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Physics. — *"On the reversible change of the remnanent magnetisation with the temperature".* By Dr. G. J. Elias. (Communicated by Prof. H. A. Lorentz).

(Communicated in the meeting of December 18, 1915).

When the temperature of a ferromagnetic body that possesses remanent magnetism rises, the magnetism changes too. Let us suppose e. g. that a decrease of the magnetisation corresponds to a rise of temperature. If then the magnet is again cooled down to its original temperature, the magnetisation increases again, but does not return to its original value. A following rise of temperature equal to the first one causes again a decrease of the magnetisation, but now a smaller one than was caused by the first rise. The next return to the original temperature brings the magnetisation only back to a value below that after the first cooling. With continued changes of the temperature this goes on in the same way; the differences between the magnetisation after two subsequent equal changes of the temperature in the same sense become always smaller, till finally a state is reached in which the changes are reversible, that is to say, that by a rise of temperature the magnetisation decreases as much as it increases again by the following equal fall of the temperature. This reversibility only holds however between the used limits of temperature; if these limits are taken wider, the cyclic process of heating and cooling must first again be gone through a few times, before the reversibility is reached. This reversible change we shall investigate here. With a change of temperature without more we shall denote the reversible change.

On this subject there are experiments of Ashworth [1]) and Durward [2]). Both have investigated different kinds of steel; and cast-iron. The first author obtained very different values for the change with the temperature, according to the kind of steel used. In most cases the coefficient α, defined by the equation

$$M_{t_2} = M_{t_1} [1 - \alpha (t_2 - t_1)] ,$$

was found to be positive. In this formula M_{t_2} resp. M_{t_1} is the magnetisation at the temperature t_1 resp. t_2; the highest value found for steel was about 0,0014, for cast-iron even 0,0029. For some kinds e.g. for piano-strings α had a negative value even down to — 0,0003. Further α proved to be strongly dependent on the thermal history (process of hardening) of the material, while also the influence

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[1]) G. R. Ashworth. Proc. Roy. Soc. A. **62** p. 210, 1898.

[2]) Durward. Sill. Journ. **5** p. 245, 1898.

of the dimensions of the magnet that was used, therefore of the demagnetising force proved to be great. So **Ashworth** found e.g. for one single piano-string of certain dimensions a negative value of α, while three equal and equally treated strings combined into a bundle gave a positive value of α.

In the experiments that are to be described here, iron and further also some kinds of steel were used.

The *iron* (soft Swedish iron from G. E. **Meister's Sohne**, *Stettin*) was investigated in the form both of bars and of a ring. In the first case the measurements were magnetometric, in the latter one ballistic. For the magnetometric measurement a **Thomson** galvanometer was used. The magnet that had to be investigated was placed horizontal and perpendicular to the direction of the small magnets in the galvanometer system. The deviation of the system by the presence of the magnet was compensated by sending a current through the coils. The intensity of this current was used as a measure for the magnetic force that was exerted by the magnet. In order to avoid the influence of terrestrial magnetism the bar was always placed perpendicular to the magnetic meredian.

The ballistic measurements were made by means of a flat coil that could be brought into the interferricum of the ring.

For the different forms used the demagnetising factors were very unequal. They had the highest value for a bundle of bars with total diameter of about 1.5 cm and 24 cm length; and the lowest one for the torus with narrow interferricum. The magnetisation was also varied within rather wide limits. The mentioned bundle gave for a variation of temperature between 10° and 100° and for magnetisations that were in the ratio 1 · 2 : 12 changes resp. of 3.7, 3,8 and 3,7 %. Between the same limits of temperature a bar of 0,5 cm diameter and 21 cm length gave a change of 4,0 % and one of 0,3 cm diameter and 17 cm length of 4,1 %. In the two last cases the magnetisation was nearly as strong as the strongest magnetisation in the case of a bundle of bars. In all cases the magnetisation did not reach its saturation value, though the strongest magnetisation did not differ much from it. For the ring made of iron of 23 mm diameter and having itself a diameter of about 10 cm with an interferricum of 2 mm a variation of 4 % was obtained for weak magnetisations between 20° and 100°.

So the values for the variations of temperature obtained for iron do not differ much from each other. It is questionable, whether these differences have a real significance; probably they must be assigned to observation errors, as the methods used did not allow great accuracy. Of all observations on iron the mean is 3.86 °/₀ for a variation of temperature between 10° and 100°.

According to the theory of the molecular magnetic field of Weiss the spontaneous magnetisation of the "elementary crystals" which Weiss regards as the building stones of the iron decreases with a rise of the temperature. The law of this decrease is given by the formula

$$\frac{M}{M_0} = \coth \frac{3\theta}{T} \cdot \frac{M}{M_0} - \frac{1}{\frac{3\theta}{T} \cdot \frac{M}{M_0}},$$

where M is the magnetisation at the temperature T, M_0 that at the absolute zero-point and θ the Curie-point. In this formula the mutual action between the different elementary crystals has been neglected. If by means of it we calculate the change between 10° and 100°, we obtain, taking for the Curie-point 757° C., 4,2 °/₀, what agrees rather well with the experimentally found variation of 3,9 °/₀ between 10° and 100°.

Also for steel the above described magnetometric method was used. To render possible however the investigation of different parts of one and the same magnet a ballistic method was used. A flat coil placed round the experimental magnet could be shifted with regard to the latter over a small distance. In order to make the deviation of the galvanometer not too great, it was for the greater part compensated by means of a second coil equal to the first one and mechanically connected with it, so that it followed its motion, moving itself however in the opposite direction; within this second coil a second magnet was placed. If now the first magnet was heated, the ballistic deviation changed and from this the influence of the heating could be investigated. By bringing respectively different parts of the experimental magnet within the first coil, compensating each time by means of the second magnet, the change of the magnetisation could be determined for the different parts.

For steel the results of Ashworth were confirmed. In the first place for different kinds of steel very different values of α were found; the highest value for a very old steel magnet viz., nearly 0.0015, for other kinds of steel α was smaller, while piano-strings even gave a negative value.

By the mentioned ballistic method was found however, that the value of α was not the same for all parts of the magnet. Near the ends α proved to be larger in the positive sense than more towards the middle. Between 20° and 100° the change for the above mentioned old steel magnet e.g. amounted to 12,9 $^0/_0$, near the middle however to 8,5 $^0/_0$; for a magnet of hardened steel the change near the end was 2,1 $^0/_0$, at a distance from the end equal to $\frac{1}{3}$ of the length 1,2 $^0/_0$. In both cases the coefficient α was positive. For a bundle of piano-strings which each had a diameter of 1,2 mm and a length of 17,5 cm the change between 20° and 100° was —3,9 $^0/_0$ at the end and — 6,1 $^0/_0$ at a distance from the end equal to $\frac{1}{3}$ of the length. After partial demagnetisation, by which the magnetisation was diminished to $\frac{1}{8}$ of its original value the change between the same temperature limits at the end was only —1,5 $^0/_0$. Magnetometrically (now we are principally concerned with the action of the end of the magnet) there was found before the demagnetisation —3,3 $^0/_0$ and afterwards —1,6 $^0/_0$ (here the temperature limits were 10° and 100°). From this we might conclude that for steel the coefficient α depends on the magnetisation in this way that it increases in the positive sense according as the latter decreases. This agrees with what was found in the investigation of different parts of one and the same steel magnet, viz. that near the end α is greater in the positive sense than in the middle; for because of the demagnetising force the magnetisation at the ends is much smaller than in the middle.

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Physics. — *"Some remarks on the hydrogen-molecule of* BOHR — DEBIJE." By Miss H. J. VAN LEEUWEN. (Communicated by Prof. H. A. LORENTZ).

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§ 1. BOHR has been the first who supposed the hydrogen-molecule to be formed by two nuclei which carry a positive elementary charge and in which nearly the whole mass of the molecule is concentrated, together with two electrons which in the normal state circulate with a constant angular velocity ω diametrically on a circle that has its centre in the middle between the nuclei and its plane perpendicular to their line of connection, the "axis" of the molecule [1]). BOHR supposes that such molecular systems do not obey the laws of classic mechanics, that on the contrary all motions of the electrons are bound by the condition that for each single electron the moment of

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[1]) N. BOHR. On the constitution of atoms and molecules III. Phil. Mag. 6, 26, 1913 p. 857.