



## XXXII. On a permanent magnetic field

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6. We shall make no attempt to recognize the true law of force acting between the molecules ; but it is obvious that  $b$  does not depend upon  $V$  any further, so that, with  $\rho$  to denote the density of the medium, our equation becomes

$$p/\rho = Rt(1 + T_1\rho), \quad . \quad . \quad . \quad . \quad (23)$$

$T_1$  being a function of the absolute temperature.

Now by similar considerations which, I think, it is unnecessary to reproduce at length, we may generalize our deduction by taking higher systems of molecules into account. Suppose we stop at  $i$ -molecular systems and neglect the number of those formed by  $i + 1$  molecules ; then the equation will be

$$p/\rho = Rt(1 + T_1\rho + T_2\rho^2 + \dots + T_{i-1}\rho^{i-1}) \quad . \quad . \quad (24)$$

(the  $T$ 's being functions of  $t$ ), and is thus seen to be of the general type suggested by Maxwell ('Scientific Papers,' vol. ii. p. 407) and recently supported by Lord Rayleigh ('Nature,' vol. xlv. p. 81). Equations of that kind are carefully discussed in Thiesen's elaborate paper in Wiedemann's *Annalen*, vol. xxiv. p. 467 ; see also *ibidem*, vol. xxxiii. p. 701. It would seem therefore that, in the proximity of the critical state, double and triple molecules are prevalent ; while (if we adopt a recent suggestion from Blümcke, *Zeitsch. für phys. Chemie*, vol. viii. p. 562) in the proximity of the solid state even the effect of systems consisting of eight molecules each may become traceable.

### XXXII. On a Permanent Magnetic Field.

By W. HIBBERT, A.I.E.E., F.I.C.\*

IN the electrical laboratory of the Polytechnic Institute, Regent Street, the earth's magnetic field varies so much that it cannot be assumed as a basis for reasonably accurate measurement. For this reason it was formerly my habit to give students a certain bar-magnet as a temporary standard, the number of lines passing out of the bar being determined afresh from time to time. This magnet was an old one, and its varied experience (now described under the term "ageing") had given it an approximate constancy. The constancy was, in fact, good enough to suggest the possibility of getting a really permanent magnet. I therefore made some tentative efforts to ascertain the effect of slight variations in the hardness and temper of steel on its magnetic properties, with the result that I found the subject too great for my resources.

\* Communicated by the Physical Society : read December 4, 1891.

But the growth of the modern idea of a magnetic circuit suggested the possibility of achieving my purpose in a way that would be largely independent of the peculiarities of different brands of steel, as well as of the various physical conditions caused by differences in tempering.

I therefore provided a short straight bar-magnet with a couple of arched pole-pieces, of such length and sectional area that there was left between them a narrow air-gap of very small magnetic "resistance." A very flat coil of wire thrust in or out of this gap gave electromagnetic impulses whose value was fairly constant. Experience with these simple instruments led me to believe that a more rigorous application of the principle would give a truly permanent magnetic field. How far this has been realized will appear from the considerations which I now have the honour to submit to the Society.

The first design that at all approximated to a closed magnetic circuit consisted of a cylindrical steel rod with hemispherical pole-pieces. For reasons into which I need not go, this has been superseded by the following modification.

Fig. 1.

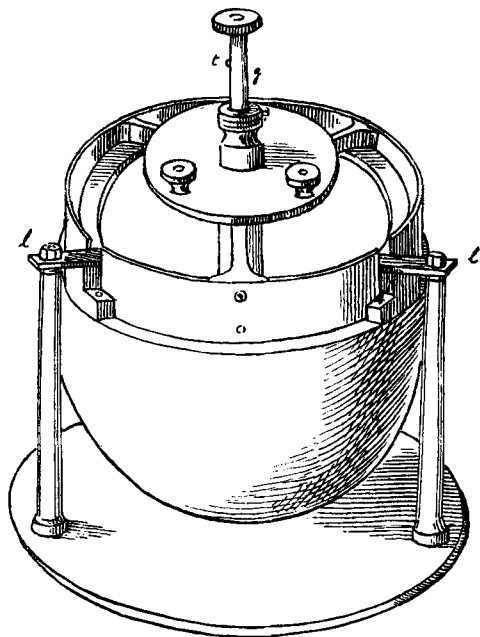
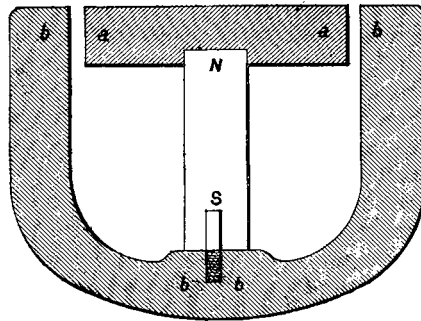


Fig 1 is a general view of the instrument. Fig. 2 is a

vertical section of the magnetic circuit. In this, *NS* is a cylindrical steel rod,  $2\frac{1}{4}$  inches long and 1 inch in diameter, attached to two cast-iron pole-pieces. The upper pole-piece, *aa*, is a circular disk, 4 inches in diameter and  $\frac{5}{8}$  inch thick, carefully bored to fit the upper end of *NS*. The lower pole-piece, *bb*, is nearly hemispherical, and about  $\frac{1}{2}$  inch thick in the wall. This is attached to the steel rod by means of an iron pin, let into *NS* and screwed into *bb*.

Fig. 2.



The opposed faces of the pole-pieces are carefully turned in the lathe, so as to leave between them a circular air-gap less than  $\frac{1}{16}$  inch wide.

The above description gives the form and dimensions of the magnetic part of the instrument. It is magnetized after being put together by a current sent through a coil wound on the steel rod.

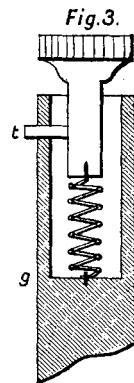
The other parts consist of :—

(1) Mechanical arrangements which will rigidly preserve the pole-pieces in position.

(2) Arrangements which will carry and guide a coil of wire as it is thrust through the field in the very narrow air-gap. Screwed to the upper surface of the disk *aa* is a brass casting with three projecting lugs *ll* (fig. 1). These lugs are screwed both to small blocks attached to the hemispherical pole-piece, and also to the tops of three brass pillars (fig. 1).

The coil is wound in a shallow groove cut on the outside of a brass ring, which is turned thin enough in the wall to slide freely through the air-gap. Attached to its upper edge are three arms which radiate from a central boss, the latter sliding up or down on the central guide-rod *g* (fig. 1). The radial arms support an ebonite disk on which are fixed the terminals of the coil.

At the upper end of the guide-rod *g* is an arrangement for allowing the ring to fall whenever the experimenter desires. The upper end of *g* is bored out (fig. 3), and a horizontal slot is cut in the thin wall thus made. In the inner space and connected with the milled head is a rod, from the side of which projects a tooth *t* passing through the slot, whilst from the lower end passes a spiral spring also fixed into the body of *g*. The tooth *t* is thus kept in a definite position, from which it can be moved aside either by a rotation of the milled head, or by the upward movement of the boss connected with the ring. On the inner edge of the boss is a slot through which *t* can pass, but cut slightly on one side of the zero position of the tooth. When an electromagnetic impulse is desired the coil is raised so that the boss, and therefore the ring, rests on *t*. The position of *t* and the height of the ring are so chosen that when the ring is at rest on *t* the coil is altogether above the gap. By a simple rotation of the milled head the coil can be made to fall through the field at any desired moment. The electromagnetic impulse then given to the circuit is, of course, equal to the number of lines inter-linked with the coil during the fall, multiplied into the number of turns of wire in the coil.



Three instruments of the type just described have been made and tested. The means adopted for testing are not the best that could be specified for the purpose. They were chosen because they give reasonable accuracy, and yet allow of a fair number of observations being taken in a limited time.

The method was to compare two throws of a galvanometer-needle, one produced by the discharge of a condenser, the other produced by the magneto-inductor.

The condenser employed was a mica condenser of 0.333 microfarad capacity. The potential difference for charging was obtained from four accumulators, whose electromotive force was determined by comparison with a Latimer-Clark cell, the comparison being made by the potentiometer method.

Having first taken a fair number of observations from the condenser, a corresponding number were taken from the magneto-inductors, the resistance in circuit with each being adjusted till the throw was practically the same as that obtained from the condenser.

I decided on this because it allowed me to use an ordinary damped reflecting-galvanometer. The object being simply

to test constancy, it was evident that the subsequent tests would be very much like the first, and that by the above method of working I might neglect damping, and also any consideration of the law of the galvanometer deflexion.

As the observations run through summer and winter they had to be corrected for temperature variation. The coefficients used were those now generally accepted, namely :—For the Latimer-Clark cell 0.077 per cent. per 1° C; for the copper wire of the galvanometer 0.38 per cent. per 1°; and for the German-silver resistances 0.044 per cent. per 1°.

It now remains to give the results obtained. As my present purpose is simply to show how far constancy of field has been obtained, it is not necessary to give many details. Before giving the results it will be proper to state the chief differences between the instruments numbered I., II., and III. in the Table.

*Hemisphere No. I.*—Air-gap a little more than  $\frac{1}{16}$  inch and not quite uniform. Magnetized by flashing current from four accumulators, July 29, 1890. Heated and cooled several times on different days. Very small decay to August 11, on which day the number of lines = 21,007. Next day, August 12, 1890, lines = 21,120. Seven months later, March 14, 1891, lines = 21,035. Accident to coil caused me to take to pieces and magnetize afresh. A current flashed through at a temperature of about 50° C.

*Hemisphere No. II.*—Most highly finished. Air-gap rather less than  $\frac{1}{16}$  inch. Magnetized by flashing. Lines about 34,000. Nearly 50 per cent. greater than in I. This showed tendency to fall. I therefore adopted the method known as “reducing,” by sending reverse current through magnetizing coil. Reduction of field about 5 per cent.

*Hemisphere No. III.*—Magnetic system not so well supported as in two previous instruments. Magnetized by flashing current, and then “reduced” about 20 per cent.

The figures in the column headed “No. of Lines” are obtained by the expression

$$N = \frac{100 \text{ CVR}}{t} \cdot \frac{d'}{d};$$

where C = capacity of condenser in microfarads,

V = potential difference in volts,

R = resistance in circuit with magneto-coil,

t = number of turns of wire on magneto-coil,

d', d = throws from magneto-inductor and condenser respectively.

The factor 100 translates from practical to absolute units.

Date.	Temperature of Inductor.	Lines in Inductor Field.		
		No. I.	No. II.	No. III.
April 16, 1891.....	50° C.	22,030		
" " " .....	20	21,790		
" 22 " .....	12·5	21,730		
" 23 " .....	13·5	21,710	32,360	
May 8 " .....	16·5	21,710	32,420	
" 23 " .....	13	21,680	32,330	
" 27 " .....	13·5	.....	.....	29,140
" 30 " .....	16	21,720	32,410	29,290
June 6 " .....	18	21,720	32,380	29,270
" 12 " .....	22	21,780	32,470	29,260
" 29 " .....	21·5	21,720	32,345	29,290
July 10 " .....	19	21,790	32,510	29,500
" 27 " .....	20	21,700	32,470	29,550
" 31 " .....	17·5	21,780	32,460	29,530
Sept. 22 " .....	16	21,690	32,400	29,470
Nov. 10 " .....	13	21,700	32,400	29,480
Density of lines in } air-gap per sq. cm. }		515	770	700

In discussing the figures it must be remembered that high accuracy was not attainable at the time of working. The observations were all made in comparatively brief intervals of leisure, and it is likely that the probable error is about 1 in 300 or 400.

There is practically no evidence of magnetic decay in seven months. Such small changes as are indicated point the other way, but I am inclined to attribute most of them to slight inaccuracy of the temperature-correction for the resistances of the circuit.

The two instruments that were reduced by a demagnetizing current (Nos. II. and III.) show a tendency to rise. This tendency is most marked in the instrument which was reduced most. It is evident that only a slight reduction is to be allowed.

No. I., which was magnetized warm, but not "reduced," fell while cooling, and then showed a very slight tendency to increase. It is better than the other two, and is constant enough to be used for any purpose for which an earth inductor is employed.

Nothing is here said of the temperature variation of this magnetic field\*. I have made some observations on that

\* Magnetic field is of course not the right name. The instrument raises once again the question of naming the quantity sometimes called "total field," "total induction," or so many "gausses."

point, and found it very small, but as the tests were made with hastily-adjusted appliances, I have thought it better to reserve the matter for further investigation. The temperature range involved in the Table is  $10^{\circ}\text{C.}$ , but the figures cannot be used for deducing the temperature-coefficient because of the other sources of error. I am inclined to think that the temperature variation of the condenser (which has not been applied to the calculations) practically neutralizes that of the inductor.

In addition to the evidence of constancy afforded by the Table, there are in my note-books several facts which point the same way. Of these I shall mention only one.

It is well known that magnetic decay is most pronounced just after magnetization, especially if the magnet is subjected to vibration. In several early cases I tested the effect of vigorous blows during and immediately after magnetization, but the evidence of loss was generally very feeble, and in some cases not measurable. In this connexion it may be worth noting that the brass ring which carries the coil is fairly heavy, and that when it falls it produces an appreciable blow. Each of the three instruments has been subject to this shock hundreds of times, but has shown no sign of decay under it.

Perhaps I may be permitted to say that I do not advance the principle of the magnetic circuit as at all novel. It has already been embodied in several well-known applications. But I believe the idea is here made subservient to new purposes.

As a material embodiment of a standard of magnetism (magnetic lines, gausses, or whatever else may be the right name) I find it helpful to many students. For this reason I propose to adjust future instruments of this size to a round number of lines, say 20,000 or 25,000, which will facilitate calculations arising out of their use.

The instrument is a most convenient standard for measuring magnetic quantities, whether it be the lines in any other magnet or the vertical and horizontal components of the earth's field. I am trying to use it for developing a new method of determining these quantities.

It enables me to simplify the magnetometer method for determining magnetic permeability. Over the ordinary magnetizing coil I wind a sufficient number of turns of a secondary. The coil with its core is fixed in *any* position that is convenient, and the *relative* number of lines determined by the magnetometer deflexion in the usual way. At the end of the magnetization the total *absolute* number of lines (corresponding to the maximum magnetometer deflexion) is found by taking



a throw from the secondary coil when the magnetizing current is reversed. This throw is then compared with that obtained from one of the inductors. By this method one is relieved from measuring distances whose cube &c. enters into the formula for reducing the observations.

I ought not to close without acknowledging the help given all through by the instrument-maker, Mr. G. Bowron, one of whose workmen, Mr. Collins, suggested the convenient method of release described in the paper.

### XXXIII. *Notices respecting New Books.*

*Annals of British Geology*, 1890. By J. F. BLAKE, M.A., F.G.S.  
8vo. 352 pages. Dulau and Co. London, 1891.

THE author, who is the President of the Geologists' Association, defines this work as "a critical digest of the publications and account of papers read during the year—with personal items." The subject-matters are limited to notes and memoirs supplied by British geologists in 1890, whether actually published, or merely announced in the Reports and Proceedings of Societies as having been read. In the former case careful and often full abstracts are here given; and the latter (the nos. of which are enclosed in square brackets) serve to indicate the lines of thought and research taken by numerous observers and thinkers, the results of which may be looked for in future Journals. Papers, maps, and sections (657), having relation to the British Isles, are mentioned at pages 1–299; papers on foreign Geology, published in Britain (95), are to be found at pages 299–339.

General, including physical and theoretical, Geology comes first in the subdivisions of subjects; then stratigraphical geology according to successive formations from the oldest to the newest; next palæontology, with vertebrates and invertebrates in zoological order, down to sponges and microzoa; palæobotany, mineralogy, petrology, and economics succeed; maps and sections follow; and then foreign geology as treated in British papers, in order like the above. Lastly, there are what are termed "Personal Items," as to the Geological and other Societies,—their Presidents, new Fellows, and Awards,—also the holders of Geological Professorial Chairs,—the Staff of the Geological Survey of Great Britain and Ireland, and of the Geological and Mineralogical Departments of the Natural-History Branch of the British Museum, and other matters. An Index of Authors, and another of Periodicals mentioned in the text, complete this comprehensive and well-arranged work.

More or less complete bibliographic lists of geological books and memoirs are supplied periodically in several countries (England, France, Germany, Russia, United States, &c.); but a separate