflection of 4.5 divisions, but continued vibration gave the definite maximum of 37.5 divisions. I give below a curve (fig. 10) which shows the maximum effect for different amplitudes of vibration.

*Hysteresis.*—Allusion has already been made as to the increased sensitiveness conferred by preliminary vibration. Being desirous of finding out in what manner this is brought about, I took a series of observations for an entire cycle, that is to say, a series of observations were taken for maximum effects, starting from  $10^\circ$  and ending in  $100^\circ$ , and backward from  $100^\circ$  to  $10^\circ$ . Effect of hysteresis is very clearly seen (fig. 10, A); there is a considerable divergence between the forward and return curves, the return curve being higher. On repeating the cycle several times, the divergence is found to be very much reduced, the wire on the whole is found to assume a more constant sensitiveness. In this steady condition, generally speaking, the sensitiveness for smaller amplitude of vibration is found to be greater than at the very beginning, but the reverse is the case for stronger intensity of vibration.

*Effect of Annealing.*—I repeated the experiment with the same wire, after pouring hot water and allowing it to cool to the old temperature. It will be seen from the cyclic curve (fig. 10, B), (1) that the sensitiveness has become very much enhanced; (2) that there is relatively less divergence between the forward and return curves. Even this divergence practically disappeared at the third cycle, when the forward and backward curves coincided (fig. 10, C). The above results show in what

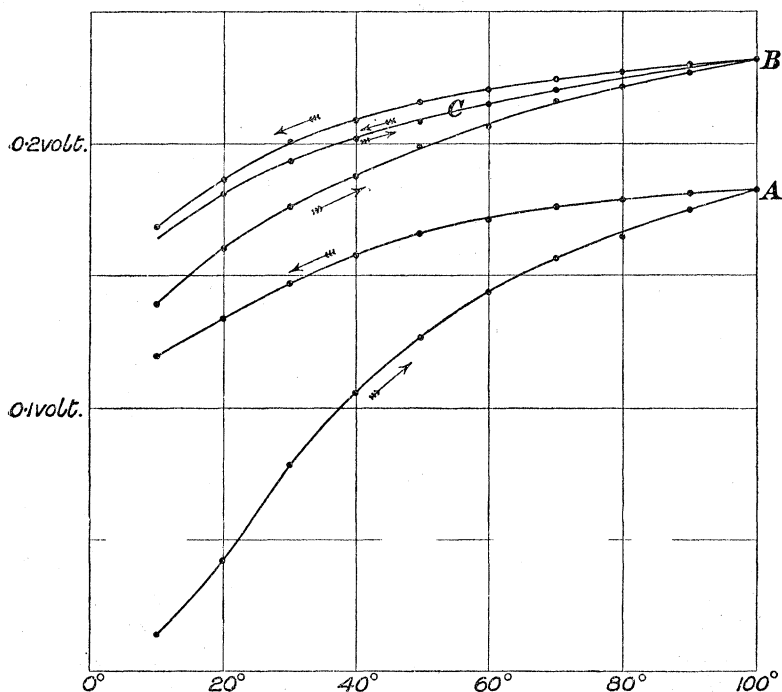


FIG. 10.—Cyclic curves for maximum effects due to increasing and decreasing amplitude of vibration. A, fresh wire; B, after annealing; C, the same after three cycles. Abscissa represents the amplitude of vibration; the ordinate represents the corresponding electromotive variation.

manner the excitability of the wire is enhanced by purely physical means.

It is very curious to notice that the substitution of  $\text{Na}_2\text{CO}_3$  solution as electrolyte produces results very similar to that produced by annealing; that is to say, not only is there a great enhancement of sensitiveness, but there is also a reduction of hysteresis. Another curious point is that, whereas with ordinary fresh wire the addition of  $\text{Na}_2\text{CO}_3$  greatly enhances the sensitiveness, after the wire has been annealed there is comparatively little further increase of sensitiveness due to the addition of the reagent.



*Effect of Chemical Reagents.*

I shall now give photographic records of a few typical cases which will graphically illustrate the influence of chemical reagents. The mode of procedure is as follows. The cell is filled with water, and photographic records are taken of responses to single vibrations of constant amplitude, applied to one of the two wires at intervals of 1 minute. The responses will be found uniform. Chemical reagent is now added, and similar vibrations applied as before. The responses will exhibit either an increase or diminution, depending on the exciting or depressing power of the reagent. It is also quite easy to obtain duplicated results by alternately vibrating the A and B wires. Uniform responses, alternately positive or negative, will be first obtained; after the addition of reagent *both* will exhibit either an increase or a diminution. As has been said before a very high external resistance, varying from 1 to 5 megohms, is interposed in the external circuit, the slight variation of internal resistance of the cell due to the addition of the reagent being then quite negligible compared with the total resistance of the circuit. That there is no appreciable variation in the total resistance can be independently verified by applying a known electromotive force before and after the addition of the reagent, when the resulting deflection will be found to be the same in the two cases. The responsive deflections are thus simply proportional to the electromotive variations produced.

*Chemical Excitants.*—The following record (fig. 11) exhibits the

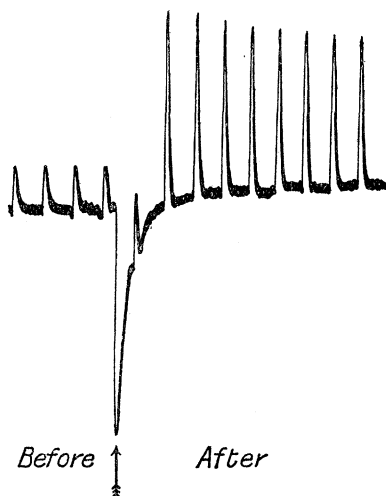


FIG. 11.—Enhanced response by the action of  $\text{Na}_2\text{CO}_3$  solution on platinum. The intensity of stimulus is kept constant throughout. The curves to the left show the responses before, and those to the right after, the application of  $\text{Na}_2\text{CO}_3$ .

increased response due to the action of  $\text{Na}_2\text{CO}_3$  on Pt. Another record shows an exactly similar effect on tin. The record of effect was taken 2 minutes after the application. Other records taken immediately after, show that the enhanced responsiveness takes place gradually with time. (See also fig. 7, and compare the general similarity between the enhancement of response produced by preliminary vibration and by the action of  $\text{Na}_2\text{CO}_3$ .)

*Depressants.*—Other reagents, like KBr (10 per cent.), produce a depression in the response. There are again others which abolish the response almost completely, for example, 3 per cent. KHO solution (fig. 12, C). One of the most effective reagents which abolishes the response is oxalic acid. The depressing effect of this reagent is so great that a strength of 1 part in 10,000 is often sufficient to produce an abolition of response.\*

*Opposite Effects of Varying Strengths of Solution.*—The most curious effect is that exhibited by some reagents when the strength of solution is varied. This is clearly seen in the following record (fig. 12), in which

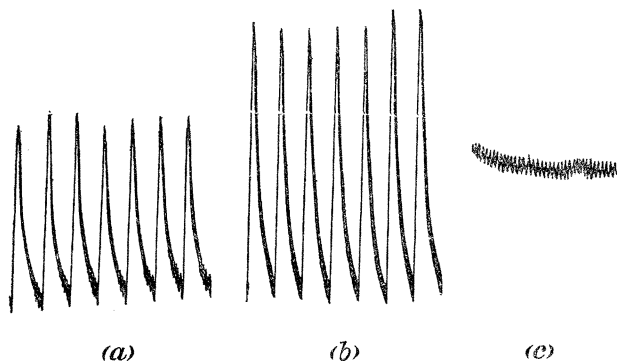


FIG. 12.—Records showing the opposite effects of weak and strong solutions. (a) Normal response; (b) increased response due to addition of 0.3 per cent. KHO; (c) abolition of response by 3 per cent. KHO. The trace (c) should have been engraved merely as a thick trace.

(a) gives the normal response in water. KHO solution was now added so as to make the strength 3 parts in a thousand and (b) shows the

\* The various phenomena connected with the response in inorganic substances—the negative variation—the relation between stimulus and response—the increased response after continuous stimulation—the abnormal response converted into normal after long-continued stimulation—the diphasic variation—the increase of response by stimulants, decrease by depressors, and abolition by “poisons,” so-called—all these are curiously like the various response phenomena in living tissues. A complete account of the mutual relation between the two classes of phenomena will be found in a work to be shortly published, “On the Response in the Living and Non-living” (Messrs. Longmans).

enhancement of response thereby produced. A further quantity of KHO was now added so as to increase the strength to 3 parts in a hundred. This caused (c) a complete abolition of response. (Refer to fig. 2, c, d.)

I shall now briefly mention some of the interesting points in connection with the action of chemical reagents. (1.) The effect of reagent is not only to increase or diminish the height of response, but also to modify the time relations. By the action of some the quickness with which the maximum effect is reached is enhanced, others produce a prolongation of the period of recovery. Curious effects of this in producing diphasic variation have already been mentioned. (2.) In a sensitive annealed wire the further enhancement of response by  $\text{Na}_2\text{CO}_3$  is not so great as in a fresh wire. The effect produced by a reagent is thus seen to depend to some extent on the previous condition of the wire. (3.) A certain time is required for the full development of this effect. With some the maximum effect takes place almost instantaneously, while with others it takes place gradually. Again, the effect may with some reach a maximum, after which there is a slight decline. The after-effect of some reagents is transitory while that of others is very persistent.

It is difficult to say how much of this modification of responsiveness by various reagents is due to "physical" and how much to "chemical" cause. It has been shown that the responsive power does not depend on the chemical activity of the substance. Tin is more responsive than zinc. Pt in distilled water shows response. Strong acids and alkalies abolish response, but very dilute KHO enhances response. Oxalic acid, even in minute quantities, abolishes it. Neutral  $\text{Na}_2\text{CO}_3$  enhances it, but dilute NaCl produces no change in the normal response. The responses of the same wire under different physical modifications are different, and under certain molecular modification the sign of response is even reversed. But continued vibration makes the response normal. Again, the enhancement of response produced by  $\text{Na}_2\text{CO}_3$  can be closely imitated by the effect of continued vibration. The stimulating effect of this reagent gradually attains a maximum. The after-effects of some chemical reagents persist even after all traces have been removed. For example, in a certain experiment the A and B wires gave each a response of 23.5 divisions. The wires were lifted from the cell, and the A wire touched with dilute oxalic acid. It was then rubbed under tap-water with a piece of cloth, so as to remove all traces of the acid. On replacing the wire on the cell, the responsiveness of the untouched B was found unchanged, but that of A had undergone an abolition. The depressing action is often so persistent and deep that I have on many occasions failed to revive the response even after the surface layers had been removed by rubbing the wire

with emery-paper. The wire so treated may, after a long time, exhibit partial recovery of its responsive power.

The facts described above seem to show that the enhancement or depression of response may, at least to a considerable extent, be due to the increase or diminution of molecular mobility conferred by the chemical reagents. With a given stimulus, the height of response and the form of the response curve will be determined by the element of molecular friction. In connection with this, it is instructive to obtain records of the vibrations of a torsional pendulum, the friction of which may be gradually increased by immersing the pendulum more or less in a viscous fluid or sand. The various types of response-curves in metals are found to be very similar to those thus obtained.

Of these I give an interesting example. With moderate friction the successive curves obtained with the pendulum are like those given in the left of fig. 13 (*a*). With increased friction the height of the curve is diminished, the maximum is reached later, and the recovery is prolonged (like the curve in the right of fig. 13 (*a*)). With still greater friction the recovery is arrested.

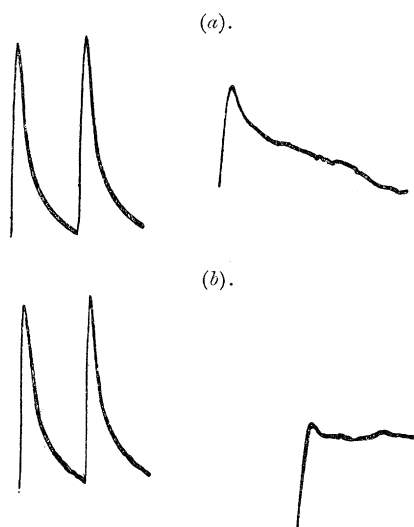


FIG. 13.—Photographic records showing the effect of “molecular arrest.” The two curves to the left of each set show the normal response; curve to the right in (*a*) shows partial and in (*b*) complete arrest, produced by the reagent.

It would appear as if the reagents which abolish response in metals produce a similar molecular arrest. The following photographic records seem to lend support to this view. If the oxalic acid be applied in large quantities, the abolition of response is complete; but

on carefully applying just the proper amount, I find that the stimulus evokes a responsive electric variation which is less than the normal, and the period of recovery is very much prolonged from the normal 1 minute before to 5 minutes after the application of the reagent (fig. 13 (a)). In the next record (fig. 13 (b)) the arrest is more pronounced, *i.e.*, there is now no recovery. Note also that the maximum is attained much later. Stimuli applied after the arrest produce no effect, as if the molecular mechanism became locked up.

### *Résumé.*

1. Molecular disturbance produced by mechanical stimulus gives rise to an electrical disturbance. In the majority of cases, under normal conditions, the responsive electrical current in a wire is from the less to the more disturbed.

2. Response may be obtained by (1) method of block, (2) by methods of negative or positive variation.

3. The electromotive variation disappears on the cessation of disturbance.

4. The intensity of the electrical variation produced by a given disturbance is modified by the molecular condition of the wire. Annealing, or previous continued vibration, enhances the electric effect.

5. The abnormal response due to molecular modification is transformed into normal by continued vibration.

6. The intensity of electromotive variation is increased with increasing intensity of stimulation.

7. In a curve—the ordinates representing the electrical effects, and the abscissæ the amplitudes of vibration—the first part is slightly convex to the abscissa, the second is approximately straight, and the third concave. With increasing stimulation there is a tendency for the electrical variation to reach a limit.

8. A maximum electrical effect is produced by continuous vibration, which is definite for a given amplitude of vibration. A curve showing the relation between the maximum effect and the amplitude of vibration exhibits the same characteristics as in the last case.

9. Hysteresis is exhibited in cyclic curves. The forward and return curves tend to coincide after several cycles. Previous annealing reduces hysteresis, and after one or two cycles the wire assumes a constant condition of sensibility.

10. Chemical reagents may profoundly modify the electric excitability. Some increase the excitability. Others depress or even abolish the excitability. The after-effects are sometimes very persistent.

11. The effect of weak solution is sometimes the opposite to that of strong solution.

12. By touching different points of the wire with different reagents, the excitability of these portions are rendered unequal. Hence a resultant electromotive variation may be obtained by vibrating the wire as a whole. The current in the wire is from the less to the more excitable.

13. By this method, invisible traces of physico-chemical change in a wire may be detected.

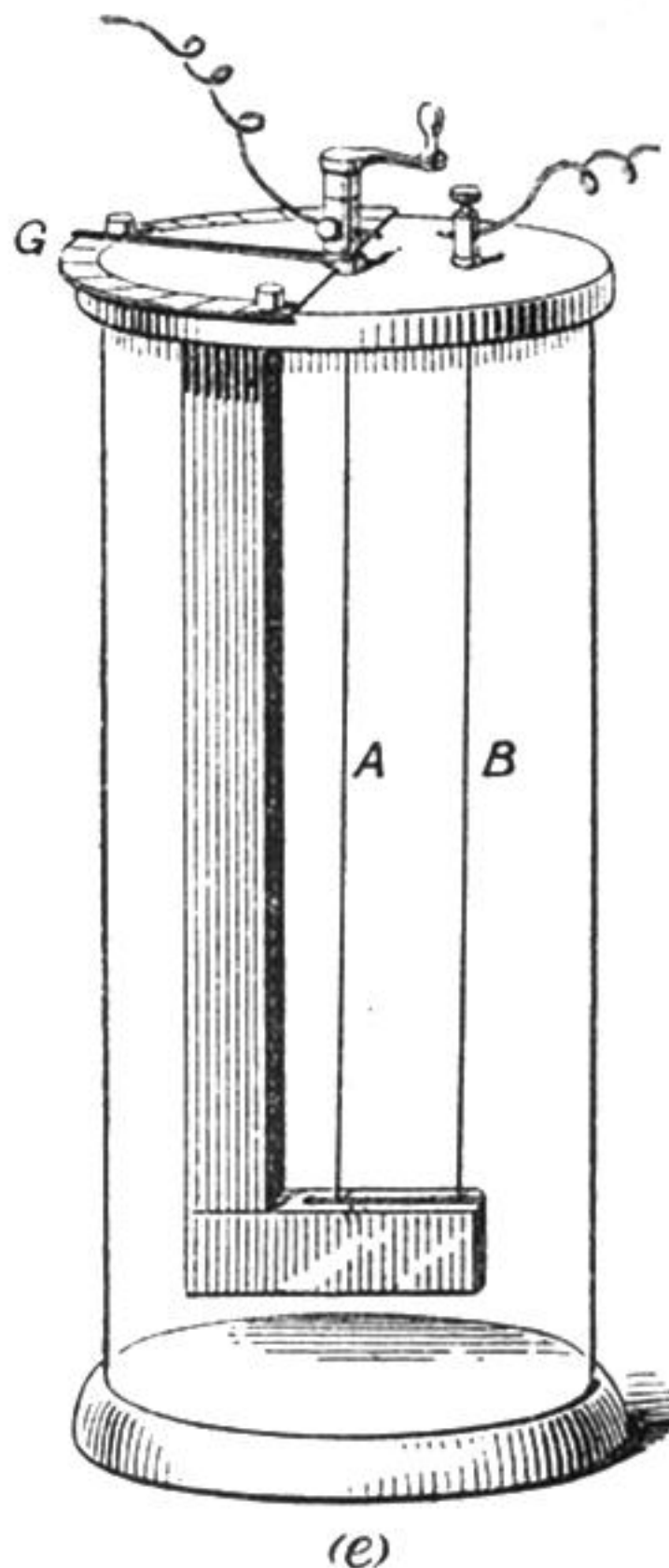
14. Chemical reagents not only change the excitability but the quickness of response. Two points having two different rates of excitation will thus, under proper conditions, give rise to diphasic effects.

I take this opportunity to thank the Managers of the Royal Institution for the facilities offered me to carry on the investigation at the Davy-Faraday Laboratory.

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“On the Effect of a Longitudinal Magnetic Field on the Internal Viscosity of Wires of Nickel and Iron, as shown by Change of the Rate of Subsidence of Torsional Oscillations.” By Professor ANDREW GRAY, F.R.S., and ALEXANDER WOOD, B.Sc., Houldsworth Research Student in the University of Glasgow. Received May 1,—Read May 15, 1902.

We can obtain information as to the nature of the magnetisation of magnetisable bodies only by testing the various hypotheses with reference to effects which it seems likely should, under these hypotheses, be produced on the physical properties of the substance. Thus, for example, the internal friction of the different parts of a solid must depend upon the size and mode of arrangement of these parts, and any alteration in their dimensions or relative arrangement ought in general to produce some change in the amount of the internal friction. Magnetisation of iron and other substances has with great probability been supposed to consist in a rearrangement and general alignment of the particles of the substance, already themselves elementary magnets, but so arranged in the unmagnetised metal as to be unproductive of any external magnetic field. It is not unusual to suppose that this unmagnetised state is one of what we may call complete absence of arrangement, and it is sometimes so represented in text-books on the subject of magnetism, where pictures are given of a perfectly confused distribution of elementary magnets, so completely mixed up as to have no preponderating magnetic moment in any one direction. Any such distribution, it is clear at once from the most elementary considerations, is impossible, as a large majority of the elementary magnets would otherwise have to remain in stable equilibrium in



**FIG. 5.**—Successive modifications of the “straight wire” ending in “cell form.”  
 (b) shows how the ends of A and B of the wire may be vibrated by ebonite clip-holders, H and H'. When A is excited, current of response *in the wire*, normally speaking, is from the unexcited B to the excited A. The stimulated wire becomes zincoïd. Note that though the current of response is constant in direction, the galvanometer deflection in (d) will be opposite in direction to (b). In (e) is shown one of the two graduated circles by which the amplitude of vibration is measured.