IV. *On the Effects of Pressure on the Magnetisation of Cobalt.*

By C. CHREE, *M.A., Fellow of King's College, Cambridge.*

Communicated by Professor J. J. THOMSON, *F.R.S.*

Received November 22,—Read December 19, 1889.

[PLATES 15, 16.]

§ 1. IN August, 1888, I commenced an investigation into the effects of pressure on the magnetic properties of cobalt, at the suggestion of Professor J. J. THOMSON. In his "Applications of Dynamics to Physics and Chemistry," he has arrived at certain conclusions as to the relations of magnetisations and mechanical strains, and the primary object of the following investigations was to obtain experimental data, whereby these conclusions might be tested.

During the process of the experiments, numerous points presented themselves whose elucidation seemed of importance for a satisfactory comparison of theory and experiment. The experiments have thus included a wider range than was originally intended, and have occupied a considerable amount of time.

Phenomena resembling very closely in some points those to be presently discussed have been noticed by previous observers in iron and nickel. As frequent references to these will be found essential for an adequate discussion of the phenomena presented by cobalt, a brief outline of the more prominent characteristics is here interposed.

§ 2. If a bar of some magnetic metal, subjected to a constant longitudinal stress, be exposed to the action of a magnetising current in a surrounding spiral it becomes magnetised, and in general simultaneously alters its length. If the current cease to flow the bar retains in general part of its magnetisation, and it may not return to its original length. On the other hand, if the bar while under the action of a constant current in the magnetising spiral, be subjected to a longitudinal stress, it in general simultaneously alters its magnetisation. Also, if the stress cease to act the magnetisation may not return to its original value. Phenomena similar to the last are also shown by the magnetisation which is residual after the break of the current.

These phenomena all depend on the *intensity* of magnetisation in the bar. The mode of this dependence will be discussed in considerable detail presently, but erroneous ideas are not unlikely to arise unless the following practical considerations be kept clearly in view.

When a bar whose diameter of cross section is comparable with its length is magnetised in a uniform field, there seems good reason to believe that the magnetisation it possesses is very decidedly less in the interior near the axis than it is near the surface, and when the bar is possessed merely of residual magnetism, the difference between the interior and surface distributions seems completely proved. When, as usual, the magnetising field is not uniform, there is in general still less reason to expect a uniform intensity of magnetisation. Thus, in general, a bar may be regarded as composed of a large number of elements, throughout each of which the magnetisation may be treated as sensibly uniform, but which may differ widely amongst themselves. The term *intensity* applied to the magnetisation of such a bar merely means some sort of average of the intensities throughout the several elements.

Now the application of a given stress to such a bar may affect very differently the magnetism of different elements. It may, for instance, increase the magnetisation of some of them and diminish that of others. Experiments as a rule give merely a sort of integral of the effects on the different elements, and this ought to be clearly recognised.

In particular I would point out that the magnetic moment of a bar, as determined by some definite method, may have the same value when the bar is exposed to the action of a certain current in a spiral, as it has after the break of a larger current in the spiral, and that notwithstanding there may be an important difference between the distributions of magnetism in the two cases. There is thus no *à priori* reason to expect the same phenomena to follow the application of a given longitudinal stress in the two cases.

Effects of Magnetism on the Length of Bars.

§ 3. Such effects have been observed by JOULE,* MAYER,† Professor BARRETT,‡ and Mr. SHELFORD BIDWELL.§

JOULE's experiments dealt with iron and steel. His method of experiment consisted in running a current through a magnetising spiral and observing the instantaneous changes in the length of the bar accompanying the make and break of the current. Observations were taken with several currents gradually rising in strength. Apparently JOULE did not demagnetise his rods in the course of his experiments, nor does he seem to have examined the effect of making and breaking the same current more than once. He concluded that in iron or soft steel bars free from stress the institution of a current in a surrounding spiral is followed by an increase in the length of the bar proportional to the square of the intensity of the magnetisation

* 'Phil. Mag.,' vol. 30 (3rd series), 1847, pp. 76–87 and 225–241.

† *Ibid.*, vol. 46 (4th series), 1873, pp. 177–201.

‡ *Ibid.*, vol. 47 (4th series), 1874, p. 51; also 'Nature,' vol. 26, 1882, p. 585.

§ 'Phil. Trans.,' A, vol. 179, 1888, pp. 205–230. Also 'Roy. Soc. Proc.,' vol. 40, 1886, pp. 109–133 and 257–266.

induced in the bar, and that on the break of the current there remains an increase in length proportional to the square of the intensity of the residual magnetisation. JOULE also found that iron and soft steel under tension lengthened or shortened when magnetised according as the tension was small or great. He believed the shortening proportional to the product of the bar's magnetisation into the strength of the magnetising current. This last conclusion, however, is certainly not warranted by the results of his experiments.

On JOULE'S p. 237, are given the results of an experiment, numbered 23, in which a soft steel wire exposed to a certain tension showed an increased length while exposed to a certain current, lengthened further when the current was broken, and then shortened on the make of a stronger current. This suggests that for the wire in question under a given load there existed a critical intensity of magnetisation, and that the bar lengthened or shortened according as the magnetisation was less or greater than the critical value. The true interpretation of this experiment seems to have been entirely missed by JOULE, and it would not appear to have attracted the notice of subsequent observers. It is thus only within the last few years that the existence of a critical field, or state of magnetisation, has been brought to light by the decisive experiments of Mr. SHELFORD BIDWELL.

§ 4. MAYER experimented with rods free from longitudinal stress, and he gives the results of the make and break of only one strength of current. The current was, however, twice made and broken in some at least of the experiments, and the results of both the magnetic cycles are recorded. Some of the results, given in a table on his p. 200, are so suggestive in the light of our present knowledge that I reproduce them here in a form slightly altered to suit the present inquiry. The numbers in the first column distinguish the rods used, all the other numbers give the lengthening, or when with a minus sign the shortening, of the rods in terms of an arbitrary unit.

Rod No.		Increase in length of rods.		
		First make of circuit.	After first break.	Second make of circuit.
Iron.	1	1·15*	·4	1·1
	2	1·6	·4	1·6
	3	2·0	1·1	2·5
	4	2·5	1·35	2·5
	5	1·65	1·05	2·05
	6	1·4	·55	1·45
Steel.	7	·8	1·4	1·15
	8	− ·25	·25	− ·25
	9	− ·4	− ·15	− ·35

* In original 1·25, but this seems a misprint.

On breaking the second currents the rods all returned to the length they possessed on the break of the first currents, so that the changes in the lengths of the rods became cyclic after a single make and break of the current. The last three experiments are, it will be observed, very far from agreeing with JOULE'S laws.

The experiments suggest that it is mainly on the intensity of the existing magnetisation that the phenomena depend, but the divergence between the figures in the second and fourth columns indicates that the previous history of the material may, in some cases at least, be of considerable importance.

In all the iron rods the induced magnetisation is clearly much below the critical. In 7, the softest of the steel rods, the induced magnetisation though below is clearly approaching the critical. In rod 8, the critical magnetisation lies between the induced and the residual; and if a critical magnetisation existed in the case of rod 9 it must have been less than the residual.

§ 5. Of Mr. SHELFORD BIDWELL'S experiments those described in the 'Philosophical Transactions,' appear the most complete. In these, he first demagnetised the specimen, and then sent through a surrounding spiral a series of currents gradually rising in strength. For each strength of current the alterations in the length of the rod accompanying two successive makes were observed and recorded. The Tables III. and IV., pp. 220 and 221, for an iron rod show a small but unmistakeable difference between the effects of the first and second makes of a current of given strength. In Table V. p. 222, for a cobalt rod the differences might well be attributed to experimental errors.

Mr. SHELFORD BIDWELL found critical fields both for iron and cobalt. Iron he found to lengthen or shorten when magnetised according as the magnetising field was below or above the critical, while cobalt presented exactly the opposite phenomena. A nickel rod shortened in all fields up to 1400 C.G.S. units, and the experiments left the existence of a critical field an open question. The critical fields for several specimens of iron varied from about 270 to 380 C.G.S. units, and the maximum elongations appeared in fields of about 80 C.G.S. units. In one cobalt rod the maximum shortening occurred in a field of about 400 C.G.S. units, and the critical field considerably exceeded 800 C.G.S. units. A second softer specimen showed a maximum shortening in a field of about 300 C.G.S. units, and had a critical field of 750 C.G.S. units. In these experiments, the rods were free from stress. Mr. SHELFORD BIDWELL'S experiments, however, described in the 'Proceedings of the Royal Society,' show that the critical fields for iron are lowered by tension, a result in exact accordance with JOULE'S experiments.

§ 6. Professor BARRETT found a cobalt rod to lengthen when exposed to a comparatively weak field. The data he supplies are too limited to enable one to judge whether his later experiments on the subject were wholly free from the objections which he himself believed to have invalidated the conclusions based on his earlier experiments. I scarcely think his results afford any reasonable ground for doubting the accuracy of Mr. SHELFORD BIDWELL's conclusions, at least for the actual cobalt rods of his experiments.

Effects of Longitudinal Stress on the Magnetisation of Rods and Wires.

§ 7. A preliminary general idea of these effects may be obtained from a consideration of the phenomena presented by a soft iron wire stretched beyond its original limit of perfect elasticity, and then subjected, in a weak magnetic field, to a stress cycle consisting of the application and removal of a definite tension for which it is perfectly elastic.

The first application of the tension causes a large increase in the magnetisation of the wire, and on the removal of the tension this increase nearly all remains, or may even be added to. The next one or two tension cycles cause a distinct progressive increase in the magnetisation. Presently, answering to the tension cycles, there appears a nearly cyclic change in the magnetisation, in which the maximum magnetisation appears when the tension is "on." Also the magnitude of the cyclic effect remains, at least approximately, constant for, at all events, a large number of tension cycles.

Subtracting the effect of the final cyclic change of magnetisation from the change accompanying the first application of tension, we get what may be fairly regarded as that portion of the effect of the first tension which is of a permanent and non-cyclic character. This quantity I have here termed the "shock-effect." If the magnetising current be broken, the first application of tension or of pressure has a large shock-effect, which invariably consists in a diminution of the residual magnetisation. The effects of beating,* or other mechanical agitation of a rod, are in many respects very similar.

The experiments on the effects of stress on magnetism which are of most importance for our present purpose are those of VILLARI,† Sir W. THOMSON,‡ Mr. SHIDA,§ and Professor EWING.‖ All these observers have, at least in practice, recognised the distinction between the effect on a bar's magnetisation of the first few applications of a given longitudinal stress and its subsequent applications.

§ 8. VILLARI unfortunately gives no clue to the strength of his magnetising fields, save the number and relative size of the DANIELL or BUNSEN elements he employed. He discovered that the non-cyclic effects of the first tension and the cyclic effects of the later tension cycles in bars—or rather stout wires—of iron in weak magnetic fields are of the character indicated in the last paragraph. In stronger fields he found

* See WIEDEMANN's 'Elektricität,' vol. 3, p. 666, &c.

† POGGENDORFF's 'Annalen,' vol. 126, 1865, pp. 87–122.

‡ 'Phil. Trans.,' 1879, pp. 55–85; or 'Mathematical and Physical Papers,' vol. 2.

§ 'Roy. Soc. Proc.,' vol. 35, 1883, pp. 404–454.

‖ 'Phil. Trans.,' 1885, pp. 523–640; 1888, A., pp. 325–337.

that, while the first application of the tension still increased the bar's magnetisation, the cyclic effect had changed sign. On his p. 91, in experiment 3, is given an instance where a soft iron bar, exposed to one of his strongest fields, lost magnetisation on the very first application of the tension. From the data supplied, however, it will be found that the shock-effect of this first tension was still an increase of magnetisation. Similar cases are also referred to on his p. 97, but no data are given from which the sign of the shock-effect can be deduced.

From VILLARI's experiments it obviously follows that a critical field, or intensity of magnetisation, must exist where the cyclic effects of tension vanish. The field in which the effect vanishes is called by Sir W. THOMSON the "VILLARI critical point." He and Professor EWING have made it clear that the field in which this phenomenon occurs depends on the amount of the tension which is applied and removed, and also on the existence of any permanent load. Professor EWING also prefers to define the VILLARI point by reference to the magnetisation existing in the rod, and not to the field producing it. Some of VILLARI's steel bars behaved like iron, but in others a critical field, if existent, was lower than the lowest field he employed.

VILLARI also observed the fall in the residual magnetisation caused by the first tension after the break of the current. He further observed that after several tension cycles there appeared a cyclic change in the residual magnetisation. Without making any restriction as to the strength of the pre-existing fields, he lays down the law, that in soft iron the residual magnetisation in the cyclic state is greatest when the tension is "on," while in hard iron and steel, it is greatest when the tension is "off." I can find no clue as to the actual strength of the pre-existing field or fields he employed.

Fitting an iron core inside a coaxial iron tube of the same length, VILLARI found that in fields between certain limits, the core and the tube showed, in response to cyclic changes of tension, cyclic changes of magnetisation of opposite signs. The phenomena, as VILLARI himself pointed out, are exactly in accordance with the view, stated in § 5, that the intensity of magnetisation is greater on the surface of a bar than in its interior.

§ 9. Sir W. THOMSON experimenting on a soft iron wire permanently stretched, and then exposed to cycles "on" and "off" of some weight causing no further permanent extension, found a critical field which was in general higher the smaller the weight employed in the tension cycles. The critical fields obtained by the magnetometric method—calculated presumably for the centre of the magnetising coil—averaged about 20 C.G.S. units, and the fields at which the cyclic effect was a maximum, were roughly about a quarter of the critical.

By the ballistic method with an induction coil at the centre of a much longer magnetising coil, critical fields such as 6·5 C.G.S. units were obtained. This Sir W. THOMSON apparently assigns to the experimental wire having its magnetisation greatest at the centre of the magnetising spiral, so that this portion of the wire would be brought into the critical state by much weaker currents than the portions under the ends of the spiral.

In his § 240, Sir W. THOMSON states that a VILLARI critical point was found in the central portions of a nickel bar, but from a note to § 239, it would appear that with the magnetometer opposite an end of the bar, no trace of a neutral field was obtained. With a magnetometer as usual opposite one end, he found in nickel and cobalt a cyclic effect the reverse of that occurring in iron in fields below the VILLARI point, *i.e.*, the magnetisation was least when tension was "on."

§ 10. Mr. SHIDA obtained VILLARI critical fields of 15 and 10 C.G.S. units respectively for two different specimens of soft iron wire, which had been permanently stretched, and on which the tension cycles were performed with weights not much less than those causing the permanent extension. With a pianoforte steel wire, he found that in the cyclic state tension "on" co-existed with a minimum of magnetisation in all his fields.

§ 11. The first thing in Professor EWING's researches that concerns us is his method of demagnetising wires. This consists in subjecting them to the action of a series of rapidly reversed currents diminishing in intensity. In § 19 of the first of his papers referred to above, he states that his wires were thereby reduced to a standard condition—different possibly, he admits, from their condition previous to their first magnetisation.

In his § 107 Professor EWING defines the VILLARI critical point as "that value of the magnetisation $\mathfrak{I}$ at which reversal occurs in the sign of the magnetic difference produced by two (assigned) states of longitudinal stress." He uses the term as applicable (1) to that value of $\mathfrak{I}$ at which no magnetic change accompanies the *repeated* alternation from one to the other of two assigned states of stress, (2) to the value of $\mathfrak{I}$ answering to the intersection of the two curves giving the relations of $\mathfrak{I}$ to $\mathfrak{H}$—the field,—when $\mathfrak{H}$ is gradually raised from zero, and separate experiments are completed with the wire in each of the assigned states of stress. He also proposes that one of the assigned states of stress should be that answering to no load. It will be noticed that Professor EWING's first usage of the "VILLARI critical field" is that which accords with Sir W. THOMSON's.

In originally soft annealed iron wires stretched beyond the limit of perfect elasticity, Professor EWING found in every case distinct VILLARI points of the first kind. These existed in lower fields the greater the weight producing the second assigned state of stress. If in a certain field the cyclic state has been reached for the loads 0 and Q, for which the magnetisation has the critical value, and the load be gradually raised from 0, then there ensues a rise in the magnetisation until the load reaches some value P less than Q, and then an equal fall as the load is increased to Q. Even in the weakest fields Professor EWING seldom found the magnetisation increase continually when the load was raised nearly to the limit of perfect elasticity.

From the figures on Professor EWING's Plate 63, it will be seen that the first application of load has effects very similar to those just described. It will appear, however, from fig. 42, § 88, that the critical fields at which the first application of a given load has no effect on the magnetisation are distinctly higher than the VILLARI points for the cyclic applications of these loads. This figure also shows that the first application of a moderate load produces a very large increase of the magnetisation in weak fields, whereas in the strongest field of 34 C.G.S. units the effect is trifling.

From fig. 40 it will be seen that in the cyclic state the effects of tension cycles on the magnetisation residual after a field of 3·33 C.G.S. units were of the same general character as appeared with an equal induced magnetisation.

Soft annealed wires, when none but very small loads were used, were found by Professor EWING to possess in weak fields a maximum of magnetisation with tension "on," agreeing so far with stretched wires. With greater loads the effects become reversed after the first application of the load. Professor EWING attributes this to *hysteresis*, and shows that when tapped these wires behave as stretched wires with low VILLARI points.

From fig. 43, Plate 64, it will be seen that soft wires respond to the first application of tension in a precisely similar way to stretched wires, but have much lower critical fields. The phenomena accompanying the application of load cycles to a soft annealed wire possessed of the magnetism residual after the break of a field of ·34 C.G.S. unit, are discussed in §§ 83–85 and shown in fig. 39. They are unquestionably of the same general character as those occurring with an equal induced magnetisation.

Iron wires, both when stretched and annealed, and a pianoforte steel wire stretched after annealing, were exposed by Professor EWING to gradually increasing magnetising currents, and the curves connecting $\mathfrak{I}$ and $\mathfrak{H}$ are given in his Plates 64 and 67.

The specimens all showed VILLARI points of the second kind, which agreed with those of the first kind in being as a rule lower, the heavier the load. These critical fields, or magnetisations, of the second kind were distinctly higher than the corresponding ones of the first kind.

Simultaneously observations were taken of the residual magnetisation whose results are shown in figures in Plates 67 and 68. In all the specimens the magnetisation residual after weak fields, and also its ratio to the induced magnetisation, were found to be largely increased by the presence of a load, the increase being greatest with the heaviest loads used. As the fields were raised the influence of the loads diminished, and in the annealed iron and the steel wires the residual magnetisation and its ratio to the induced became eventually less under the heavier loads than in the absence of a load.

§ 12. In his papers in 'Phil. Trans.,' A., 1888, Professor EWING found that in fields from 0 to 116 C.G.S. units, the presence of a tension on a thin nickel wire diminished its induced and residual magnetisations, and also the ratio of the residual to the induced. Also cyclic changes of tension "on" and "off" were accompanied by cyclic changes of magnetisation, in which the magnetisation, whether induced or residual, was least when the tension was "on."

The effects of pressure on a nickel bar were exactly the opposite of those of tension, and the increase in the susceptibility was extremely large, especially near the "Wendepunkt"—or point where $\mathfrak{I}/\mathfrak{H}$ is a maximum. Professor EWING looked for a VILLARI point in low fields but found no trace of its existence.

Theoretical Considerations.

§ 13. The experimental results already stated will enable Professor J. J. THOMSON'S theoretical conclusions to be understood.

Let e denote the strain in an isotropic elastic cylinder parallel to its axis, f and g the strains in the cross section perpendicular to and along the radius vector. Also let $\mathfrak{H}$, $\mathfrak{I}$ and κ denote respectively the strength of the magnetic field, the intensity of magnetisation, and the coefficient of magnetic induction, assumed everywhere the same throughout the cylinder.

In the case of a uniform longitudinal stress $g = f$. Thus, assuming

$$\frac{d\mathfrak{I}}{dg} = \frac{d\mathfrak{I}}{df} \quad \ldots \ldots \ldots \ldots \quad (1),$$

Professor THOMSON obtains for this case, on his p. 51, two equations (48), of which the first may be put in the slightly altered form

$$\kappa \frac{de}{d\mathfrak{I}} = \mathrm{C} \left(1 - \mathfrak{H} \frac{d\kappa}{d\mathfrak{I}}\right) \left(\frac{d\mathfrak{I}}{de} - 2\sigma \frac{d\mathfrak{I}}{df}\right) \quad \ldots \ldots \quad (2).$$

Here C denotes a positive constant depending only on the elastic properties of the cylinder, and σ is POISSON'S ratio.

All the differential coefficients must of course apply to some one definite state of the cylinder, and in determining $d\mathfrak{I}/de$ and $d\mathfrak{I}/df$ the strength of the field must be kept constant.

It is pointed out by Professor THOMSON that according to EWING'S experiments $1 - \mathfrak{H}\, d\kappa/d\mathfrak{I}$ is positive for iron. It is obviously positive for any magnetic metal in any field exceeding that which answers to its "Wendepunkt." It also appears to be positive for nickel and cobalt throughout the experiments of Professor ROWLAND.* Thus it is probably safe to regard it as essentially positive.

Under a uniform longitudinal stress

$$g = f = -\sigma e.$$

* 'Phil. Mag.,' vol. 48, 1874, p. 321.

If then, through a small increase in the stress, there be increases δe, δf, δg in the strains, we must have

$$\delta g = \delta f = -\sigma \delta e \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3).$$

If $\delta \mathfrak{J}$ be the consequent increase in the magnetisation, the field remaining constant,

$$\delta \mathfrak{J} = \frac{d\mathfrak{J}}{de}\,\delta e + \frac{d\mathfrak{J}}{df}\,\delta f + \frac{d\mathfrak{J}}{dg}\,\delta g,$$

and so by (1) and (3)

$$\delta \mathfrak{J} = \delta e \left(\frac{d\mathfrak{J}}{de} - 2\sigma \frac{d\mathfrak{J}}{df} \right).$$

Thus from (2)

$$\kappa \frac{de}{d\mathfrak{J}} = \mathrm{C}\left(1 - \mathfrak{H}\,\frac{d\kappa}{d\mathfrak{J}}\right)\frac{\delta \mathfrak{J}}{\delta e} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4);$$

where $\delta \mathfrak{J}$ and δe denote the small increments in the magnetisation and longitudinal strain which follow a small change in the longitudinal stress.

If (4) were a complete representation of the state of matters, then $de/d\mathfrak{J}$ and $\delta \mathfrak{J}/\delta e$ should always have the same sign, and should vanish for the same value of the magnetisation.

It should be carefully noticed that in employing (4) we tacitly assume the changes in the strains to be very small, and thus the value of $\delta \mathfrak{J}/\delta e$ should be obtained by experiments in which the change in the longitudinal stress is very small.

Thus, in particular, the magnetisation at which $\delta \mathfrak{J}/\delta e$ vanishes is the VILLARI point, as determined by experiments in which the difference between the two assigned states of stress is very small. And thus, in accordance with the experiments of Sir W. THOMSON and Professor EWING, this theoretical VILLARI point may well be very much higher than those hitherto found by experiment.

It may also be as well to point out that the magnetisation answering to the vanishing of $de/d\mathfrak{J}$ is not the critical magnetisation observed by Mr. SHELFORD BIDWELL where the rod resumes its original length, but the much lower magnetisation where the rod, if iron, has its greatest extension, if cobalt, its greatest shortening.

Comparison of Theory and Experiment.

§ 14. The experiments already recorded sufficiently show that in iron, there is in weak fields, and again, in very strong fields, an agreement in sign between $de/d\mathfrak{J}$ and $\delta \mathfrak{J}/\delta e$, both expressions changing from positive to negative as the strength of the field is raised. It will be noticed, however, that the magnetisations obtained experimentally for the VILLARI point are much lower than those obtained for the point of maximum lengthening of the rod. This difference is certainly in some measure accounted for by the lowering of the VILLARI point by the comparatively large stresses practically employed. Professor THOMSON also has pointed out that MAXWELL'S distribution of stress should produce an independent system of strains in the bar, the strain in the direction of the lines of force being an extension. Though apparently a very small effect this would tend in iron to raise the magnetisation where $de/d\mathfrak{J}$ vanishes somewhat over the VILLARI point.

In nickel we see from the experiments of Sir W. THOMSON, Mr. SHELFORD BIDWELL, and Professor EWING, that $de/d\mathfrak{J}$ and $\delta\mathfrak{J}/\delta e$ are both negative in all ordinary fields. If the results obtained by Sir W. THOMSON in the central portions of a nickel bar, in a strong field, be accepted, then there does actually exist a very high critical magnetisation at which $\delta\mathfrak{J}/\delta e$ vanishes. There should accordingly be, not in weak fields where Professor EWING looked for it, but in very high fields, a critical magnetisation where a nickel bar would cease to contract. Such a phenomenon cannot be said to have its existence demonstrated by Mr. SHELFORD BIDWELL, but at the same time it is certainly not disproved by his experiments.

In cobalt, according to Sir W. THOMSON, $\delta\mathfrak{J}/\delta e$ is negative in weak fields, and so also is $de/d\mathfrak{J}$ if we accept the results of Mr. SHELFORD BIDWELL. According to the latter observer, however, $de/d\mathfrak{J}$ changes sign in fields much higher, it is true, than the corresponding fields for iron, but still easily obtainable. Further, the cobalt not only recovers from the very considerable shortening it has experienced, but lengthens considerably as the field is raised. It would thus appear impossible to assign the phenomenon in any essential degree to the MAXWELL effect. If then Professor THOMSON'S theoretical conclusions are sound, $\delta\mathfrak{J}/\delta e$ should change sign from negative to positive in a cobalt rod for a magnetisation quite within the reach of experiment.

Experimental Verification of Theory in Cobalt.

§ 15. The question whether or not a VILLARI point of the above kind exists in cobalt was the primary object of the following experiments, and a decided answer in the affirmative was obtained. Under the moderate stress employed, $\delta\mathfrak{J}/\delta e$ was negative in weak fields and positive in strong, and an unmistakeable VILLARI point appeared in a field of about 120 C.G.S. units.

This, it will be noticed, is a much lower *field* than those which Mr. SHELFORD BIDWELL obtained for the vanishing point of $de/d\mathfrak{J}$ in either of the specimens he employed, and the MAXWELL effect would here tend to lower these latter fields. In my specimen, however, as the field was raised from 120 to 300 C.G.S. units the *magnetisation* increased by less than 20 per cent. The accordance of theory and experiment would thus, in reality, appear to be closer in cobalt than in any recorded experiments on iron.

Preliminary Sketch of Phenomena Observed.

§ 16. As the phenomena observed are somewhat complex, their mutual relationships might be hidden under the multiplicity of facts, which the full discussion of each separate phenomenon introduces. A brief outline of some of the more important and certain results will, it is hoped, serve as a key to the subsequent more complete discussion.

It is important to notice that all the phenomena were observed in a given specimen of cobalt, magnetised by a current in a given coil, and that it was found by repeating several of the sets of observations at various periods of the research, that the character of the specimen had not to all appearance been altered during the process of the experiments. The importance of this, when an attempt shall be made to connect the phenomena together, and explain them as consequences of one or more fundamental principles, will be at once obvious to any one who has noticed the variety in the phenomena observed in different specimens of iron.

At the same time, when various specimens of the same magnetic metal—or even of different magnetic metals—are exposed to gradually increasing magnetic fields, and curves drawn in which the abscissæ give the strength of the field and the ordinates the intensity of magnetisation, experiment shows that the fields in which corresponding points of the several curves occur may widely differ, but that there exists a general resemblance in the form of the curves, which may be made much closer by properly altering the scale of abscissæ.

Thus, while the particular field at which a certain phenomenon presents itself in a particular specimen may so largely depend on the individual peculiarities of the specimen that it may be of little value as an isolated fact, yet the determination of the point on the curve where the phenomenon occurs, and the position it occupies relative to the points where other phenomena occur, may lead to the recognition of general laws.

Phenomena Observed in the Induced Magnetisation.

§ 17. The "Wendepunkt," or point where the coefficient of induced magnetisation is a maximum, is a point in the curves that can easily be recognised. Very probably the most satisfactory comparison of the phenomena observed in different specimens would be obtained by expressing the magnetisation of each specimen in terms of the magnetisation it possesses at its Wendepunkt as a unit. The Wendepunkt of the specimen employed occurred in a field of about 35 C.G.S. units.

For the reasons just stated, the relations of both the induced and residual magnetisations to the strength of the field, though not a primary object of investigation, were observed under various conditions as to pressure. These relations, in the case of the induced magnetisation, are shown in figs. 1–4 (Plate 15).

The difference between the effects on the induced magnetisation of the first few and subsequent applications of longitudinal stress, referred to in § 7 as occurring in iron, is equally characteristic of cobalt, so long as the magnetisation is not much in excess of that of the critical or VILLARI point. In the present experiments the stress applied was a pressure, and so δe being always negative, and the magnetisation in the weaker fields greatest when the rod was under pressure, $\delta\mathfrak{I}/\delta e$ was, as already stated, negative in fields below the critical.

The effect of the first application of pressure may, as explained in § 7, be regarded as the sum of the cyclic effect and of a non-cyclic or shock-effect. In all fields below 200 C.G.S. units the shock-effect gave an unmistakeable increase of magnetisation. In all stronger fields, up to at least 725 C.G.S. units, the magnitude of the shock-effect was so small that its sign even was a doubtful matter. Thus, in cobalt, the shock-effect, so long at least as it is an appreciable quantity, gives an increase of magnetisation. This consequence of the shock-effect, even in fields much above the VILLARI point, is known from VILLARI's experiments, recorded in § 8, to be also characteristic of iron.

The absolute measures, both of the shock-effect of the first pressure and of the cyclic effect, possessed maxima in the neighbourhood of the Wendepunkt. Relative, however, to the magnetisation existing prior to pressure, both these effects increased continually in importance as the strength of the field was reduced within the actual limits of the experiments.

The total effect of the first application of pressure had a critical field of about 160 C.G.S. units; which, it will be noticed, is decidedly higher than the critical field for the cyclic effect. As stated in § 11, in discussing Professor EWING's experiments, the existence of a higher critical field for the first application of stress than for the cyclic application, is equally characteristic of iron.

As it is important to know how far, if at all, the nature and magnitude of the cyclic effect of pressure depend on the circumstances attending the process of magnetisation, the rod was sometimes subjected to pressure before and during its introduction into the magnetising spiral. It was found that there was no material alteration in the cyclic effect. The mode of variation of the effects of the first and of the cyclic application of pressure with the strength of the field is exhibited in figs. 5–8 (Plate 15).

Phenomena Observed in the Residual Magnetisation.

§ 18. Comparing figs. 1 and 9, it will be seen that the residual magnetisation approaches "saturation" in much lower fields than does the induced.

The intensity of the residual, as of the induced, magnetisation was found to depend on the treatment of the rod during the flow and the break of the current. When the rod was free from pressure at the instant the current was broken, the residual magnetisation in all fields below 120 or 130 C.G.S. units was increased by the application of pressure cycles during the flow of the current. In stronger fields no certain effect could be attributed to the pressure cycles. The effect, as may be seen from fig. 10, was greatest in very weak fields.

The existence of pressure during the break of the current proved to have a considerable influence on the intensity of the residual magnetisation. As might have been anticipated it increased the residual magnetisation in weak fields, but the effect changed its sign in fields far below the VILLARI point, and showed no signs of vanishing even in a field of 400 C.G.S. units.

The ratios of the residual magnetisation to the strength of the pre-existing field and to the intensity of the induced magnetisation under various conditions as to pressure are shown in figs. 11 and 12 (Plate 16). From these it appears that in the absence of all pressure the intensity of the residual magnetisation is extremely small in weak fields. In this case the phenomena closely resemble those noticed by many observers in iron. The only essential difference apparently is that the fields at which certain phenomena appear in cobalt are much higher than the fields at which the corresponding phenomena appear in ordinary iron. This is in exact agreement with the views already expressed as to the relative positions of the Wendepunkt.

The application of pressure cycles during the flow of the current increased immensely the intensity of the residual magnetisation in weak fields. The increase, in fact, due to this cause in the residual magnetisation in the weakest experimental fields, was even greater proportionally than in the induced, so that the ordinates of curves *c* and *d* of fig. 12 continually increase as the strength of the field is reduced.

The effects of the application or removal of pressure in shaking out the residual magnetisation were also observed, and are shown in Curve II., fig. 13, and in figs. 14 and 15. From the first of these curves it appears that the percentage of residual magnetisation shaken out by a series of pressure cycles continually diminished as the strength of the field was raised.

When the rod was free from pressure during the break of the current, the percentage of the residual magnetisation, shaken out by the first application of pressure, was in weak fields decidedly diminished by the previous application of pressure cycles during the flow of the current. In fields over 70 or 80 C.G.S. units, however, the effect of previous pressure cycles was extremely small. In weak fields the removal of a pressure that had existed during the break of the current was fully as effective in shaking out residual magnetisation as was the application of a pressure when the rod, during the break of the current, remained free from pressure. In fields over 30 or 40 C.G.S. units, however, the removal of pressure became decidedly less effective than the application.

As has been stated in §§ 8 and 11, VILLARI and Professor EWING found that cyclic applications of stress were followed by cyclic changes in the residual magnetisation of the same character as those produced in the induced magnetisation. As it seemed important to test the generality of these conclusions, the cyclic effects of pressure on the residual magnetisation were here observed when the treatment of the rod during the flow and break of the current was varied.

When pressure cycles were applied during the flow of the current, and pressure was "on" during its break, the cyclic effect had invariably the same sign while the strength of the field was raised from 11 to 400 C.G.S. units. The effect in this case was in the same direction as in the induced magnetisation below the VILLARI point, *i.e.*, the magnetisation was greatest when pressure was "on."

When, however, the rod was free from pressure during the break of the current, a critical field was found to exist. In the magnetisation residual after fields above the critical, the magnetisation was least when pressure was "on." This critical field was raised by the application of pressure cycles during the flow of the current, but it was in any case much lower than the critical field for the induced magnetisation. It follows, of course, that the intensity of the critical residual magnetisation was very much less than that of the critical induced.

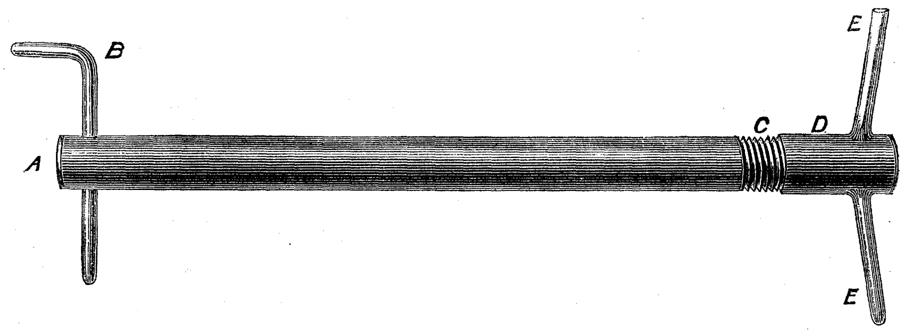
The amounts of the cyclic effects under the various conditions are shown in the fifth columns of Tables II. and VIII., and in the sixth columns of Tables VI. and VII. These results show conclusively that for cobalt, and so in all probability for iron, the relations between stress and residual magnetisation must be largely dependent on circumstances other than the so-called intensity of magnetisation. This, as pointed out in § 2, was *à priori* far from improbable, and should act as a warning against extending to residual magnetisation laws proved only for the induced.

The fact that in fields over 60 or 70 C.G.S. units both the intensity of the residual magnetisation and the character of the cyclic effect of pressure are very little affected by the application of pressure cycles during the flow of the current, while markedly influenced by the existence of pressure during the break of the current, seems worthy of special notice.

All the phenomena observed in the residual magnetisation apparently altered but little in magnitude, as the strength of the field was raised from 100 to 400 C.G.S. units. This further emphasises the difference between them and the phenomena observed in the induced magnetisation.

The Apparatus.

§ 19. The rod experimented on was supplied by Messrs. JOHNSON and MATTHEY. The mean of a series of measurements gave 16·98 cms. for its length and ·546 sq. cm. for the area of its cross section. During the experiments the rod was contained in a brass tube, the closed end of which was sufficiently thick to afford an unyielding resistance to the rod when under pressure. The rod could be slid in or out of the tube, but the fit was tight enough to prevent any lateral movement. On the outside of the brass tube, at its open end, a screw of small pitch was cut, answering to the screw cut on the inside of a brass cap. The cap carried a projecting arm, forming a diameter of a cross section, by means of which a considerable couple could be exerted. The pressure was applied to the cobalt by means of a sort of ram-rod rigidly attached to the inside of the brass cap. When the cap was screwed on this ram-rod advanced into the brass tube, and came to bear on the end of the cobalt rod.



Drawing of the brass tube containing the cobalt rod, removed from the coil.

A Closed end of brass tube.
B Pin which can be slipped through the holes in the cheeks attached to one face of the coil and, as in the figure, through the diametral hole bored in the solid end of the brass tube.
C Screw cut on the outside of the brass tube at its open end.
D Brass cap with screw cut on its inside answering to C, and carrying ram-rod arrangement for applying pressure to the cobalt rod.
EE Projecting arm, by means of which the cap is screwed on.

In the original experiments, conducted in August, 1888, the brass tube was firmly imbedded in a block of wood, fixed inside a magnetising coil. This coil had a length of 19·8 cms., and consisted of five layers of very thick copper wire. A current of one ampère produced a field varying from 9·26 C.G.S. units at the centre of the rod to 6·85 units at its ends. This, it must be admitted, is not a very uniform field, but the fall occurred mainly within a centimetre or two of the ends of the rod.

In this preliminary investigation the observations were taken somewhat roughly. The reason they are referred to here is that they clearly showed the existence of a cyclic and a non-cyclic effect of pressure, and also the existence of a VILLARI point for the former effect. Further, the result of experiments on several different occasions agreed in giving 120 C.G.S. units as a close approximation to the strength of the field due to the current at the centre of the rod when the VILLARI point appeared. The mode of variation of the several effects with the strength of the field showed also a general agreement with the subsequent more accurate observations taken with a different coil. This seems to warrant the belief that the phenomena observed do not owe any of their essential features to peculiarities of the apparatus.

When it was attempted to obtain accurate results with the original apparatus various difficulties were encountered. In overcoming these I am much indebted to the ingenuity of Mr. BARTLETT, the assistant at the Cavendish Laboratory, who constructed the new apparatus.

The new coil had a length of 18·15 cm., an internal diameter of 1·4 cm., and an external diameter of 7 cm. It consisted of thirteen layers of copper wire of ·24 cm. diameter when covered. In the solid end of the brass tube holding the cobalt a diametral hole was bored at right angles to the length of the tube, and a corresponding hole was made in each of two cheeks projecting from one of the faces of the coil. By slipping a pin through these holes the tube was firmly secured in a fixed position relative to the coil, and when the pin was withdrawn the tube and its contained cobalt could be removed and replaced without the least risk of disturbing the remainder of the apparatus.

A current of 1 ampère in the new coil produces a field varying from 65·7 C.G.S. units at the centre to 43·9 units at the ends of the cobalt rod. Throughout the greater portion of the rod, however, the field is very nearly the same as at the centre. These figures refer entirely to the action of the current, no attempt having been made to allow for the action of the rod itself.

In all the following calculations the values assigned to the field $\mathfrak{H}$ are calculated from the action of the current alone at the centre of the rod, and so are somewhat higher than the mean values of the actual fields. The difficulty of determining the actual fields at the different elements of the rod would be very great even treating the permeability as constant, a most erroneous supposition; and, considering the differences to be expected between different specimens of the same metal, an attempt at great accuracy in this department seems entirely supererogatory.

§ 20. Throughout the whole investigation the ordinary magnetometric method was employed. The axis of the coil was perpendicular to the magnetic meridian, and the magnetometer was situated in the direction of this axis produced. The magnetometer needle carried a mirror which formed on a millimetre scale, set parallel to the magnetic meridian, an image of a vertical wire placed across a slit in the centre of the scale behind which a lamp stood. The direct action of the coil current was neutralised by a compensating coil traversed by the same current. The strength of the current was recorded by a Thomson graded ammeter in circuit with the coil. The current was derived from the storage cells of the laboratory, and its strength was varied by changing the number of cells and the resistance in a wire bridge in circuit with the coil.

§ 21. In order to render apparent the relative magnitudes of the several phenomena some common system of magnetic measurements was essential. Thus all the scale readings have been reduced, and in the following tables and diagrams only C.G.S. units appear. From the previous remarks as to the method of calculating $\mathfrak{H}$ it will be clearly understood that the values given for the strengths of the fields, and consequently for the coefficients of magnetic induction κ, cannot rigidly be held to apply to the actual condition of the rod, in which $\mathfrak{H}$ and κ varied from point to point, but must be regarded as giving an approximation to the mean state of the rod, and more particularly as indicating by their variation the amounts of the changes actually occurring.

It should also be understood that in calculating the intensity of magnetisation $\mathfrak{J}$ the rod was treated as magnetised solenoidally. In some of the experiments, *e.g.*, those on residual magnetism, a direct calculation on this basis might have introduced a considerable error, owing to the small distance of the rod from the magnetometer. The actually observed readings, however, were first reduced by direct comparison of the readings obtained in an independent set of experiments, in which the rod in a given magnetised condition was placed first of all in the positions it was about to occupy in the course of the main observations, and then in a certain standard position, where its distance from the magnetometer was so great that the precise position of the "poles" was of comparatively little moment. As stated in § 2, $\mathfrak{J}$ in reality doubtless varies from point to point of the rod, and the values here recorded indicate merely a sort of average.

Disturbing Agencies.

§ 22. Before discussing the experiments in detail it will be as well to refer to two disturbing agencies, the one of importance mainly in weak fields, the other in strong.

The former, the residual effects of previous magnetisations, affected very considerably some of the earlier experiments here recorded. In weak fields so important was this that the rod was sometimes found, after showing a considerable induced magnetisation, to possess, on breaking the circuit, residual magnetism of opposite sign. The application of pressure in general increased this residual magnetisation of opposite sign, sometimes to a very considerable extent. Or, supposing the residual magnetisation to be at first of the same sign as the preceding induced, it might change sign on the application of pressure. These effects were produced at pleasure with the greatest ease when the rod was treated in accordance with the following hypothesis :—

Calling the ends of the rod A and B, a weak current makes A, say, a north pole, and on breaking the current A is left with a quantity, N_1', of northern polarity. A smaller reverse current shakes out only so much of this residual magnetism, leaving a quantity, N_2, in A, which exists alongside of a larger quantity, S_1, of southern polarity. The end A thus appears a south pole of strength $S_1 - N_2$. On breaking this second current, A is left with a quantity S_1', less than S_1 of residual southern magnetism, and a quantity N_2', probably less than N_2, of residual northern magnetism. Whether A appears a south or a north pole depends on whether S_1' or N_2' is the greater. On applying pressure, a considerably greater proportion of S_1' is shaken out than of N_2', and the polarity of the end A may thus change sign.

Similar phenomena, proceeding doubtless from the same cause, are described by WIEDEMANN as occurring in iron. They fit in well enough either with WEBER'S theory or with the view that the deep-seated magnetic molecules are less affected by weak fields than are the surface molecules.

The total removal of this disturbing agency would require the complete demagnetisation of the rod. The method of demagnetisation employed at first consisted of applying a few reverse currents gradually diminishing in intensity. The magnetisation left in the rod seemed infinitesimal, but the unsatisfactory character of the result will be easily seen on reference to Tables I. and II. The method finally adopted was to expose the rod to a succession of diminishing reverse currents—the first current in the case of a weak field considerably exceeding that in existence during the pressure cycles—and then to tap it vigorously. The first attempt was by no means always successful, and the loss of time was a distinct objection to the method.

It is, of course, impossible to be sure that the rod was ever demagnetised, in the sense of being restored to its condition prior to its first magnetisation, but it was, at all events, reduced to such a condition that successive experiments made with the same field showed an excellent agreement. In strong fields demagnetisation appeared to be, at least for many purposes, of very little importance.

§ 23. The second disturbing agency, the heating of the coil and thence of the rod, by means of the current, was troublesome only in fields over 400 C.G.S. units. The heating of the coil wires increases their resistance, and so tends to diminish the strength of the field; while the heating of the rod increases its permeability, as has been shown by Professor ROWLAND.* For a rise of temperature of 225° C. he found the maximum value of the coefficient of induced magnetisation to increase by about 70 per cent., and to appear in a distinctly lower field.

This explains why, in some of my stronger fields, the scale reading kept altering in a direction indicating a progressive increase in the rod's magnetisation. This did not, of course, annul the cyclic changes accompanying cyclic changes of pressure, but it rendered impossible any very great accuracy in the determination of their magnitudes. The determination of the effect of the first application of pressure was found particularly difficult.

Lest it should be supposed that the cyclic changes in the magnetisation may in reality be due to the heating and cooling of the rod produced by the application and removal of pressure, I would here point out that the cyclic changes of magnetisation alter in sign in a comparatively low field, while the increase in the permeability accompanying heating was observed by ROWLAND in fields of all strengths, from 50 to 1470 C.G.S. units.

First Series of Experiments.

§ 24. With the new apparatus four principal series of experiments were performed. The first series took place in December, 1888, and the results are given in Tables I. and II. The general order of conducting these experiments was as follows:—

The rod, after being demagnetised by reverse currents alone without tapping, was removed to a distance. The number of storage cells and the bridge resistance were

* 'Phil. Mag.,' 4th series, vol. 48, 1874, p. 321.

then adjusted to give the field desired. When the ammeter and the scale reading became steady, the rod was brought up and pushed rapidly into the coil, and the pin secured. The difference between the scale readings when stationary, before and after the introduction of the rod, supplied the data for calculating the initial value of the induced magnetisation.

A considerable number of cycles of pressure "on" and "off" were then performed, the scale reading, when become stationary, being usually taken after each "on" and "off." Sometimes when readings had been taken of the effects of the first four or five pressure cycles, some five or six cycles were applied in rapid succession and then the taking of readings once more resumed. When a sufficient number of readings had been taken for the calculation of the average effect of a pressure cycle, the circuit was suddenly broken, the rod being always free from pressure during the break.

When the scale reading had become stationary after the break and had been observed, some six pressure cycles were applied, readings being taken after each "on" and "off." A series of six pressure cycles were then applied whose effects were not observed. These were followed by some six or seven more pressure cycles whose effects were observed. Finally the rod was removed to a distance and the magnetometer zero taken. The difference between the scale reading taken immediately after the break of the current and that taken after the removal of the rod supplied the data for calculating the initial value of the residual magnetisation.

TABLE I.

$\mathfrak{H}$.	$\mathfrak{I}_1$.	κ_1.	$\mathfrak{I}_2-\mathfrak{I}_1$.	κ_2.	First "on."	Cyclic "on"—"off."	$\frac{\text{Shock-effect}}{\mathfrak{I}_1}$	$\frac{\text{Cyclic "on"—"off"}}{\mathfrak{I}_2}$
·80 S (13)	1·54	1·9	1·08	3·3	·77	..	..	..
1·15 N (12)	4·01	3·5	3·09	6·2	3·09	·80	·57	·11
1·44 N (15)	4·63	3·2	2·47	4·9	2·93	·65	·49	·09
1·61 S (14)	3·55	2·2	2·32	3·6	1·39	·11	·36	·02
1·9 N (11)	8·9	4·7	2·8	6·2	3·7	1·2	·27	·10
4·3 N (10)	19·6	4·5	6·9	6·1	7·4	1·6	·30	·059
7·8 N (9)	38·0	4·8	9·7	6·1	10·0	2·8	·19	·059
9·9 N (8)	50·0	5·0	13·1	6·4	13·9	3·0	·21	·048
18·4 N (2)	107·5	5·8	15·7	6·7	19·1	5·0	·13	·041
19·2 S (1)	113·7	5·9	13·9	6·6	16·7	4·8	·11	·037
25·6 S (3)	148·5	5·8	16·8	6·5	24·4	5·8	·12	·035
36·8 S (4)	218·1	5·9	15·2	6·3	20·6	7·2	·06	.031
66·9 S (5)	368·8	5·5	10·6	5·7	15·0	4·4	·029	·012
100·7 N (6)	..	..	..	..	8·4	1·4	·015*	·003*
126·6 N (7)	..	..	..	..	4·0	− 0·7	·009*	− ·001*

* The values employed here for $\mathfrak{I}_1$ and $\mathfrak{I}_2$ are derived from subsequent tables.

TABLE II.

$\mathfrak{H}$.	$\mathfrak{I}_1'$.	$\mathfrak{I}_2'$.	First "on."	Cyclic "on" — "off."	$\mathfrak{I}_1'/\mathfrak{I}_2$	$\frac{\text{Shock-effect}}{\mathfrak{I}_1'}$	$\frac{\text{Cyclic "on" — "off"}}{\mathfrak{I}_2'}$
1·15 N (12)	3·40	2·17	— ·62	+ ·46	·48	— ·32	·21
1·44 N (15)	2·62	1·23	·62	+ ·51	·37	·43	·41
1·61 S (14)	4·32	N	4·32	..	·74	1·0	..
1·9 N (11)	5·9	3·4	1·1	+ ·42	·50	·26	·124
4·3 N (10)	8·6	4·9	2·0	+ ·49	·33	·29	·100
7·8 N (9)	13·1	6·9	3·7	+ ·54	·28	·32	·078
9·9 N (8)	16·4	9·0	4·6	+ ·62	·26	·32	·069
18·4 N (2)	27·9	15·7	8·6	+ ·26	·23	·32	·017
19·2 S (1)	29·9	19·0	5·4	+ ·15	·23	·19	·008
25·6 S (3)	39·4	25·3	9·5	+ ·15	·24	·25	·006
36·8 S (4)	51·0	34·6	12·9	— ·22	·22	·25	— ·006
66·9 S (5)	66·1	40·4	17·2	— 1·07	·18	·24	— ·027
100·7 N (6)	68·5	45·6	16·9	— 1·20	·14	·23	— ·026
126·6 N (7)	70·9	48·6	17·8	— 1·38	·13	·23	— ·028

§ 25. In Table I. $\mathfrak{H}$ is the strength of the field calculated as is explained in § 19, $\mathfrak{I}_1$ is the intensity and κ_1 the coefficient of induced magnetisation in the rod previous to the application of any pressures; while $\mathfrak{I}_2$ is the intensity and κ_2 the coefficient of induced magnetisation in the rod free from pressure after all the pressures cycles have been applied. Thus $\mathfrak{I}_2 - \mathfrak{I}_1$ is the increase in the magnetisation taking place during the application of the pressure cycles. Their application occupied a considerable time, during which absolute steadiness in the current could hardly be expected; and so $\mathfrak{I}_2 - \mathfrak{I}_1$ is probably in no case an absolutely exact measure of the increase in the magnetisation due to the pressure cycles. By *first "on"* is meant the increase in the magnetisation caused by the first application of pressure. *Cyclic "on" — "off"* gives the average algebraic excess of the magnetisation existing when pressure is "on" over that existing when pressure is "off." As already explained the *shock-effect* is the algebraic excess of the *first "on"* over the *cyclic "on" — "off."*

The second last column gives the ratio of the shock-effect to the intensity of the magnetisation prior to pressure, while the last column gives the ratio of the cyclic "on" — "off" to the intensity of magnetisation in the cyclic state. Thus the figures in these two columns may fairly be regarded as measuring the importance in the different fields of the shock-effect and the cyclic effect respectively.

In the weakest field the last three columns have no entries, because the experiments determining the cyclic effect of pressure failed to indicate a clear result.

The entries in the two last fields indicate, as they do elsewhere, that no observations of the corresponding quantities were obtained. In these fields when the compensating coil exactly balanced the coil current so that in the absence of the rod the spot was at the centre of the scale, the introduction of the rod drove the spot off the scale. The compensating coil was thus moved so as to neutralise part of the effect of the rod, and so bring the spot near the centre of the scale. In the absence of the rod the spot was now off or nearly off the scale, so that accurate measures of the induced magnetisation were impossible.

The effect of the changed position of the compensating coil was allowed for in reducing the observations. A similar use of the compensating coil was subsequently made in some of the higher fields. It had the disadvantage of making the scale reading more disturbed by slight irregularities in the current. In these strong fields, however, the cyclic changes were so small compared to the total induced magnetisation that the alternative of increasing the distances of the coils from the magnetometer possessed greater disadvantages.

§ 26. In Table II., $\mathfrak{H}$ is the field existing prior to the break of the current. $\mathfrak{I}_1'$ is the residual magnetisation prior to the application of any pressure, $\mathfrak{I}_2'$ that finally existing after what was approximately a constant number of pressure cycles. A minus sign represents, as elsewhere, a diminution in the magnetisation, and when placed at the head of a column it applies to all the entries in that column. The *shock-effect* is obtained by subtracting from the algebraic value of the total effect of the first pressure the algebraic value of the *cyclic* "*on*" — "*off*."

The second last column gives the ratio of the *shock-effect* to the intensity of the residual magnetisation prior to pressure, while the last column gives the ratio of the *cyclic* "*on*" — "*off*" to the intensity of the residual magnetisation in the cyclic state.

§ 27. In both the Tables I. and II. the letter N signifies that a certain end of the rod, which we shall call A, was a north pole ; S, that it was a south pole. The numbers in brackets in the first columns give the order in which the experiments took place.

It was intended to apply as nearly as possible the same degree of pressure in every single case. Still, as the pressure was applied by hand, a certain amount of irregularity was bound to exist. The smallness in the variations shown by the individual observations of the cyclic effect in each separate field, and the smoothness of the several curves obtained prove that throughout any single series of experiments a pretty uniform standard must have been maintained. As a considerable interval of time elapsed between some of the successive series of experiments, notably those made in December and January, the standard probably varied somewhat from one series to another ; fig. 7, at all events suggests that in February the standard pressure was somewhat less than in December.

§ 28. The results of Table I, and II. will be presently discussed along with the corresponding results from subsequent tables, but certain peculiarities illustrative of the first difficulty stated in § 22, claim a special attention.

A glance at the values of κ_1 and κ_2 in Table I., shows that the supposed demagnetisation following the strong field (7) had not sufficed to remove all its effects. A comparison of the fields (14) and (15), or of (12) and (13), shows a much smaller susceptibility for currents making A a south pole, than for those making it as in (7) a north pole. From the results subsequently obtained with a more perfect system of demagnetisation, and contained in Tables IX. and X., it appears that in those of the eight weakest fields of Table I., in which A was a north pole, the values obtained for κ_1, κ_2, and the cyclic effect are all undoubtedly somewhat too great.

The effects of the residual polarity appear still more decidedly in Table II. in the case of field (14). Here, what must be regarded as an abnormally large amount of residual magnetism, was originally present. Every trace of this was, however, removed by a single pressure, and with subsequent pressures magnetism of opposite sign became apparent. An even more striking case, that of field (13), does not appear in Table II. because no absolute measures were taken. In this case, the residual magnetism on the break even of the current was of opposite sign to the induced, and it increased on the application of pressure.

Second Series of Experiments.

§ 29. In the next principal series of experiments—taken in January, 1889—the method of taking the observations was much the same as in the first series, but the distances between the pieces of the apparatus were varied. Thus the distance of the centre of the rod from the magnetometer needle was 73·6 cm., 50 cm., or only 39·2 cm., according as the quantity under examination was the intensity of the induced magnetisation, the effect of pressure on the induced magnetisation, or the residual magnetisation. The compensating coil and the scale remained screwed to the beam carrying the apparatus, while the three positions of the magnetising coil and the corresponding positions of the magnetometer were indicated by pencil marks on the beam. There was no shaking of the rod, or variation in the current caused by the movements of the coil and magnetometer.

The fields in this series of experiments varied from 84·8 to 725 C.G.S. units. Preliminary experiments in the weakest of these fields, showed that demagnetising the rod had no appreciable influence on the magnitude of the cyclic effect of pressure. There was thus in none of the recorded experiments, as given in Tables III. and IV., any attempt at demagnetisation; but the weaker fields were taken first so as to avoid the disturbing influence of any residual effects that might originate with very strong currents.

TABLE III.

$\mathfrak{H}$.	$\mathfrak{I}_1$.	κ_1.	$\mathfrak{I}_2 - \mathfrak{I}_1$.	First "on."	Cyclic "on"—"off."	$\frac{\text{Shock-effect}}{\mathfrak{I}_1}$.	$\frac{\text{Cyclic "on"—"off"}}{\mathfrak{I}_2}$.
84·8	409	4·8	7·4	+ 9·2	+ 2·2	+ ·017	+ ·005
106·4	472	4·4	4·6	+ 5·0	+ 0·7	+ ·009	+ ·001
126·6	526	4·1	..	..	..	..	..
155 *m*	554	3·6	2·3	— 1·2	— 2·1	+ ·002	— ·004
181	582	3·2	..	— 1·8	— 2·4	+ ·001	— ·004
210	611	2·9	3·1	..	— 3·2	..	— ·005
270 *m*	629	2·3	1·3	— 2·4	— 3·6	+ ·002	— ·006
282	624	2·2	..	..	..	..	..
293	613	2·1	1·1	— 2·4	— 2·9	+ ·001	— ·005
339	654	1·9	..	..	..	..	..
357	669	1·9	..	— 4·5	— 3·2	— ·002	— ·005
406 *m*	690	1·7	7·9	— 2·8	— 3·8	+ ·001	— ·005
541	707	1·3	17·0	— 1·5	— 2·3	+ ·001	— ·003
633	777	1·2	34	— 5·2	— 3·4	— ·002	— ·004
725	791	1·1	{22·9, 1·3}	..	— 2·2	..	— 003

TABLE IV.

Number of fields.	Limiting fields.	Average first "on."	Average cyclic "on"—"off."	Average shock-effect ÷ $\mathfrak{I}_1'$.
7	85–210	— 16·4	— 1·14	— ·21
8	250–355	17·4	1·09	·21
4	400–725	14·6	·80	·19

§ 30. In Table III., which gives the observations on the induced magnetism, the headings have the same meanings as in Table I. When *m* is attached to the strength of the field, two or three separate experiments were conducted with fields of approximately this strength, and the results given in the table are the averages of those obtained. The blanks are mainly due to unsteadiness in the scale-readings brought about by fluctuations in the strength of the magnetising current.

In no case probably, as already explained, does the column headed $\mathfrak{I}_2 - \mathfrak{I}_1$ give with perfect accuracy the change in the magnetisation produced by the pressure cycles alone, and in fields over 400 units the changes under this head must mainly be due to a totally different cause, viz., the heating of the rod. In these high fields the scale-reading did not remain stationary in the absence of pressure, but showed a progressive increase of magnetisation. To obtain the cyclic effect, the pressures were applied and removed at as nearly uniform intervals as possible, and the changes in the magnetisation occurring in successive intervals were compared.

In the strongest field, after the application of a large number of pressure cycles, during which an increase of 22·9 units of magnetisation appeared, the current was broken, and after a short interval re-made, before the rod had cooled much. During a second almost equally numerous series of pressure cycles an increase of only 1·3 unit of magnetisation appeared. At the commencement of the second part of the experiment most of the coil was doubtless colder than the contained rod, so that the temperature of the rod would not alter much for some time after the re-make of the current. This last experiment indicates, I think conclusively, that in fields of this strength the permanent change in the magnetisation brought about by pressure cycles must be small, whatever its sign may be.

The values given for the *First "on"* in the strongest fields cannot claim great accuracy. The rod began to get heated before the oscillations of the magnetometer needle following the introduction of the rod into the coil had sufficiently subsided to permit of a reading being taken. The progressive increase of magnetisation was, in fact, going on most rapidly when the first pressure was applied. There had thus occurred a considerable progressive change before the next scale-reading could be taken, so that it was very difficult to deduce the true effect of the first pressure.

The values obtained in these high fields for the intensity of the induced magnetisation must also have been to some extent unduly raised by the heating, so that the curve of fig. 1 is, in its higher portions, not so flat as it ought to be.

§ 31. Table IV. gives merely certain average results, calculated from the large number of observations actually made on the residual magnetisation. On comparing the results after the conclusion of the experiments, it became apparent that the magnitudes of the several phenomena varied so little with the strength of the pre-existing field within the limits of the observations, that trustworthy deductions as to the exact modes of their variation were rendered impossible by the small variations in the distances of the pieces of the apparatus which the method of experiment was sure to introduce. The measurements of the effects of pressure are, in addition, exposed to possible irregularities in the magnitude of the pressure, but this ought not to affect sensibly the average results recorded in the Table.

Third Series of Experiments.

§ 32. In the next series of experiments, extending from January to February, the residual magnetisation alone was under investigation. Every single piece of apparatus was bolted or screwed to the supporting beam, so as to prevent any relative movement. The magnetometer needle was distant 82 cm. from the scale and 38 cm. from the middle of the rod.

First of all a set of observations were taken of the initial amount of the residual magnetisation as the strength of the pre-existing field was raised by steps from 1·7 to 79·4 C.G.S. units. The rod was apparently very nearly demagnetised by reversed currents previous to the first experiment, but no subsequent demagnetisation was performed. No pressure or tapping was applied to the rod throughout these observations. The current was always in the direction making the end A the north pole.

The results, as recorded in Table V., are deduced from the scale readings taken (1) with the rod in its place inside the coil immediately after the break of the current, (2) with the rod removed to a distance. In general, two observations were taken for each strength of field. The mean of the two observations is the $\mathfrak{I}_1'$ of the Table. By $\mathfrak{H}$ is meant the strength of the field due to the current just broken, and by κ_1' the ratio of $\mathfrak{I}_1'$ to $\mathfrak{H}$. The mode of variation of $\mathfrak{I}_1'$ with $\mathfrak{H}$ is shown in curve *a*, fig. 10; while the mode of variation of κ_1', which is subsequently termed the *residual susceptibility*, is shown in curve *a*, fig. 11.

Table V.

$\mathfrak{H}$.	$\mathfrak{I}_1'$.	κ_1'.	$\mathfrak{H}$.	$\mathfrak{I}_1'$.	κ_1'.
1·7	·22	·13	14·1	12·9	·91
2·6	·29	·11	16·1	15·8	·98
3·5	·56	·16	18·0	21·4	1·20
4·4	·95	·22	22·3	27·5	1·23
5·0	1·3	·25	25·0	28·5	1·14
5·6	2·0	·36	27·3	31·5	1·15
6·0	2·4	·40	38·0	43·0	1·13
7·0	3·8	·55	45·4	50·1	1·10
9·4	6·6	·70	54·6	56·4	1·03
11·5	9·1	·79	70·4	61·9	·88
12·2	10·2	·84	79·4	63·8	·80

§ 33. In continuation of these experiments a much more elaborate set of observations were taken, with the object of determining whether the amount of the residual magnetisation or its properties depended on the treatment of the rod during the flow or break of the current. In one set of experiments, spoken of in future as the L type, no pressure at all was applied during the flow of the current. In a second set, the M type, six cycles of pressure "on" and "off" were applied, the current being broken when pressure was "off." In a third set, the N type, a pressure was applied after six pressure cycles, the current being broken when pressure was "on." In these, as in all the other experiments, the rod was introduced into the coil after the scale reading showed that the current had become steady. The experiments of the several types were not conducted separately, but on the following plan. Starting with a certain number of storage cells and a certain resistance in circuit, complete observations were made for the corresponding field with each of the three types in the order L, M, N, say. Then with a greater number of cells, or a reduced resistance, observations were taken for the next higher field, in the order M, N, L, and so on, in cyclic order. Care in fact was taken that the experiments of any given type should not unduly often be either the first experiment of the day or the first experiment with a given strength of field. This variation in the order was adopted lest during the application for several hours of a succession of pressure cycles, interrupted only by the demagnetisations, the rod might become less responsive to pressure, developing a sensible amount of what may be termed *fatigue.* Under the actual conditions, if this did happen, it would not affect the experiments of one type more than those of another.

The strength of the pre-existing fields was raised step by step from 1 to 400 C.G.S. units, and until fields of 350 units, or thereby, were reached, the rod was demagnetised, before each single experiment, by reversed currents and vigorous tapping. In the stronger fields the rod was merely exposed to a preliminary reverse current, of the same strength as that about to be used in the experiment. During the actual observations the end A was invariably the north pole.

In each experiment of each of the three types, with the exception of some of the weakest fields, the following operations were conducted. When the spot on the scale had become stationary, after the break of the current, a reading was taken. The pin was then withdrawn and the rod carefully removed, being kept at right angles to the magnetic meridian. The scale reading when stationary having been observed, the rod was gently restored to its place and the pin secured. With a little practice this operation was accomplished without shaking out any sensible amount of magnetism, as the coincidence of the scale readings before the rod's removal and after its restoration sufficiently testified. Pressure was then applied once and removed in the experiments of types L and M, being simply removed in those of type N, and the corresponding scale readings observed. Twelve pressures cycles were then applied, the effects of the last six only being observed. The rod was then removed and the constancy of the magnetometer zero tested.

The various observations obviously supplied sufficient data for calculating the *initial residual* magnetisation, the *first* "*on*" or *first* "*off*" of pressure, the *cyclic effect* of pressure, and the *final residual* magnetisation, *i.e.*, the residual surviving a definite number—13 for types L and M—of pressure cycles.

§ 34. The results of the experiments of type L are given in Table VI. All the headings have been already explained, except *next* "*off*." This means the change in the magnetisation accompanying the removal of the first pressure applied after the break of the current. In the two weakest fields the amount of the initial residual magnetisation alone was observed, and in the three next weakest fields the effects of only one pressure cycle were taken. Thus no data existed for calculating the cyclic effect in these fields; and the first three results given in the last column are unduly large, because the values there assigned to $\mathfrak{J}_2'$ are the magnetisations existing after the application of only a single pressure cycle.

In the fields over 90 C.G.S. units the changes in the properties of the residual magnetism accompanying the rise in the fields are so small that the small irregularities in the magnitudes of the pressures applied become important. Thus the stronger fields are grouped into two sets, and the average effects for each set alone are given.

In like manner the results of the experiments of type M are given in Table VII., and those of type N in Table VIII. In these, too, the cyclic effects of pressure were unfortunately not observed in the weakest fields. In the six weakest fields of Table VII. the value assigned to $\mathfrak{I}_2'$ is the residual magnetisation when only one pressure cycle has been applied, while in the seven weakest fields of Table VIII. the value assigned it is the residual left on the removal of the pressure existing during the break of the current. The corresponding results in the last columns of these tables are consequently all unduly large. In the strongest fields average results alone are given as in Table VI.

The results of Tables VI., VII., and VIII. supply the data from which the curves *b*, *c*, *d*, respectively, of figs. 9 to 15 (Plate 16) are drawn.

Table VI.

$\mathfrak{H}$.	$\mathfrak{I}_1'$.	κ_1'.	First "on."	Next "off."	Cyclic "on"—"off."	Ratio of Shock-effect of first "on" to $\mathfrak{I}_1'$.	Ratio of Shock-effect of next "off" to Shock-effect of first "on."	$\mathfrak{I}_2' \div \mathfrak{I}_1'$.
2·6	1·26	·48	..	..	..	..	..	..
4·2	2·43	·58	..	..	..	..	..	..
5·6	5·0	·89	− 3·0	− ·15	..	−·60	·05	·37
8·9	8·4	·95	4·7	·29	..	·56	·06	·40
11·5	10·7	·93	5·8	·29	..	·54*	·05*	·43*
18·0	24·4	1·36	8·5	·95	0	·35	·11	·57
24·0	32·7	1·36	10·7	·87	− ·32	·32	·11	·61
35·0	44·2	1·26	13·7	·94	·62	·28	·12	·61
46·7	49·7	1·06	13·5	1·00	·49	·26	·11	·65
59·0	57·3	·97	14·3	·86	·57	·24	·10	·67
74·8	61·7	·82	14·4	1·22	·34	·23	·11	·71
93·2	64·9	·70						
109	65·7	·60						
122	66·3	·54						
133	68·2	·51	15·2	·85	·53	·22	·09	·72
147	68·0	·47						
173	68·5	·40						
207	68·7	·33						
242	70·2	·29						
292	70·5	·24						
353	70·6	·20	14·1	·69	·49	·19	·08	·75
385	71·4	·18						
414	71·1	·17						

* In the entries above this point, in absence of experimental data, the *cyclic "on"—"off"* is neglected. Thus the results above this point are not strictly comparable with those below.

Table VII.

$\mathfrak{H}$.	$\mathfrak{I}_1'$.	κ_1'.	First "on."	Next "off."	Cyclic "on"—"off."	Ratio of Shock-effect of first "on" to $\mathfrak{I}_1'$.	Ratio of Shock-effect of next "off" to Shock-effect of first "on."	$\mathfrak{I}_2' \div \mathfrak{I}_1'$.
0·95	2·32	2·44	— 1·2	— ·15	..	— ·51	·13	·43
1·27	2·65	2·09	1·0	·44	..	·39	·43	·44
1·84	3·53	1·92	1·5	·46	..	·42	·33	·46
2·7	3·9	1·44	1·9	·29	..	·49	·15	·43
6·0	9·0	1·50	4·2	·77	..	·46	·18	·45
8·9	13·8	1·51	5·2	1·06	..	·39	·20	·54
11·6	19·4	1·68	6·4	1·86	+ ·53	·36*	·19*	·48*
18·0	30·2	1·68	7·9	2·04	+ ·47	·28	·20	·61
22·8	36·1	1·58	8·8	1·63	+ ·21	·25	·16	·62
34·9	50·4	1·45	12·8	1·72	— ·27	·25	·16	·61
46·7	53·8	1·15	12·2	1·65	— ·14	·23	·15	·67
57·5	59·7	1·04	14·2	1·27	— ·32	·23	·11	·69
76·2	65·4	·86	14·3	1·12	— ·54	·21	·12	·68
94·2	66·1	·70						
109	66·4	·61						
121	66·9	·55						
134	68·2	·51	14·0 (94·2 to 207)	·97	— ·56	·20	·11	·73
147	68·7	·47						
173	68·7	·40						
207	68·7	·33						
242	70·2	·29						
301	70·2	·23	12·2 (242 to 397)	·79	— ·48	·17	·11	·77
350	70·6	·20						
397	70·6	·18						

* In the entries above this point, in absence of experimental data, the *cyclic "on" — "off"* is neglected. Thus the results above this point are not strictly comparable with those below.

TABLE VIII.

$\mathfrak{H}$.	$\mathfrak{I}_1'$.	κ_1'.	First "off."	Cyclic "on" — "off."	Shock-effect of first "off" ÷ $\mathfrak{I}_1'$	$\mathfrak{I}_2' \div \mathfrak{I}_1'$.
·98	2·05	2·09	− 1·17	. .	− ·57	·43
1·61	3·52	2·19	2·27	. .	·65	·35
1·96	4·26	2·17	2·64	. .	·62	·41
2·65	4·84	1·83	3·01	. .	·62	·39
3·8	6·2	1·64	3·5	. .	·57	·43
6·1	10·1	1·66	5·6	. .	·55	·45
8·7	13·9	1·59	6·3	. .	·45	·53
11·5	20·2	1·76	8·8	+ ·58	·41*	·47*
17·3	31·4	1·82	12·1	·69	·36	·52
22·9	37·6	1·64	11·3	·54	·29	·62
36·0	49·4	1·38	11·4	·35	·23	·68
46·7	53·3	1·14	12·5	·36	·23	·69
57·5	58·1	1·01	10·6	·09	·18	·69
79·1	61·3	·76	12·4	·20	·20	·73
93·6	63·6	·68				
111	64·1	·58				
124	65·3	·53				
134	65·3	·49	11·6	·17	·18	·75
147	65·6	·45				
180	66·2	·37				
213	66·9	·32				
224	66·8	·30				
299	67·4	·23				
348	67·9	·19	11·9	·20	·18	·77
400	67·8	·17				

Fourth Series of Experiments.

§ 35. In the last series of experiments, which extended into March, the effects of pressure on the induced magnetism were more particularly under investigation. Except on one or two occasions, the magnetometer was distant 50 cms. from the centre of the magnetising coil, and 81 cms. from the scale. Previous to each experiment the rod was demagnetised by reversed currents followed by vigorous tapping.

After the introduction of the rod into the coil, fourteen pressure cycles were in general applied, readings being taken of the effects of the first four and the last four cycles. From these the effect of the first pressure and the cyclic effect are calculated. Then, leaving the current untouched, the rod was usually removed to a distance and replaced, scale-readings being taken. The comparison of the reading taken when the rod was out with that taken prior to its original introduction into the coil, tested the constancy of the magnetometer zero. From the readings taken before and after the rod's removal, we find the magnetisation $\mathfrak{I}_2$ of the rod at the end of the pressure cycles; while from the readings taken before and after the rod's re-introduction we find the magnetisation $\mathfrak{I}_3$ on the second introduction of the rod into the coil. Thus, $\mathfrak{I}_2 - \mathfrak{I}_1$ is, as in former experiments, the increase in the magnetisation during the application of the pressure cycles, while $\mathfrak{I}_2 - \mathfrak{I}_3$ is the magnetisation lost during the removal of the rod from the coil and its re-introduction.

* In the entries above this point, in absence of experimental data, the *cyclic* "*on*" — "*off*" is neglected. Thus the results above this point are not strictly comparable with those below.

The compensating coil was intentionally placed so as to somewhat more than balance the magnetising coil, and so, in some of the strongest fields, the spot was off the scale when the rod was removed. Thus, in these fields, there were no data for calculating $\mathfrak{I}_1$, and in calculating $\mathfrak{I}_2 - \mathfrak{I}_1$ and $\mathfrak{I}_2 - \mathfrak{I}_3$ it had to be assumed that the magnetometer zero had not altered in the intervals that elapsed during the application of the pressure cycles and during the absence of the rod from the coil. The latter interval was always short, so that any sensible alteration during it was improbable. During these observations the end A of the rod was always the north pole.

There then followed in general, while the current remained unchanged, some observations intended to test the residual effects of the pressure cycles. In these the rod was repeatedly removed from the coil, it might be when free from or when subjected to pressure, and while out its state, as regards pressure, might or might not be changed. Not infrequently, too, the ends were changed while it was out, so that on its re-introduction the end A might be either a north or a south pole. Sometimes on the re-introduction of the rod *first "ons"* or *first "offs"* of pressure were taken, with the object of determining whether their magnitude was affected by repetition or by a change in the end of the rod. The results of this last series of experiments are contained in Tables IX. and X. They are the results on which most of the curves in figs. 1–8 (Plate 15) are based.

TABLE IX.

$\mathfrak{H}$.	$\mathfrak{I}_1$.	κ_1.	$\mathfrak{I}_2-\mathfrak{I}_1$.	κ_2.	$\mathfrak{I}_2-\mathfrak{I}_3$.	$\mathfrak{I}_A$ "on"—"off."	$\mathfrak{I}_B$ "on"—"off."	"Off" $\mathfrak{I}_A-\mathfrak{I}_B$.	"On" $\mathfrak{I}_A-\mathfrak{I}_B$.
1·8	4·1	2·3	2·4	3·6	..	..	1·4	..	..
2·2 *p*	8·2	3·8	1·9	4·7	1·4	..	..	·2	..
*3·4	11·0	3·2	3·4	5·0	2·7	..	..	3·8	..
4·3 *p*	20·2	4·7	·3	4·8	2·7	1·7	..	..	..
8·1 *p*	41·5	5·1	5·0	5·8	5·2	2·4	..	9·9	..
8·6	37·3	4·3	10·2	5·5	5·1	..	..	9·7	..
*12·5	61·7	4·6	5·1	6·2	..	..	..	..	10·3
23·4 *p*	147·1	6·3	3·4	6·4	13·5	..	..	..	..
23·7	141·1	6·0	13·2	6·5	11·6	..	..	5·3	..
35·2 *p*	253·8	7·2	6·2	7·4	16·5	..	..	..	..
35·7	233·4	6·5	13·3	6·9	10·4	..	..	2·9	..
46·0	290·0	6·3	12·3	6·6	12·0	9·0	..	..	..
47·5 *p*	312·3	6·6	4·7	6·7	9·2	..	..	·5	..
57·5	339·5	5·9	10·6	6·1	9·5	..	..	..	..
57·5 *p*	375·7	6·5	−4·1	6·5	11·6	8·1	..	·5	..
72·6	397·3	5·5	6·9	5·6	10·5	7·4	..	·6	..
79·8	405·8	5·1	8·6	5·2	10·2	6·3	..	1·9	..
92·0	427·0	4·6	8·1	4·7	8·4	7·3	..	·6	..
103·5	491·5	4·7	6·1	4·8	4·5	4·2	..	3·0	..
115	510·4	4·4	3·8	4·5	4·7	1·8	2·1	2·2	..
128	530	4·1	2·4	4·2	4·4	2·1	..	1·8	..
144	550	3·8	3·0	3·8	..	1·4	..	..	..
158	554	3·5	2·8	3·5	2·8	·5	..	..	..
174	..	..	1·0	..	1·1	−0·6	..	0	..
198	..	..	1·6	..	1·6	−1·6	..	−0·4	−1·1
224	..	..	..	..	1·4	−1·6	..	−0·7	..
270	..	..	1·2	..	0·2	−4·1	−2·2	−4·4	−5·0
351	..	..	..	..	..	−4·1	−3·1	−5·1	−5·6

* Current fell markedly during pressure cycles. κ_1 is calculated on its initial, κ_2 on its final value.

TABLE X.

$\mathfrak{H}$.	First "on."			First "off."			Cyclic "on" — "off."	First "on" Shock-effect ÷ $\mathfrak{J}_1$.		First "off" Shock-effect ÷ $\mathfrak{J}_1$.		Cyclic "on" — "off" $\mathfrak{J}_2$
	A_1.	A_2.	B_2.	A_1.	A_2.	B_2.		A_1.	A_2.	A_1.	A_2.	
1·8	2·4	..	..	..	..	..	·29	·51	..	..	..	·044
2·2 *p*	..	..	..	1·3	..	..	·34	..	..	·2	..	·034
3·4	4·8	..	..	..	..	..	..	·34	..	..	..	..
4·3 *p*	..	..	..	·1	..	..	·72	..	..	·04	..	·035
8·1 *p*	..	5·8	7·0	2·3	..	..	1·7	..	·10	·098	..	·036
8·6	10·1	..	..	..	..	..	1·2	·24	..	..	..	·026
12·5	9·9	..	..	..	— ·3	1·5	1·8	·13	..	..	·024	·027
23·4 *p*	..	..	16·1	·3	..	..	2·6	..	..	·02	..	·017
23·7	16·3	..	17·3	..	..	..	2·5	·09	..	..	..	·016
35·2 *p*	..	..	..	— 2·6	..	..	4·4	..	..	·007	..	·017
35·7	16·6	..	..	..	..	..	5·3	·048	..	..	..	·021
46·0	17·0	13·8	..	..	— 1·0	..	4·6	·043	·032	..	·012	·015
47·5 *p*	..	12·4	12·7	— 1·4	..	..	3·6	..	·028	·007	..	·011
57·5	16·5	12·9	14·8	..	— 1·6	..	4·1	·036	·026	..	·007	·012
57·5 *p*	..	10·0	12·5	— 2·3	— 1·2	..	3·3	..	·018	·003	·005	·009
72·6	10·9	10·5	10·5	..	— 1·2	..	2·4	·022	·020	..	·003	·006
79·9	11·7	10·5	..	..	— 1·1	..	2·4	·023	·020	..	·003	·006
92·0	11·0	10·0	..	..	— ·8	..	2·1	·021	·018	..	·003	·005
103·5	5·2	5·5	4·7	..	+ ·7	..	·7	·009	·009	..	·003	·001
115·0	4·7	..	..	..	+ 1·1	..	·45	·008	..	..	·003	·001
128	2·6	2·1	1·8	..	+ 1·1	..	— ·51	·006	·005	..	·001	— ·001
144	1·2	0·9	0·9	..	+ 1·6	..	— ·9	·004	·003	..	·001	— ·002
158	0·9	0·6	..	..	+ 2·0	..	— 1·1	·004	·003	..	·002	— ·002
174	— 1·4	— 0·4	..	..	+ 2·1	..	— 1·4	0	·002	..	·001	— ·0025
198	— 2·4	— 0·5	— 0·3	..	+ 2·8	..	— 1·7	—·001	·002	..	·002	— ·003
224	— 1·3	..	— 1·1	..	+ 2·6	..	— 1·6	·001	..	..	·002	— ·003
270	— 2·7	— 1·8	— 2·2	..	+ 3·0	+ 3·0	— 2·2	—·001	·001	..	·001	— ·004
351	..	— 2·7	— 2·4	..	+ 3·4	+ 3·4	— 2·7	..	0	..	·001	— ·004

§ 36. In Table IX. the first six headings have been already explained. The letter p after the numerical measure of the field in the first column signifies that the rod was under pressure previous to and during its introduction into the coil. In such a case the entries under $\mathfrak{I}_1$ and κ_1 refer to the magnetisation existing before this pressure was removed, and so are on a different footing from the other entries under these headings. The entries under the other headings are also in such a case doubtless indirectly affected, but to a much smaller degree.

In the last four headings the suffix indicates which end of the rod was the north pole when the magnetisation in question was measured. The results under these headings are deduced from the readings obtained by removing and replacing the rod subsequent to the application of the pressure cycles, during which application it must be remembered A was always the north pole.

The seventh column gives the excess of the magnetisation existing when the rod was under pressure when reintroduced into the coil over that existing when it was free from pressure when reintroduced, the end A being in each case the north pole of the reintroduced rod. The eighth column differs from the seventh only in that the end B was in each case the north pole of the reintroduced rod. The ninth column gives the excess of the magnetisation found when A was the north pole of the reintroduced rod over that found when B was the north pole, the rod in each of its reintroductions being free from pressure. The tenth column differs from the ninth only in that the rod during each of its reintroductions was under pressure.

§ 37. In Table X. *First "on"* is, as previously, the total change in the magnetisation—cyclic and non-cyclic—due to the first application of pressure. A_1 gives the effect when the rod, immediately after being demagnetised, has been exposed for the first time to the field in question. A_2 gives the effect of the first pressure applied after the *reintroduction* of the rod in a state free from pressure, and with the end A a north pole. In the case of the results under A_2, there have intervened since demagnetisation a complete series of pressure cycles applied with A a north pole, and at least one removal and reintroduction of the rod. In some cases there were several removals and reintroductions, and the mean of the observations is recorded. Under B_2 we get the effect when, on its reintroduction, the rod has B for its north pole. In this case it must be borne in mind that the pressure cycles applied since the preceding demagnetisation occurred when the opposite end A was the north pole.

First "off" is the total effect of the removal of a pressure existing previous to and during the introduction of the rod into the coil. A_1 refers to the case when demagnetisation has immediately preceded the observation, A_2 and B_2 to the cases when a complete series of pressure cycles, with A the north pole, and at least one removal and reintroduction have intervened since demagnetisation. The distinction between A and B is the same as in the case of the *First "on."*

Cyclic "on"—"off" has its usual meaning. Under the next two headings are given the non-cyclic portions of the effects of the first application of pressure and of the first removal of a pre-existing pressure. A_1 and A_2 refer to the results recorded in the first two columns under the headings *First* "*on*" and *First* "*off*." The last heading has been already explained. As usual .. indicates that no observations were taken. When no algebraic sign is attached to a figure + is understood.

§ 38. To a casual observer the fluctuations that appear in the results of the foregoing tables may seem excessive. It should, however, be borne in mind that most of the pressure effects are very small compared to the total amount of the induced magnetisation—sometimes as little as one-thousandth part. Thus the small irregularities in the magnetising current which are produced by the slightest want of constancy in the cells, or by the vibrations communicated to the resistance wires from shakings of the floor, may produce commensurable effects. Such irregularities were frequently recognised through a continual quivering motion of the spot on the scale, while the ammeter reading appeared steady enough. Of course, when the unsteadiness was very marked, observations were suspended, but comparatively little of the work done would have been accomplished in the time if observations had been taken only when absolute steadiness prevailed.

§ 39. A separate discussion of the results of each table would involve a good deal of repetition. It has thus appeared best, as a rule, to embody the most trustworthy results in curves, and to discuss particular points in connection with the features of the individual curves. In every curve the horizontal coordinate gives the strength of the field, $\mathfrak{H}$, calculated after the manner explained in § 19. In the case of the residual magnetism, $\mathfrak{H}$ is of course the strength of the pre-existing field.

In fig. 1 (Plate 15), the ordinates give the initial magnetisation when the rod is introduced into the magnetising coil free from pressure. In fig. 3 the ordinates give the coefficient of induced magnetisation under the same conditions. The first portions of both curves, in which the individual observations are indicated by dots, are based on Table IX., while the second portions, in which the individual observations are indicated by crosses are based on Table III.

These curves are of the same general character as those obtained by many observers for iron. In fields below 8 or 9 C.G.S. units, the magnetisation increases comparatively slowly as the strength of the field is raised. There then ensues, as is most clearly shown by the steepness of the commencing portion of the curve of fig. 3, a much more rapid increase of magnetisation. The rate of increase attains a maximum, as shown in fig. 3, in a field of about 35 C.G.S. units; which, accordingly, is the *Wendepunkt* for the specimen. The rate of increase of the magnetisation then falls off, but at first in a comparatively gradual manner. There is thus no very clear indication of an approach to "saturation" until the strength of the field approaches 200 C.G.S. units. Even in the strongest experimental fields the rate of increase is by no means infinitesimal, though, as already stated, this is probably in part accounted for by the heating of the rod.

§ 40. The smallness of the scale of fig. 1, does not allow the effect of pressure on the induced magnetisation to be shown, but the enlarged scale of fig. 2 shows the effect in fields below 30 C.G.S. units, where it is of most importance.

The thick line *a*, with the individual observations indicated by dots, is merely the initial portion of fig. 1 on an enlarged scale. The dotted line *b*, with the individual observations indicated by circles, gives the induced magnetisation after the application of the pressure cycles. The curves, *a* and *b*, are based on the same experiments, and the difference between their ordinates answers to the values in the column $\mathfrak{I}_2 - \mathfrak{I}_1$ of Table IX. in those experiments in which the rod was originally free from pressure.

The third curve *c*, with the individual observations indicated by crosses, gives the induced magnetisation prior to the application of pressure cycles, in these experiments denoted by a *p* in Table IX., in which the rod was under pressure when introduced into the coil.

In fig. 4 the ordinates give the coefficients of magnetic induction in the three cases of fig. 2. The data are taken from the same table, and the letters, &c., have the same significations.

The difference between the curves *a* and *b* shows the very large effect of the pressure cycles in increasing the magnetisation in the weaker fields. It should be remembered that between the corresponding pairs of observations on which these curves are based there intervened no break of the current, nor any change in the resistance, or in the position of the ammeter. Thus any error in the zero or orientation of the ammeter would affect each curve alike, and leave the difference of the ordinates practically unaffected. Variations, it is true, in the strength of the current during the application of pressure cycles, would affect curve *b* without affecting curve *a*. Such variations, however, could escape notice in the weaker fields only when very small, because the ammeter was then in its most sensitive position.

The comparison of the curves *c* with the others is not so satisfactory. During the time of most of the experiments the ammeter was being used for other purposes, and so had to be set up afresh every other day. Thus, though its position was carefully adjusted, small differences were certain to occur.

For these and other reasons it would be unsafe to draw any conclusions from the crossing of the curves *b* and *c* in fig. 4. It may, however, be regarded as perfectly certain that in the weaker fields the curve *c* lies between the curves *a* and *b*, and that within the limits of fig. 4 the curve *c* lies very distinctly above the curve *a*.

The form of all these curves of fig. 4, suggests that under all conditions as to pressure the coefficient of magnetic induction becomes extremely small in very weak fields. There may, however, be a turning point in one or all of the curves in fields lower than those experimented on.

§ 41. In curve *a* of fig. 5 the ordinates give the total change in the magnetisation produced by the first pressure in those experiments of Table IX. in which the rod was free from pressure when introduced into the coil. The change in magnetisation is measured with the pressure " on," and so is really the algebraic sum of the cyclic and non-cyclic effects. The individual observations are indicated by dots, whose distances from the curve are in no case serious.

The curve shows that the total effect of the first pressure attains a distinct maximum in a field of about 45 C.G.S. units—which somewhat exceeds the Wendepunkt—and then diminishes somewhat rapidly as the strength of the field is raised. An unmistakeable critical field, where the effect vanishes, appears at about 160 C.G.S. units, and in stronger fields the total effect of the first pressure is a diminution of magnetisation. From the form of the curve it would appear that the diminution does not increase indefinitely as the strength of the field is raised. But the experiments leave it uncertain whether this diminution of magnetisation attains a maximum in a field of about 350 C.G.S. units, or whether it continually approaches an asymptotic value.

§ 42. In curve *b* of fig. 5, the ordinates give the loss in the induced magnetisation accompanying the removal of the rod from the coil, after the application of the pressure cycles, and its reintroduction. The curve is based on the column $\mathfrak{J}_2 - \mathfrak{J}_3$ of Table IX.

The ordinate corresponds more or less closely to the non-cyclic effect of the sum of the pressure cycles applied during the flow of the current prior to the rod's removal. There are two reasons however, why it cannot be regarded as an exact measure of this effect, more especially in the weaker fields. In the first place, even when no pressures are applied it is well known that the magnetisation of iron is not exactly the same on the second exposure to a certain field as it is on the first. Some occasional observations on the cobalt itself gave a somewhat greater magnetisation on a second exposure than on the first. The difference was, however, unimportant, and in fields over the Wendepunkt it was, if existent, extremely small. In the second place part of the effect of the pressure cycles unquestionably survives a removal of the rod from the magnetic field. As will be seen from § 65, this residual effect is of considerable importance in fields below 30 units. Owing to both these causes the effect of the pressure cycles in fields below 30 or 40 units must be decidedly greater than the curve *b* would indicate. No observations exist to show whether or not the curve *b* eventually crosses the axis of abscissæ. Not improbably this would be a very difficult point to settle owing to the heating of the rod.

The reason for drawing a curve for $\mathfrak{J}_2 - \mathfrak{J}_3$ in preference to one for $\mathfrak{J}_2 - \mathfrak{J}_1$, is that only a few minutes elapsed between the taking of the readings giving $\mathfrak{J}_2$ and $\mathfrak{J}_3$, while the reading which gives $\mathfrak{J}_1$ might have been taken over an hour previously. Thus under ordinary circumstances the variation of the current could not but be utterly insignificant in the one instance, whereas in the other it occasionally reached a measurable quantity.

In Table IX. omitting of course the fields marked *p*, the values of $\mathfrak{J}_2 - \mathfrak{J}_1$ and $\mathfrak{J}_2 - \mathfrak{J}_3$ show a very fair agreement. In fields below the Wendepunkt the former quantity is, as the above reasoning suggests, distinctly the larger ; but in stronger fields the one is sometimes the larger and sometimes the other. In no single case was a negative value obtained for either quantity, though in fields over 200 C.G.S. units, both become unquestionably very small.

The only safe conclusion appears to be that if a critical field existed for the non-cyclic or shock-effect of the pressure cycles it exceeded 275 C.G.S. units. Considering, however, that the critical field for the cyclic effect of the pressure cycles is only about 120 C.G.S. units, this seems an important result.

§ 43. In the curve of fig. 6, which is based on Table X., the ordinates give the ratio of the increase in the induced magnetisation produced by the non-cyclic part of the first pressure relative to the amount of the induced magnetisation existing previous to the pressure. The ordinates may thus be held to measure the relative importance in fields of various strengths of the non-cyclic portion of the effect of the first pressure.

The curve shows in a striking manner how the relative importance of the non-cyclic portion of the effect of the first pressure continually diminishes as the strength of the field increases. In the weakest field employed, viz., 1·8 C.G.S. units, the first pressure permanently increases the magnetisation by one half its original value, whereas in a field of 160 C.G.S. units the increase is certainly less than one part in two hundred.

In stronger fields, as appears from the ninth and tenth columns of Table X., this shock-effect becomes extremely small, and continues to be so within the range of the experiments.

The experiments cannot be said to settle conclusively the sign even of the effect, but the evidence is decidedly in favour of its remaining positive in fields of at least 270 C.G.S. units. It will, in fact, be observed that in the tenth column of Table X., a decrease of magnetisation was in no single case obtained. Now in the higher fields the results in this column are calculated from the mean of two or three observations, whereas those in the preceding column answer, of course, to only one observation.

Effects of the Removal of Pressure.

§ 44. It might appear at first sight that the increase in the magnetisation invariably found to accompany the application of the sum of the pressure cycles in fields up to 270 C.G.S. units is in itself sufficient proof that the non-cyclic effect of the first pressure must be within the same limits an increase of magnetisation. The increase, however, in the former case might be due to the removals not the applications of pressure.

The removal of pressure from a rod occasions relative displacements of its parts to pretty much the same extent as does the application of pressure, and so it too may be expected to have some permanent influence on the magnetisation. This effect was actually found to exist, and its magnitude relative to the original magnetisation is given in the eleventh and twelfth columns of Table X. Comparing these with the two previous columns, it will be seen that in weak fields the non-cyclic effect of the removal of the original pressure, though much less important than the corresponding effect of the application of the first pressure, is by no means a negligible quantity. It may, however, be easily overlooked, because in the weaker fields, where its importance is greatest, it is in the opposite direction to the cyclic effect of the removal of pressure. Also in fields between 25 and 95 C.G.S. units, as appears from the thirteenth column of Table X., the cyclic part of the effect is numerically the larger, and so between these limits the removal of an original pressure appears to be accompanied by a diminution in the magnetisation. In fields over 120 C.G.S. units the non-cyclic effect has the same sign as the cyclic, and so the increase in magnetisation accompanying the removal of an original pressure is fairly conspicuous.

Cyclic Effect of Pressure on the Induced Magnetisation.

§ 45. In fig. 7 the ordinates give the cyclic change in the induced magnetisation accompanying the pressure cycles. The thick line *a*, in which the individual observations are indicated by dots, is based on Table X., the broken line *b* with individual observations indicated by crosses, on Table I., and the dotted line *c* with individual observations indicated by circles, on Table III.

These curves agree in showing a critical or VILLARI field of about 120 C.G.S. units. The magnetisation is greatest or least when the rod is under pressure according as the strength of the field is less or greater than that of the critical field.

It will be seen from fig. 1 that the magnetisation of the rod in the critical field is about 520 units. According to both the curves, *a* and *b*, the absolute magnitude of the cyclic effect attains a maximum in a field of about 35 C.G.S. units. This, it will be remembered, is the field found for the Wendepunkt in § 39. In general form the two curves *a* and *b* could hardly agree better than they do, and the difference in the absolute lengths of their ordinates might well be due to a difference between the standard pressures adopted at the times. Both curves, it will be noticed, pass through almost all their experimental points. Near the critical field all three curves would lie so close together that only the experimental points of *c* are there shown.

The highest field in Table IX. is 351 C.G.S. units, and the form of the curve *a* leaves it uncertain whether the cyclic effect attains an algebraic minimum in a field somewhat higher than this and then diminishes numerically, or whether it continually approaches an asymptotic value. The former alternative is unquestionably supported by the form of the curve *c*, which extends to a field of 725 C.G.S. units. The deviations of the experimental points from this curve are, however, so large that it would be rash to attach much weight to its precise form. Probably all we are entitled to infer is that, if an asymptotic value exists for the cyclic effect, its numerical value cannot much exceed that found in a field of 400 C.G.S. units; whereas, if a second critical field exists, where the effect changes sign a second time, its value must very considerably exceed 700 C.G.S. units.

It should be noticed that the ordinates in fig. 7 are drawn on double the scale of those in fig. 5. Thus, comparing in those figures the two curves *a*, which are based on the same series of experiments, we see that, in fields below the VILLARI point of fig. 7, the total effect of the first pressure is invariably very considerably larger than the cyclic effect of pressure. The maximum value attained by the former effect is about thrice that attained by the latter.

§ 46. In fig. 8 the ordinates give the ratio of the cyclic increase in magnetisation accompanying pressure "on" to the amount of the induced magnetisation existing when the cyclic state is reached. They thus show what proportion of the magnetisation takes part in the cyclic change.

The curves *a* and *c* are derived from the same experiments as the corresponding curves *a* and *c* of fig. 7. The form of *a*, near the vertical axis, shows how much the relative importance of the cyclic effect increases as the strength of the field is reduced.

In comparing the relative magnitude of the cyclic effect and of the shock effect of the first pressure, it should be noticed that the ordinates of fig. 8 are drawn on a scale ten times that on which the ordinates of fig. 6 are drawn. Thus, in the weakest fields, the shock effect is fully ten times the cyclic effect.

Residual Magnetisation.

§ 47. In figs. 9 and 10 (Plate 16) the ordinates give the amount of the residual magnetisation existing immediately after the break of the current. The curves *b* and *d* are shown in both figures, but on a different scale. The curve *a* is based on Table V. The rod was here demagnetised before exposure to the weakest field, but not subsequently, and remained entirely free from pressure. The curve *b* is based on Table VI. The rod was here demagnetised by reverse currents and vigorous tapping before each introduction into the coil, but no pressures were applied while it was under the influence of the magnetising currents. The curves *c* and *d* are based on Tables VII. and VIII. respectively. In both cases the rod was demagnetised, as in the case of curve *b*, but was subjected to six pressure cycles while under the influence of the magnetising current. In the case of *c* the pressure was "off" when the current was broken, whereas in the case of *d* the pressure was "on." The individual observations are indicated by dots for the curves *b*, by circles for the curve *c*, and by crosses for the curves *a* and *d*. With the scale of fig. 9 the curve *c* would be indistinguishable from the curve *d* in weak fields, and from the curve *b* in strong fields.

Effects of Pressure on the Amount of the Residual Magnetisation.

§ 48. The curves *a* and *b* of fig 10 agree in showing only a small amount of residual magnetisation on the break of weak fields; but in fields below 5 C.G.S. units the ordinates of *b* are at least double those of *a*. The difference is surprisingly great, considering the similarity of the conditions under which the corresponding experiments were conducted. It must, presumably, be mainly attributed to the residual effect of the shocks employed in completing the demagnetisation in the experiments on which the curve *b* is based.

In weak fields, as the difference between the curves *c* and *d* on the one hand, and the curves *a* and *b* on the other abundantly proves, the effect of pressures applied during the flow of the current in increasing the residual magnetisation is simply enormous. It would thus appear *a priori* probable that the application of shocks immediately before the starting of the current should have some appreciable tendency in the same direction. Fortunately I happened to observe the induced as well as the residual magnetisation for the field 2·6 C.G.S. units in the experiments on which curve *a* is based. The numerical value of the induced magnetisation was 8·3, which is almost exactly the value obtained by interpolation for the same field from Table IX. Consequently, in this field, and so presumably in other weak fields, the difference between the curves *a* and *b* cannot be attributed, in any important degree, to an increase in the induced magnetisation brought about by the process of demagnetisation employed in the case of curve *b*.

As the strongest field in Table V. is only 79 C.G.S. units, no data exist for drawing the curve *a* in higher fields. It is only, however, in fields below 45 or 50 C.G.S. units that there is any clear difference between the results of Tables V. and VI. We are thus probably justified in concluding that the process of demagnetisation has an appreciable effect on the amount of the residual magnetisation only in fields below 50 C.G.S. units.

As already stated, the results of Table V. are each the mean of two observations taken in close succession with the same current. Almost invariably the second observation showed a slightly larger amount of residual magnetisation than the first. This property has been noticed by several observers in iron.

The difference between the curves *b* and *c* of fig. 10, which are based on experiments in which the same process of demagnetisation was applied, shows how effective pressure cycles are in increasing the amount of the residual magnetisation in weak fields. In stronger fields than those of fig. 10 the curves gradually approach one another, and in fields exceeding 120 or 130 C.G.S. units they cannot with certainty be said to differ. Thus, in fields below 120 or 130 C.G.S. units, the application of pressure cycles during the flow of the current increases the amount of the residual magnetisation, but in stronger fields no effect can with certainty be said to exist.

In fields below 30, or at all events 20 C.G.S. units, the difference between the curves *c* and *d* is, though small, perfectly clear and incontestable. The existence of pressure during the break of the current is the only point in which the experiments on which curve *d* is based differed from those on which curve *a* is based. As the effect of pressure " on " during the flow of the current is an increase of induced magnetisation in fields below 120 C.G.S. units, an excess in the ordinates of curve *d* over those of curve *c* in weak fields might reasonably have been expected. The difference, however, as will more fully be seen presently, is somewhat greater than might have been anticipated.

The crossing of the curves *c* and *d* in a field of from 35 to 40 C.G.S. units, and thus far below the VILLARI field, appears a somewhat striking fact. In fields over 120 C.G.S. units the curve *c*, if shown in fig. 9, could not be distinguished from curve *b*, and the difference between its ordinates and those of curve *d* seems then truly remarkable. In fields over 150 C.G.S. units this difference remains nearly constant, and amounts to about 4 per cent. of the ordinates of *c*. If it be remembered that according to the last column of Table X. the percentage of the induced magnetisation, which is cyclic for the same pressure "on" and "off," is in fields between 150 and 400 C.G.S. units never in excess of ·4, the significance of this result will be more fully understood.

§ 49. The ratio of the residual magnetisation existing in the rod immediately after the break of the current to the numerical value of the strength of the pre-existing field will, for shortness, be here termed the *residual susceptibility*. It is denoted by κ_1' in Tables V. to VIII., and its values are represented graphically by the ordinates of the curves of fig. 11. In this and in the subsequent figures the letters *a*, *b*, *c*, *d* denote curves obtained from the same series of experiments as are the respective curves *a*, *b*, *c*, *d* of fig. 10. In fig. 11 and the subsequent figures, however, the individual observations are indicated by crosses for curves *a* and *c*, by dots for curve *b*, and by circles for curve *d*.

In the absence of pressure, as shown by curves *a* and *b*, the residual susceptibility is very small in weak fields, but increases rapidly, attaining a maximum in a field a little over 20 C.G.S. units. This, it will be noticed, is not much over half the field which gives the Wendepunkt for the induced magnetisation. The greatest value actually observed for κ_1' in the case of curve *b*, was only 1·36. After the maximum is passed there is a continuous, but gradual, diminution in the residual susceptibility.

The difference between the commencing portions of curves *a* and *b* shows, even more clearly than in fig. 10, the large effect in weak fields of the process of demagnetisation. In fields over 50 C.G.S. units the two curves practically coincide, and are drawn as one.

The crossing points for the various curves in fig. 11 are, of course, the same as in figs. 9 and 10. Within the range of the figure the curve *c* lies distinctly above the curve *b*. In fields over 55 C.G.S. units, the curve *d* is not drawn, as it could hardly within the remaining limits of the figure be distinguished from curve *b*.

Commencing with the strongest experimental fields, the ordinates of the curves *c* and *d* increase gradually as the strength of the field is reduced, and show maxima values in somewhat lower fields than do the curves *a* and *b*. As the strength of the fields is further reduced, the ordinates of *c* and *d* pass through distinct minima values, and then increase rapidly as the strength of the fields approaches the lowest experimental value. The value of κ_1' cannot, of course, exceed that of κ_1; so either the ordinates of c and d must be rapidly approaching second maxima, or else the ordinates of the curves b and c of fig. 4 must possess minima values in fields lower than were experimented on.

§ 50. In comparing the amounts of the residual and induced magnetisations, the employment of the term *retentiveness* in an exact way will be found serviceable. It is here used in accordance with the following definition :—

The retentiveness is the ratio of the residual to the induced magnetisation, both quantities being measured with the rod exposed to one and the same state of mechanical stress, and the stress remaining constant during the interval that elapses between the measurements.

In fig. 12 the ordinates give the retentiveness of the rod in the cases illustrated by the curves b, c, d. As the residual magnetisation alone was observed in the experiments recorded in Tables VI., VII., and VIII., the necessary values of the induced magnetisation were derived by interpolation from Tables IX. and X. In curve b the induced magnetisation is that existing prior to the application of pressure, or is the $\mathfrak{J}_1$ of Table IX. In curve c the induced magnetisation is $\mathfrak{J}_2$; for after six pressure cycles the increase in the magnetisation accompanying further pressure cycles is, for our present purpose, quite negligible. In the experiments answering to curve d, the rod, after experiencing six pressure cycles, was under pressure when the current was broken. Thus, for curve d the induced magnetisation is got by adding to $\mathfrak{J}_2$ the algebraic value of the *cyclic* "*on*"—"*off*" of Table X.

The curve b shows that, in the absence of pressure, the retentiveness attains a maximum in a field of about 15 C.G.S. units, a field somewhat below that at which the maximum residual susceptibility occurs in the corresponding curve of fig. 11. A great similarity exists between curve b and the curve for zero load in Professor EWING's fig. 57. The principal difference is that the field at which the maximum retentiveness appears is considerably higher in cobalt than in iron.

The curves c and d of fig. 12 bear a considerable resemblance to the corresponding curves of fig. 11; but there are no longer distinct maxima or minima. Comparing these curves with curve b we see that in the weakest experimental fields pressure cycles increase the retentiveness in the ratio of four or five to one. The tendency to become tangential to the vertical axis shown by the curves c and d—which cannot, however, go on indefinitely as the fields are further reduced—is not exhibited by any of the curves for the retentiveness of loaded iron-wire occurring in Professor EWING's fig. 57. Possibly if he had employed lower fields he might have found similar phenomena, so it would not be safe to assume that iron and cobalt actually differ in this particular.

The ordinates of curve d being greater in weak fields than those of curve c, it follows that in fields below 30 C.G.S. units, where the curves cross, the retentiveness of the rod is greatest when it is under pressure while the current is broken. In fields over 30 C.G.S. units the retentiveness is least when the current is broken with pressure "on," and in fields over 50 units the difference is not inconsiderable. In fields over the VILLARI point, of 120 C.G.S. units, the induced magnetisation is greater for curve *c* than for curve *d*, so that in such fields the excess of the ordinates of curve *c* over those of curve *d* would, relatively to their absolute magnitude, be somewhat less in the case of fig. 12 than in the case of fig. 11.

Similar considerations lead to the conclusion that in fields over 130 C.G.S. units the curve *b* would be, if anything, slightly above the curve *c*. In other words, in fields over 130 C.G.S. units the effect of pressure cycles is, if anything, slightly to diminish the retentiveness. This effect is, however, insignificant compared to that proceeding from the existence of pressure "on" during the break of the current.

The curves *b* and *d* cross in a field of about 40 C.G.S. units. The curve *d* would then become the lower, but it would be for a time so close to *b* that it is not attempted to show it separately in the figure.

The conclusions which the preceding considerations lead to are the following:—

In fields below 30 C.G.S. units the application of cycles of pressure "on" and "off" during the flow of the current, and the existence of pressure "on" during the break of the current, both tend to increase the retentiveness, the former agency being in fields below 10 C.G.S. units far the more important. In fields between 30 and 120 C.G.S. units, or thereby, the application of cycles of pressure still increases the retentiveness, but the effect continually diminishes as the strength of the field is raised. In fields over 130 C.G.S. units up to at least 300 or 400 C.G.S. units the effect of pressure cycles is very small, but is, if anything, a diminution of the retentiveness. In fields from 30 C.G.S. units up to at least 300 or 400 C.G.S. units the existence of pressure "on" during the break of the current diminishes the retentiveness, and the effect is of the same order of magnitude as that due to the same cause in fields below 30 C.G.S. units. In fields between 30 and 40 C.G.S. units, or thereby, the increase in the retentiveness occasioned by the pressure cycles exceeds the diminution occasioned by the existence of pressure "on," but in stronger fields the latter effect is the larger, and its superiority appears continually to increase with the strength of the field.

§ 51. Curve *b* of fig. 12 is repeated in Curve I. of fig. 13, in order that its form in fields over 75 C.G.S. units may be seen. There appears a continual but very slow diminution in the retentiveness as the field is raised to 400 C.G.S. units. Curve II. of fig. 13 will be discussed presently.

§ 52. In fig. 14 the ordinates give the absolute amount of the residual magnetisation which seems to disappear with the first alteration of stress after the break of the current.

Comparing the curves *b* and *c*, in which the loss of magnetisation accompanies the application of pressure, with the curve *d*, in which it accompanies the removal of the pressure existing during the break of the current, we see that the effect must be to a large extent independent of the precise character of the change of stress, and would doubtless follow more or less any mechanical agitation of the rod.

The curve *b* is drawn through nearly all the experimental points, but in the stronger fields of *c* and *d*, especially the latter, the experimental points are somewhat widely scattered. These latter curves accordingly cannot be trusted in their minute details. The curves are based on the data in the fourth columns of Tables VI., VII., and VIII. These tables give only certain average results for fields over 90 C.G.S. units, but they indicate that the ordinates of *b* and *c* would attain maxima values in fields somewhere between 100 and 200 C.G.S. units. Thereafter the ordinates of *c* would apparently diminish the more rapidly of the two, so that in fields of 400 C.G.S. units the curve *c* would have approached pretty close to the curve *d*, which remains apparently nearly horizontal.

§ 53. The application of cycles of pressure causes cyclic changes in the magnetisation, whose character will presently be discussed. In consequence of this the effects of the first change of stress on the residual magnetisation are only, in part, of a non-cyclic character. To get the exact quantity of magnetisation whose *permanent* disappearance is secured by the first change of stress, the cyclic effect must be allowed for.

Suppose, for instance, a field of 50 C.G.S. units is broken when pressure is "off." The cyclic effect is then a diminution of magnetisation when pressure is "on." Consequently the loss of magnetisation accompanying the first application of pressure exceeds the quantity whose permanent disappearance is secured by the amount which takes part in the cyclic change. Subtracting from the total loss the numerical value of the cyclic effect, we get what may be regarded as the true loss of residual magnetisation due to the first application of pressure. This quantity is that here termed the shock-effect of the first pressure.

In the case of residual magnetism the cyclic effect is in general small compared to the shock-effect, so that a considerable error in the cyclic effect will seldom seriously affect the calculation of the shock-effect.

§ 54. In fig. 15 the ordinates represent the ratio of the shock-effect of the first alteration of pressure to the amount of the pre-existing residual magnetisation. They may thus be regarded as measuring the efficacy of the first change of pressure in shaking out the residual magnetisation. Unfortunately no readings were taken of the cyclic effects of pressure in the weaker fields in the series of experiments on which the curves are based. Thus up to the points where the transverse lines are drawn, the ordinates represent the ratio of the *total* effect of the first change of pressure to the initial residual magnetisation. Consequently, as will be seen presently, in the commencing portions of the curves the ordinates of *b* and *c* are probably somewhat underestimated, and those of *d* on the other hand overestimated. The corrections could, however, hardly modify the relative positions of the curves.

The curves all show that the efficacy of the first change of pressure in shaking out the residual magnetisation, as measured by the percentage got rid of, continually diminishes as the strength of the field is increased. According to the seventh columns of Tables VI. and VII., and the sixth column of Table VIII., on which the curves are based, this diminution most probably goes on up to fields of 400 C.G.S. units at least. The difference, however, between the percentages shaken out in the case of fields of 100 and 400 C.G.S. units is under all conditions very small.

Comparing curves *b* and *c*, in figs. 14 and 15, and the seventh columns of Tables VI. and VII., we see that while in fields below 15 C.G.S. units an absolutely larger amount of residual magnetisation is shaken out by the first pressure when pressure cycles have been applied during the flow of the current, still in these and in all higher fields within the experimental limits a greater percentage is removed by the first pressure when no pressures have been applied during the current.

We thus see that in fields below 100 C.G.S. units, pressure cycles during the flow of the current diminish simultaneously the percentage of the induced magnetisation got rid of by breaking the current, and the percentage of residual magnetisation got rid of by the subsequent application of a pressure. In fields from 130 to at least 400 C.G.S. units pressure cycles during the flow of the current appear slightly to increase the percentage of induced magnetisation got rid of by breaking the current, while simultaneously diminishing the percentage of residual magnetisation got rid of by the subsequent application of a pressure. In these strong fields, however, both these effects are comparatively insignificant.

§ 55. In the experiments on which the curves *b* and *c* are based the effects of removing the first pressure applied after the break of the current were also observed. The invariable result was a loss of magnetisation, and its magnitude is recorded in the fifth columns of Tables VI. and VII. In considering how much of this loss is permanent, the cyclic effect of the change of pressure must be allowed for. This has been done in calculating the eighth columns of Tables VI. and VII., which give the relative importance of the first pressure and its removal in permanently reducing the magnetisation.

When no pressures have been applied during the flow of the current we see from Table VI. that, in fields between 18 and 75 C.G.S. units, the removal of the first pressure produces uniformly about one-ninth of the effect of its application. In the higher fields the relative importance of the removal of pressure shows a distinct diminution.

Comparing Tables VI. and VII. we see that in fields below 50 C.G.S. units the importance of the removal of the first pressure after the break of the current relative to its application is largely increased by the application of pressure cycles during the flow of the current. In fields over 50 C.G.S. units the effect of the removal bears to that of the application of the first pressure in the case of Table VII. the apparently nearly constant ratio of 1 : 9, which still somewhat exceeds the ratios found in the corresponding fields of Table VI.

The fact that the importance of the removal of the first pressure relative to its application is greatest in weak fields must, I think, be connected with the fact that in weak fields, as shown by curves *c* and *d*, fig. 15, a larger proportion of the residual magnetisation is shaken out by the removal of a pressure existing during the break of the current, than by the application of an equal pressure when the rod is free from pressure during the break of the current. In the weak fields pressure cycles, which exist in the case of curves *c* and *d*, cause a large permanent increase in the induced magnetisation, and, of this, a much larger proportion is due to the application than to the removal of pressure. Thus, the phenomena suggest that the residual magnetisation arising from the portion of the induced magnetisation which the application of pressure enables the rod to acquire is more easily shaken out by the removal of pressure than is the remainder of the residual magnetisation.

It may also be worth mentioning that by increasing the magnitude of the first pressure after the break of the current the effect of its application was increased, but the effect of its removal diminished absolutely as well as relatively.

Cyclic effect of Pressure on the Residual Magnetisation.

§ 56. The cyclic effects of pressure cycles on the residual magnetisation during the experiments on which the curves *b*, *c*, *d* are based, are shown in the sixth columns of Tables VI. and VII. and the fifth column of Table VIII. The cyclic effects were also observed in the December experiments, and are recorded in the fifth column of Table II. In the experiments of Table II. the demagnetisation was incomplete, but otherwise the conditions were identical with those of the experiments of Table VII.

The cyclic effect was found very difficult to measure accurately, partly on account of its smallness, and partly, doubtless, on account of its sensitiveness to small variations in the treatment of the rod during the flow, and more especially the break of the current. In the weaker fields the cyclic effects were observed only in the experiments of Table II., which were inferior in accuracy to the later observations.

For these reasons the numerical values attributed to the cyclic effects in the tables cannot claim to be more than somewhat rough approximations. Thus, while believing the results to represent correctly the general features of the phenomena, I have not embodied them in curves, as the precise forms of these might have owed too much to the imagination.

§ 57. Taking first the case when pressure cycles were applied during the flow of the current but no pressure existed during the break, we see from Tables II. and VII. that the cyclic effect in the residual magnetisation is an increase or a decrease of magnetisation when pressure is "on," according as the pre-existing field is below or above a certain critical field. So far the parallelism between the residual and induced magnetisations seems complete. The critical field, however, for the residual magnetisation is according to both tables only about 30 C.G.S. units, and so only about a quarter of that for the induced magnetisation, and the intensity of the critical magnetisation in the former case is less than an eleventh of that in the latter. Table VII. shows no sensible variation in the magnitude of the effect as the field is raised from 70 to 400 C.G.S. units.

Taking next the case when no pressures were applied during the flow of the current, we see from Table VI. that in a field of 18 C.G.S. units—the lowest in which observations of the effect were taken—no sure cyclic effect was detected. Thus a critical field must exist at or very close to this field. In higher fields there is a clear diminution of magnetisation accompanying pressure "on," and in fields over 100 C.G.S. units the results agree as closely with those of Table VII. as they well could. Thus, the only conspicuous difference in the cyclic effect produced by pressure cycles during the flow of the current is a rising of the critical field.

Table VIII., however, shows that a truly remarkable difference occurs in the phenomena when pressure exists during the break of the current. In this case, in fields from 11·5 to 400 C.G.S. units, the residual magnetisation in the cyclic state is invariably greater when pressure is "on" than when it is "off." The magnitude of the cyclic effect apparently diminishes at first as the field is raised, but in fields of from 70 to 400 C.G.S. units, it is at least approximately constant.

It thus appears that the sign even of the cyclic change of the residual magnetisation accompanying cycles of pressure, is altered by such a seemingly trifling circumstance as the existence of pressure during the break of the pre-existing current.

It seems almost unnecessary to point out that the facts stated in this paragraph convincingly show that the effect on the magnetisation of cyclic applications of pressure is not determined solely, or in some circumstances even principally, by the measure of the rod's magnetic moment, or its so-called intensity of magnetisation.

§ 58. As the conclusions of the last paragraph as to the cyclic effect seem of considerable importance, it may not be out of place to supply data by which the value of the evidence on which they are based may be fairly judged.

The precautions taken in varying the order of the experiments have been already mentioned in explaining the Tables VI., VII., and VIII.

Now in fields stronger than the critical field of Table VII., there were, in all, 46 separate experiments of the types L, M, and N. Answering to pressure "on," there appeared a minimum of magnetisation in each of the 31 experiments of the types L and M, a maximum in each of the 15 experiments of type N. As the difference was wholly unexpected, and the observer had no preconceived ideas on the subject, it is difficult to conceive how the evidence could be stronger.

§ 59. The ordinates of Curve II. of fig. 13, give the fraction of the residual magnetisation, which is removed by a definite number of pressure cycles in the experiments of Table VI., or type L.

The percentage removed continually diminishes as the strength of the pre existing field rises. The rate of diminution in the percentage removed is very rapid as the strength of the field is raised to 30 or 40 C.G.S units, but very slow when the field is raised over 150 C.G.S. units.

A comparison of this curve with the curves of figs. 4 and 6 brings out clearly the fact that the residual magnetisation, which is most easily removed by pressure cycles, is that left on the break of those fields in which pressure cycles have the greatest effect on the induced magnetisation.

The data in the last columns of Tables VII. and VIII. would lead to curves very closely resembling Curve II. Thus the preceding remarks apply equally to the experiments of types M and N.

§ 60. Comparing Curves I. and II. of fig. 13, we see that in fields over 30 C.G.S. units, the increase in the percentage of the induced magnetisation removed by breaking the current, and the diminution in the percentage of the residual magnetisation removed by a definite number of pressure cycles, go hand in hand.

It has been already mentioned that the application of a particularly severe first pressure after the break of a current lessened the effect of the removal of the pressure, and it also lessened the joint effect of succeeding pressure cycles, in which the pressure was of the normal intensity.

Thus the close resemblance of Curves I. and II. in the stronger fields suggests that the sudden break of a current acts in some respects as a mechanical shock, and that the magnitude of this shock-effect continually increases as the strength of the field is raised.

Separation of the Effects of the Application and Existence of Pressure.

§ 61. There are still some points connected with the fundamental character of the effect on the rod's magnetisation produced by the application of pressure, on which Tables IX. and X. throw some light.

We have seen that in general the first application of pressure after the rod's introduction into a given field, causes a change in the magnetisation. Further, as a rule, the greater portion of this change survives the removal of the pressure, so that for its continued existence the existence of pressure is not essential. It thus seems of importance to determine whether the change depends solely on the existence of pressure for a finite time during the flow of the current, or is due in whole or in part to the actual application of pressure.

Taking WEBER'S hypothesis for illustration, the change must consist either in a sub-permanent increase in the general mobility of the ultimate magnetic molecules, or in a swinging round of some of them into extreme positions, where they are kept by molecular friction even after the removal of the pressure. The application of pressure produces doubtless molecular movements, during which the rotations of the ultimate magnets might be expected to go on more freely, so that on this theory we should *à priori* be disinclined to attribute the entire effect to the mere existence of pressure.

In practice it is difficult if not impossible wholly to separate the effects of the application of pressure from those of its mere existence. When the rod is put under pressure before its introduction into the magnetising coil, and not introduced until sufficient time has elapsed for any molecular motion to die out, the magnetisation might at first sight be supposed to differ from that possessed by the rod when the pressure is applied after its introduction by an amount which exactly measures the effect of the actual application of the pressure. It must be remembered, however, that sudden magnetisation, altering as it does the rod's length, must act in part as a mechanical shock and set up molecular movements, whose character and amplitude would naturally depend to some extent on the state of the rod as to pressure.

In the following remarks the difference between the magnetisations of the rod under pressure in the two circumstances of its introduction is entirely attributed to the effect of the application of pressure, but the previous statements should be taken as a warning against accepting this as more than an approximation to the truth.

§ 62. Certain experiments bearing on the question have been already referred to in § 40 in discussing the curves of fig. 4. These experiments were limited to fields under 60 C.G.S. units; but within that range they showed conclusively that in a freshly demagnetised bar the existence of pressure applied before the rod's introduction into the magnetising coil increases the susceptibility. In the weaker fields of fig. 4 the curves show a greater susceptibility when the application of the pressure has succeeded than when it has preceded the introduction of the rod into the coil, and the evidence for this was considered satisfactory. In fields from 30 to 60 C.G.S. units the reverse is the case according to the curves, but reasons were given for regarding the evidence on this point as insufficient.

In these experiments when pressure existed during the introduction of the rod into the coil it had always been applied some minutes previously, so that any molecular movements set a-going by the process had presumably pretty well subsided. Further, any such movements must have been inconsiderable compared to those occasioned by the vigorous tapping which accompanied the demagnetisation of the rod shortly before its introduction in both sets of experiments.

We are thus in all probability entitled to conclude from these experiments that in a freshly demagnetised rod the mere existence of pressure, apart from the consequences of its application, has, in fields up to at least 60 C.G.S. units, the effect of permanently increasing the induced magnetisation, while in the weakest fields there can be no doubt that the actual application of pressure has an independent effect in the same direction.

§ 63. The results of a more complete series of observations bearing on the same point are given in the seventh column of Table IX., under the heading $\mathfrak{I}_A$ "*on*"—"*off*." This signifies, as already stated, the excess of magnetisation possessed by the rod when introduced into the coil under pressure, over that it possesses when introduced free from pressure. The circumstances of the rod are, except as regards the pressure, identical in the two cases. The rod was not, as in the experiments discussed in the last paragraph, in a freshly demagnetised condition, but had just been exposed to numerous pressure cycles in a field of the same strength and sign.

This column agrees with fig. 4 in showing in weak fields an increase of magnetisation due to the existence of pressure. An unmistakeable critical field, however, ensues, the effect eventually changing sign. Thus the character of the effect of the mere existence of pressure varies in the same way as does that of the joint effect of the application and existence of pressure, which we have already discussed in § 41.

In this case an exact basis of comparison exists, because in the third column of Table X., under the heading *First "on"* A_2, we have the combined effect of the application and existence of pressure when the previous treatment of the rod was the same as in the experiments of the seventh column of Table IX.

A comparison of these two columns shows that the fields in which the effects attain their maxima, and the critical fields must be nearly the same, if not absolutely identical in the two cases. The magnitudes of the effects are, however, decidedly different. There can be no question that in the weaker fields the effect is very considerably greatest when the application of the pressure succeeds the introduction of the rod into the coil, and this effect of the application of the pressure clearly continues until the field of 128 units is reached. From this to somewhat over the critical field neither the application nor the existence of pressure has effects large enough for satisfactory determination. In the fields of 198 units and upwards the diminution of magnetisation due to pressure was in every case found greatest when its application preceded the introduction of the rod.

Thus in all fields up to 128 C.G.S. units the actual application of pressure during the flow of the current produces in the condition of the rod during these experiments an unmistakeable increase in the magnetisation, and not improbably this tendency to increase the magnetisation exists in all the fields within the range of the experiments.

In the eighth column of Table IX are a few results from experiments on the same point. The circumstances of these experiments differed from those of the preceding column, only in that the previous fields of equal strength in which pressure cycles had been applied, were of opposite sign to those in which the effects were observed. The phenomena are clearly of the same general character as those of the previous column, and the existence of a critical field is unmistakeable. The observations are insufficient to determine the exact position of the critical field, but it is obviously not far from the critical field of the preceding column.

The Polar or Non-polar Character of the Effects of Pressure.

§ 64. Another very important question is whether the effects of the application and removal of pressure on the magnetisation are of a *polar* or a *non-polar* character. The meaning of these terms will be best understood from an illustration.

Let us suppose the induced magnetisation increased by a series of pressure cycles applied during the flow of a current, which makes A the north pole. The effect is non-polar if the rod be brought into the condition of an unstrained rod of a different material possessed of a higher susceptibility. The effect is polar if the susceptibility, while increased in fields making A a north pole, is equally diminished in fields of opposite sign—supposing for the moment that an opposite field could be introduced without altering the rod's temporary properties. If the susceptibility be simply altered by different amounts in fields of opposite sign the effect may be regarded as a combination of a polar and a non-polar effect.

It is probably impossible to arrive at a complete knowledge of the character of the effect, because the introduction of an opposite field implies a break and make of the magnetised current affecting the temporary properties of the rod. It is only in so far as the effects of pressure cycles are residual that their polar or non-polar character admits of direct investigation.

If, after the application of pressure cycles in a certain field, an increase of susceptibility, not otherwise accounted for, be found in fields both of the same and of opposite polarity, the existence of a non-polar effect would seem to be established. The same conclusion follows if there be a decrease of susceptibility irrespective of the sign of the field. If the susceptibility be found less in fields of the same name as that existing during the pressure cycles, than in fields of opposite name, it is difficult to think of any probable explanation other than a *true* polar effect.

If, however, the susceptibility be greater in fields of the same sign as that existing during the pressure cycles than in fields of opposite sign, the phenomenon may be explained without assuming a *true* polar effect.

The reasons for these statements will probably be most clearly presented by embodying them in language literally applicable only to WEBER's theory of magnetism. According to this theory, the only way in which we can imagine the application or removal of pressure to produce a permanent change in the magnetisation is either by endowing the ultimate magnetic molecules with an increased or diminished mobility, or by enabling them to swing round into extreme positions, where they stick. The change in the molecular mobility is non-polar if the molecules turn as freely in fields of one sign as in fields of the opposite sign, otherwise the change is polar.

Now when the susceptibility is found increased in fields both of the same and of opposite sign to that existing during the pressure cycles, or when it is diminished irrespective of the sign of the field, or, lastly, when it is less in a field of the same sign as that during which the pressures were applied than in a field of opposite sign, it is clear that the phenomena cannot be attributed to the magnetic molecules having stuck in positions into which they swung while under the directive influence of the original field. Thus, in these cases, the phenomena must be ascribed to some change in the mobility of the magnetic molecules, and so there must be a true polar or non-polar effect. It is obvious, however, that if the magnetic molecules swung round and stuck in the way imagined, then the magnetisation would naturally be greater in a field of the same sign as the original than in a field of opposite sign. This is not regarded here as a *true* polar effect, though producing in the induced magnetisation phenomena identical with those which would arise from a true polar change in the molecular mobility. The turning round of the molecules has been already discussed in §§ 22 and 28, where its occurrence was demonstrated. The effect on the induced magnetisation will here be referred to as a *quasi* polar effect.

§ 65. The ninth column of Table IX. may be regarded as measuring the combined *true* and *quasi* polar effects of a numerous series of pressure cycles, in so far as they survive the break of the field during which the pressures were applied, and the make of an equal field of the same or opposite sign. The exact quantity measured is the algebraic excess of the magnetisation in a field of the same sign as that existing during the pressure cycles over that in a field of opposite sign, the rod being in each case introduced free of pressure into the second fields.

The results obtained with the weakest field of the table, 1·8 C.G.S. units, differed so much from the others that it was inconvenient to include them in the table. They were as follows :—

Circumstances of rod.	End a north pole.	Pressure.	$\mathfrak{I}$.
First introduction	A	off	4·1
After pressure cycles . . .	,,	,,	6·5
Out, re-introduced. . . .	B	,,	4·8
Kept in	,,	on	6·5
Out, re-introduced. . . .	,,	,,	6·2
,, ,, ...	A	off	4·1
,, ,, ...	B	,,	5·5
,, ,, ...	A	,,	4·1
Kept in	,,	on	6·5
Out, re-introduced. . . .	,,	off	5 3
,, ,, ...	B	,,	5·1

There are here two or three instances of an increase of susceptibility of a non-polar character, and also clear indications of a polar effect. Considering how small the total induced magnetisation is, both the polar and non-polar effects are of considerable importance.

In the next field, 2·2 C.G.S. units, the rod was originally under pressure, and yet $\mathfrak{I}_2 - \mathfrak{I}_1$ exceeds $\mathfrak{I}_2 - \mathfrak{I}_3$. Thus, as $\mathfrak{I}_A - \mathfrak{I}_B$ is only ·2, there occurred a very decided residual increase of susceptibility, mainly of a non-polar character.

In all the fields, from 3·4 to 35·7 C.G.S. units, the residual effect is largely of a polar character. Take, for instance, the field 8·6. Here the pressure cycles raise the magnetisation by 10·2. Of this, 5·1 survives the break and re-make of the current, and so only about the half of the increase is lost.

The difference, however, in this case between $\mathfrak{I}_A$ and $\mathfrak{I}_B$ amounts to no less than 9·7, and thus the susceptibility, when B is the north pole, is lowered by nearly as much as the susceptibility, when A is a north pole, is increased. The residual effect is, in fact, almost entirely of a polar character. This appears to be about the strength of field at which the polar effect is largest.

In the fields from 35·7 to 128 C.G.S. units the results show too large fluctuations to lay any claims to great accuracy. They may, however, be regarded as satisfactorily proving that within these limits the polar residual effect is small, and that it has the same sign as in the weaker fields.

In the field of 174 C.G.S. units no residual polar effect could be detected, and in stronger fields the effect changes sign. There is thus a neutral field, which if not identical with, is certainly very near that at which the total effect of the first pressure on the induced magnetisation vanishes. In weaker fields the susceptibility of the rod is greatest when the field is of the same sign as that existing during the pressure cycles, in stronger fields the susceptibility is in these circumstances least.

In fields above this neutral field there is thus, according to the previous reasoning, a *true* polar effect. In fields again, such as 12·5 C.G.S. units, a *quasi* polar effect unquestionably existed, because there could then be obtained the phenomenon of the reversal of the rod's polarity on the break of an equal reverse current described in § 22. This phenomenon could not be obtained in a field of 23·7 C.G.S. units.

There is thus positive proof that a *true* polar effect exists in strong fields and a *quasi* polar effect in weak fields, and most probably in all but certain critical fields they exist simultaneously.

§ 66. We have seen that the residual polar effect has practically the same critical field as the total effect of the first pressure, or *First "on"* of Table X. Also both these effects are relatively very large in weak fields, and it might thus be supposed they stood in some intimate relationship to one another. In fields of 30 to 50 C.G.S. units, however, the residual polar effect is very small, while the *First "on"* is about its maximum.

An explanation of the discrepancy is supplied by a consideration of the curves *b* and *c* of fig. 12. The difference between the ordinates of these curves in a field of 8 C.G.S. units is great compared to the difference in a field of 30 C.G.S. units. Thus in the former field pressure cycles are much more effective in increasing the retentiveness than in the latter. A consideration of the numerical data shows that of the additional magnetisation which the pressure cycles enable the rod to acquire the loss on the break of the current is proportionally much less in a field of 8 than in a field of 30 C.G.S. units. Thus the *quasi* polar residual effect must be much smaller in the latter field than in the former, which doubtless accounts for the rapid falling off in the value of the total polar effect as the field is raised.

In the last column of Table IX. there are a few results bearing on the same point. These are derived from experiments in which the rod was under pressure when reintroduced into the coil after being subjected to a series of pressure cycles in a previous field of the same strength. So far as they go the results are very similar to those of the previous column, from which it follows that the residual polar effect is, at least in its general character, independent of the state of the reintroduced rod as to pressure.

§ 67. Further results bearing on the polar character of the residual effects of pressure are given in the second, third, and fourth columns of Table X. These give the total algebraic increase of the induced magnetisation due to the first application of pressure. The headings A_1, A_2, B_2 show the condition of the rod as explained in § 37.

Comparing the columns headed A_1 and A_2, we see that in fields below 50 or 60 C.G.S. units the increase in the magnetisation caused by the application of the first pressure is very considerably greater when the rod is in a freshly demagnetised condition than when it has recently been subjected to a numerous series of pressure cycles in a field of the same strength and sign. In fields between 60 and 90 C.G.S. units the effect of pressure is still distinctly larger in the freshly demagnetised rod, but whether considered absolutely or relatively the difference between the results in the two columns is small. In stronger fields the numerical value of A_1, whether it signify an increase or a decrease of magnetisation, appears almost invariably greater than that of A_2. Both quantities, however, are then small, and in the strongest fields the effects of the first pressure were difficult to measure exactly, as the irregularities in the column headed A_1 would suggest. It would thus be unsafe to build too much upon the differences between the two columns in fields over 90 C.G.S. units. The evidence, however, clearly supports the conclusion that even in the strongest fields the numerical value of the change in the magnetisation due to the first pressure is, *ceteris paribus*, greatest in a freshly demagnetised bar.

The observed differences between the columns headed A_1 and A_2 are exactly of the character we should have expected from the already discussed experiments on the residual effects of pressure. In the weaker fields, we saw that the residual effect is very considerable. Thus the rod on its second exposure to a given field, under the circumstances of the experiment, is more or less in the state of a rod already subjected to pressure. Thus its condition, when the pressure A_2 is applied, is somewhat intermediate between its conditions before and after the application of the pressure A_1. Now the effect of the second pressure, after the introduction of the rod into the coil, was invariably, in the weaker fields, small compared to the effect of the first pressure. Consequently, in such fields, the pressure A_2 would naturally have a smaller effect than the pressure A_1, which is precisely the phenomenon observed.

Comparing the fourth column of Table X. with the previous two, we see that in fields up to 60 or 70 C.G.S. units, the increase in the magnetisation of the reintroduced rod, due to the first pressure, is distinctly greater when the field is of the opposite sign to that existing during the pressure cycles, than when it is of the same sign. In stronger fields, the sign of the field existing during the pressure cycles appears practically immaterial.

A difference between the effects of the pressures A_1 and A_2, or A_1 and B_2, might be due either to a polar or a non-polar residual effect of pressure, but a difference between the effects of the pressures A_2 and B_2 must be due entirely to a polar residual effect. Thus the experiments on the first pressures afford independent proof of the existence of a residual polar effect in fields up to 60 or 70 C.G.S. units. This is in accordance with the results of § 65.

There would also appear to be evidence of the existence of a non-polar effect in the weaker fields. In such a field, we have already shown the existence of a very considerable *quasi* polar residual effect. Now the application of a pressure in a field of opposite sign, would unquestionably shake out part of this *quasi* polar effect, and might be expected to produce, in addition, a polar effect of its own, equal or nearly equal to that of the first pressure in the original field. Thus, if there were not a non-polar residual effect, we should expect the pressure B_2 to have, in weak fields, a larger effect than the pressure A_1. This does not, however, appear to be the case.

The positions of the critical fields for the vanishing of the total effect of the first application of pressure, indicated by the second, third, and fourth columns of Table X. are in good agreement. Consequently, it would appear that the position of this critical field depends but little on the treatment of the rod since its last demagnetisation.

§ 68. The results given under the heading *First "off"* in Table X., show that in the strongest fields of that table the residual polar effects, due to the application of pressure cycles in pre-existing fields of the same strength, have no appreciable influence on the magnitude of the increase of magnetisation which accompanies the removal of the pressure existing during the re-introduction of the rod into the magnetising coil.

Combining this phenomenon with the close agreement in the stronger fields of the magnitudes of the effects of the first pressures A_2 and B_2, we seem entitled to conclude that the residual polar effect of pressure cycles in a strong field, of whose existence the two last columns in Table IX. give clear proof, is not sensibly diminished by the application or removal of a single pressure in a subsequent equal field, whether of the same, or of opposite sign.

Resemblances between the Phenomena shown by Iron and Cobalt.

§ 69. Most of the following resemblances between the phenomena shown by the cobalt rod and those shown by the stretched iron wires of Professor EWING'S experiments, have been already incidentally noticed, but a formal statement and comparison may be useful. In the following statements, *stress* signifies *tension* in the case of the iron wires, and *pressure* in the case of the cobalt.

1. The strengths of the fields in which the changes in the magnetisation produced by the first application of a given stress, or by its cyclic repetitions, bear the greatest ratios to the pre-existing magnetisations, are very low, if indeed they possess a finite value.

2. The fields in which the changes in the magnetisation produced by the first application of a given stress, or by its cyclic repetitions, are absolutely greatest, are not very far from the region of the Wendepunkt.

3. The maximum cyclic effect appears, however, in a distinctly lower field than does the maximum effect of the first application of stress.

4. Both the cyclic effect and the effect of the first application of stress possess critical or VILLARI points, and the critical magnetisations are both considerably greater than that answering to the Wendepunkt.

5. The critical field, however, for the cyclic effect is decidedly lower than that for the first application of stress.

6. The residual magnetisation approaches "saturation" in much lower fields than does the induced.

7. The *residual susceptibility*—or the ratio of the residual magnetisation to the strength of the pre-existing field—when the specimen is free from stress, attains a maximum when the pre-existing field is very considerably lower than that answering to the Wendepunkt.

8. The *retentiveness*—or the ratio of the residual to the induced magnetisation—in the absence of stress, attains a maximum in a field decidedly lower than that in which the *residual susceptibility* is a maximum.

9. Stress increases largely the residual susceptibility and the retentiveness in weak fields, and decidedly lowers the fields in which these magnitudes present their maxima.

§ 70. If the magnetisation answering to its Wendepunkt be taken as the unit for each individual specimen, the following Table gives approximately the induced magnetisations existing during certain critical events in the magnetisation of the cobalt rod, and three samples of stretched iron wire examined by Professor EWING.

TABLE XI.

	Maximum Retentiveness.	Maximum residual susceptibility.	Critical point for cyclic effect.	Critical point for first stress.
Cobalt	·40	·58	2·31	2·53
1st iron wire . .	. .	. .	1·60	1·87
2nd " . .	·53	·70		
3rd " . .	·55	·70		

This will serve to show the kind of evidence on which the above statements as to the relations between cobalt and iron are based. Considering also that the intensities of the magnetisations answering to the Wendepunkte of the stretched iron wires were on an average nearly thrice that answering to the Wendepunkt in the cobalt rod, that the wires were practically of infinite length, and that the critical fields observed in them answer, as a rule, to stresses considerably more severe than the normal stress applied to the cobalt, it seems not unlikely that by taking the position of the Wendepunkt in the absence of stress as a standard for comparison, it may be possible to trace general laws underlying the varied phenomena occurring in the different magnetic metals, and thus throw light on the material changes in which the process of magnetisation consists.

NOTE.

[The referees to whom the paper was submitted having suggested the desirability of an examination into the chemical character of the rod, I add the following analysis, for which I am indebted to Mr. R. H. ADIE, of Trinity College, Cambridge, who kindly undertook the work :—

	Percentages.
Cobalt	91·99
Nickel	4·36
Manganese	1·86
Iron	1·37
Carbon, &c.	·42
	100·00

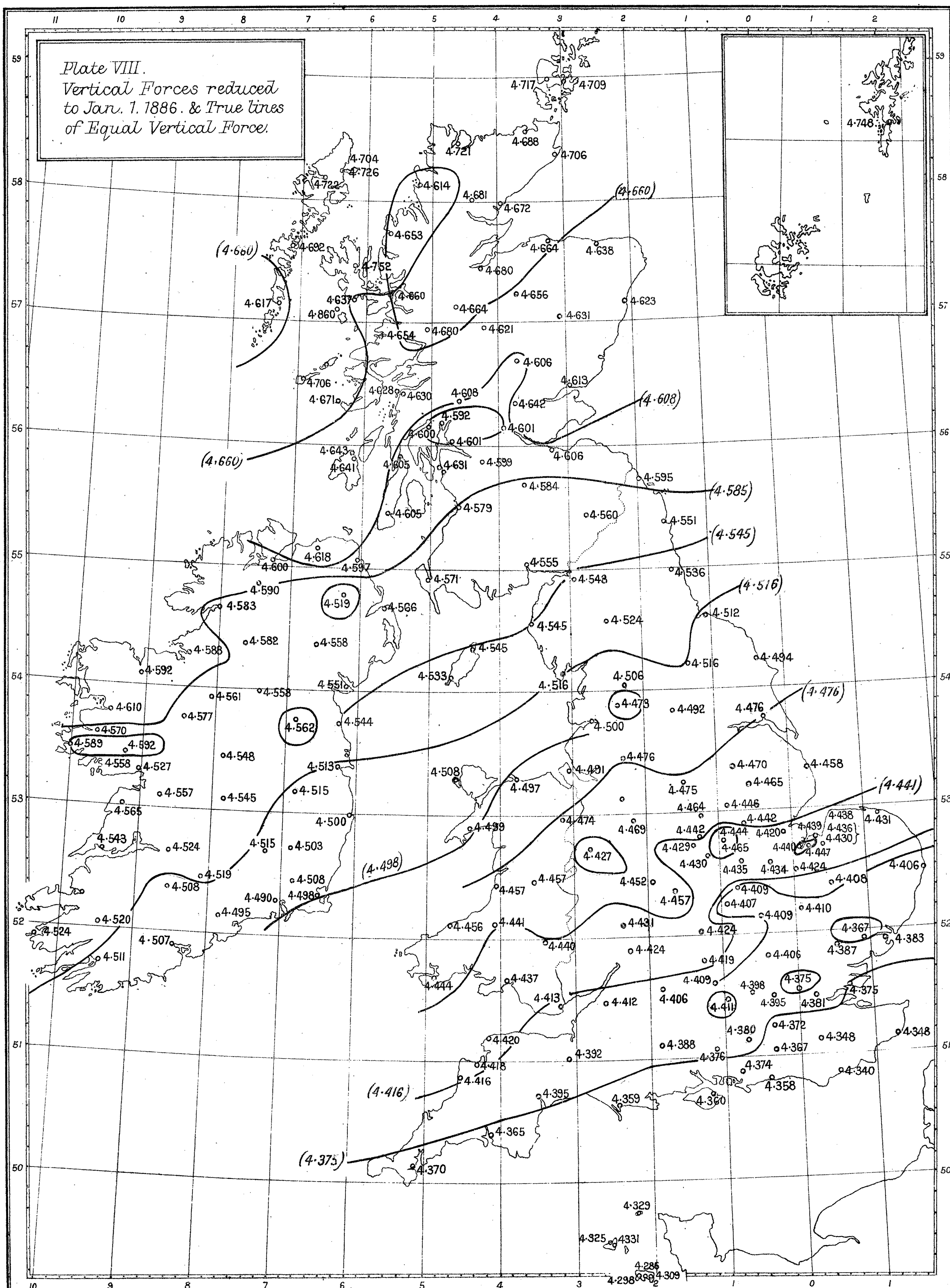
The rod is thus not a pure specimen of cobalt. The principal impurity, however, is nickel, which closely resembles cobalt in its magnetic properties, though in general regarded as less strongly magnetic. The effects of pressure on the magnetisation of nickel are of the same general character as in the case of cobalt in fields below the critical, though probably more intense. One would thus expect the critical field to be slightly raised in consequence of the presence of the nickel.—April 16, 1890.]

INDEX.

(Numbers refer to paragraphs.)

INDEX FOR FIGURES (PLATES 15, 16).

Plate 15, figs. 1–8 ; Plate 16, Figs. 9–15.



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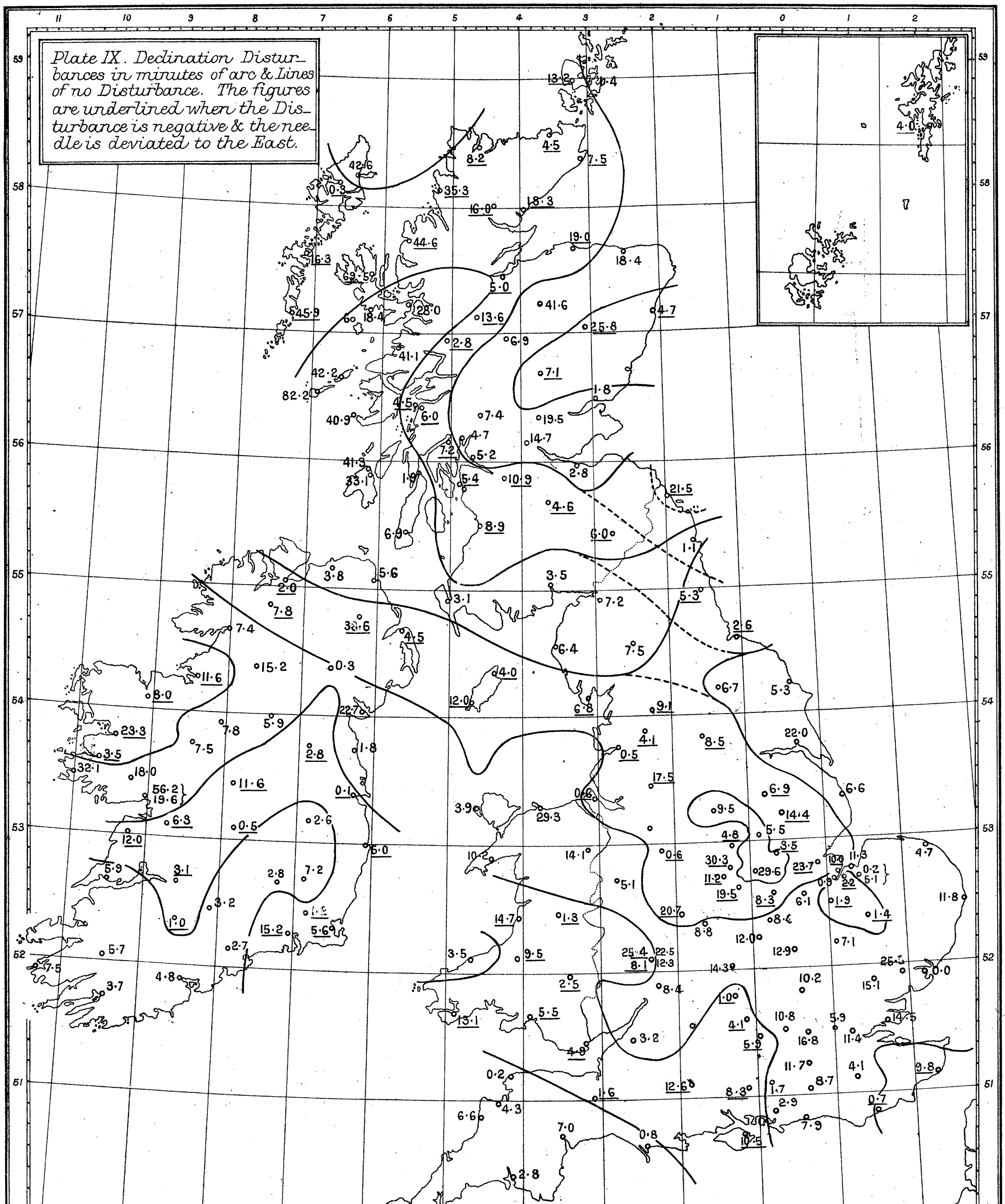

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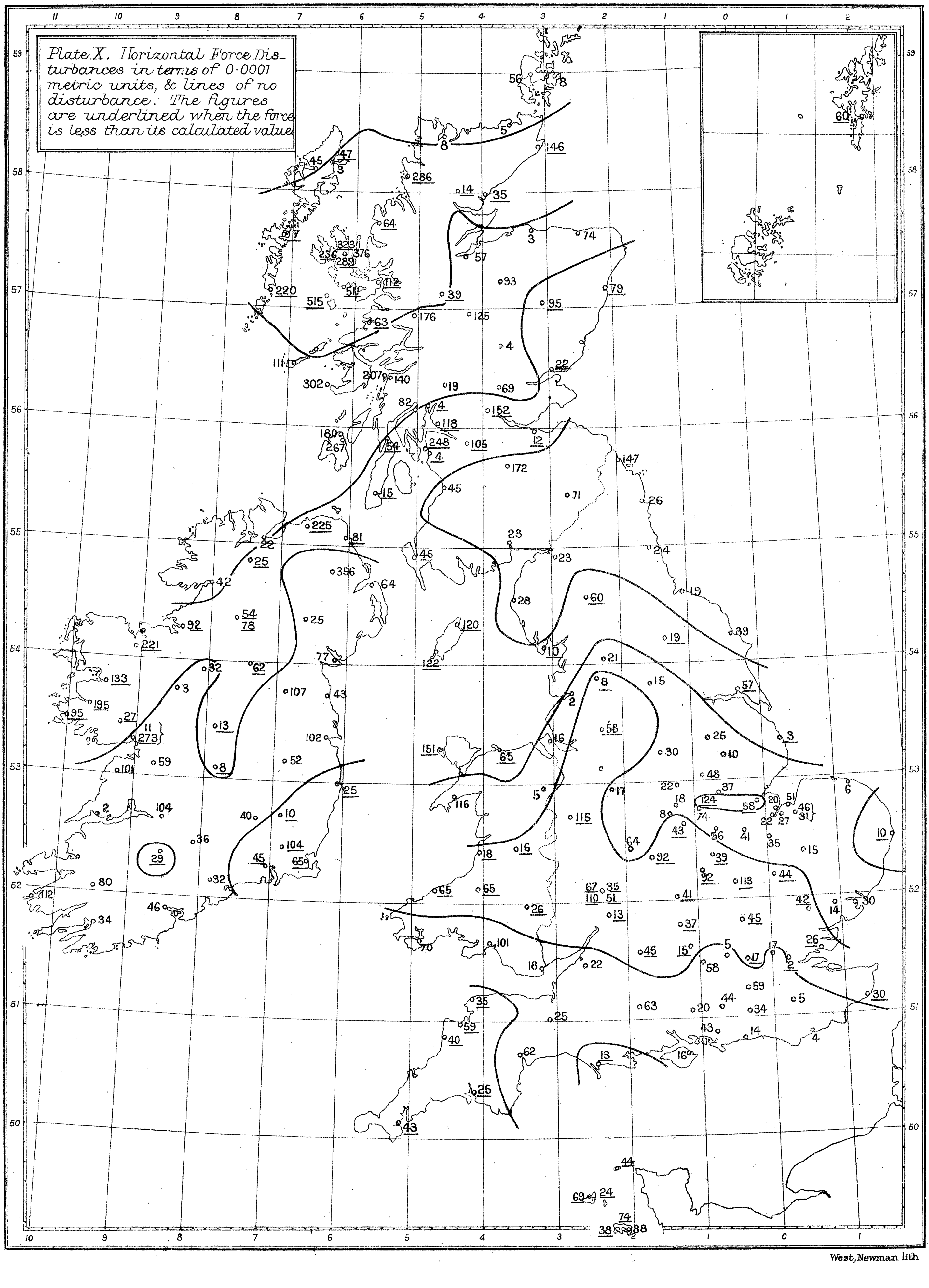

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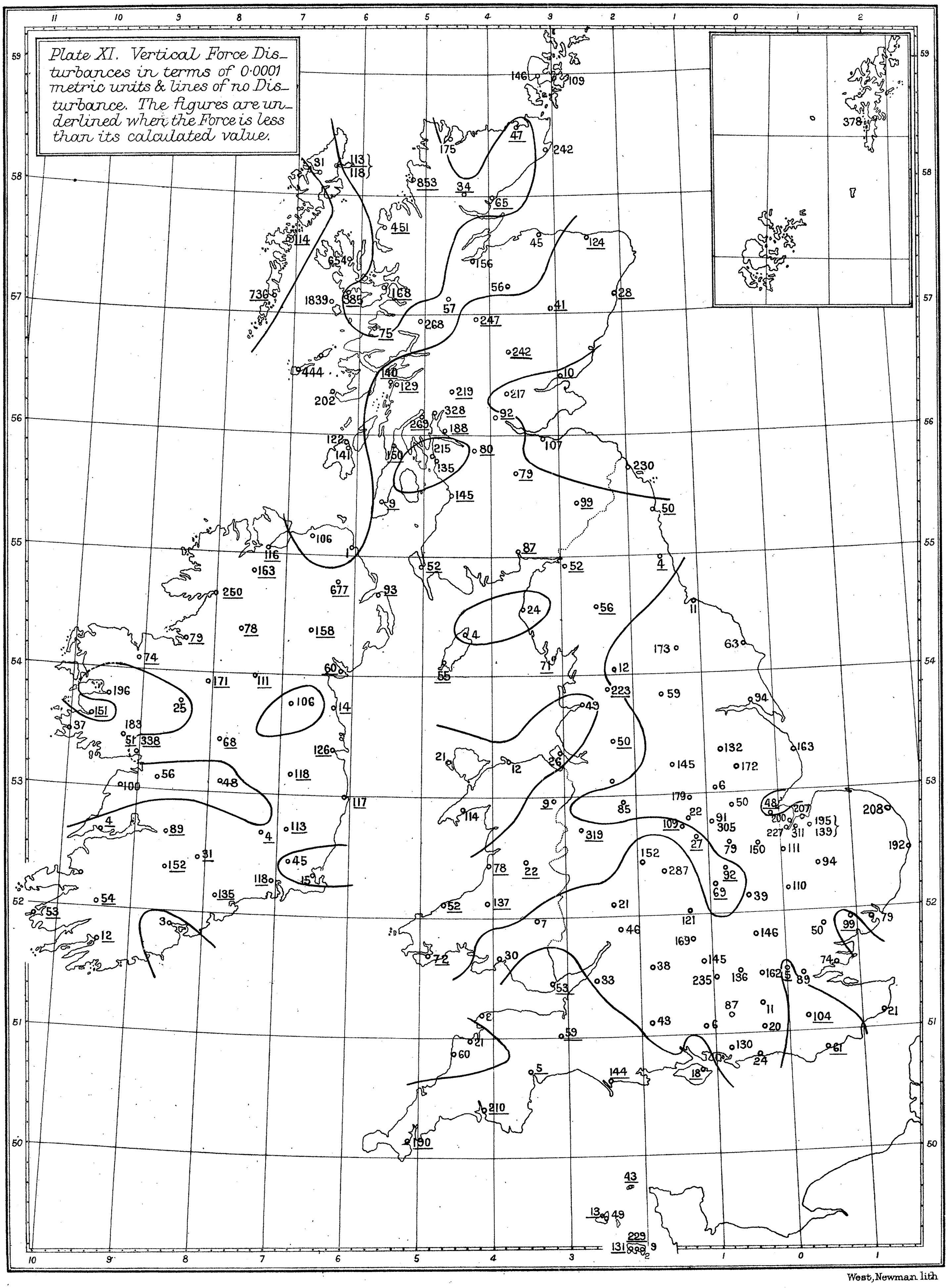

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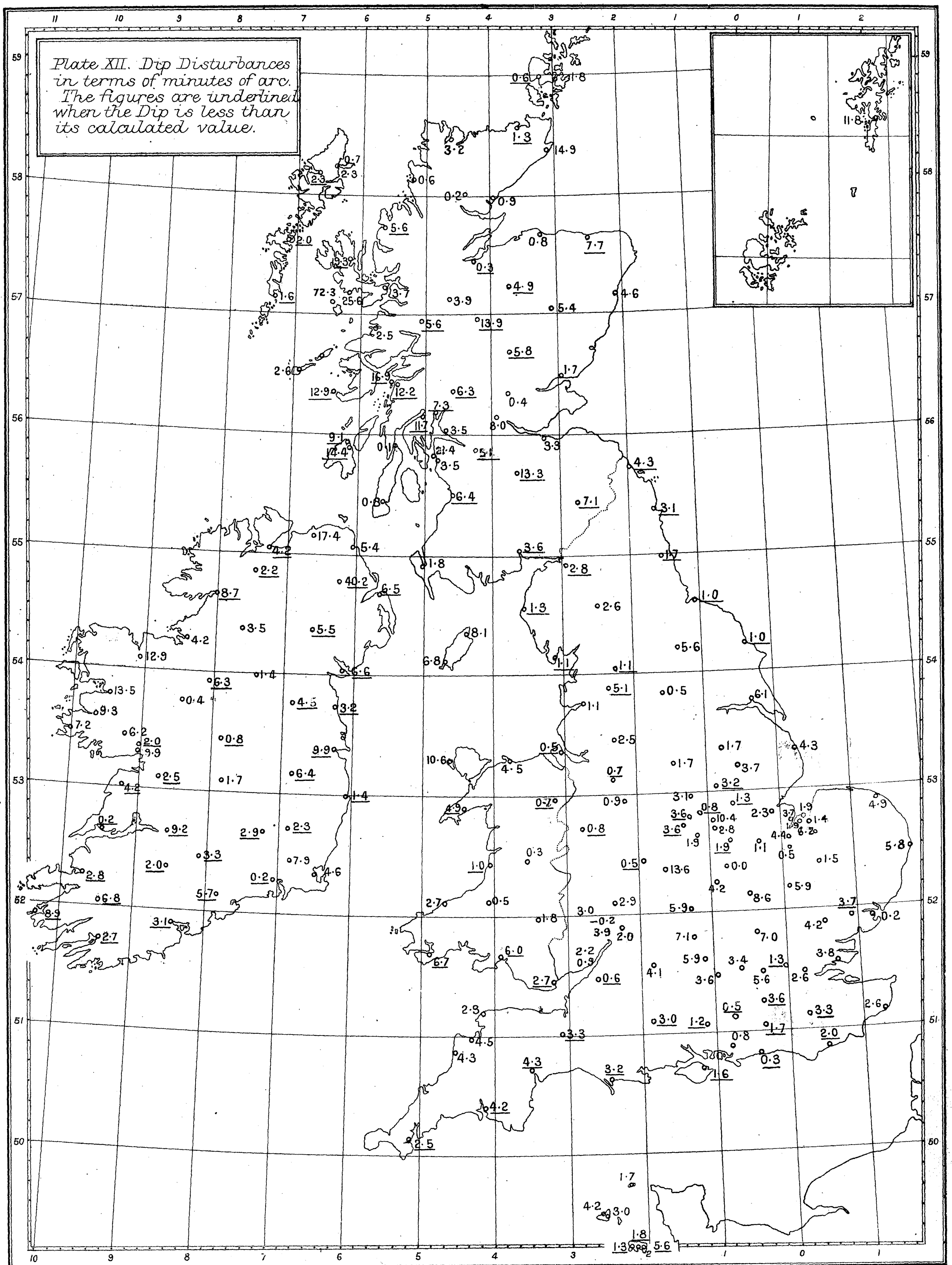

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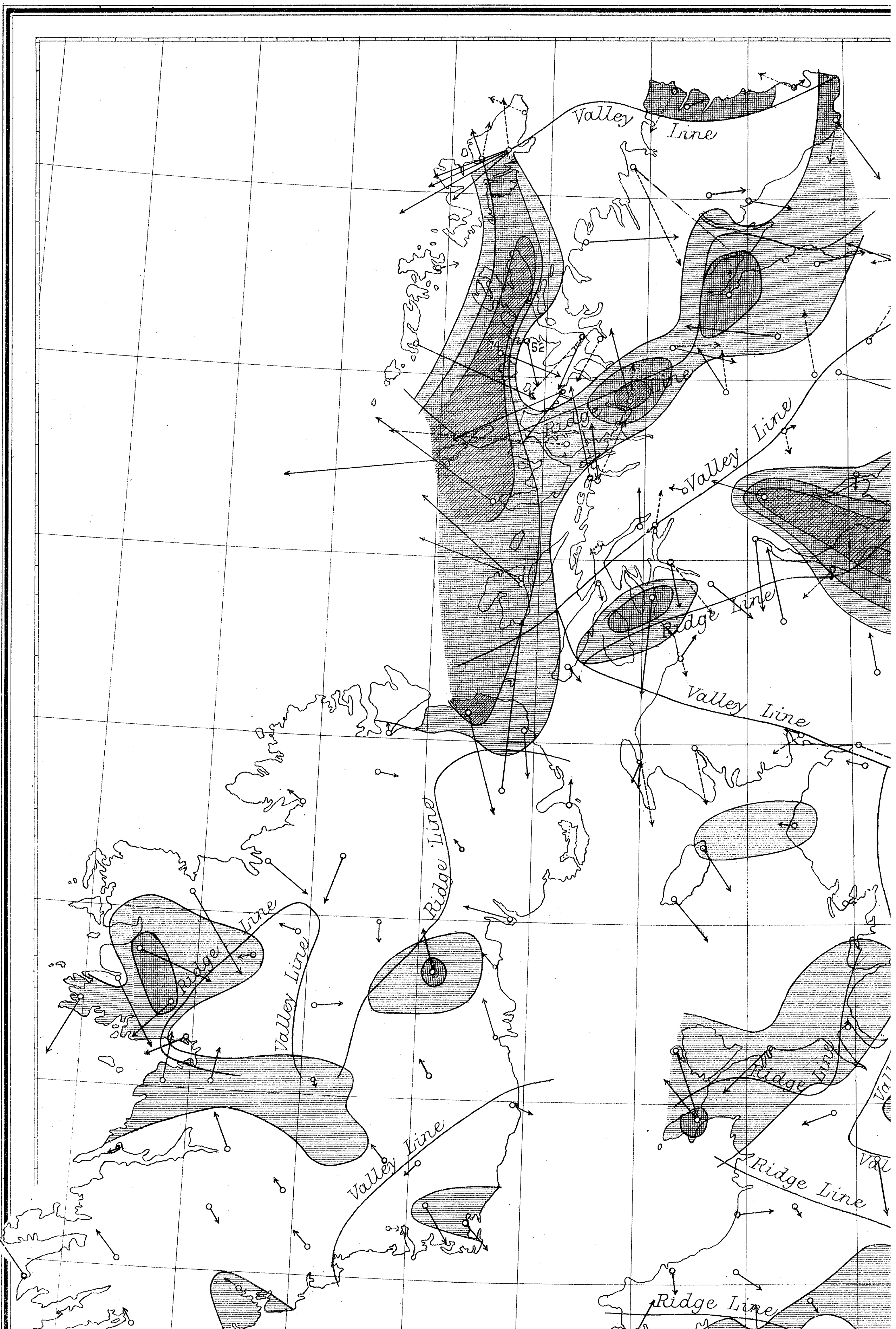
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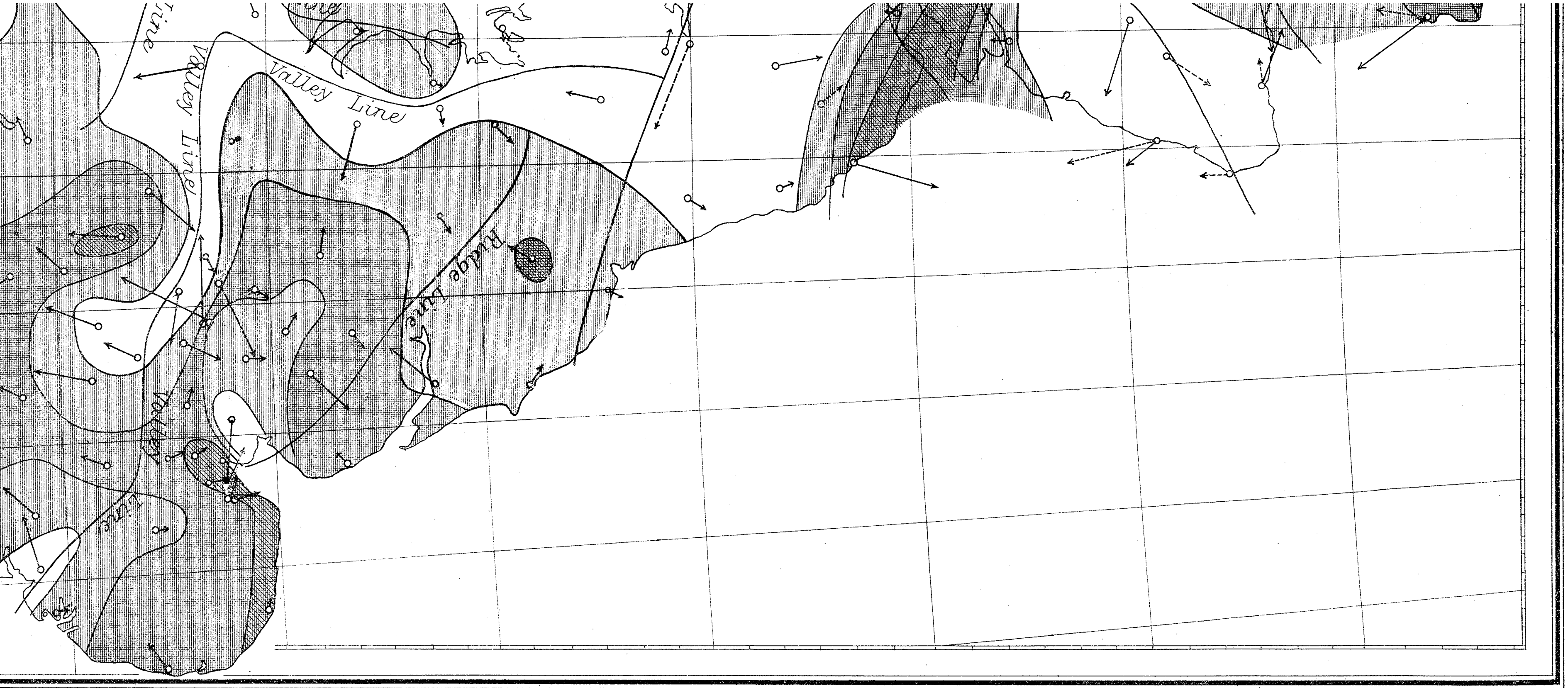

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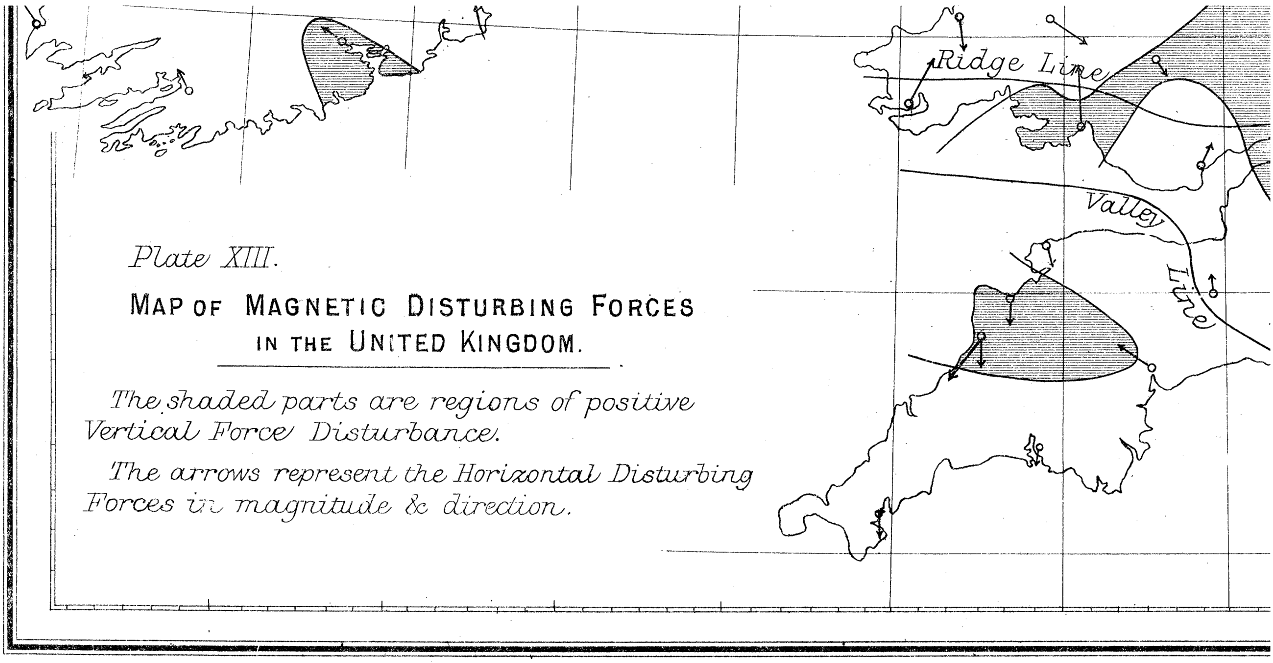


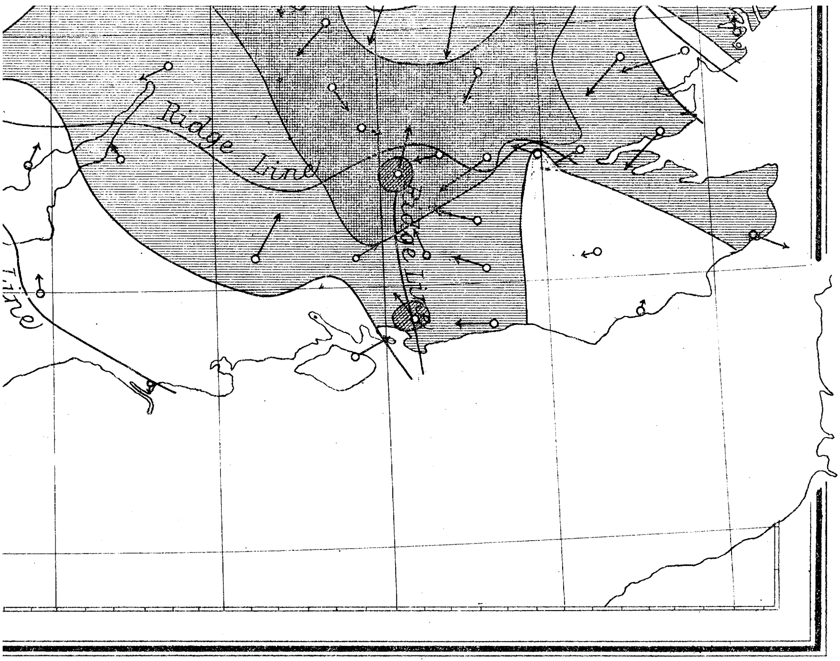
Plate XIII.

MAP OF MAGNETIC DISTURBING FORCES IN THE UNITED KINGDOM.

The shaded parts are regions of positive Vertical Force Disturbance.

The arrows represent the Horizontal Disturbing Forces in magnitude & direction.

Rücker & Thorpe.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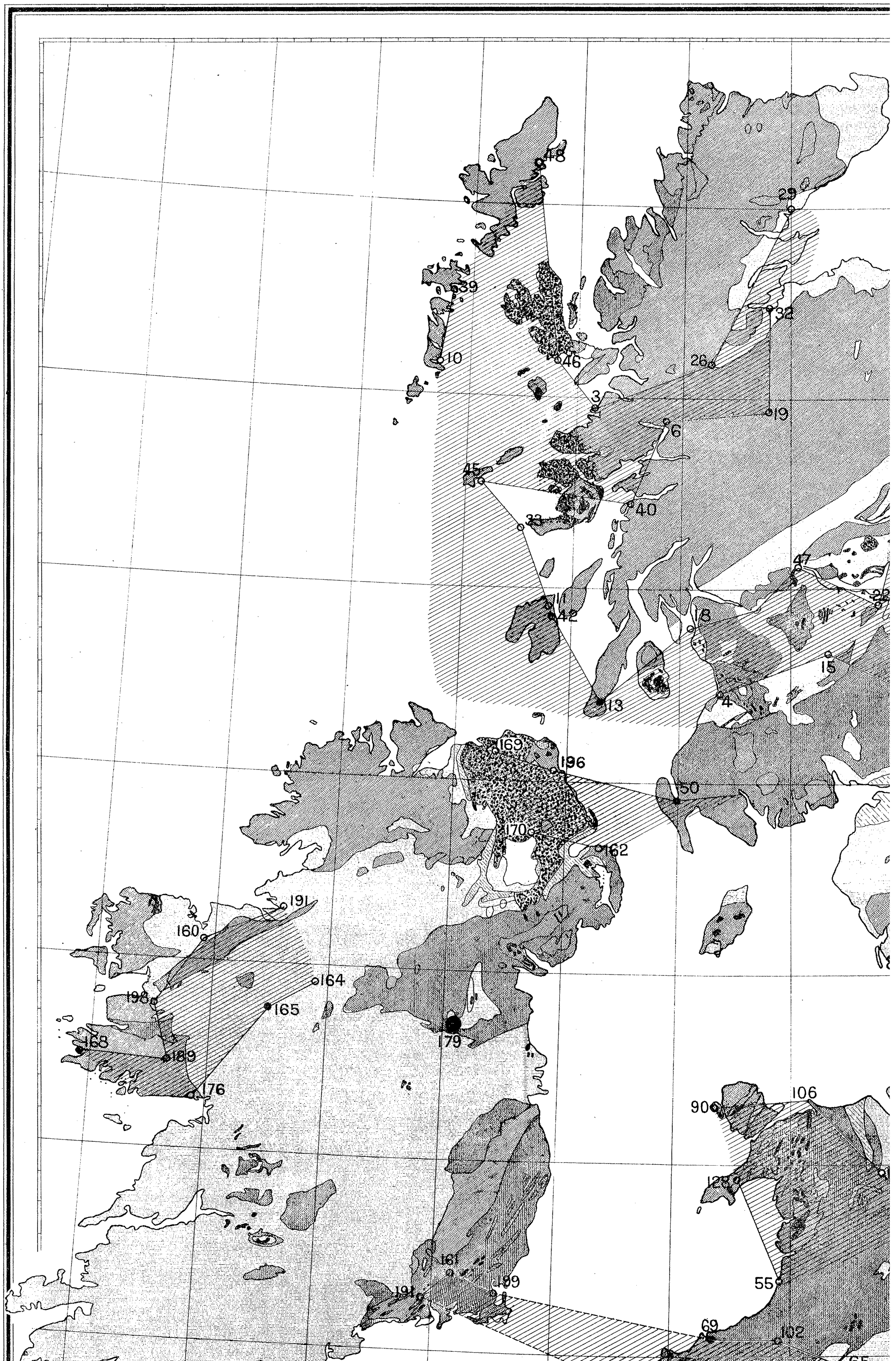
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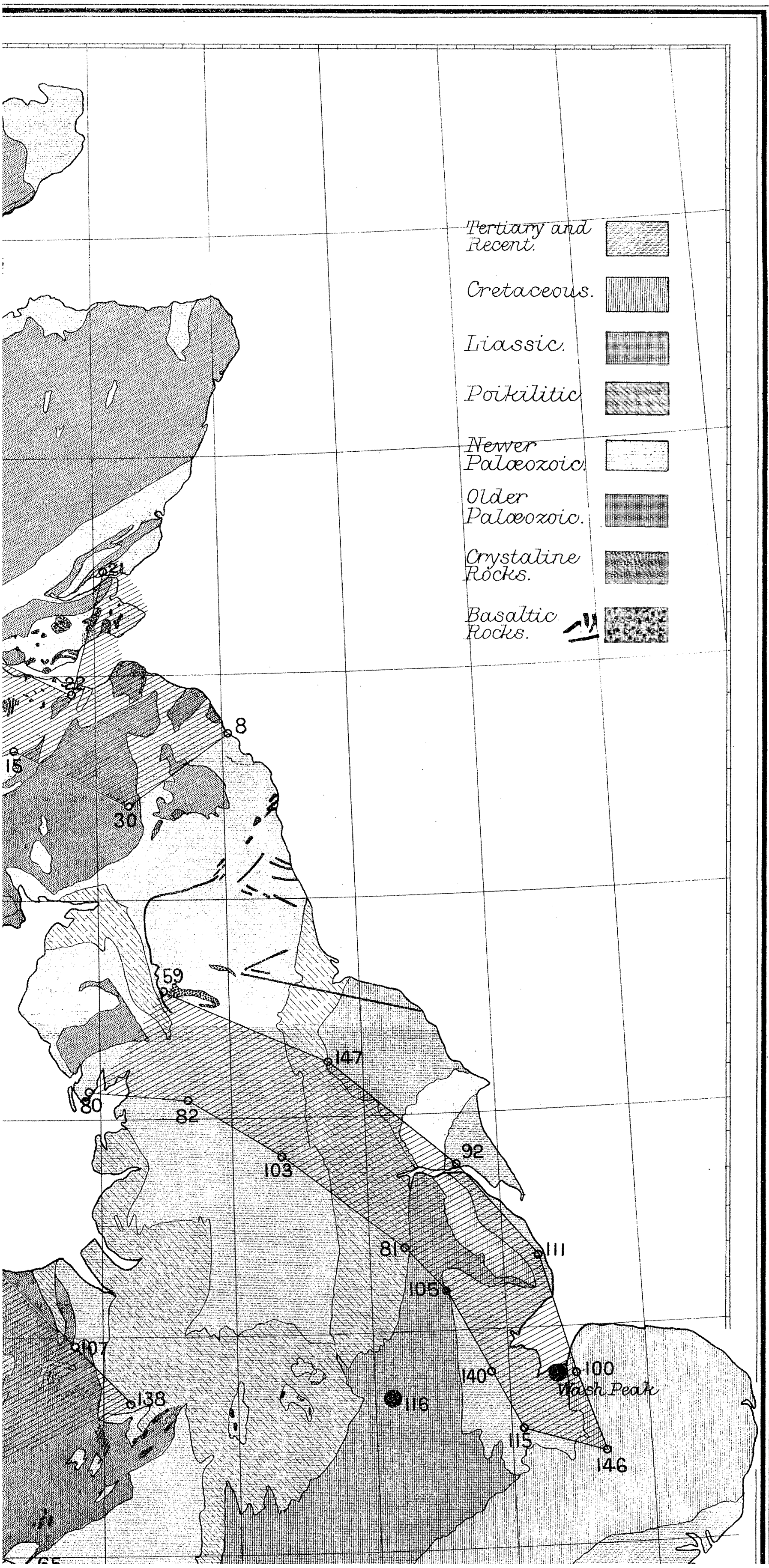

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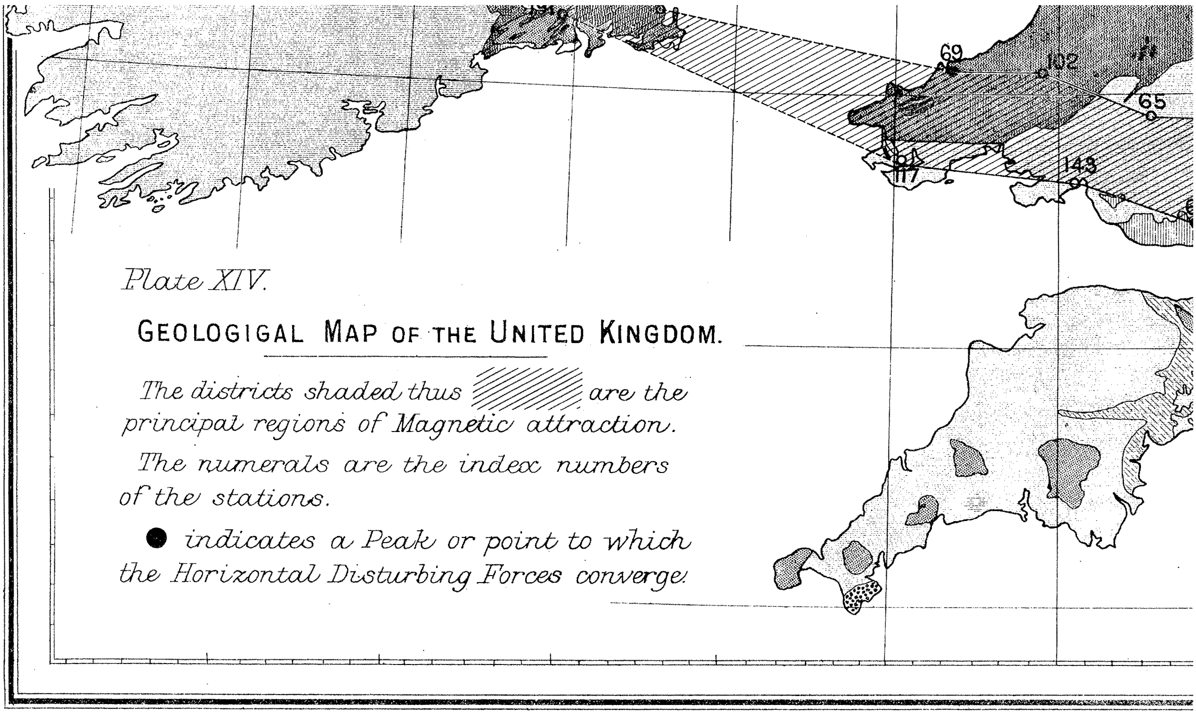
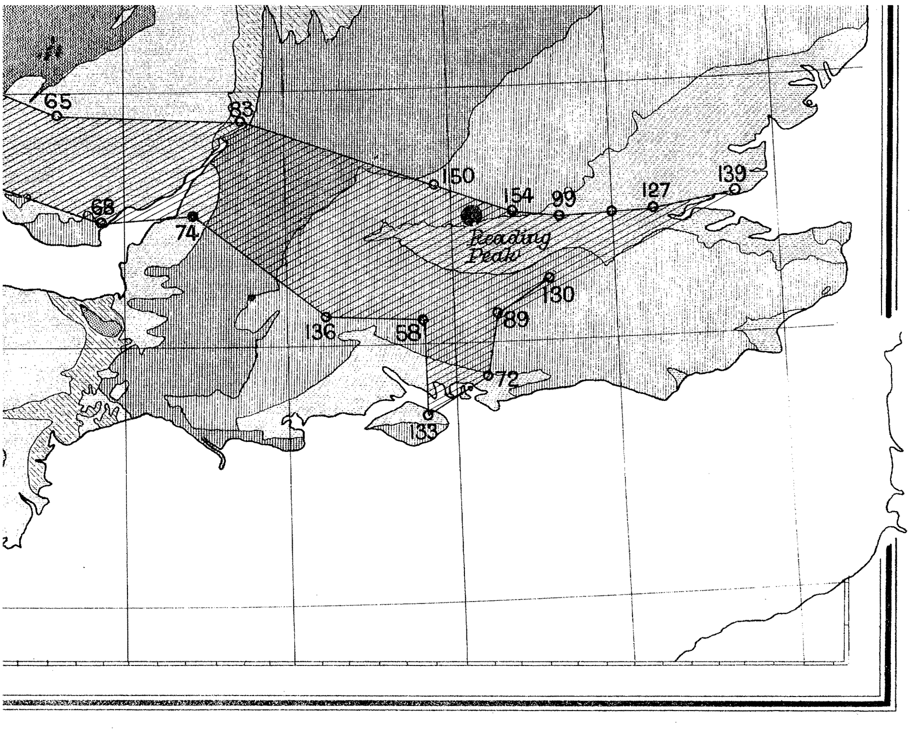


Rücker & Thorpe.



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Reading Peak
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136
58
89
72
133

Chree.

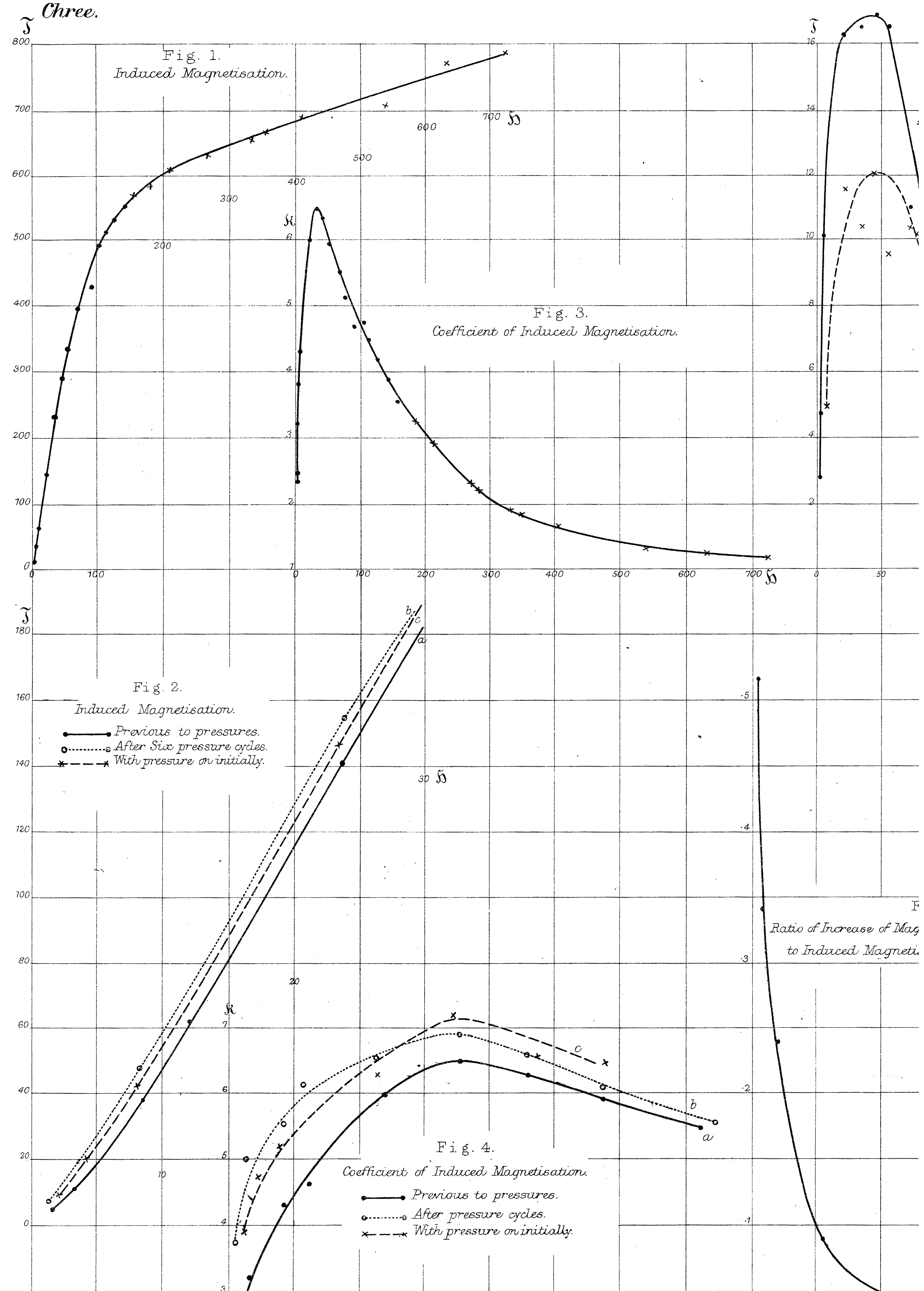


Fig. 1.
Induced Magnetisation.
Fig. 2.
Induced Magnetisation.
Previous to pressures.
After Six pressure cycles.
With pressure on initially.
Fig. 3.
Coefficient of Induced Magnetisation.
Fig. 4.
Coefficient of Induced Magnetisation.
Previous to pressures.
After pressure cycles.
With pressure on initially.
Ratio of Increase of Mag
to Induced Magneti

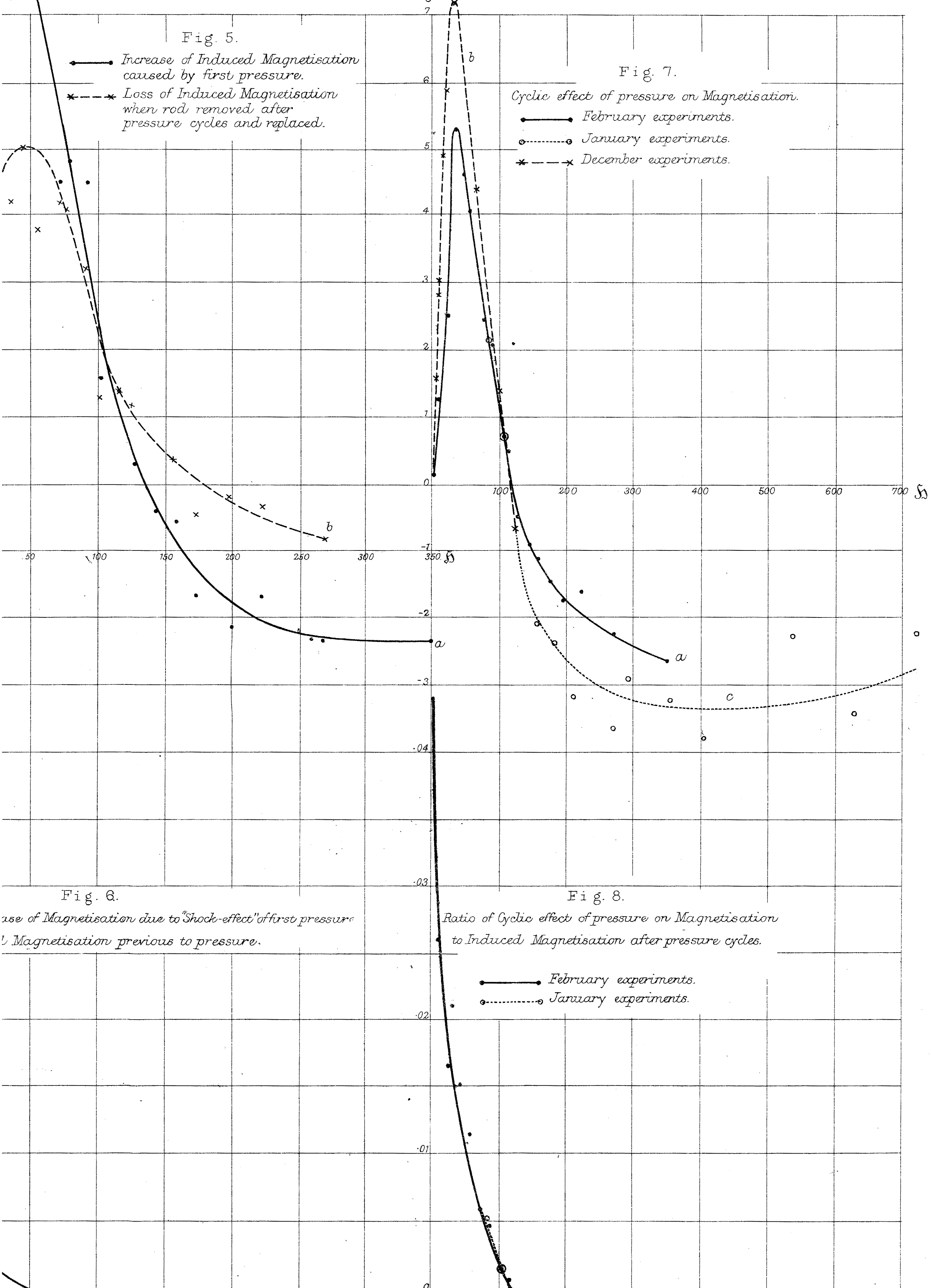
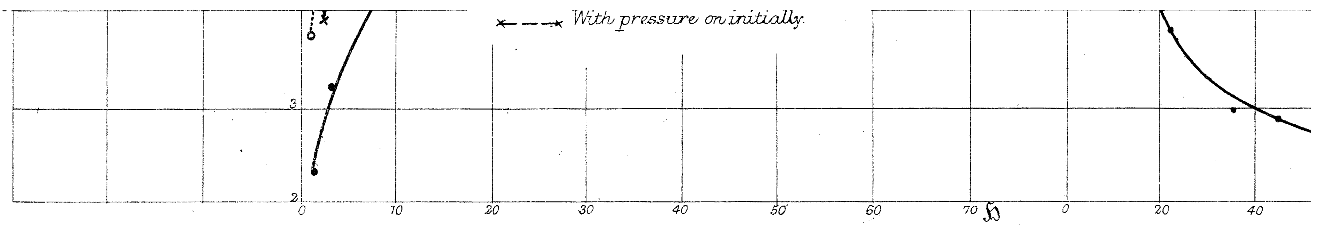


Fig. 5.
Increase of Induced Magnetisation caused by first pressure.
Loss of Induced Magnetisation when rod removed after pressure cycles and replaced.
Fig. 6.
ase of Magnetisation due to "Shock-effect" of first pressure
Magnetisation previous to pressure.
Fig. 7.
Cyclic effect of pressure on Magnetisation.
February experiments.
January experiments.
December experiments.
Fig. 8.
Ratio of Cyclic effect of pressure on Magnetisation to Induced Magnetisation after pressure cycles.
February experiments.
January experiments.
50
100
150
200
250
300
350
700
·04
·03
·02
·01



With pressure on initially.
3
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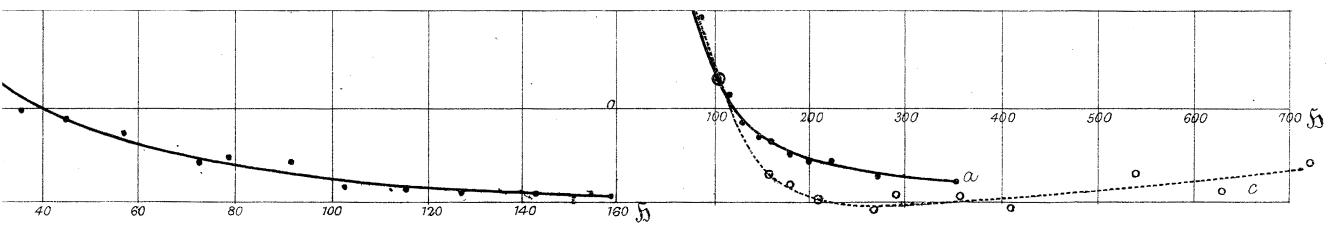
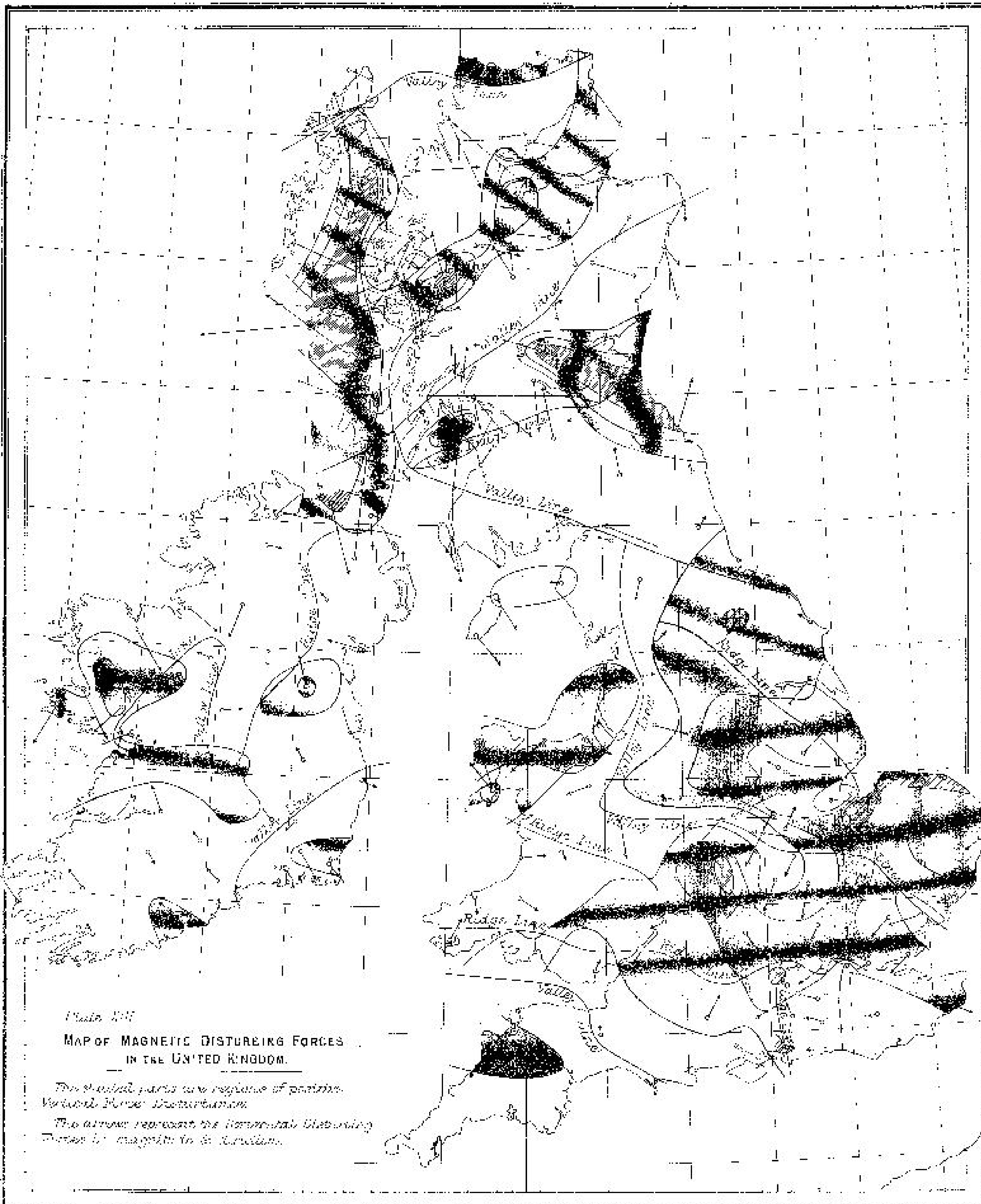
10
20
30
40
50
60
70
0
20
40



West, Newman, lith.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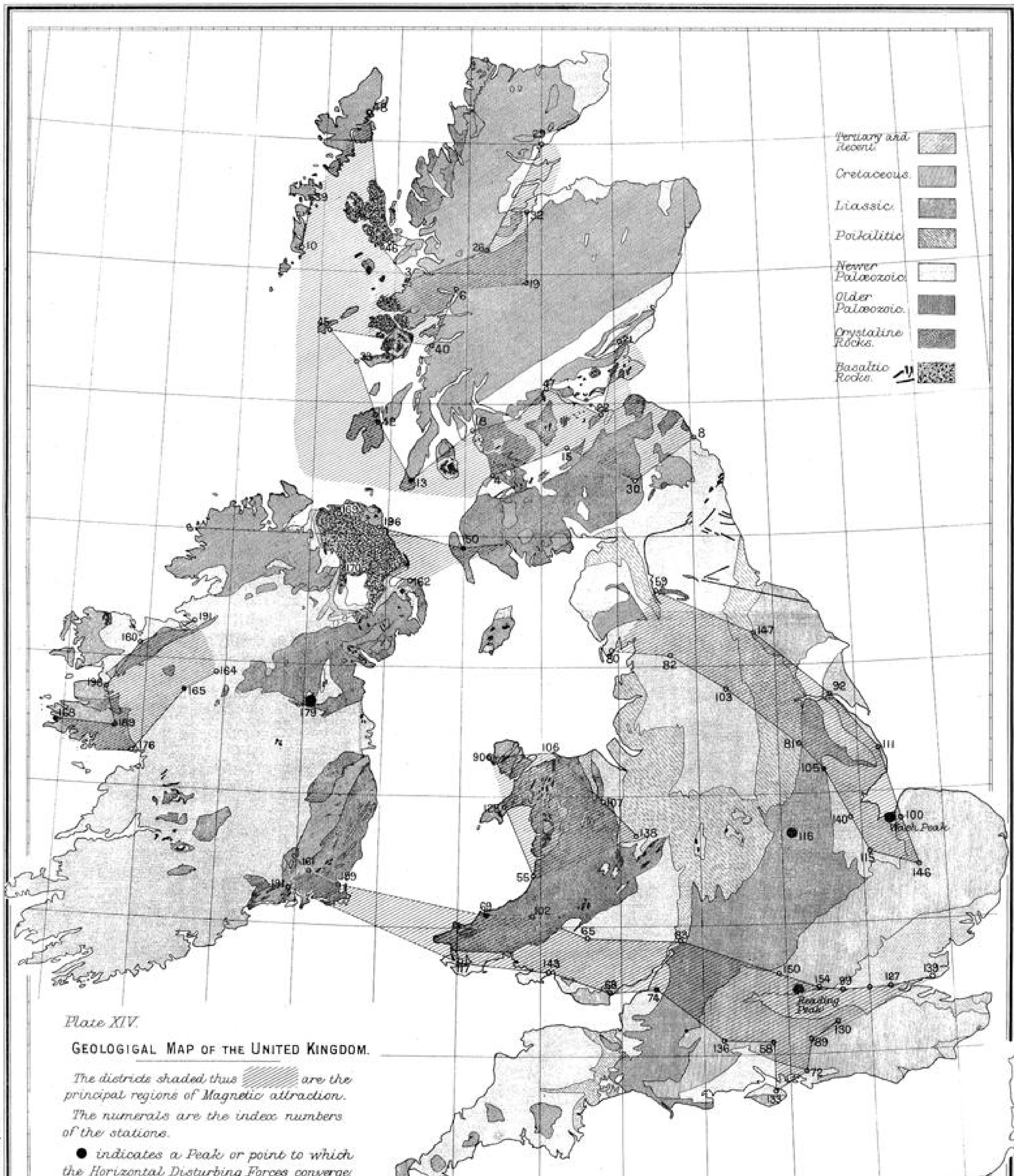
Ridge Line
MAP OF MAGNETIC DISTURBING FORCES
IN THE UNITED KINGDOM.

West, Newman imp.



Rücker & Thorpe.