produces a difference of potential of 38 volts between its surface and centre, a globe of a kilometre diameter, electrified to the same electric density, reckoned according to the total electricity in any small volume (electricity of air and of spherules of water, if there are any in it), would produce a difference of potential of 38 million volts between its surface and centre. In a thunderstorm, flashes of lightning show us differences of potentials of millions of volts, but not perhaps of many times 38 million volts, between places of the atmosphere distant from one another by half a kilometre.

## II. "On the Effect of Magnetisation upon the Dimensions of Iron Rings in Directions perpendicular to the Magnetisation, and upon the Volume of the Rings." By Shelford Bidwell, M.A., LL.B., F.R.S. Received March 2, 1894.

A recent communication* to the Society contained an account of some experiments relating to the effects of magnetisation upon the dimensions of two iron rings, one of which was annealed and the other hardened. The rings had the form of short cylinders about 6 cm. in diameter, 3 cm. in height, and 0·4 cm. in thickness. The experiments in question were concerned with the circumferential variations which took place along the lines of magnetisation; those to be here described deal with the concomitant variations in the height of the cylinders (width of the rings) transversely to the magnetisation. On the assumption that variations similar to the latter occur at the same time in the thickness of the metal, it is possible to deduce the changes in the volume of the ring which attend magnetisation.

Fig. 1, from a photograph, shows how the rings were prepared for the experiments. Four brass rods were hard-soldered to the iron, two of them being in a line with a diameter, while the other two were attached to the edges, opposite to one another, and parallel to the axis of the ring. The ring was inserted in a wooden case, also shown, through holes in which the four brass rods projected. Insulated wire for carrying the magnetising current was wound over the wooden jacket.

For the new experiments the ring was placed in a horizontal position, one of the edge rods resting upon a brass socket on the adjustable base of the instrument, and the other, which had a chisel-shaped end, actuating the lever.† To counterbalance the weight of the ring a horizontal arm, carrying a sliding weight, was fixed to the lower rod.

* 'Roy. Soc. Proc.,' vol. 55, p. 228.

† The chisel-shaped terminal piece was removable and is not shown in fig. 1.

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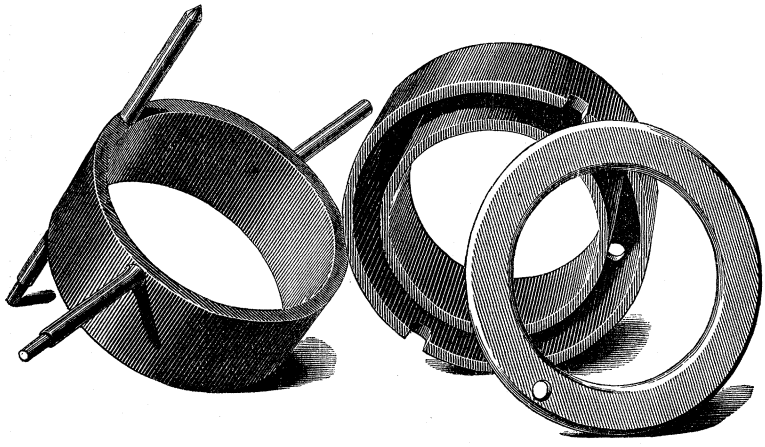
FIG. 1.



It need hardly be said that the experimental difficulties in the way of determining to a ten-millionth part the changes which took place in a length of less than $1\frac{1}{4}$ in. were very considerable.

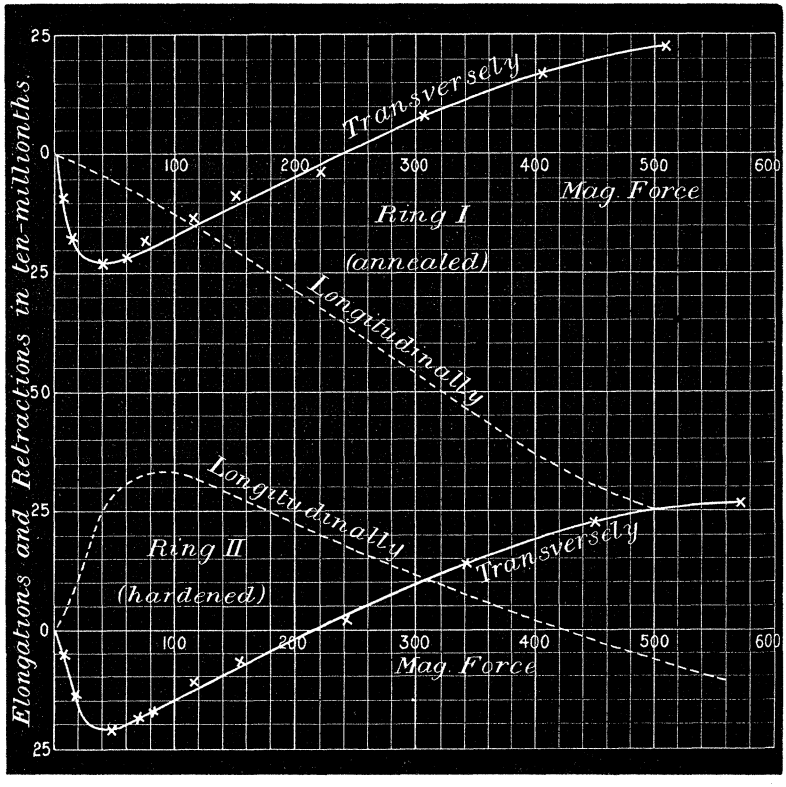
The annealed ring will, as before, be distinguished as Ring I, and the hardened one as Ring II.

Table I.

| Ring I (annealed). | | Ring II (hardened). | |
|---|---|---|---|
| Magnetising force, c.g.s. units. | Elongations in ten-millionths. | Magnetising force. | Elongations. |
| 6 | − 9 | 7 | − 5 |
| 17 | −18 | 18 | −13·5 |
| 41 | −23 | 47 | −21 |
| 59 | −21 | 69 | −18 |
| 75 | −17 | 82 | −17 |
| 116 | −13 | 117 | −11 |
| 151 | − 9 | 155 | − 7 |
| 220 | − 4 | 242 | 2·5 |
| 306 | 8 | 342 | 14 |
| 405 | 17 | 451 | 23 |
| 509 | 23 | 570 | 27 |

The changes observed in the widths of the two rings (transversely to the magnetisation) are indicated in Table I and in the curves of fig. 2. It will be seen that they are quite similar in the two cases,

FIG. 2.




The curves marked "longitudinally" relate to circumferential changes, *along* the lines of magnetisation.

Those marked "transversely" relate to changes in the width, *perpendicularly* to the magnetisation.

little or no effect being produced by annealing. Under gradually ascending forces both rings first become narrower, and then recover their original width, and ultimately become wider than when unmagnetised.

The only previous experiments that I know of relating to magnetic changes of dimensions in directions perpendicular to the magnetisation are those of Joule,* who used a piece of iron gas-piping 1 yd. long and $\frac{3}{8}$ in. in mean diameter, having an insulated wire inserted into it, and bent over the sides, so as to form a magnetising coil of $1\frac{1}{2}$ convolutions. The greatest current he used seems to have been about 12 ampères, and the magnetising force therefore about 8 c.g.s.

* Joule's 'Scientific Papers,' p. 263.

units. With this he found a contraction in the length of the pipe of 7 ten-millionths, a result which agrees very well with that obtained by myself for the same small magnetising force.

As was shown in my last paper, the effects along the lines of magnetisation are very different in the two rings. The annealed ring (Ring I) begins to contract circumferentially with the smallest forces, and continues to contract with the large ones; while the hardened ring expands with small forces and contracts with large ones. These effects are indicated in the figure by the dotted curves.

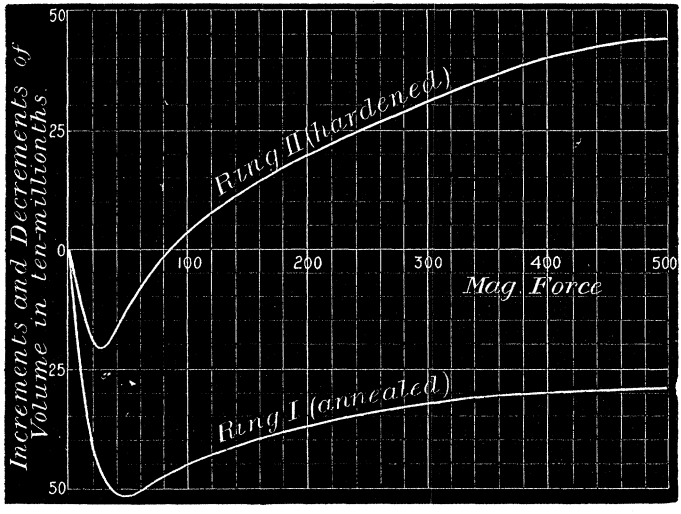
By combining the results of the old and of the new experiments we can ascertain the nature of the changes produced by magnetisation in the volumes of the rings.

If $k$ = elongation (+ or −) along the lines of magnetisation,

$l$ = elongation (+ or −) transversely to the lines of magnetisation,

then the increment or decrement of volume when the ring is magnetised is approximately* $k+2l$.

FIG. 3.




From the two sets of curves in fig. 1 corresponding values of $k$ and $l$ can be found, and thence the changes of volume may be deduced. These are given in Table II and fig. 3, which show that the volume of the annealed ring is rather suddenly diminished by a small magnetising force, passes a minimum under a force of about 50 units,

* Neglecting $l^2$ and products of $k$ and $l$.

Table II.

| Magnetising force, in c.g.s. units. | Increments and decrements of volume in ten-millionths. | |
|---|---|---|
| | Ring I (annealed). | Ring II (hardened). |
| 10 | −27 | −11 |
| 20 | −42 | −20 |
| 30 | −47 | −20 |
| 40 | −51 | −17 |
| 60 | −51 | − 9 |
| 80 | −48 | − 2 |
| 100 | −46 | 3 |
| 140 | −42 | 11 |
| 180 | −39 | 17 |
| 220 | −37 | 22 |
| 260 | −35 | 26 |
| 300 | −32·5 | 30 |
| 400 | −30 | 40 |
| 500 | −29 | 44 |

and then slowly increases, until, with a force of 500 units, it is about 30 ten-millionths less than at starting. The unannealed ring also at first suffers diminution, but its original volume is recovered with a force of about 90 and with higher values is increased.

The behaviour of this latter ring may be regarded as probably similar to that of the great majority of rods and rings, the annealed ring used in these experiments being the only specimen of iron that has yet been found to contract along the lines of magnetisation with the smallest forces that produced any effect at all.

Experiments upon the volume changes produced by magnetisation have been previously made by Joule, Barrett, and Knott.

Joule* concluded that the volume of an iron bar was altogether unaffected by magnetisation, even though the magnetising current which he employed "was quite equal to saturate the iron." It was at that time believed that "saturation" was produced by a force of from 80 to 100 units, and, assuming that Joule's force was of about that value, an inspection of the curve for unannealed iron in fig. 3 will show the probable reason of his having failed to detect any change of volume. There is, in fact, none at all with a force of about 90 units.

Barrett,† experimenting in the same manner as Joule, "enclosing the bars in a vessel of water terminating in a capillary tube, and

* Joule's 'Scientific Papers,' p. 236.

† 'Nature,' vol. 26, p. 485.

surrounding the vessel by a powerful magnetising helix," also obtained a negative result, perhaps for the same reason.

Knott's* experiments were made with hollow iron tubes, 45·7 cm. in length, 3·84 cm. in external diameter, and of different bores, ranging from 0·7 cm. to 3·19 cm. "Each tube was closed below, and into the upper end a nut screwed tightly, through a perforation in which issued a fine capillary glass tube. The nut was adjusted under water, so that the whole of the interior space of the metal tube was filled with liquid, and also part of the glass tube. When the tube was set vertically in the heart of the magnetising coil, the changes of volume were measured by the motions of the liquid meniscus in the capillary tube." "A few experiments were made on the external change of volume of a few of the tubes, which were enclosed in a thin-walled brass tube. The brass tube yielded because of its thinness, so that the results were not certain. But there was no doubt that with the specimens of iron tried there were large changes of volume."

The changes observed by Knott in the interior volume appear in the case of a tube of large bore to have been of the same nature as those in my unannealed ring; while with a tube of smaller bore they rather resembled the changes exhibited by the annealed ring. His published investigations are, however, only of a preliminary character, and it is not at present possible to make a satisfactory comparison between his results and my own. But he was undoubtedly the first to show that magnetisation is generally attended by considerable changes of volume.

## III. "Note on the Possibility of obtaining a Unidirectional Current to Earth from the Mains of an Alternating Current System." By Major P. CARDEW. Communicated by LORD KELVIN, P.R.S. Received May 10, 1894.

In carrying out some tests on the high-pressure alternating current system of the Metropolitan Electric Supply Company Ltd., of a combination intended to act as an indicator of leakage to earth, the existence under certain conditions of an excess of current in one direction to earth by leakage through the dielectric of the cables, or through small faults therein, has been demonstrated. The combinations and connexions used are shown in fig. 1, where A is the alternating current generator, $M_1$ and $M_2$ the distributing mains, TT the transformers, B a battery of a few Leclanché cells, G a

* 'Edin. Roy. Soc. Proc.,' 1891, p. 315; 1892, pp. 85, 249; 'Brit. Assoc. Rep.,' 1892, p. 659. The quotations are from the latter.

FIG. 1.

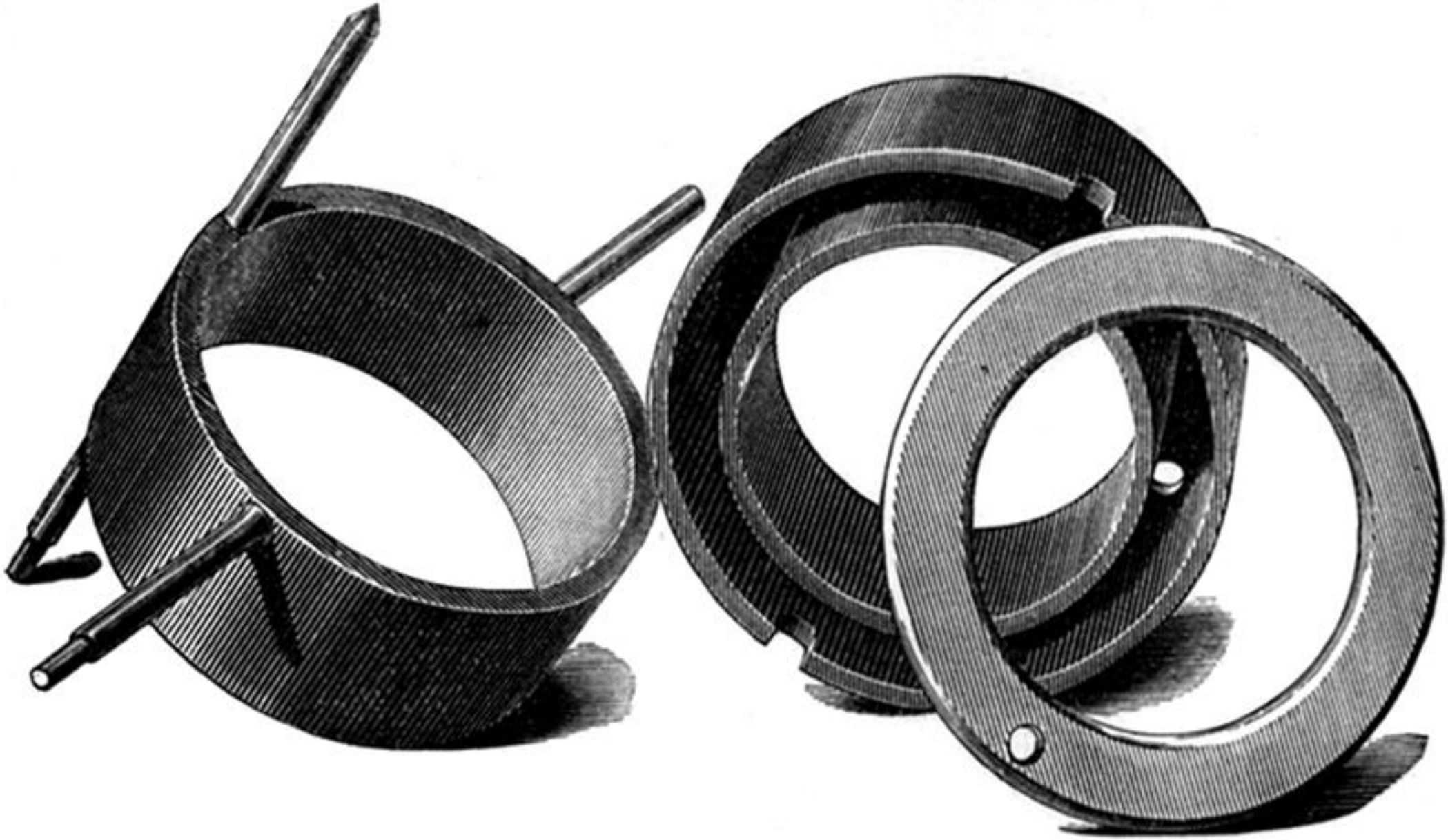
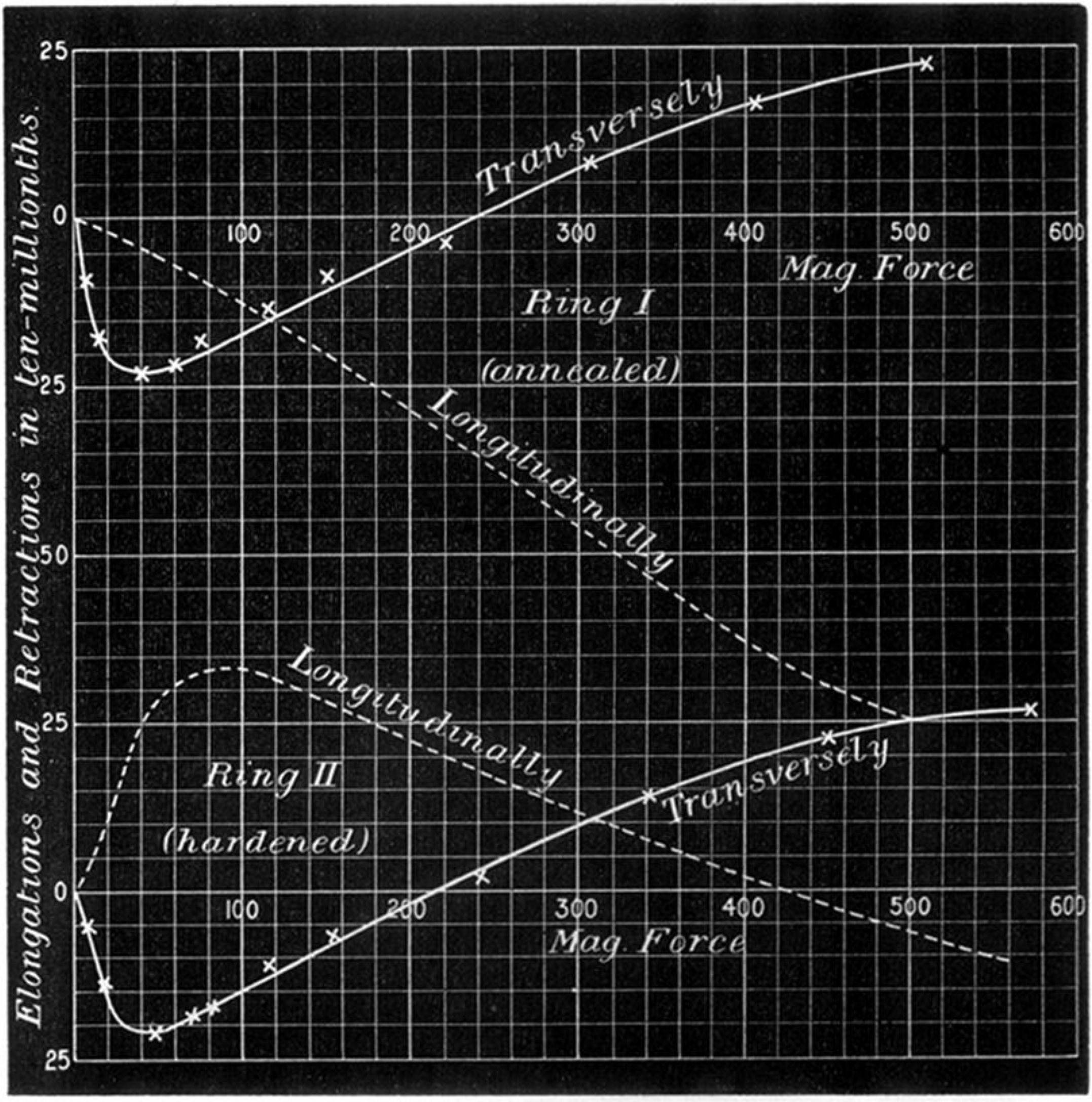


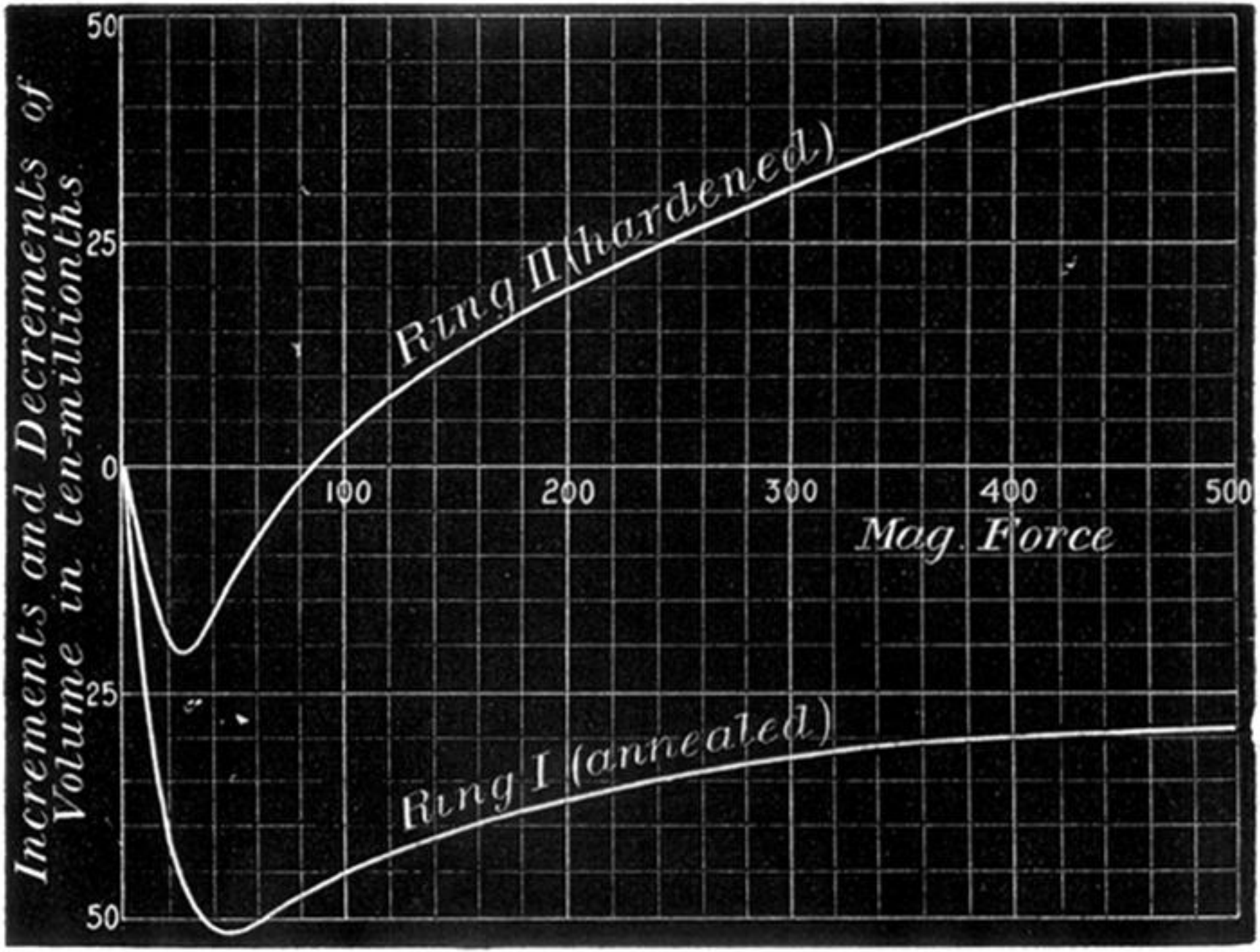
FIG. 2.




The curves marked "longitudinally" relate to circumferential changes, *along* the lines of magnetisation.

Those marked "transversely" relate to changes in the width, *perpendicularly* to the magnetisation.

FIG. 3.


Increments and Decrements of Volume in ten-millionths.
50
25
0
25
50
100
200
300
400
500
Mag. Force
Ring II (hardened)
Ring I (annealed)