Physics. - On the Magnetic Susceptibility of Oxygen of low pressure. By E. C. Wiersma, W. J. de Haas and W. H. Capel. (Comm. N ${ }^{0} .215 b$ of the Physical Laboratory of Leiden).
(Communicated at the meeting of April 25, 1931.)
Introduction. The magnetic susceptibility of oxygen has been investigated under different conditions. Perrier and Kamerlingh Onnes ${ }^{1}$ ) studied the magnetic properties of liquid mixtures of oxygen and nitrogen. In these the nitrogen was considered only as a neutral diluting agent necessary to obtain the same density of oxygen at different temperatures. The results of their investigations may be written as follows:

$$
\chi(T+a \varrho)=C,
$$

a special form of the Curie-Weiss law $\chi(T-\theta)=C$, i.e. they found that those mixtures had negative Curie temperatures, the values of which were proportional to the density $\varrho$ of the oxygen. Kamerlingh Onnes and Oosterhuis ${ }^{2}$ ) investigated the susceptibility of gaseous oxygen of about one hundred times the normal density. They found only very small deviations from the Curie law $\chi T=C$, but when they tried the formula $\chi(T+a \varrho)=C$ with the same value for $a$ as found by PERRIER and Onnes, they found that this gave a somewhat better representation of their measurements. In order to decide, whether that formula really holds good for gaseous oxygen in general also, Woltjer, Coppoolse and Wiersma ${ }^{3}$ ) investigated this substance at high densities with a more accurate method ${ }^{4}$ ). The result was, that the formula of Perrier and Onnes is not valid for gaseous oxygen. No $\theta$ proportional to the density could be found, but the simple Curie formula was not followed either. For all densities there occurred a deviation, which reached $1 \%$ at about - $120^{\circ} \mathrm{C}$. The deviation seemed to be independent of density. In these investigations the densities varied from $\varrho=0.152$ to $\varrho=0.443$. We decided to investigate oxygen under low pressure with the apparatus we used recently for the determination of the susceptibility of NO at low temperatures ${ }^{5}$ ), in order to decide whether the same deviations do occur at low densities.

[^0]Method. The apparatus used was the same as that used for NO. The manometer has been replaced by a closed manometer, read by means of a cathetometer. This was necessary as the oxygen could not be measured at pressures of about one atmosphere, as was the case with NO. The force on the bulb would have been too large in that case: the displacements of the point of suspension, necessary when one atmosphere was used, were larger then those allowed by the dimensions of the apparatus. The pressures have been chosen in such a way, that as large a displacement as was possible to measure resulted for each temperature. The oxygen has been specially purified by means of fractionated distillation.

Results. The table gives the values of $\chi$ for three different fields, obtained by putting 30,45 and 60 amperes through the coils of the magnet, divided by the values of $\chi$ for those fields at $249.04^{\circ} \mathrm{K}$. As our purpose was not to make absolute measurements but only relative ones, we used the values, obtained at the highest temperature as the references to which the others were compared. The next column of the table gives the mean of these three values, then this mean multiplied with $T$ and finally this value multiplied with $T+1.7$.

It is clear, that $\chi / \chi_{249.04} \times T$ is not constant. Deviations from the Curie law do occur, and if we extrapolate to $293^{\circ} \mathrm{K}$., we see that the difference between the values at this temperature and $150^{\circ} \mathrm{K}$. is about $1 \%$, i. e. the same value as formerly obtained by WOLTJER, Coppoolse and WIERSMA ${ }^{1}$ ). Figure 1 gives a representation of the values of $\frac{1}{\chi / \chi_{249.04}}$ plotted against $T$. In first approximation it may be said that the substance follows the law $\chi(T-\theta)=C$ with $\theta=-1.7$.

Figure 2 gives the values of $\chi / \chi_{249.04} \times T$ plotted against $T$. It must be remembered, that if the points lie on a straight line in one figure, they do not lie on a straight line in the other figure. In fact the straight line in fig. 1 is given by

$$
\begin{aligned}
& \chi(T-\theta)=C \text {, in fig. } 2 \text { by } \chi T-a T=C, \text { or } \\
& \chi T=C+\theta \chi \text { and } \chi T=C+a T, \text { or again } \\
& \chi T=C+\theta \chi \text { and } \chi T=C+\frac{a}{\chi} .
\end{aligned}
$$

In this case the deviations from both representations are so small as compared with the accuracy of the measurements, that no decision can be made between them. Measurements over a larger range of temperatures would be necessary to decide this.

It may be stated that in this case we did not find such difficulties in the calculations of the densities as in the case of NO, as the equation of state is well known ${ }^{2}$ ).

[^1]

Fig. 1.


Fig. 2.

## Summary.

The susceptibility of $\mathrm{O}_{2}$ at low pressures has been measured. Deviations from Curie's law have been found for these low densities, which agree within the limits of accuracy with those obtained by Woltjer, Coppoolse and Wiersma for gaseous oxygen at high densities. The results do not agree with the results of Perrier and Kamerlingh Onnes for liquid oxygen.

| $T$ | $\chi / \chi_{249.04}$ $\text { at } 30 \mathrm{~A} \text {. }$ | $\begin{aligned} & \chi / \chi_{249.04} \\ & \text { at } 45 \mathrm{~A} . \end{aligned}$ | $\chi / \chi_{249.04}$ $\text { at } 60 \mathrm{~A} \text {. }$ | Mean of $\chi / \chi_{249.04}$ | $\chi / \chi_{249.04} \times T$ | $\chi / \chi_{249.04} \times(T+1.7)$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 249.04 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 249.04 | 250.7 |
| 228.87 | 1.0922 | 1.0895 | 1.0875 | 1.0897 | 249.40 | 251.2 |
| 215.63 | 1.1547 | 1.1508 | 1.1506 | 1.1520 | 248.41 | 250.4 |
| 170.46 | 1.4523 | 1.4543 | 1.4518 | 1.4528 | 247.64 | 250.1 |
| 163.18 | 1.5192 | 1.5176 | 1.5158 | 1.5175 | 247.63 | 250.2 |
| 156.82 | 1.5791 | 1.5786 | (1.5684) | 1.5789 | 247.60 | 250.3 |
| 149.85 | 1.6487 | 1.6463 | 1.6453 | 1.6468 | 246.77 | 249.6 |
| 142.86 | 1.7277 | 1.7273 | 1.7240 | 1.7263 | 246.62 | 249.6 |
| 111.43 | 2.2235 | 2.2150 | 2.2137 | 2.2174 | 247.08 | 250.8 |
| 104.82 | 2.3621 | 2.3510 | 2.3563 | 2.3565 | 247.01 | 251.0 |
| 97.79 | 2.5249 | 2.5160 | 2.5161 | 2.5190 | 246.33 | 250.6 |
| 77.56*) | 3.1843 | 3.1950 | 3.1980 | 3.1924 | 247.60 | 253.0 |


[^0]:    ${ }^{1}$ ) A. Perrier and H. Kamerlingh Onnes, These Proceedings 16, 901, 1914. Comm. Leiden $\mathrm{N}^{0}$. 139d.
    ${ }^{2}$ ) H. Kamerlingh Onnes and E. Oosterhuis, These Proceedings 15, 1404, 1913. Comm. Leiden ${ }^{\circ}{ }^{0}$. 134 d.
    ${ }^{3}$ ) H. R. Woltjer, C. W. Coppoolse and E. C. Wiersma, These Proceedings 32, 1329. 1929. Comm. Leiden No. 201d.
    ${ }^{4}$ ) E. C. Wiersma and H. R. Wolijer, These Proceedings 32, 1046, 1929. Comm. Leiden $\mathrm{N}^{0}$. 201c.
    5) E. C. Wiersma, W. J. de Haas and W. H. Capel, These Proceedings 33, 1119, 1930, Comm. Leiden No. $212 b$.

[^1]:    ${ }^{1}$ ) H. R. Woltjer, C. W. Coppoolse and E. C. Wiersma, These Proceedings 32, 1329. 1929. Comm. Leiden No. 201 d.
    ${ }^{2}$ ) G. P. Nijhoff and W. H. Keesom. These Proceedings 28, 963, 1925. Comm. Leiden $\mathrm{N}^{0} .179 b$.

