

XVII.—The Superposition of Mechanical Vibrations (Electric Oscillations) upon Magnetisation, and Conversely, in Iron, Steel, and Nickel. By James Russell.

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That mechanical vibrations affect magnetisation has long been known. The simple experiment of hammering an iron rod (GILBERT) in the earth's magnetic field needs only to be mentioned

About twenty years ago EWING published investigations upon the effects of vibrations on magnetism.* These have been summarised in his subsequent work, *Magnetic Induction in Iron and other Metals*. He states (§ 84, 3rd ed.) that the "influence of vibrations and mechanical disturbances generally" "may be succinctly described by saying that vibration lessens those differences of magnetic condition to which hysteresis gives rise. Thus, if we tap a piece of iron during the application and removal of a magnetising force, we find at each stage of the application that tapping increases the susceptibility, and at each stage of the removal it reduces the retentiveness."

The effects of vibrations upon magnetism have in general been investigated by tapping. That is to say, vibrations have been superposed upon field (induction). But the effect of vibrations cannot be limited to one method of relative superposition of

* *Phil. Trans.*, 1885, p. 564.

vibrations and field. Change of field may be superposed upon continuously acting vibrations of uniform intensity for the time being. Moreover, if the tapping be described as "vigorous," it may be assumed that its effect upon magnetisation will have reached a limiting value. If, however, we wish to investigate the effect of vibrations within this limiting value, tapping the magnetic metal would afford a very imperfect method of so doing.

Many questions arise to which, so far as I know, no definite answers have been given.

For instance:—What is the effect of superposing vibrations upon magnetisation, relative to the effect of superposing magnetic change upon magnetic metals kept in a state of continuous vibration? What is the effect of superposing vibrations of various intensities at all stages of cyclic fields? If the vibrations be continuous, how does the energy loss during a magnetic cycle vary with maximum field, how with maximum induction? In what metal, or in what condition of that metal, is any given effect a maximum, or any given effect a minimum?

Further, it may well be asked whether the reduction of residual magnetisation by vibration is a necessary consequence of the molecular theory of magnetisation. In the present state of theoretical knowledge, would some such deduction as the following not be equally valid? Vibrations will give the molecular magnets intervals of freedom and allow them to assume more stable positions when the magnetic force is acting, so that when the force is withdrawn the residual magnetisation will be increased.

The above queries indicate the scope of the present investigation. They were in the first instance suggested by experiments upon the effects of electric oscillations on the magnetic properties of iron.* Little doubt existed in the mind of the author that the effects of mechanical vibrations would be found to be very similar to the effects of electric oscillations, provided that in the experimental methods employed the same distinction between the two methods of relative superposition of vibrations and field—the importance of which was insisted upon—also obtained.

APPARATUS.

To obtain satisfactory quantitative measurements, the vibrations must be produced in such a way that they can readily be put "on" and "off," and that when on they remain constant in character and intensity. Such a result was very approximately attained by experimenting with wires attached to the gong of an ordinary electric bell of substantial construction. The wires were hooked at their ends, and one extremity of a wire could be linked into a small hole drilled near the edge of the gong, the other end being linked to the vertical arm of an L-shaped lever, either directly or, preferably, by means of a short length of thread. The latter method eliminates a possible source of uncertainty in the results due to minute torsional effects, which were much greater in

* "Notes on the Effect of Electric Oscillations (co-directional and transverse) on the Magnetic Properties of Iron," *Proc. R.S.E.*, vol. xxvi. p. 33, 1905.

annealed than in quenched nickel, negligible so far as observed in other cases. A weight of 11 ozs. suspended from the horizontal arm of the lever kept the wire from sagging, and made its contact with the gong such that the vibrations were transmitted to the thin wire supporting the weight with little apparent loss of intensity.

The dimensions and other particulars of the six wires used are given in the following table :—

Metal.	Condition.	Diameter.	Length.
Steel (mild).	Annealed.	·092 cms.	100 cms.
	Quenched.	·092 cms.	"
Iron (not "soft").	Annealed.	·0907 cms.	"
	Quenched.	·091 cms.	"
Nickel (commercial).	Annealed.	·092 cms.	"
	Quenched.	·0909 cms.	"

The three wires were annealed in a horizontal position normal to the earth's field, at a red heat, by passing a Bunsen flame slowly along their entire length. The other three wires, cut from the same hanks, were heated to redness by an electric current, and quenched by plunging in water a moment after the current was broken.

An exploring coil was wound on the central portion of a glass tube 41 cms. long and 0·8 cm. bore. Another glass tube of the same length but of greater diameter surrounded that of smaller bore and supported a magnetising coil of two layers of copper wire. This arrangement was adjusted in position so that the wire, supported at one end by the gong and at the other end by the lever as above described, coincided with the axis of the concentric tubes at right angles to the earth's magnetic field.

The exploring and magnetising coils were each in series with one of two solenoids concentrically wound, so connected and adjusted that, before the magnetic wire was introduced, the maximum current produced no motion of the more delicate of the two ballistic galvanometers used.

The accessory apparatus was such that all the operations could readily be performed, and readings of the galvanometer accurately taken, without the assistance of a second observer.

THE EFFECT OF THE LOAD.

The weight (11 ozs.) used throughout the experiments subjected each wire under test to a pulling stress not greater than 0·5 kilo. per sq. mm. of sectional area. The four tables submitted show the effects of this load upon magnetisation.

Annealed Steel.			Quenched Steel.		
16/3/06. H	Without Load. B_0	With Load. B_L	18/3/06. H	Without Load. B_0	With Load. B_L
·27	142	148	·45	100	105
·42	252	258	·95	260	270
·78	594	630	1·15	345	352
1·02	915	1000	1·50	515	520
1·22	1420	1640	2·18	1000	1030
1·46	2742	3310	2·93	1960	2035
1·81	6050	6900	3·83	3390	3460
3·20	12880	12940	5·57	5620	5760
4·85	14520	14600	7·62	7460	7580
5·73	15000	14930	8·75	8105	8250

Annealed Nickel.			Quenched Nickel.		
21/3/06. H	Without Load. B_0	With Load. B_L	22/3/06. H	Without Load. B_0	With Load. B_L
·26	40	34	1·13	38	36
·62	122	91	1·50	51	45
1·06	348	200	2·17	123	94
1·27	592	284	3·9	257	224
1·86	1560	697	5·8	353	329
3·65	2936	1900	8·18	510	465
5·44	3610	2660	9·45	890	626
7·48	3900	3080	14·0	2330	2150
8·50	4050	3280	23·2	3200	3060

After annealing or quenching, as the case may have been, the wires were, by means of a revolving commutator, demagnetised by decreasing reversals without load, after which the measurements given under columns B_0 were obtained. Each measurement is one-half of the average induction change obtained ballistically on the 30th and 35th (+ and – respectively) reversals of the magnetising force H.

The wires were again demagnetised and then linked between the electric bell and the L-shaped lever, which operation puts on the load. By intermittent pressure on the lever the load was virtually put “off” and “on” twelve times. The wires were again demagnetised by decreasing reversals, and the measurement given under columns B_L (induction with load) taken, the same routine being observed as before. H, B_0 , and B_L are in C.G.S. units.

It will be noticed that the effect of the load to increase magnetisation is greater for annealed than for quenched steel, and that in the former condition only has the Villari critical point just been reached. Annealed and quenched iron exhibit respectively similar although somewhat less differences, and for this reason the readings have not

been tabulated. On the other hand, the effect of the load in decreasing magnetisation in nickel is very much greater in the annealed than in the quenched condition.

Note on the Effect of Torsion.—When the annealed nickel wire was linked directly to the lever, and not by means of a thread, as is here the case, the effect of the load to reduce the magnetisation was less. The load curve might even exceed the normal curve without load for a short distance where dB/dH was greatest. I could trace this rise to no other source than a minute torsional effect which disappeared entirely when the method of connecting the wire eliminated such a possibility. The effect could be reproduced in an exaggerated form by twisting the wire a very few degrees per 100 cms. of length.

Strictly speaking, therefore, the experimental results are based upon the effects of vibrations upon that particular condition which has been reached by subjecting the magnetic metals first to annealing and then to demagnetisation by decreasing reversals with a load not exceeding 0.5 kilo. per sq. mm. of sectional area, the load remaining on throughout the experiments. It may be observed that, while load may either increase or decrease permeability, the effect of vibrations is always to increase permeability.

A few experiments were made in which the wires were soldered to the gong and no load used. These will be referred to later.

SUPERPOSITION OF VIBRATIONS AND FIELD.

The importance of the order and manner in which mechanical vibrations and field (magnetisation) may be superposed the one upon the other has already been mentioned. The order of superposition is distinguished in the same way in which the superposition of electric oscillations and field was distinguished in the paper already referred to.

A. Mechanical vibrations are superposed upon constant field.

B. A change of field is superposed upon mechanical vibrations permanently acting.

EXPERIMENTAL METHODS UNDER *A* CONDITIONS.

After demagnetisation by decreasing reversals (the revolving commutator being in all cases used), the field is put on by steps of increasing reversals,* followed by thirty to thirty-five reversals of the pre-arranged field maximum. One-half the average of two consecutive galvanometer readings determines the value of the induction at this field maximum. Single steps (the first being zero) are then taken from the fixed maximum to a sufficient number of points all round the normal loop. At each point, mechanical vibrations are superposed by simply ringing the electric bell. This *necessitates demagnetisation*, followed by thirty reversals of the maximum field value after each step taken and before the next observation is made.

Two curves result from the galvanometer readings taken during this process. The

* This process tends to preserve the symmetry of the loops with reference to the origin.

first is the $B-H$ hysteresis loop determined by what is virtually EWING's method of single steps from a maximum. The second measures the instantaneous change of induction which takes place when mechanical vibrations are superposed at any and all stages of the normal cycle.

EXPERIMENTAL METHODS UNDER B CONDITIONS.

After demagnetisation as before, the mechanical vibrations are put on. They remain "on" until any set of readings has been completed. Under these conditions the usual curves showing either the relationship between H and B or the $B-H$ hysteresis loops are determined, as the case may be. In the former case, one-half the average induction change on the 30th and 31st reversals determines the value of B , commencing in the usual way with the lowest values of H , and finishing with the highest. In the latter case, the loops are determined by what is now exactly EWING's method of single steps from a fixed maximum. The area enclosed by this loop, like the normal cycle above described, and with which it is compared, measures the energy loss per cycle, when the properties of the magnetic metal are altered by permanently acting mechanical vibrations. It is hardly necessary to point out that the loop delineating the instantaneous changes due to superposed vibrations under the A conditions does not do so.

DIAGRAMS.

The experimental results are shown in the diagrams. The abscissæ are in all cases values of H in C.G.S. units. The ordinate values of B are likewise in C.G.S. units. In those figs. (III., IV., V., XII., XIII., XIV.) where ratio ordinates also occur, the ratio values are on the left, those of B on the right.

It was found, on plotting the diagrams, that the observations with vibrations fell as readily into line as when no vibrations were acting. When the fields are cyclic, each arm of the loops is obtained by plotting the average readings taken on both arms. This secures symmetry of the diagrams in reference to the origin.

INTENSITY OF VIBRATIONS, VARIED.

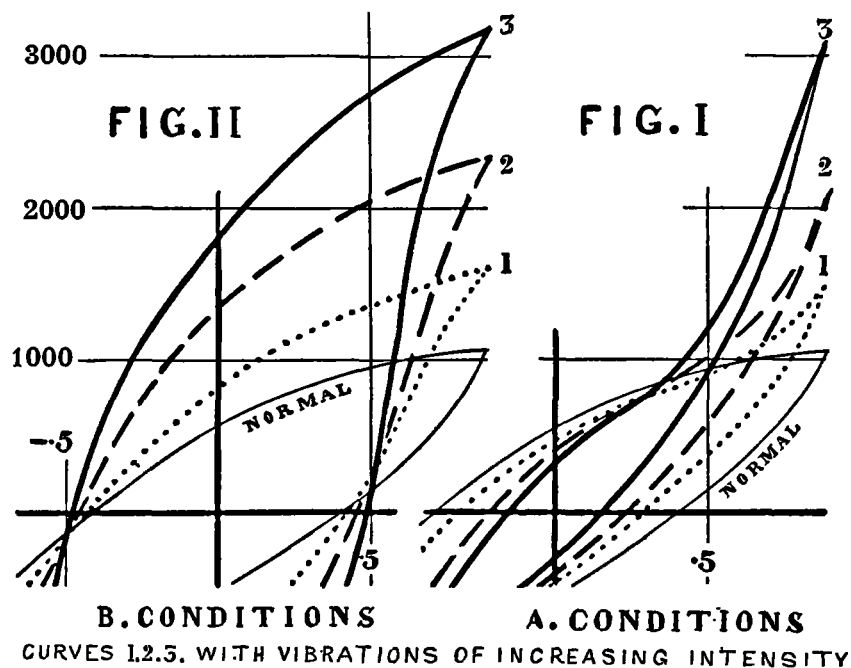
The intensity of the vibrations could be increased by increasing the voltage at the terminals of the electric bell. When the voltage was too great, the fundamental note of the bell was entirely lost in the louder rattle of the hammer, and the tingling sensation felt by the fingers on touching the vibrating wire was markedly reduced. In the following experiments the musical note of the gong was not overpowered in this way even with the highest voltage used.

Figs. I. and II. show, for annealed iron and for one low value of field ($H = 0.92$), the cyclic results obtained under the A and B conditions respectively, for three different in-

tensities of mechanical vibrations. The normal cycles are the same in both cases. The other curves show the effect of increasing the intensity of vibrations in the ascending order indicated by the numerals 1, 2, and 3. The induction reached at cyclic extremes is greater, the greater the intensity of vibrations, irrespective of the order of superposition.

It may be noted, however, that one-half the average induction change with vibrations permanently acting (fig. II.) is in all three cases a little greater than the induction reached when vibrations are superposed at the limit of the normal cyclic obtained without vibrations (fig. I.).

As the cyclic extremes are departed from, a glance at the curves shows that the



order of superposition under the *A* and *B* conditions produces apparently very different results.

A Conditions.—The induction change due to superposed vibrations is greater with increasing field, and is always in the same direction as the field change; but if the field be decreasing the induction change due to vibrations is first against, afterwards with, the field change. Increase of the intensity of vibrations thrusts the neutral point towards the vertical axis, producing at the same time a progressive collapse of the two arms of the loops.

B Conditions.—For any given intermediate value of cyclic field, the rate at which induction is changing is progressively increased with vibrations of increasing intensity. But the rate of magnetic change always remains greater with increasing than with decreasing field. Hence the areas of the loops (energy loss per cycle) progressively increase with vibrations increasing in intensity.

A and B Conditions.—If the cyclic field be not unduly increased, the curves cross each other under the *A* conditions when both field and induction are decreasing, but under the *B* conditions when both field and induction are increasing. They cross the vertical and horizontal axes in inverse order under the two conditions of relative superposition of vibrations and field. Consequently, under the *A* conditions residual magnetisation and coercive force are progressively decreased, but under the *B* conditions progressively increased, with increasing intensity of vibrations.

Note, however, that if the cyclic field were sufficiently increased the increase of induction at cyclic extremes would nearly vanish, and in all probability the loops would be progressively decreased with vibrations of increasing intensity. In all probability also the curves would cross the vertical and horizontal axes in the same order as they do under the *B* conditions.

Experiments, however, were not continued in this direction; indeed, the vibrations were varied more for the purpose of determining the most suitable intensity to use throughout the experiments now to be described, than for completely investigating the effects of such variations at all stages of magnetisation.

INTENSITY OF VIBRATIONS, CONSTANT (pages 498 to 508).

We now pass on to consider the effects of vibrations, not when their intensity is varied, but when the field and consequent magnetisation are varied, the intensity of vibrations remaining the same. The three magnetic metals are all tested in this way, both in the annealed and in the quenched condition.

The strongest vibrational intensity, corresponding to curves 3 of figs. I. and II., is now used throughout.

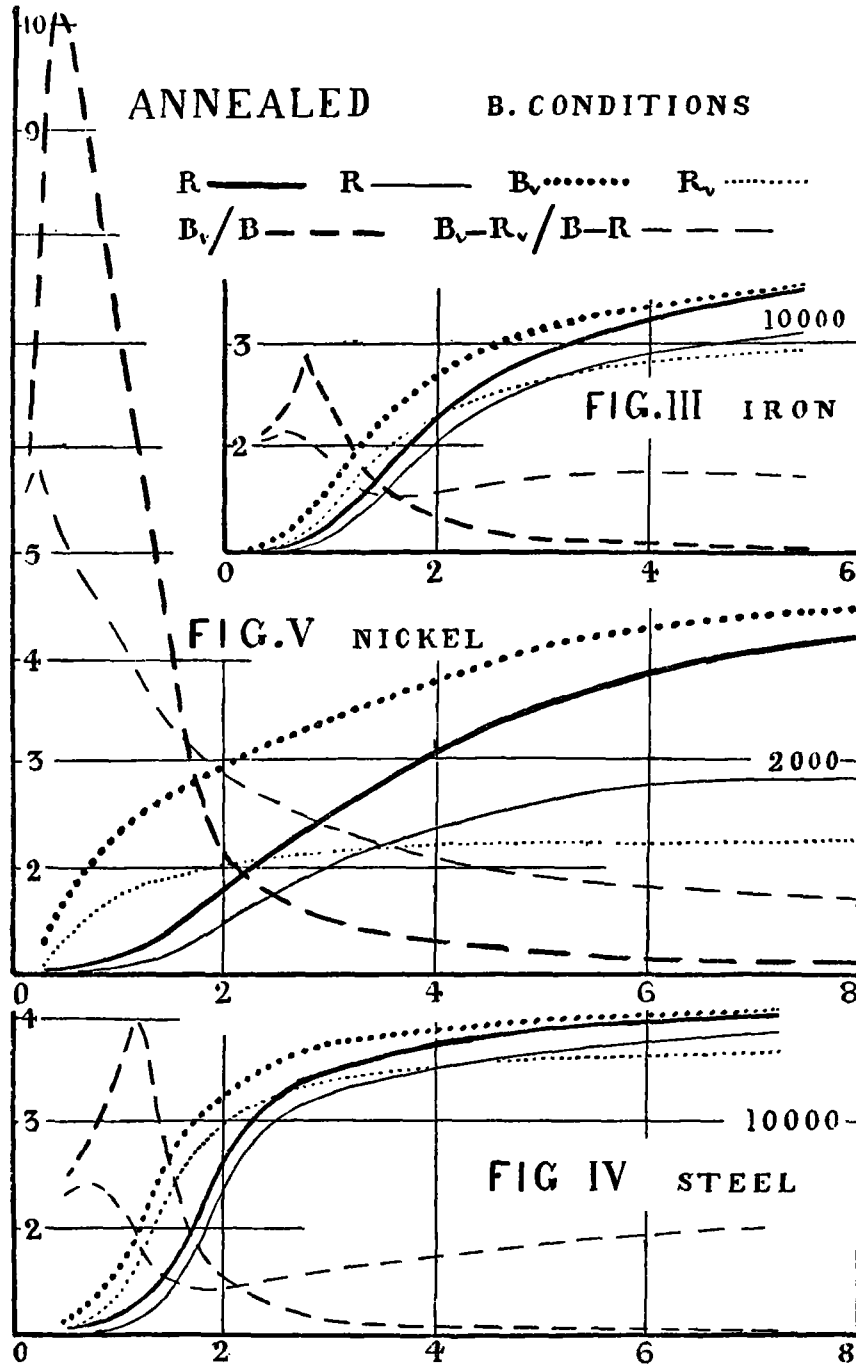
Annealed Metals, B Conditions.

Permeability and Retentivity Diagrams.—Figs. III., IV., and V. show, for the annealed condition of iron, steel, and nickel respectively, the usual *B*, *H* curves obtained in the manner already described, also curves of residual magnetisation (likewise plotted against *H*) obtained by withdrawing the field at all values of the induction measured. The full and faint continuous lines are the normal induction and the normal residual magnetisation curves respectively without vibrations. The full and faint dotted lines are the induction and residual magnetisation curves respectively with permanently acting vibrations.

The full and faint dash curves show the ratios B_v/B and $B_v - R_v/B - R$ respectively, for all values of *H*. *B* and *R* signify the induction and residual magnetisation without vibrations; B_v and R_v , the induction and residual magnetisation with vibrations.

The ordinates and abscissæ (*H*) are drawn to the same scale in the three figs., except that the scale of the ordinates for the permeability and retentivity curves in fig. V. (nickel) have been increased five times. The values of the ratio ordinates

(B_v/B and $B_v - R_v/B - R$) are to the left, the values of the induction ordinates to the right. It may be repeated that H and B are in C.G.S. units in all the diagrams.



EXPERIMENTAL RESULTS.

Permeability.—Permanently acting vibrations increase permeability. B_v/B is approximately a maximum when dB_v/dH is a maximum. But the actual difference

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$B_v - B$ is not a maximum until, on the further increase of H , the maximum value of dB/dH is more nearly approached.

In the former case the increase is much greater in nickel than in either iron or steel. In nickel, the maximum value of $B_v/B = 10$, while in iron and steel it is only about 3 and 4 respectively. As H passes beyond these values, B_v/B rapidly falls, and in sufficiently strong fields approximates to unity (strong dash-line curves).

In the latter case the actual maximum difference ($B_v - B$) is greatest in steel (4500), less in iron (2300), least in nickel (1250). It should be noted that the steel is more permeable than the iron wire used.

Residual Magnetisation in Relation to Field. — Permanently acting vibrations increase or decrease residual magnetisation as the fields are low or high. Both these effects are greatest in annealed nickel.

When the field is sufficiently increased, the induction and retentivity curves are always in the following descending order: B_v or B , R , R_v . This final relationship is very marked in annealed nickel, much less so in iron, least in steel.

It is instructive to consider, not merely the residual magnetisation, but the ratio of the negative induction changes with and without vibrations when the field is withdrawn ($B_v - R_v/B - R$). In this way a ready comparison may be made with relative positive induction change with and without vibrations when the field is acting (B_v/B).

The effect of vibrations in increasing the negative induction change in low fields when H is withdrawn is much greater in annealed nickel than in either iron or steel. In nickel (faint dash-line curves), the maximum value of $B_v - R_v/B - R = 5.8$, while in iron and steel it is only 2.2 and 2.6 respectively. These maxima occur at or near the lowest field values used. As H is somewhat increased these ratios rapidly fall in all the three metals. In nickel, as H is further increased this fall takes place slowly, and continues to do so at the maximum value of field used, viz. $H = 15$.

In iron and steel, on the other hand, these ratios increase in value when the field is higher than about 2 C.G.S. units.

Consequently, in annealed nickel, $B_v - R_v/B - R$ is much greater in low than in high fields. In iron and steel, on the other hand, this difference is comparatively small.

The faint dash-line curves show the comparative results fully.

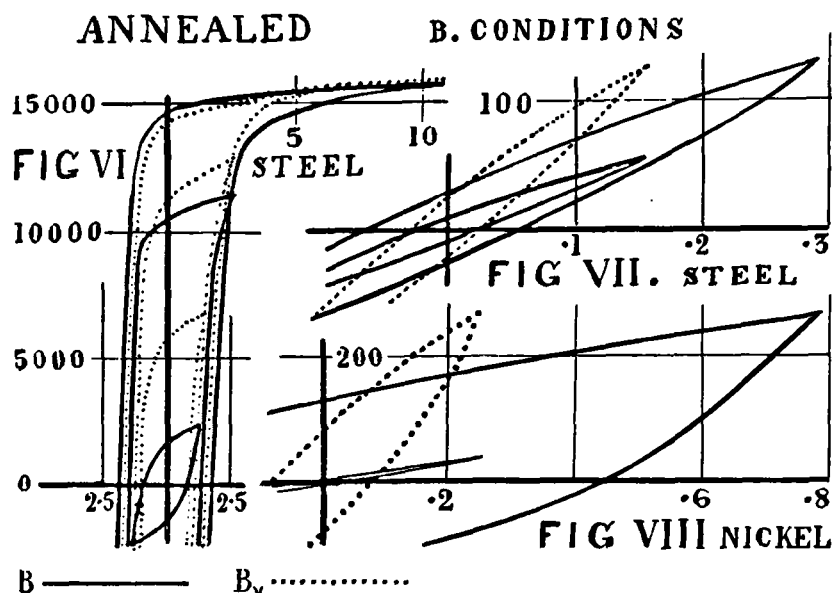
Residual Magnetisation in Relation to Induction. — If R and R_v be plotted against B and B_v respectively, it is seen that the residual magnetisation is less with than without permanently acting vibrations, when the field supporting the same induction in both cases is withdrawn. This decrease is greatest in annealed nickel.

See results under the same conditions for quenched nickel (p. 506).

Cyclic Diagrams.—Figs. VI., VII., and VIII., taken in conjunction with fig. II. for iron (curve 3 having the same intensity of vibrations as now used), show the changes in the hysteresis loops when a cyclic field is superposed upon permanently acting vibrations

in the manner described on p. 496. The dotted and continuous lines represent the cycles with and without vibrations. Figs. VI. and VII. show, for annealed steel, loops with and without vibrations, corresponding to the following four maximum values of field, viz. $H = 0.16, 1.46, 2.6$, and 11.0 . The induction at cyclic extremes covers the wide range between $B = 56$ and $B = 15,750$ without vibrations. These loops are typical of others taken at intermediate values of field. The cyclic curves for annealed iron are essentially similar to those for annealed steel (see fig. II., curve 3).

In figs. VII. and VIII. the smaller and larger of the two continuous-line loops (without vibrations) enable comparison to be made with the dotted-line loops (with vibrations)



for the same value at cyclic extremes of field and induction respectively. Fig. VII. is for annealed steel, fig. VIII. for annealed nickel.*

EXPERIMENTAL RESULTS.

Coercive Force.—Permanently acting vibrations increase coercive force when the values of field are low. This effect soon disappears as the fields are taken higher, and thereafter vibrations decrease coercive force. For the same value of induction, coercive force is always decreased.

* Fig. VIII. is one of the earlier experiments, and a thread was not introduced between the lever and the nickel wire under test. These observations have been repeated with this alteration, and the larger loop ought to be more sheared over than shown in this figure. The coercive force remains the same, the residual magnetisation is reduced to within 15 C.G.S. units of the dotted loop, and the value of H is increased to 1.25 . These corrections give the values of R and B at the cyclic extreme the same as in fig. V. for the same value of field. The increase of permeability and residual magnetisation is due to a *minute* torsional stress imparted to the nickel wire when no thread is introduced. The two smaller loops with and without vibrations remain exactly as shown, as also fig. XI., p. 503. The experimental results, therefore, relative to coercive force and hysteresis loss, remain as stated in the following section.

At low inductions and in low fields the decrease and the increase of coercive force respectively are both enormously great in annealed nickel as compared with iron or steel.

Hysteresis Loss in Relation to Field.—Permanently acting vibrations increase hysteresis loss in low fields, diminish hysteresis loss in high fields. The former is relatively the larger effect. In iron and steel the increase becomes less if the field be unduly decreased, the ratio then being about two to one. In nickel, on the other hand, the increase of hysteresis loss in similarly low fields of the order of $H = 0.2$ units is enormous. Fig. VIII. shows that the hysteresis loss with vibrations must be about twenty times as great as when no vibrations are acting.

As the fields are increased, however, the increase and final decrease of energy loss with vibrations in the three metals become quite compatible with each other.

Hysteresis Loss in Relation to Induction.—When the induction at cyclic extremes is the same, permanently acting vibrations cause a diminution of energy loss per cycle in the three magnetic metals at all values of induction. For moderately small inductions the decrease is approximately the same as that in my previous paper for iron with electric oscillations (say about three times). As the induction is increased, the diminution of energy loss becomes relatively less.

When, however, the induction is further decreased than above indicated, the decrease of energy loss is much greater in annealed nickel (see fig. VIII., where the induction at cyclic extremes is $B = 260$). In iron or steel, on the other hand (see fig. VII., where the induction at cyclic extremes is $B = 127$), the decrease of energy loss is less than at somewhat higher inductions, thus making the relative difference between nickel and either iron or steel more marked at these low induction values.

Annealed Metals, A Conditions.

Cyclic Diagrams.—Figs. IX., X., and I. show for iron, and fig. XI. for nickel, the effects of superposing vibrations under the *A* conditions. The dash-line curves measure the instantaneous induction change which occurs when vibrations are superposed at all stages of the normal loops (continuous-line curves). Figs. IX. and X., for iron, are for low and high cyclic induction values respectively, fig. I. for an intermediate value. The curves for steel are not given, as they are essentially similar.

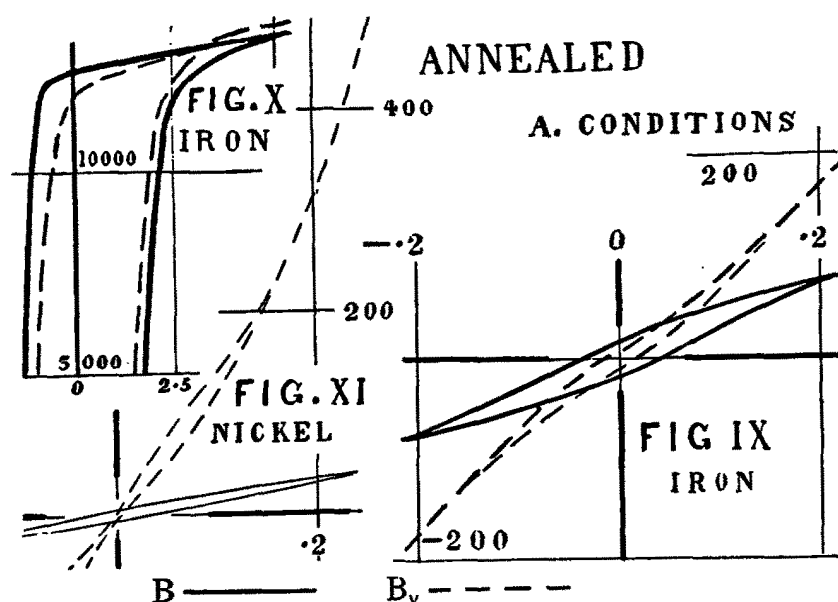
EXPERIMENTAL RESULTS.

The superposition of vibrations at cyclic extremes produces, for all values of field, an increase of induction. In high fields B_v/B approximates to unity.

The increase is enormous in nickel when field is sufficiently reduced. When $H = 0.2$, $B_v/B = 13$ (fig. XI.). In iron and steel this large increase in low fields is entirely absent (fig. IX.).

In nickel, the induction reached is much greater when vibrations are superposed (*A* conditions) than one-half the induction change on reversals when vibrations are permanently acting (*B* conditions). Compare figs. XI. and VIII. As we have seen, the reverse holds for iron and steel. Compare figs. I. and II. No systematic investigation, however, was made as to how these relative effects, under the *A* and *B* conditions, may vary through wide ranges of field, in nickel as compared with iron or steel.

As the cyclic extremes are departed from, the induction change which occurs when vibrations are superposed follows the field, not the field change. This effect, however, is a decreasing one, and a point is reached when the field is decreasing where superposed vibrations produce no induction change whatever.



It should be noted that, unless demagnetisation precedes each observation (*A* conditions), thus wiping out the effects of the immediately preceding superposition of vibrations, it is highly improbable that any induction change, opposite in sense to the field change, would be observed. For instance, if, as in EWING'S experimental method, field change and vibrations alternated all round the loop, the possible induction change would be exhausted on the up-curve at or near the cyclic extreme; and since the effect is a decreasing one, no induction change opposing the field change would be obtained with the same or any less intensity of vibrations when the cyclic extreme is departed from.

When this neutral point is passed, the superposition of vibrations produces induction change, in the same sense as the field is changing, and continues to do so until the first conditions are reverted to at the other cyclic extreme.

In low fields the neutral point occurs close to the vertical axis (fig. IX. for iron, fig. XI. for nickel). In high fields it is thrust from the vertical axis, and towards the

cyclic extremes (fig. X. for iron). Fig. I. shows an intermediate position at moderate values of field and induction.

But the position of the neutral point also depends, as we have seen (p. 497), upon the intensity of the vibrations, and it is now apparent that the shift of the neutral point depends upon the relative intensity of vibrations and cyclic field (induction). Unless possibly when the normal cyclic induction is extreme, increase (decrease) of cyclic field has the same effect as decrease (increase) of vibrational intensity in thrusting the neutral point from (towards) the vertical axis.

In all cases the induction change is greatest when mechanical vibrations are superposed on an increasing field. For low fields this occurs at or near cyclic extremes, where the slope of the curves is greatest. But as the cyclic field maxima are increased, the greatest induction change occurs at an earlier stage of the increasing field, where in this case also the normal curves are steepest.

Quenched Metals, B Conditions.

Permeability and Retentivity Diagrams.—Figs. XII., XIII., and XIV. show, for the quenched condition of iron, steel, and nickel respectively, the usual permeability and residual magnetisation curves with and without permanently acting vibrations, in the same way as figs. III., IV., and V. show these curves for the annealed condition. The corresponding ratio curves are also given. The scale of the horizontal ordinates of fig. XIV. has been diminished three times as compared with fig. V., on account of the lower permeability of quenched nickel.

The effects of quenching the three metals in water from a red heat may be noted by comparing the full (B) and faint (R) continuous-line curves of figs. XII., XIII., and XIV. with the corresponding curves of figs. III., IV., and V., for the annealed condition of these metals. We are not, however, concerned with the effect of quenching, but with the effect of mechanical vibrations upon the quenched condition.

EXPERIMENTAL RESULTS.

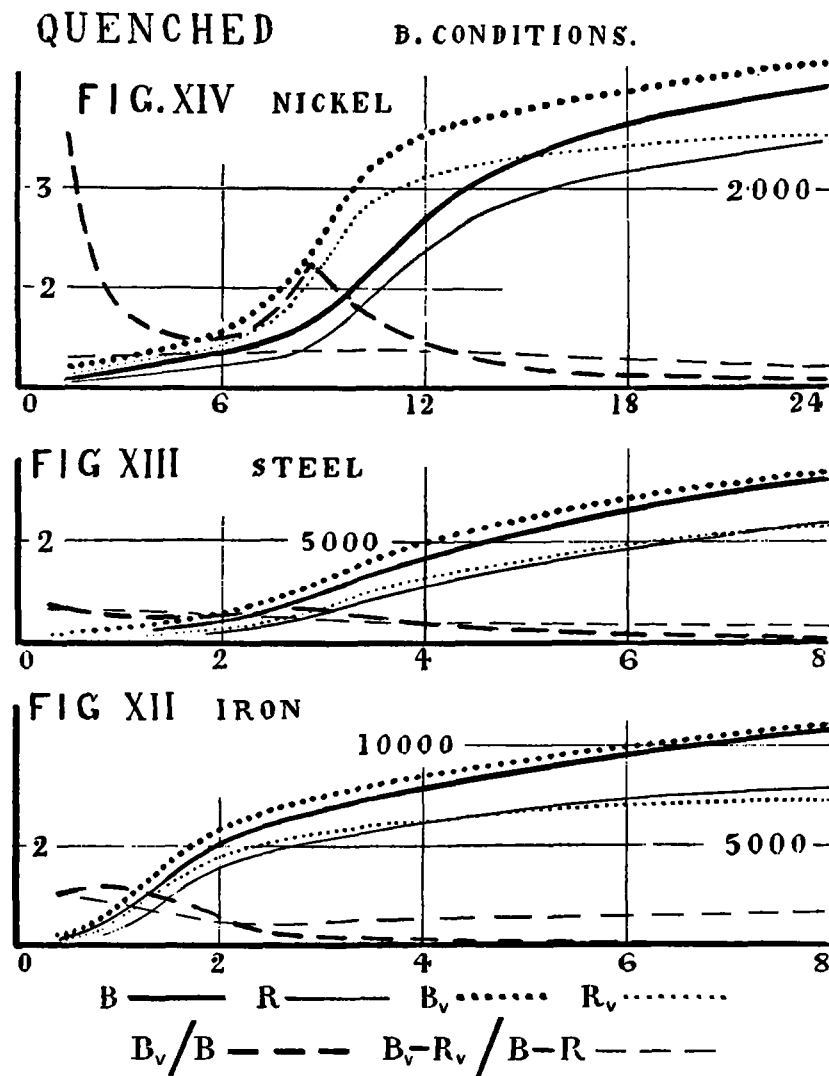
Permeability.—The effect of permanently acting vibrations in increasing permeability is very much reduced in quenched as compared with annealed iron and steel. The reduction of the ratio B_v/B is somewhat more marked in quenched steel than in quenched iron (figs. XII. and XIII., full dash-line curves).

In quenched nickel, on the other hand, the full dash-line curve B_v/B (fig. XIV.) shows the existence of two maxima, the second where dB_v/dH is a maximum. In another series of experiments both maxima approximated to $B_v/B = 3$, and in lower fields than here shown the ratio fell as in the annealed metals. In quenched steel corresponding maxima are just indicated. Quenched iron shows, like the annealed metals, one maximum where approximately dB_v/dH is greatest.

Further, the increase of permeability with vibrations is very much greater in quenched

nickel than in quenched iron and steel. In this respect quenched nickel more nearly resembles the annealed metals.

The observations from which these curves were plotted show that $B_v - B$, as in the annealed metals, does not reach a maximum until H is further increased. In nickel, $B_v - B$ is a little greater than in either iron or steel (1000 as against 700). In the annealed metals the opposite was the case.



Residual Magnetisation in Relation to Field.—Permanently acting vibrations increase or decrease residual magnetisation as the fields are low or high; but the former effect is very much less in quenched iron and steel than in quenched nickel. This accounts for the fact that in quenched iron and steel the retentivity curves with vibrations (R_v) never rise above the normal induction curves without vibrations (B), as they do in the annealed metals and in quenched nickel.

When the field is sufficiently increased, the induction and retentivity curves for quenched iron and steel occur in the same descending order as in the annealed metals: B_v or B , R , R_v . The field has not been carried high enough to show with certainty whether this final relationship occurs in quenched nickel.

Consider now the ratio of negative induction change $(B_v - R_v / B - R)$ with and without permanently acting vibrations. This ratio does not differ much from 1.2 to 1.4 for all the three metals in a quenched condition for all values of field; but in the additional experiments referred to in the preceding page this ratio for quenched nickel increased as the field was decreased below $H = 3$.

Retentivity in Relation to Induction.— Permanently acting vibrations do *not* decrease retentivity in all the quenched metals and at all values of induction, as is the case, so far as observed, in the annealed condition of the same metals (see p. 500).

In quenched nickel the residual magnetisation is decidedly greater with than without vibrations for low values of induction. For inductions under 500 or 600 the increase of retentivity with vibrations is relatively great. The cyclic curves of fig. XVI. may also be referred to. The residual with vibrations (dotted curve when $H = 0$) is substantially greater than the residual without vibrations (stronger full-line curve when $H = 0$), the maximum induction before the field is withdrawn being in both cases 180 C.G.S. units.

For inductions ranging between 1000 and 3000 no certain conclusion was reached. Fig. XVII. shows the residual with vibrations to be greater (by 20 magnetic lines) than the residual without vibrations, the induction in both cases being 2400. On the other hand, another experiment made at a different time, with an induction in both cases of 2230, showed the residual to be less (by 6 magnetic lines) with than without vibrations.

In any case, no doubt exists that in quenched nickel the residual magnetisation is greater with than without permanently acting vibrations when the field producing in both cases the same induction of the order of hundreds is withdrawn; further, that at the highest inductions used (3000 to 4000) the decrease of residual magnetisation with vibrations, if it exists, is very small.

In quenched steel, on the other hand, permanently acting vibrations decrease the residual magnetisation for all values of induction.

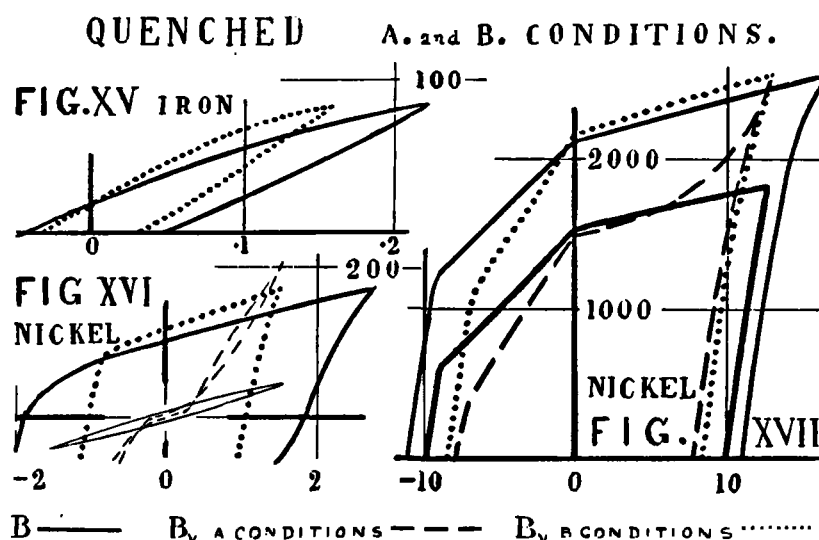
For low values of induction, quenched iron takes an intermediate position. For the same maximum induction, with and without vibrations, the residual magnetism is the same. This is shown in fig. XV., where the maximum value of $B = 85$. But as the induction is taken higher, permanently acting vibrations increasingly decrease residual magnetisation.

Cyclic Diagrams.—Figs. XVI. and XVII. show the effects both of permanently acting and superposed vibrations for quenched nickel in low and higher cyclic fields respectively. The continuous-line curves are the normal hysteresis loops for two values of field in each figure. The dash-line curves measure the instantaneous induction change when

vibrations are superposed (*A* conditions) at all stages of the smaller of the normal loops (lower field). The dotted loops, on the other hand, measure the hysteresis loss for permanently acting vibrations (*B* conditions) for the same maximum value of field (compare with the smaller normal loops in each figure), and also for the same maximum value of induction (compare with the larger normal loops in each figure).

Fig. XV. shows the effect of permanently acting vibrations only for quenched iron upon hysteresis loss (and residual magnetisation for the same maximum value of induction ($B = 85$) already referred to). The dotted and full-line curves have the same signification as before.

Attention may here be called to the shape of the loops in the case of quenched nickel. The areas are bounded practically by six straight lines, rather more marked



when the induction is of the order of thousands (fig. XVII.) than hundreds (fig. XVI.). The abrupt changes which occur during the cyclic process may be compared with those first observed by NAGAOKA * when nickel wire is subjected to torsion combined with longitudinal pull. The same abrupt changes were obtained without load.

Note that vibrations have little or no effect in lessening the rectilinear character of the normal loops. Indeed, for low values of field, vibrations rather increase this characteristic than otherwise.

Coercive Force.—The general effect of permanently acting vibrations is the same in the quenched as in the annealed condition, and the same differences also exist when quenched nickel is compared either with quenched iron or steel. These latter metals call for no further remark. Their behaviour is normal. But the decrease of coercive force for the same value of low induction is less in quenched than in the annealed

* *Magnetic Induction in Iron*, EWING, 3rd ed., p. 248; *Jour. Coll. Science Imp. Univ. Japan*, vol. ii. p. 304.
TRANS. ROY. SOC. EDIN., VOL. XLV. PART II. (NO. 17).

nickel. On the other hand, its increase for the same maximum value of low field is greater in quenched than in annealed nickel. Compare figs. XVI. and VIII.

Hysteresis Loss.—The same general conclusions applicable to the annealed condition also apply to the quenched condition of the three metals. Iron and steel call for no special remark. In quenched nickel the increase of hysteresis loss caused by permanently acting vibrations for the same value of low field is (as in annealed nickel) enormously greater than in iron and steel. On the other hand, for the same value of induction, the reduction of hysteresis loss caused by vibrations is very much less in quenched than in annealed nickel. In both cases figs. XVI. and VIII. (annealed nickel) may be referred to.

Quenched Metals, A Conditions.

EXPERIMENTAL RESULTS.

The superposition of vibrations at all stages of the normal hysteresis loop produces the same general effects in the quenched as in the annealed condition of the three metals. But in quenched nickel a striking peculiarity is found to exist. The neutral point is not so well defined as in the annealed condition of the three metals, and in quenched iron and steel. When this point is reached, the increase of induction has disappeared, but the decrease of induction is very small until the field has passed through zero and has changed sign. This is shown in figs. XVI. and XVII. It will be observed that, when the increase of induction has disappeared, the dash-line curves bend sharply towards the vertical axis, thus closely hugging the normal loop for some distance. Fig. XVII. shows that, when the cyclic induction is considerable, the decrease of induction due to superposed vibrations becomes almost immediately and increasingly well marked after the field supporting the normal loop has changed sign. On the other hand, when the cyclic induction is small (fig. XVI.) the dash-line curve still hugs the normal loop for some distance after the field has been reversed. The dash-line curves of fig. XVI. may be contrasted with fig. XI. for annealed nickel.

Superposed vibrations, therefore, have relatively very little effect in reducing residual magnetisation in quenched nickel. It is interesting to compare this result with that recently obtained by Prof. ANDREW GRAY.* He found that vigorous tapping at the temperature of the room had no effect in reducing the residual magnetisation of a rod of a certain sample of HEUSLER'S magnetic alloy, although previous tapping at the temperature of 100° produced a considerable reduction in the residual magnetisation. It is obvious that quenched nickel approximates closely to this magnetic alloy, in resisting the usual effect of vibrations to lower residual magnetisation, whether superposed under the *A* or under the *B* conditions. But in the latter case vibrations increase residual magnetisation at low inductions (see p. 506).

* "Note on Heusler's Magnetic Alloy," *Proc. Roy. Soc.*, vol. lxxvii., Series A, p. 256.

SUMMARY OF EXPERIMENTAL RESULTS.

Vibrations may be superposed upon constant field (*A* conditions), or change of field may be superposed upon permanently acting vibrations (*B* conditions).

A and B Conditions.

Permeability. --In all cases vibrations increase induction. In high fields B_v/B approximates to unity. The relative magnitude of this effect under the *A* and under the *B* conditions depends upon the magnetic metal and possibly on the field intensity. In nickel, the induction reached is greater (if field be not unduly increased) when vibrations are superposed (*A* conditions) than one-half the induction change on reversals when vibrations are permanently acting (*B* conditions). The reverse is the case for iron and steel.

B Conditions.

Permeability. --In all cases B_v/B is approximately a maximum when dB_v/dH is a maximum. In annealed nickel the maximum value of $B_v/B = 10$; in annealed iron and quenched nickel, about 3; in annealed steel, 4; and in quenched iron and steel, a decided minimum. In quenched nickel the B_v/B curve shows two well-marked maxima: the second when dB_v/dH is a maximum, the first at a lower value of field. Two corresponding maxima are merely indicated in quenched steel. In no other case are they observable.

On *H* being further increased, maximum values of $B_v - B$ occur, so far as observed, a little earlier than maximum values of dB/dH . In annealed steel the maximum value of $B_v - B = 4500$; in annealed iron, 2300; in annealed nickel, 1250; but in quenched iron and steel rather less (700) than in quenched nickel (1000).

Negative Induction Change.—The ratio of the negative induction change when field is withdrawn, with and without vibrations ($B_v - R_v/B - R$), distinguishes the quenched from the annealed condition. In the quenched metals this ratio does not differ greatly from 1.3 for all values of field other than the lowest. In the annealed metals, on the other hand, it varies largely with field, reaching a maximum in annealed nickel (5.8), and minimum values (1.6) in annealed iron and steel, when *H* is approximately = 2. (In quenched iron a corresponding minimum is merely indicated.) In nickel $B_v - R_v/B - R$ is much greater in low than in high fields. In annealed iron and steel this difference is less marked. In all cases and in the lowest fields used $B_v - R_v/B - R$ approximates to B_v/B .

Coercive Force, Retentivity, and Hysteresis Loss in Relation to Field.—These are increased or decreased as the field is low or high, but in quenched nickel the decrease of residual magnetisation, if it exists at all, is very small.

The relative increase of coercive force is greater in annealed and quenched nickel than in iron and steel. Increase passes into decrease earlier in the case of coercive force than of residual magnetisation.

The increase of hysteresis loss in low fields is relatively greater than its decrease in high fields. In annealed and quenched nickel its relative increase is enormously great in the lowest fields used. There is nothing corresponding to this when field is unduly decreased in iron and steel.

Coercive Force and Hysteresis Loss in Relation to Induction.—In all cases for the same value of induction at cyclic extremes, coercive force and hysteresis loss are decreased. At high inductions the decrease of energy loss is relatively smaller than at lower inductions. At very low inductions the decrease of loss produced by vibrations is a decided maximum in *annealed* nickel.

Retentivity in Relation to Induction.—Vibrations do not in all cases decrease residual magnetisation. In quenched nickel, when the field producing the same induction of the order of hundreds in both cases is withdrawn, the residual magnetisation is greater with than without permanently acting vibrations. At low inductions in quenched iron R_v may equal R ; in all other cases R_v is less than R .

The effect of permanently acting vibrations in reducing residual magnetisation at high inductions is greater in annealed nickel than in annealed or quenched iron and steel. In quenched nickel this effect, if it exists at all, is very small.

A Conditions.

When vibrations are superposed at all points of the normal hysteresis loop, the induction change as the cyclic extremes are departed from is first against, afterwards with, the field change. The position of the neutral point depends upon the relative intensity of vibrations and cyclic field (induction). The smaller the cyclic field and (so far as my experiments have gone) the greater the vibrational intensity, the closer is the neutral point thrust towards the vertical axis; the higher the cyclic field and the less the vibrational intensity, the closer is the neutral point thrust towards the cyclic extreme. Thereafter the induction change continues to follow the field change until the other cyclic extreme is reached.

In all cases the induction change is greater when vibrations are superposed on the normal loop when the field is increasing. For low fields the maximum change occurs at or near cyclic extremes, where the slope of the curve is greatest. But as the cyclic field is increased, the maximum induction change occurs at an earlier stage of the increasing field, where in this case also the normal curve is steepest.

Vibrations of increasing intensity produce a progressive collapse, by no means complete, of the two arms of the loops. The imperfect nature of this collapse is well exhibited in quenched nickel in low fields. The curves cross at two points, three loops being thus formed. This peculiarity is not confined to quenched metals.

MAGNETIC HYSTERESIS.

When field varies cyclically, the loop formed by the curves connecting B and H is said to be the result of *magnetic hysteresis*; no loop, no hysteresis.

The effect of vibrations superposed at all stages of the normal loop (A conditions) is, generally speaking, to lessen those differences of magnetisation to which hysteresis *without vibrations has already given rise*.

But if the vibrations continue, and the field becomes cyclic, the effects of vibrations cannot be stated concisely in terms of the effects of magnetic hysteresis. To do so, when cyclic field is superposed upon permanently acting vibrations (B conditions), requires as complete a knowledge of the B, H loop as is required without vibrations.

The loops obtained when vibrations are permanently acting (B conditions) are stable to subsequent "offs" and "ons" of the same vibrations. The loops obtained without vibrations are not stable to superposed vibrations (A conditions).

Obviously EWING's statements quoted at the beginning of this paper are not universally applicable. Although his experimental methods, in which field change and tapping alternated, almost certainly precluded the observation of the neutral points, his statements are quite applicable to the A conditions whatever the intensity of the vibrations. They are, however, not applicable when applied to the B conditions, when the intensities of the vibrations are such that their effects have not reached a limiting value.

MOLECULAR THEORY.

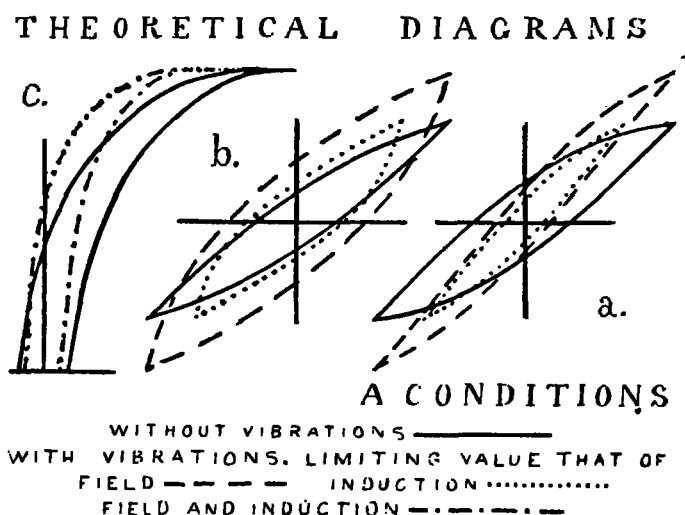
§ 182 of *Magnetic Induction in Iron* may be consulted. The general nature of the argument is shown by the following quotation:—"Any kind of disturbance that will give the molecular magnets intervals of freedom, or of diminished constraint, will tend to do away with hysteresis." This statement also appears completely applicable if the disturbances be superposed under the A conditions. Under the B conditions I prefer a deduction relative, not to hysteresis, but to the rate of magnetic change with field change, subject to any condition which the molecular theory may demand. However much B_v may exceed B in low fields, the ratio B_v/B must in high fields approximate to unity. Consequently, if the differential permeability in low fields be greater with than without vibrations, in high fields the reverse necessarily follows.

My deductions therefore are: (1) that if the cyclic amplitude be not unduly increased the differential permeability will be greater with than without permanently acting vibrations; (2) that the increase of differential permeability with vibrations may be associated either with increase or decrease of residual magnetisation, coercive force, or hysteresis loss, but that there is greater probability that those magnetic properties which depend upon hysteresis will be increased with vibrations for the same value

of field than for the same value of induction, and conversely, that there is greater probability that they will be decreased with vibrations for the same value of induction than for the same value of field.

The diagrams *a* and *b* illustrate the above deductions, and are self-explanatory. The continuous lines represent the normal loops without vibrations; the dash and dotted lines, the loops with permanently acting vibrations for the same values of field and induction at cyclic extremes respectively.

The experimental results show that the first deduction is fulfilled for the three magnetic metals examined, in the annealed and in the quenched condition alike. At every corresponding point of the loops the differential permeability is, so far as observed, greater with than without permanently acting vibrations. The second deduction is also supported by the results in so far as residual magnetisation, coercive force, and



hysteresis loss are invariably increased for the same value of low field at cyclic extremes, while coercive force and hysteresis loss are decreased, residual magnetisation only being increased in quenched nickel, for the same value of induction at cyclic extremes.

Further, the experimental results obtained do not exhaust all the possibilities of the effects of vibrations on magnetisation. For the same value of induction amplitude the descending and ascending arms of the loops, with and without vibrations, generally cross in the first and third quadrants respectively, as represented in diagram *a* (dotted curve), but in quenched nickel in the second and fourth quadrants respectively (see fig. XVI.), a position between the extreme positions represented by diagrams *a* and *b* (dotted curves).

The question therefore arises whether a condition of some magnetic metal or alloy could not be found, so that the arms of the loops would cross in the third and first quadrants respectively, as represented in diagram *b* (dotted curves). In this case not

only would residual magnetisation be increased with permanently acting vibrations (as in quenched nickel), but also coercive force and hysteresis loss, relative to the same value of induction. Such a result may be highly improbable, but its possibility does not appear to be excluded by these general theoretical considerations, and in the case of quenched nickel the experimental results are certainly converging in this direction.

Observe further that, however much the cyclic amplitudes be increased, the full and dotted line curves of diagrams *a* and *b* might still be used to illustrate the possibilities under deduction (2); but as the limiting value of magnetisation is approached, the vertices of both cycles would coincide, and the slope of the curves at high inductions would be less with than without vibrations, if the reverse held at low inductions.

Hence, when saturation values are departed from, the rate of magnetic change with field change would be less with than without permanently acting vibrations. Diagram *c* may be referred to, illustrating a position as regards the crossing points midway between the extremes shown in diagrams *a* and *b*.

ELECTRIC OSCILLATIONS.

The similarity between the effects of electric oscillations and mechanical vibrations was, as stated at the outset, anticipated. It has long been recognised that disturbances other than mechanical produce effects upon magnetisation essentially vibratory. A rise or a fall of temperature increases induction, decreases residual magnetisation.* Similarly, transverse magnetisation (which contributes nothing to the result) supplies the first molecular tap, which, if superposed at a cyclic extreme, produces increase of induction, or, if superposed when the field is withdrawn, a decrease of residual magnetisation. The experiments of GEROSA and FINZI and others of a similar nature are well known.

But in these latter cases the purely vibrational effects are materially altered by the direct magnetic effects of the subordinate unidirectional or alternating currents, and sooner or later the analogy becomes imperfect. Permeability is lowered in high fields, and direct hysteresis effects are unavoidable. On the other hand, as the direct magnetising action of high-frequency currents is very greatly reduced, it appeared reasonable to suppose that the vibrational effects due to high frequency would be increased, and consequently that the analogy between the magnetic effects of electric oscillations and mechanical vibrations would be more complete.

It became immediately apparent, as soon as this investigation was commenced, that the effects of mechanical vibrations upon magnetisation were essentially the same as those produced by electric oscillations in coils surrounding the iron previously dealt

* *Magnetic Induction in Iron*, 3rd ed., p. 181 (WIEDEMANN).

with (*Proc. R.S.E.*, vol. xxvi. p. 33). The experimental methods being the same in both cases facilitates comparison. Under both the *A* and *B* conditions the similarity extends to details.

It also appears evident that, had the experimental methods of the earlier investigations dealing with the effects of purely mechanical vibrations upon magnetisation been such as to elucidate the various phenomena involved under the *A* and *B* conditions, the results of later investigators (ASCOLI, ARNO, WALTER and EWING, GARIBALDI, MARCONI, MAURAIN, PIOLA, WILSON, and others) relative to the effects of electric oscillations upon magnetisation would have fallen more readily into line with each other* and with the effects of purely mechanical vibrations.

The effects, therefore, of electric oscillations upon magnetisation are essentially the same as those produced by mechanical vibrations.

CONCLUSION.

The experimental results given in this paper, summarised on pages 509 to 510, and discussed in their relation to magnetic hysteresis, molecular theory, and electric oscillations in the pages which follow, answer more or less completely the questions propounded when the effects of mechanical vibrations upon magnetisation have not reached a limiting value.

The experiments, however, were made, as has been stated, with wires subjected to a small load. A few of these have been repeated without load; wires of annealed iron and nickel were soldered to the gong, and supported in the glass tube by means of loose pads of cotton wool. The general relation of the curves to each other, as shown in figs. III. and V., were not found to be materially altered, although in the case of nickel the increase of the induction and residual magnetisation curves is considerable owing to the absence of load (see table, p. 494).

The results, therefore, in so far as common to the three magnetic metals examined in an annealed and quenched condition, may be concisely stated, without reference to load, as follows:—

(1) In all cases vibrations increase permeability (induction), but in high fields the ratio B_v/B approximates to unity.

(2) The effect of vibrations superposed at all stages of the normal loop (*A* conditions) is, generally speaking, to lessen those differences of magnetisation to which hysteresis *without vibrations has already given rise*.

(3) When change of field (cyclic or increasing from zero) is superposed upon permanently acting vibrations (*B* conditions), the differential permeability is increased in low fields, diminished in high fields. In sufficiently high fields vibrations must delay demagnetisation.

(4) The effects of electrical oscillations upon magnetisation supported by an

* "Notes on the Effect of Electric Oscillations on Magnetism," L. H. WALTER, *Electrician*, May 5, 1905.

independent field (which may be zero) are essentially the same as those produced by purely mechanical vibrations.

Within the limits stated under (1), (2), and (3), the effects of vibrations upon magnetisation exhibit striking differences between iron, steel, and nickel in the annealed and in the quenched conditions, which involve, more especially under (3) with cyclic fields, a complete study of the curves in each case (see summary of experimental results). The investigation cannot in any sense be regarded as exhaustive. Many additional inquiries present themselves, among which the following may be mentioned:—If the vibrations were such as to exhaust the possible increase of induction with increasing field, would hysteresis loss (for instance) be decreased instead of increased for the same value of low field at cyclic extremes? Under the same conditions, would residual magnetisation in quenched nickel be decreased instead of increased for the same value of low induction at cyclic extremes? The induction reached when vibrations are superposed (*A* conditions) is greater in nickel, less in iron and steel, than one-half the induction change on reversals when vibrations are superposed (*B* conditions). Does this fact throw any light on the relative inter-molecular controlling forces as they exist in these different metals?

In conclusion, this investigation was, as has already been pointed out, directly suggested by previous work on the effects of electric oscillations upon magnetisation, with which it is intimately associated. The results and suggestions obtained with purely mechanical vibrations undoubtedly facilitate further investigation in its theoretical and practical aspects (magnetic detectors) dealing with the primary objects of those researches for which the Royal Society of London placed at my disposal a Government grant, which I desire to acknowledge.

I also desire to express my indebtedness to Dr Peddie for advice kindly given at all times; and to Professor Macgregor for facilities to quench the wires, which I did not possess.

(Read December 17, 1906.)

In a paper* on "The Effect of Electric Oscillations on Iron in a Magnetic Field," read to the Physical Society on 22nd June 1906, Dr ECCLES, in referring to my paper (*Proc. R.S.E.*, vol. xxvi. p. 33) on the same subject, states: "RUSSELL applied to his iron the oscillations passing through a coil connected directly in series with a small induction coil. This last method appears to the writer to subject the iron to very violent treatment of a nature not easily described accurately; for how far the mere surgings of secondary current overwhelm in importance the genuine oscillations, it will be difficult to say."

I formally assumed that the effects upon magnetisation of oscillations produced as above described would not differ essentially from oscillations produced in wires by means of Hertz waves.

* *Phil. Mag.*, August 1906; *Electrician*, August 24, 1906.

On 14th and 15th July last I found this assumption to be absolutely correct. Oscillations (produced in the usual way by means of two small Leyden jars fed by induction coil, spark gap, and loosely coupled oscillation transformer) could either be passed directly through a long iron wire, .041 cms. diameter, or through a coil of one layer surrounding it. In both cases the effects of these oscillations, when superposed under the *A* and also under the *B* conditions, were essentially the same as the effects of purely mechanical vibrations upon magnetisation. Any of the corresponding curves of figs. I. and II. (present paper) show the results obtained with sufficient accuracy.

I should like, however, to point out an essential particular in which Dr ECCLES' experimental methods differ from my own. He states that "the effects of the spark are recorded as if the observations had been taken only on the ascending half of the hysteresis curve; the figures given being, in fact, the means of the measured effects at points symmetrical with regard to the origin on the ascending and descending branches." Consider, say, the 100 cycle of Table I. (*Phil. Mag.*, August 1906, p. 113). When the field is +100 the effect of the spark is +1.18. But this result has been obtained by taking the means at both cyclic extremes; hence, when the field is -100, the spark effect is -1.18. No readings are given in the third column when field is -75, but when it is reduced to -50 the effect of the spark is +0.27. The experiments, therefore, do not show how the transition from -1.18 at the negative cyclic extreme (field -100) to +0.27 when the field is reduced to -50 has taken place. This 100 cycle is typical of the other three cycles given.

Consequently, in the series of figures plotted from Table I. the curves measuring the effect of the spark on the ascending half of the hysteresis curve begin in the second and finish in the first quadrant, when in reality they ought to be represented by a continuous curve beginning in the third and finishing in the first quadrant.

Dr ECCLES states that he found it possible "to get over and over again practically the same magnetometer deflection for every spark, provided the effect of previous oscillations was wiped out by taking the iron through *a cycle*." The fact that the observations could be repeated does not prove that the effect of previous oscillations had been wiped out. The cycle so obtained is not symmetrical about the origin, its want of symmetry being determined by the "set" or permanent deformation given to the magnetisation by the preceding oscillations. This is in accordance with the known facts of magnetisation. Moreover, I found, previous to determining my own experimental methods under the *A* conditions, that *repeated reversals of the cyclic field* were not sufficient to wipe out the effect of immediately preceding oscillations, and that to do so the magnetic metal must be demagnetised by decreasing reversals after each superposition of an electric oscillation or of a mechanical vibration.

One of the conclusions arrived at is as follows:—"It is evident, moreover, that the magnitude of the effect at any point is closely connected with the slope of the hysteresis curve." It is quite true that the maximum spark effect is closely connected with that point of the loop where the slope is greatest, but the occurrence of a neutral

point, now well established, after a cyclic extreme is departed from, and which may even occur close to the vertical axis, disposes of any connection between the value of dB/dH at *any point* and the magnitude of the spark effect. The spark effect, or the difference $B_v - B$ when vibrations are used, may be a simple function of dB/dH at *any point* when the B, H curve is determined by increments from zero; but this cannot be so during the cyclic process.

Dr ECCLES' experimental method reproduces to a certain extent the working conditions of the first form of MARCONI's magnetic detector of electric waves, and confirms the latter's experience that the magnitude of the spark effect is small as a cyclic extreme is departed from. But in neither case are oscillations superposed upon a hysteresis loop which has not already been modified by the effect of previous oscillations. In neither case are the A conditions fulfilled.