LXIII. Electromagnets.—VI. The tension of lines of force

R.H.M. Bosanquet

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LXIII. *Electromagnets*.—VI. *The Tension of Lines of Force*.
By R. H. M. BOSANQUET.

To the Editors of the Philosophical Magazine and Journal.

GENTLEMEN,

THE experimental determination of the magnetic attraction corresponding to measured values of magnetic induction has long been in my mind. It has some bearing on my theory of permeability (see *Phil. Mag.* ser. 5, xix. 1885, p. 87 (note) and p. 94, in both of which places $\mathfrak{B}_2$ is inadvertently printed for $\mathfrak{B}^2$); but its independent interest is considerable.

After the following experiments were arranged, a paper on a somewhat similar subject was read to the Royal Society by Mr. Shelford Bidwell. From the accounts which have been so far published, the method of this paper appears to be entirely

different from mine, as the magnetizing force and the weight were alone directly measured: and in other respects the method differs essentially from that which I have adopted.

The sketch represents the instrument constructed for these experiments. This consists of two cylindrical iron magnets, each 20 centim. long and .526 centim. in diameter. Each is wound with 1096 coils of wire. One magnet is fixed in a wooden frame, while the other moves exactly under it smoothly and without friction, between two brass collars (not shown), through a vertical distance of about a quarter of an inch. The magnets were at first ground together so as to ensure a perfect contact. The lower or sliding magnet has attached to its lower end an iron hook, which passes through the table and sustains the wooden pan for the reception of the weights. To this magnet also is firmly attached a brass collar, in which are two holes for the pivots of the beam. The beam which carries the counterpoise is about 18 inches long; it moves on knife-edges, and has at one end a half-round fork, which embraces freely the collar on the lower magnet, and is pivoted thereto. On the other end of the beam is hung a lead counterpoise exactly balancing the wooden pan and magnet.

The magnetizing current was sent through both electromagnets, while the induction was measured* by small coils placed round the point of contact of the two magnets. The inductions were measured by reversal. Weights were carefully added until the contact was broken, and the greatest weight sustained was taken as the observed number. This could be observed with certainty to the nearest ounce.

The first result is that the formula,

$$(W_1) \text{ weight in grammes} = \frac{S\mathfrak{B}^2}{8\pi \cdot 981} \quad (S = \text{section of contact}),$$

derived from (vol. ii.) Clerk Maxwell's 'Electricity and Magnetism,' p. 256, represents the values well on the whole; but for very small inductions the weight sustained is several times as great as it should be according to this theory. And this did not arise from residual induction; for when the magnetizing current was interrupted, no power was left to sustain any weight at all.

I therefore framed the empirical formula W , involving both $\mathfrak{B}$ and $\mathfrak{B}^2$; this represents the lower and middle values fairly, but not the highest.

It cannot, however, escape notice that the observed values are best satisfied by adding about 4 oz. to all weights calculated from W_1 . Since, however, this addition must vanish for $\mathfrak{B}=0$, we cannot thus obtain a general formula. Note

* For the method see Phil. Mag. ser. 5, xix. p. 75.

that the induction has been forced up to the high value of 18,500. I have shown in recent papers that this quantity has no fixed limit in bar-electromagnets. This accords to some extent with the conclusions of Mr. Shelford Bidwell in the paper before referred to.

The table of experiments is followed by one containing the means of the errors of the formulæ W_1 and W_2 for the groups into which the experiments are divided.

Finally there are set out a few experiments made with the electromagnets not in contact, but separated to the distances mentioned by slips of card and wood. These experiments are not approximately satisfied by the foregoing formulæ; but they would agree to some extent with W_1 if, instead of the coefficient

$$\frac{1}{8\pi \cdot 981} = \cdot 00004056,$$

we took about half that quantity, say $\cdot 000026$. The experiments at distance $\cdot 2$ would require a formula of the type of W_2 . At present I am unable to give any explanation of these numbers.

The general truth of the law

$$\text{Tension} \propto S\mathfrak{B}^2$$

is sufficiently established.

In my theory of permeability I have assumed the tension within the magnetic body $\propto \mathfrak{B}$. It is clear that this assumption leads in that case to consequences which correspond with reality, and that the assumption tension $\propto S\mathfrak{B}^2$ does not do so in that case. I am at present unable to explain the divergence between the two points of view.

The weights have all been reduced to lbs. and ozs. to facilitate comparison with the actual experiments.

Batteries were used for weights up to about 5 lb.; the dynamo from about 2 lb. upwards.

*Comparison of Observed Weights sustained with Calculated
Weights W_1 and W_2 .*

$$W_1 = \frac{S \mathfrak{B}^2}{8\pi \cdot 981}, \quad \log S = -14671.$$

$$W_2 = S(\kappa \mathfrak{B}^2 + l \mathfrak{B}); \quad \log \kappa = 5 \cdot 55391; \quad \log l = 2 \cdot 76660.$$

Date.	$\mathfrak{B}$.	W obs.	W_1 .	Diffs.	W_2 .	Diffs.
		lb. oz.	lb. oz.	lb. oz.	lb. oz.	lb. oz.
July 17.	767	0 3	0 1.2	-0 1.8	0 3.3	+0 0.3
" 20.	894	0 4	0 1.6	-0 2.4	0 4.0	0
" 6.	800	0 5	0 1.3	-0 3.7	0 3.4	-0 1.6
" 8.	800	0 5	0 1.3	-0 3.7	0 3.4	-0 1.6
" 6.	825	0 6	0 1.4	-0 4.6	0 3.6	-0 2.4
" 17.	1,534	0 6	0 4.7	-0 1.3	0 8.6	+0 2.6
" 20.	1,845	0 8	0 6.8	-0 1.2	0 11.4	+0 3.4
" 8.	1,663	0 10	0 5.6	-0 4.4	0 9.7	-0 0.3
" 17.	2,544	1 0	0 13.0	-0 3.0	1 3.0	+0 3.0
" 8.	2,818	1 6	1 0	-0 6	1 6	0
" 20.	3,180	1 6	1 4	-0 2	1 11	+0 5
" 8.	3,113	1 9	1 3	-0 6	1 10	+0 1
" 17.	3,607	1 12	1 10	-0 2	2 1	+0 5
" 17.	4,549	2 13	2 9	-0 4	3 2	+0 5
" 8.	5,000	3 6	3 2	-0 4	3 11	+0 5
" 17.	5,148	3 9	3 5	-0 4	3 15	+0 6
" 17.	5,222	3 13	3 7	-0 6	4 4	+0 7
" 20.	5,205	3 13	3 6	-0 7	3 15	+0 2
" 2.	5,588	4 4	3 15	-0 5	4 7	+0 3
" 20.	7,047	5 11	6 4	+0 9	6 12	+1 1
" 22.	6,630	5 11	5 8	-0 3	6 1	+0 6
" 8.	6,759	5 12	5 12	0	6 4	+0 8
" 2.	6,516	5 13	5 5	-0 8	5 13	0
" 5.	6,841	6 1	5 14	-0 3	6 7	+0 6
" 2.	6,594	6 2	5 7	-0 11	6 0	-0 2
" 23.	7,110	6 8	6 5	-0 3	4 9	-1 15
" 23.	7,464	6 10	6 15	+0 5	7 8	+0 14
" 2.	7,209	6 12	6 13	+0 1	7 1	+0 5
" 9.	6,977	6 12	6 2	-0 10	6 10	-0 2
" 19.	6,645	7 1	5 9	-1 8	6 1	-1 0
" 23.	7,510	7 1	7 1	0	7 9	+0 8
" 23.	7,414	7 2	6 14	-0 4	7 7	+0 5
" 20.	8,360	8 8	8 12	+0 4	9 4	+0 12
" 20.	9,195	10 0	10 10	+0 10	11 0	+1 0
" 9.	8,636	10 2	9 6	-0 12	9 13	-0 5
" 9.	9,059	11 7	10 5	-1 2	10 11	-0 12
" 5.	11,235	15 13	15 13	0	16 0	+0 3
" 19.	12,237	21 2	18 12	-2 6	18 12	-2 6
" 22.	12,587	21 3	19 14	-1 5	19 13	-1 6
" 5.	14,211	26 7	25 7	-1 0	24 15	-1 8
" 19.	14,342	28 2	25 13	-2 5	25 6	-2 12
" 22.	15,429	30 12	29 13	-0 15	29 2	-1 10
" 19.	16,015	34 5	32 2	-2 3	31 4	-3 1
" 5.	16,384	35 1	33 11	-1 6	32 11	-2 6
" 22.	16,433	35 4	33 14	-1 6	32 14	-2 6
" 19.	16,387	35 15	33 11	-2 4	32 11	-3 4
" 2.	17,302	36 5	37 8	+1 3	36 4	-0 1
" 2.	17,876	36 9	40 1	+3 8	38 9	+2 0
" 2.	17,731	36 14	39 6	+2 8	38 0	+1 2
" 22.	17,292	36 13	37 8	+0 11	36 3	-0 10
" 2.	17,554	37 3	38 10	+1 7	37 4	+0 1
" 19.	17,379	41 3	37 14	-3 5	36 9	-4 10
" 22.	18,582	41 9	43 5	+1 12	41 9	0
" 5.	17,596	41 12	38 13	-2 15	37 7	-4 5
" 22.	19,519	44 3	47 12	+3 9	42 11	-1 8
" 19.	17,905	44 5	40 3	-4 2	38 11	-5 10
" 5.	18,497	45 0	43 13	-1 3	41 3	-3 13

W obs.	Arithmetic mean of errors of W_1 and W_2 .		Number of experiments.
	W_1 .	W_2 .	
From 0 3 to 1 6	lb. oz. -0 3.21	lb. oz. 0 0.34	10
From 1 6 to 5 11	lb. oz. -0 3.1	lb. oz. +0 5.6	10
From 5 11 to 7 1	lb. oz. -0 5.6	lb. oz. -0 1.2	10
From 7 1 to 26 7	lb. oz. -0 9.5	lb. oz. -0 5.7	10
From 26 7 to 36 13	lb. oz. -0 4.1	lb. oz. -1 4.8	10
From 36 13 to 45 0	lb. oz. -0 11.0	lb. oz. -2 13.2	7

Weights sustained by Magnets when separated.

$$\kappa = \frac{W}{S B^2}.$$

Date.	W obs.	B .	κ .	Distance of magnets apart.	Mean κ .
1886. August 2nd.	lb. oz.				
	2 0	4803.5	.00002805	in. .028	.00002638
	5 0	8022.1	.00002514		
	10 12	12667	.00002168		
	16 4	13893	.00002724		
	17 14	14588	.00002718		
	19 2	14858	.00002803		
3rd & 4th.	25 13	17464	.00002738	.060	.00002584
	1 5	3736.4	.00003042		
	3 5	6330.2	.00002675		
	7 5	9709.6	.00002510		
	10 9	11743	.00002478		
	12 5	12449	.00002571		
	14 5	13878	.00002404		
4th & 5th.	17 11	15415	.00002408	.2	
	0 7	1611.8	.00005449		
	0 10	2545.1	.00003122		
	1 5	4371.3	.00002222		
	2 5	6095.6	.00002014		
	2 14	6909.7	.00001948		
	3 12	8034.0	.00001880		
	5 9	10437	.00001652		