Physics. — *"An improved semicircular electromagnet"*. By Prof. H. E. J. G. du Bois. (Communication from the Bosscha-Laboratory).

(Communicated in the meeting of June 26, 1909).

Starting from my theory of the split-ring magnet and its experimental confirmation by H. Lehmann [1]) I designed a large ring-electromagnet in 1894, which I believe may claim to be considered the prototype of various apparatus since described [2]). Since the general introduction of magnetically efficient cast material it proved feasible to deviate from that simple shape and to redesign it (in 1898) as a so-called semicircular magnet [3]); this was much lighter and handier in many respects and a great number of this type have since been in use in laboratories.

Within a cylindrical "interferric" space of 1 mm. length and 6 mm. diameter their field amounts to 38—40, averaging rather more than 39 kilogauss, in consequence of the somewhat variable properties of cast material. After some ten years of varied experience it now again appears desirable — as indeed it does for most kinds of instruments — to further revise the design with a view to practical use. As the resources of a well-equipped experimenter will in many cases enable him to do good work within narrower interferric spaces, I could attempt to increase the field up to 50 kilogauss without exceeding a total weight of about 300 kg. — distributed over three equally heavy pieces; the apparatus remaining sufficiently easy to handle and carry about in laboratories.

In the meantime Prof. Pierre Weiss described an electromagnet of great power [4]), which uses up to 18 kilowatt and weighs about 1300 kg.; by this, however, probably only a few privileged laboratories are benefited, and it appears, moreover, less adapted for the important class of modern magneto-optic investigations on account of the long path of the rays of about 125 cm. I could, however, partly, avail myself of his theoretical considerations and results as well as of some details of his design.

Fig. 1 is reproduced at a tenth of the real size. The base part

[1]) H. du Bois, Wied. Ann. **46**, p. 485, 1892. — H. Lehmann, Wied. Ann. **48**, p. 406, 1893.

[2]) H. du Bois, Wied. Ann. **51**, p. 537, 1894.

[3]) H. du Bois, Verh. Berl. physik. Ges. **17**, p. 99, 1898; Zeitschr. für Instr.kunde **19**, p. 357, 1899; Ann. der Physik. (4) **1**, p. 199, 1900.

[4]) P. Weiss, l'Eclairage électr. **15**, p. 481, 1898; Journ. de Phys. (4) **6**, p. 353, 1907. — G. Zindel, Electrotechn. Zeitschr. **30**, p. 446, 1909.

rests on a broad ball frame with a divided circle, so that the apparatus may easily revolve round a vertical axis; it can also be fixed by means of 3 set-screws. The adjusting screws on the left-hand side are useful for the vertical position of the magnetic axis occasionally required (see fig. 2); the hand-wheel allows gradual displacement of the left-hand core. In practice it is extremely useful and convenient to divide the magnetic circuit by the upper horizontal plane of the base part of the apparatus, so that each of the two cores may slide as well as revolve on it. Each core corresponds to about one third of a toroid and its lower end terminates in a cast flange. Its vertical circular end-planes have a diameter of 93 mm.; towards the bottom this gradually increases.

The investigation of the FARADAY and ZEEMAN effects carried out in this laboratory enforced the condition of great intensity of light, which may be fulfilled by concentration of the beam of rays in the interpolar space, so that it may form a strongly diverging double cone of light. Evidently the borings in the iron must correspond with this, from which the further condition of a short path of the rays immediately follows, as the width of the boring is naturally limited. Conical holes were bored 1 : 5 of a length of only 15 cm.; one of the iron filling-plugs to be used in non-optical experiments is represented in fig. 1; the length of the path of the rays within the iron is restricted to these borings themselves by the peculiar design of angular flanges, which appears sufficiently clearly in the figure. These flanges are provided with regularly spaced nuts, to which optical and other appliances may be screwed, so as to lie just at the mouth of the boring. The polar ends of the cores are surrounded by a thin copper tube for water circulation; 50 litres of water per hour works sufficiently well; moreover an inner circulation may be arranged within the borings; besides the pole-shoes may be provided with external cooling-spirals, such as are clinically used for cooling parts of the human body [1]).

The external shape of the coils appears from fig. 1; the polar flanges are conically truncated in order to make the interpolar space more accessible. When, however, the highest degree of magnetisation is required, two extra detached polar coils may be fixed around the pole-shoes; in accordance with a well-known rule of KIRCHHOFF's the purpose of this is to saturate the polar pieces as far as possible; this principle was, moreover, already applied by H. LEHMANN in his investigation (loc. cit. p. 424). We then obtain 100 (120) kiloampère-

[1]) Cooling the wire-coils themselves, e.g. by circulating oil is certainly desirable, but rather elaborate and expensive.

turns with 5(6) kilowatts, and the heat generated by the current amounts to 1,2 (1,45) kilocalories per second.

With this apparatus the usual disk-poles and plane polar pieces are supplied to obtain extensive uniform fields. For stronger fields the diameter is reduced in the first place from 93 to 43 mm. by means of "pole-shoes" P of special broken truncated shape (fig. 3 real size). They consist of annealed Swedish laminated iron; their most efficient form was again empirically determined and hardly deviates from the shape used until now [1]). Interpolar pieces of different kinds may then be placed between the two smaller circular end-planes, as required for experiments.

The comparatively small diameter of 43 mm. makes it easy and desirable for every laboratory itself to have such pole-tops Q turned out of Swedish iron, as are best adapted to any special purpose. Their contribution to the total field amounts to 80 to 90 percent, and thus far exceeds that of the pole-shoes, which as a rule only contribute 10 to 20 percent; the influence of the conic surface-elements increases very much as they lie nearer the extremities, where they should be carefully shaped and centred; this purpose is effected by special centred distance-pieces of unmagnetic material. Thus in course of time polar pieces were made for cryo- and pyromagnetic experiments, for micro-magnetic and magneto-optical investigation (FARADAY, KERR and ZEEMAN-effect), for the torsion-balance and magneto-hydrostatic method and that of the isthmus for magnetic stress determinations. A fuller description of these various arrangements would claim more space than we can afford to give it here; it will appear elsewhere with a discussion of the general principles for the design of such intrapolar apparatus, as are adapted to various purposes.

In the conic borings (see fig. 3) split cores or solid filling-plugs may be introduced according to the nature of the experiments. With the pole-tops reproduced in fig. 3, whose end-planes have a diameter of 3,6 mm. the strongest field was empirically obtained through calculation, measurement and mechanical shaping proceeding simultaneously. On the other hand the dotted lines represent the well-known theoretical optimum form consisting of a cone with a vertex semi-angle of 54°44′, and part of the "isthmus". The theory must start from the assumption of absolute saturation in the direction of the axis, which can never really be fulfilled; hence the actual deviation,

1) Since 1901 slightly rounded pole-shoes were supplied with large half-ring electro-magnets. No pole-shoes were required for the smaller ones, and it proved useful, on the contrary, to provide their pole-tops with a bevilled edge, which peripherically increases the effective conic surface. (see fig. 4).

though it is rather slight. It proved useful again to let the vertex angle increase from the centre towards the edge, from about 56° to 59°; instead of by a broken line, this transition can also take place by means of an arc of 3°, and corresponding — rather large — radius; the surface of revolution then becomes somewhat toroidal.

A great number of field measurements with a very small test-coil were first made in order to gradually approximate towards the optimum form, to which, however, rather a "flat maximum" corresponds, which leaves the designer a certain margin. The final results are contained in the following table

End planes: distance (mm.)	6 mm. Field (kgs)	3.6 mm. Field (kgs)	
0	50 (extr.)	55 (extr.)	
0,5	48.7	52.2	(46)
0,9	—	50	—
1,0	47	—	(42.5)
1,5	45.3	46.5	(39)
2,0	43.7	44.5	—

These fields were obtained with 124 kiloampère-turns (with extra polar coils); the first limiting value has been linearly extrapolated and is of some theoretical interest; for some experiments intervals below 0,5 mm. are already sufficient. I have placed between parentheses the field values obtained by screwing the same polar pieces into the old ring-electro magnet, 108 kiloampère-turns (without extra polar coils) being used in this case.

In fig. 2 a smaller type is represented in an erect position at $^1/_5$ of the real size. This is essentially a simplified linear reduction to about $^2/_5$; it is well-known that small electro-magnets are relatively much more efficient than larger ones, though it is more difficult to spare sufficient space for the ampère-turns required in the same linear ratio. The conic pole-tops with their bevilled edges — as in fig. 4 — are cast in one piece with the cores themselves, and properly finished on the lathe. This apparatus weighs but 33 kg.; with 24 kiloampère-turns — only $^1/_5$ of the above-mentioned value — the following approximate results were obtained:

End planes: distance (mm.)	6.7 mm. Field (kgs)	3.6 mm. Field (kgs)
0	36 (extr.)	40 (extr.)
0,5	34	37
1,0	32	34
1,5	30	31

I wish to express my great indebtedness to Prof. Kōtarō Honda for his kind assistance in carrying out the necessary field measurements.

Fig. 1.

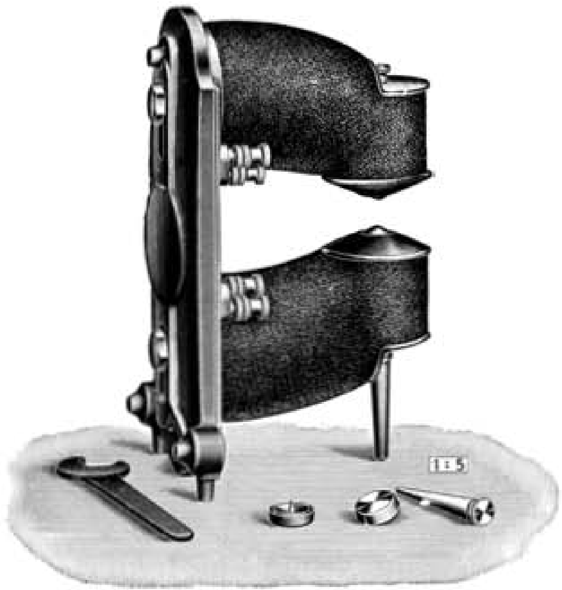

Fig. 2.

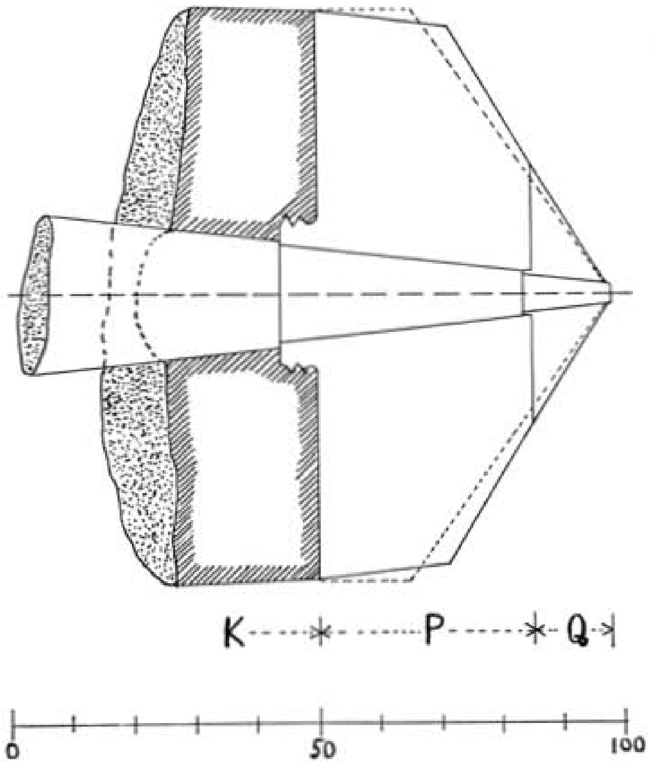

Fig. 3.

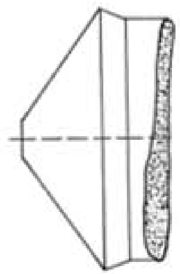

Fig. 4.