RESEARCHES ON MAGNETISATION AT VERY LOW TEMPERATURES.

Professor Pierre Weiss also communicated the following abstract* of a Paper by himself and **Professor H. Kamerlingh Onnes** on "Researches on Magnetisation at Very Low Temperatures."

The question has often been asked if a gap which cannot be bridged over exists between the ferromagnetic metals of the iron group on the one hand and the paramagnetic metals of the same group on the other, or if the latter metals should also exhibit a very low Curie-point if the temperature were sufficiently lowered.

Ch. Ed. Guillaume† says, with reference to the Heusler alloys of Mn, Al, Cu and Mn, Sn, Cu which are ferromagnetic: "The reason for this can be found in the fact that aluminium or tin, when compounded with manganese, a metal from the magnetic group, raises its transformation temperatures, which, following an hypothesis already suggested by Faraday, ought to lie very low." It can indeed be seen that aluminium and tin raise the melting points of various alloys which they form with other metals (the series Al—Au, Al—Sb, Na—Sn), and seem to possess the general property of raising temperatures of transformation.

We might, therefore, expect that vanadium, chromium, and manganese should at very low temperatures exhibit either the characteristics of ferromagnetism (magnetisation not proportional to strength of field, saturation, hysteresis), or, in conformity with Curie's law, a strongly increased paramagnetism. The susceptibility at the temperature of solid hydrogen should be about twenty times as great as at ordinary temperature.‡ At this time we were not yet aware of the results published by H. du Bois and Honda,§ from which it appears that the inverse proportionality of paramagnetism to the absolute temperature is but one of the possible cases. To get an idea of the order of magnitude of the expected phenomena we may suppose that

* See *Verslagen van de Afdeling Natuurkunde der Kon. Akad. van Wetenschappen te Amsterdam*, 26 February, 1910.

† Ch. Ed. Guillaume, *Actes de la Soc. helv. des Sc. nat.*, vol. i., p. 88, 1907.

‡ A similar supposition formed the starting-point of a research by H. Kamerlingh Onnes and A. Perrier, closely connected with the present subject. This investigation was undertaken at the same time as the present research, and will shortly be published. Using the method of the maximum couple and the hydrostatic rise, the magnetisation of liquid oxygen at various temperatures, and of solid oxygen at the temperatures of boiling and solidifying hydrogen were measured. The increase of the magnetisation at low temperatures was found to be very great, though not so much as was expected, and a distinct deviation from Curie's law and a characteristic curve were found.

§ H. du Bois and Honda, *Proc. Kon. Akad. van Wet.*, January, 1910.

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the paramagnetic γ iron still exists at 14° K. (Kelvin degrees) with the same Curie constant (product of absolute temperature by susceptibility). In that case a value of about 400 is found for the magnetisation of this substance in a field of 20,000 gauss.

When we now introduced into our apparatus roughly formed ellipsoids of Moissan vanadium and Goldschmidt chromium and manganese in succession, the awaited change did not appear. In every case the deflection at the temperature of solid hydrogen as well as at that of hydrogen boiling under

atmospheric pressure remained the same as it was at ordinary temperature, that is, to a few tenths of a millimetre, and these must be ascribed to the magnetism of the suspending apparatus. There was therefore no ferromagnetism, and we were obliged to choose between the following two hypotheses for these substances. We were either dealing with paramagnetism of a new kind or with diamagnetism, which is also found in copper, while most of the salts of this metal are paramagnetic. Du Bois and Honda's paper, in which these three metals are classified under those whose para-

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magnetism is invariable or increases with the temperature, shows that the first assumption is the correct one. The behaviour of copper made us consider the other hypothesis a reasonable one.

One could always assume that the paramagnetism, which, as a general rule, is ascribed to the metallic manganese, results from the presence of its oxides, which are strongly magnetic, or of a small quantity of iron. To put this assumption to the proof we prepared very pure manganese from Merck's pure chloride, which had been proved free from iron. The preparation was accomplished by electrolysing the salt between a cathode of distilled mercury and an anode of platinum alloyed with 40 per cent. of rhodium, which is not attacked by the chloridion. The amalgam obtained in this way was separated in a stream of pure, dry hydrogen. In this way a grey powder was obtained which, when compressed in a glass tube as a mould, took the shape of a solid rod. A rod prepared in this manner exhibited paramagnetism. A glass tube with the powdered manganese was also paramagnetic. The same manganese contained in a magnesia boat was thereupon fused in an electric-resistance furnace, and in an atmosphere of hydrogen. In this way an ingot was obtained which was covered with a light oxidised crust. It was found impossible to grind away this crust with quartz powder, since the metal was of the same hardness as quartz. Emery could not be used as it is magnetic. The impure crust was therefore turned off with a diamond tool, and a small cylinder of pure substance was obtained.

This cylinder was found to be ferromagnetic. The accompanying figure gives the hysteresis curve for this substance. The maximum value of the specific magnetisation is 100 times weaker than that of iron, and the coercive field is 670 gauss, that is to say, 10 times as strong as the coercive field of steel which is used for the preparation of good permanent magnets. This peculiar substance seems moreover to have striking magneto-crystalline properties. The rod was strongly attracted between the poles of a magnet and placed itself perpendicular to the field.

Manganese of the same degree of purity can therefore occur in two states : paramagnetic and ferromagnetic.

As regards the ferromagnetism of manganese, this had already been observed by Seckelson* with electrolytic manganese that was liberated at 100° C. from the chloride upon a platinum wire, and with a regulus prepared by Bunsen from manganese fluoride. The very indefinite observations concerning the magnetisation which he published do not contradict with our measurements.

* Seckelson, *Wied. Ann.*, lxxvii., p. 37, 1899.