THE MAGNETIC SUSCEPTIBILITY OF OXYGEN, HYDROGEN AND HELIUM

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Abstract

The method used was that of balancing the gas magnetically against an aqueous solution of nickel chloride. By varying the concentration of the solution it could be given a susceptibility approximately the same as that of the gas; then by varying the pressure of the gas or the temperature of the gas and solution, both could be given the same susceptibility. A *manometric balance of great sensitivity* enabled the observer to tell when the susceptibilities of the gas and the solution were the same. For both paramagnetic and diamagnetic gases, formulas are derived from which the susceptibility may be calculated from pressure and temperature observations on the gas when it is magnetically neutral against the solution. The volume susceptibility under a pressure of one atmosphere at the temperature 20°C was found to be $+0.1447 \times 10^{-6}$ for oxygen; -1.64×10^{-10} for hydrogen, and -0.81×10^{-10} for helium. The result found for helium is about 25 times less than Tänzler's value, but when substituted in the formula derived by W. Pauli Jr. for the diamagnetic susceptibility of a monatomic gas, it yields a result bearing on the dimensions of the atom which is compatible with our knowledge obtained from other sources.

S EVERAL papers have been published dealing with the magnetic properties of one or more of the gases oxygen, hydrogen and helium, but the results obtained by a considerable number of observers are not in as close agreement as is desirable. It was thought worth while, therefore, when the opportunity[1] presented itself to undertake further research on the magnetic properties of these gases.

The method used in the present investigation consists in balancing the gas magnetically against a liquid of known susceptibility by varying either the pressure of the gas or the common temperature. The device used for this purpose was a manometric balance.

The Manometric Balance

A diagrammatic sketch of the device is shown in Fig. 1. Here, A is a cylindrical metal container with a cover B. Inside the container is a cylindrical glass vessel C, connected to which is a glass tube D, which passes through the bottom of the container and is then bent as shown. The gas inlet E to the container is shown on the left. Opposite the inlet

[1] The appointment of the senior writer as Ernest Kempton Adams fellow enabled him to secure the collaboration of Mr. Hector.

there is a hole through the wall of the container through which passes a
glass tube F of small bore. After being bent as shown this tube is con-
stricted at G and then joined with the tube D.

The angular region between the vessel C and the container A is filled
with cement up to the neck of the vessel; and the tube F where it passes
through the container is firmly cemented to it. The cover B of the con-
tainer is secured in place by screws, and a gasket between cover and
container ensures that no gas escape between them. Through the center
of the cover there is screwed a hollow insert plug H with a contracted
opening at the top to admit connection by means of small copper tubing
to a manometer. Upon removal of the plug the liquid can be conveniently
introduced into the vessel C.

After the liquid is introduced and before the manometer opening is
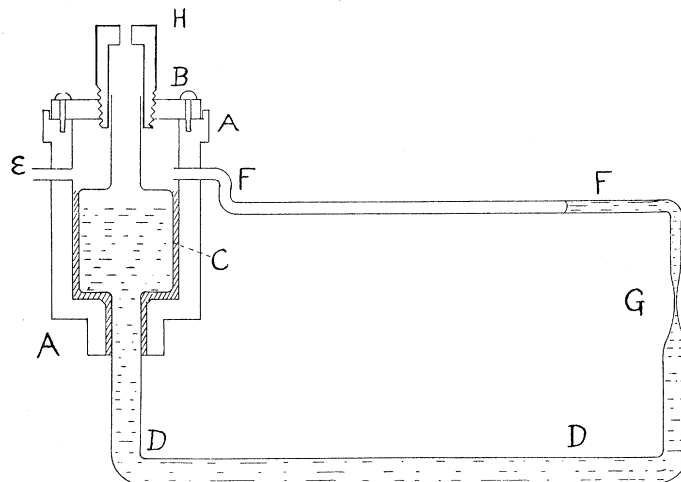closed the gas to be investigated is allowed to flow through the device

Fig. 1. Manometric balance.

until the air has been thoroughly flushed out. Then the manometer
opening is closed and the device arranged so as to bring the meniscus in
the tube F between the poles of a powerful electromagnet. When the
device is properly adjusted the tube F is very nearly horizontal, which
is the position for maximum sensitivity.

The motion of the meniscus in the tube F one way or the other when
the magnet is excited enables the observer to decide whether the gas is
more magnetic or less magnetic than the liquid. To detect very small
motions a microscope is used. This is focussed upon a colloidal particle
of gum-mastic suspended in the liquid at the point of contraction G of
the tube F. At this point the movement of the liquid is much greater

than in the unconstricted portion of the tube and the observer may esti-
mate with remarkable nicety the magnetic equality of gas and liquid.

Auxiliary Apparatus. A purifying tube for the gas was introduced
between the supply tank and the balance; likewise a temperature regu-
lation coil, this coil being placed in a water bath at room temperature.

A thermostat served to regulate the room temperature.

An ordinary mercury manometer was used to measure the gas pres-
sures when the latter did not exceed two atmospheres. For greater
pressures a mercury manometer specially designed for the purpose was
used. This was capable of measuring with great accuracy pressures as
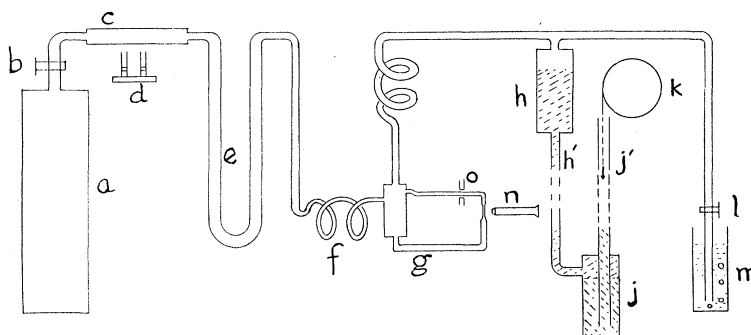high as 26 atmospheres.

Fig. 2.   General diagram of apparatus.

a Gas tank	h' Kerosene tube
b Throttle	j Mercury cistern
c Purifying tube	j' Mercury tube
d Bunsen burners	k Iron wheel
e Drying tube	l Outlet valve
f Cooling coil	m Water bottle
g Balance	n Microscope
h Kerosene reservoir	o Magnet poles

Referring to the general diagram given in Fig. 2, the steel manometer
tube *j'* was about 25 meters long with an approximate bore of 0.5 cm.
The cylindrical kerosene reservoir *h* was about 30 cm long with an
approximate bore of 7 cm; and the mercury reservoir *h* has approximately
the same dimensions.

The iron wheel *k* is mounted upon a fixed axle. The face of this wheel
is threaded with 20 threads to the inch. One end of a fine flexible silk
covered wire is attached to the first thread of the wheel and then wound
between the threads around the face of the wheel. The other end of the
wire is attached to a metal sounding bob with a fine point. Insulation
around the bob prevents it from touching the walls of the manometer
tube; but when the bob is lowered until its point comes in contact with

the mercury column it completes an electric circuit containing a bell which announces the contact. The fixed axle supporting the wheel is threaded and likewise the hole in the hub of the wheel through which the axle passes, so that as the wheel turns and advances along the fixed axle the wire which carries the bob is always in line with the axis of the manometer tube. The diameter of the wheel is such that one turn of the wheel causes the bob to rise, or fall, one meter approximately. One edge of the face of the wheel is indexed. A fractional turn of the wheel corresponding to an elevation or depression of the bob of one half millimeter could be estimated with precision.

The pressure of the gas is communicated to the mercury in the reservoir j through the kerosene in the reservoir h and the connecting tube h'.

THEORY OF THE METHOD

Under the conditions of experiment the gas and liquid in the manometric balance constitute a system in thermal and magnetic equilibrium, assuming the adjustment to equality of the volume susceptibilities of the gas and liquid to have been made.

The liquid used was in all cases an aqueous solution of nickel chloride.

In accordance with Wiederman's law if m and χ denote respectively mass and magnetic susceptiblity per unit mass and if the subscripts l, w, s refer respectively to solution, water and salt:

$$m_l\chi_l = m_w\chi_w + m_s\chi_s. \tag{1}$$

Let R denote the ratio m_w/m_s; then since $m_l = m_w + m_s$ this equation may be written:

$$\chi_l = (R\chi_w + \chi_s)/(1+R); \tag{2}$$

or, if R_0 denote the value of R which makes $\chi_l = 0$:

$$\chi_l = [(R-R_0)/(1+R)]\,\chi_w. \tag{3}$$

The solutions were obtained by mixing water with a mother solution of nickel chloride. For the concentrations used it was found that the density of the solution could be calculated with adequate precision on the assumption of no change of volume of the constituents upon mixing, from the formula:

$$\rho_l = [(1+R)/(1+R-K)]\,\rho_w, \tag{4}$$

where:

$$K = (1-\rho_w/\rho_c)\,m_c/m_s, \tag{5}$$

ρ denoting density and the subscript c referring to the mother solution.

If volume susceptibility be denoted by κ, then $\kappa_l = \rho_l\chi_l$ and from (3) and (4) we obtain:

$$\kappa_l = [\rho_w\,(R-R_0)/(1+R-K)]\,\chi_w. \tag{6}$$

It is possible through elimination of R from this expression with the aid

of (4) to express κ_l as a linear function of ρ_l and of quantities which are constant at a given temperature. It thus appears that $d\kappa_l/d\rho_l$ is constant for an isothermal change in the state of the solution.

Equations for a paramagnetic gas in contact with a solution. Under the conditions of experiment the gas was of necessity always contaminated with water vapor. When a magnetic balance obtains for the gas and solution it is therefore the sum of the volume susceptibilities of the gas and vapor which is equal to the volume susceptibility of the solution. But even if the vapor be supposed saturated the susceptibility of the vapor is negligibly small in comparison with that of a paramagnetic gas at normal pressure or greater. The pressure of the gas, which will be denoted by p will not, however, be the same as the observed pressure, which will be denoted by P. But we may assume that the partial pressure due to the vapor is constant for an isothermal change and write $dp = dP$ for such a change.

For a paramagnetic gas:

$$\kappa = ap, \tag{7}$$

where:

$$a = [\theta_0^2/p_0\theta^2]\,\kappa_0, \tag{8}$$

κ denoting its volume susceptibility at pressure p and temperature θ and κ_0 its volume susceptibility for the standard pressure p_0 and the standard temperature θ_0.

Now, supposing gas and liquid to be in magnetic equilibrium, since for a change at constant temperature $d\kappa_l/d\rho_l$ is constant, as pointed out above, and since from (7) $d\kappa/dp$ is also constant it follows that for an isothermal change in the state of the system:

$$d\rho_l/dp = d\rho_l/dP = A, \tag{9}$$

where A is a constant.

From (6) and (7):

$$ap = [\rho_w(R - R_0)/(1 + R - K)]\,\chi_w. \tag{10}$$

Upon differentiation of this expression, assuming an isothermal change, and taking (4) and (9) into account we obtain:

$$a = -[A(1 + R_0 - K)/K]\,\chi_w. \tag{11}$$

Again assuming an isothermal change and taking P as independent variable we obtain upon differentiation of (4) and taking (9) into account:

$$A = -[\rho_w K/(1 + R - K)^2]\,dR/dP,$$

which upon integration gives:

$$K/(1 + R - K) = AP/\rho_w + 1/a, \tag{12}$$

where $1/a$ is a constant of integration.

Now when $R = R_0$ we must have $P = 0$ and hence:

$$K/(1 + R_0 - K) = 1/a, \tag{13}$$

a formula from which R_0 may be found after a is known.

From (8) and (11) and (13) we now find the working formula for a paramagnetic gas:

$$\kappa_0 = aA \frac{p_0 \theta^2}{\theta_0{}^2} \chi_w. \tag{14}$$

The constant A is found from two observations at the same temperature of the density ρ_l and the corresponding pressure P in accordance with (9); and the constant a is determined from (12) by an observation of the equilibrium pressure P corresponding to a solution having the known ratio R, the constant K being also known.

Equations for a diamagnetic gas in contact with a solution. In the experimental determination of the susceptibility of a diamagnetic gas the most convenient method was found to be one which utilized the property of the solution of changing its susceptibility with temperature.

The procedure was to vary the common temperature of the gas and solution a small amount $\Delta\theta$, thus disturbing the magnetic equilibrium of the gas and solution, and then to change the pressure by an amount ΔP so that equilibrium was again established.

Neglecting the very small change in the susceptibility of the water vapor contained in the gas and also the small change in the susceptibility of the gas due to the small change of temperature we have:

$$\frac{\partial \kappa}{\partial P} \Delta P = \frac{\partial \kappa_l}{\partial \theta} \Delta\theta. \tag{15}$$

For a diamagnetic gas:

$$\kappa = (p\theta_0/p_0\theta)\, \kappa_0. \tag{16}$$

By differentiation of this expression we obtain:

$$\partial\kappa/\partial p = \partial\kappa/\partial P = (\theta_0/p_0\theta)\, \kappa_0. \tag{17}$$

By differentiation of (6), neglecting the small change in ρ_w and noting that χ_w, R and K are not dependent on the temperature we find:

$$\frac{\partial \kappa_l}{\partial \theta} = -\left[\rho_w \frac{dR_0}{d\theta} \Big/ (1+R-K)\right] \chi_w. \tag{18}$$

We now obtain from (15) (17) and (18) the working formula for a diamagnetic gas:

$$\kappa_0 = -\frac{dR_0}{d\theta} \frac{\Delta\theta}{\Delta P} \frac{p_0\theta}{\theta_0} \frac{\rho_w}{1+R-K} \chi_w. \tag{19}$$

The quantity $dR_0/d\theta$ was determined in the course of the experiments on oxygen and $\Delta\theta/\Delta P$ was determined by experiments on the diamagnetic gas in question with the manometric balance.

OXYGEN

The gas was prepared electrolytically from a solution of caustic soda. According to the analysis furnished by the company making the gas it

contained 99.6 to 99.7 per cent oxygen with traces of hydrogen, water-vapor and caustic soda.

Before the gas was introduced into the manometric balance it was passed through a hot paladium sponge, causing the hydrogen to combine with oxygen to form water vapor. Errors due to the presence of water-vapor were avoided as pointed out in the theoretical discussion above.

Chemical analysis of the mother solution from which the solutions used in the experiments were prepared by mixing with water showed it to contain 0.20681 of nickel chloride per gram of solution, with impurities amounting to 0.08, of which cobalt was doubtless the most important. From this result the value of the constant K was calculated to be 0.88102.

After the solution had been introduced into the balance the gas was allowed to flow steadily through the device for several hours to make sure that all air was flushed out.

In the final series of experiments four solutions of different densities were used. Experiments were made on each solution at a temperature closely approximating 296° K in each case, to determine the pressure of the gas when magnetically neutral against the solution. In the following table the results are given, the numbers under P representing pressures expressed in mm of mercury at 0° C.

TABLE I

	Solution 1		Solution 2		Solution 3		Solution 4	
	$R = 29.334$		$R = 21.452$		$R = 17.004$		$R = 12.919$	
	$\rho l = 1.02744$		$\rho l = 1.03834$		$\rho l = 1.04893$		$\rho l = 1.06501$	
	θ	P	θ	P	θ	P	θ	P
	296.13°K	2321	296.20°K	4579	296.20°K	6764	296.10°K	10088
	296.20	2324	296.00	4575	296.10	6764	296.05	10085
	295.84	2322	295.90	4569	295.90	6759	296.05	10082
	295.91	2315	296.00	4573	296.10	6763	296.06	10085
Mean	296.02	2320	296.02	4574	296.07	6762	296.06	10085

From the data here given six values are obtained for the constant A ($=d\rho/dP$) and also, with the aid of (12) four values for the constant a. The mean values are as follows at 296.04° K:

$$A = (4.838 \pm 0.001) \times 10^{-6}$$
$$a = (53.593 \pm 0.004) \times 10^{-6}$$

Collecting the additional data required in (14) for the calculation of the volume susceptibility of oxygen under the standard pressure p_0 and at the standard temperature θ_0 we have:

$$\theta = 296.04° \text{ K,} \qquad\qquad p_0 = 760 \text{ mm,}$$
$$\theta_0 = 293.10° \text{ K,} \qquad\qquad \chi_w = -0.720 \times 10^{-6}.$$

The value here given for χ_w, the mass susceptibility of water, is that now commonly accepted; it is probably correct to within one half per cent.

Inserting these values in formula (14) and performing the numerical calculations we find:

$$\kappa_0 = 0.1447 \times 10^{-6}$$

for the volume susceptiblity of oxygen under a pressure of one atmosphere at a temperature of 20° C.

Susceptibility determinations on oxygen at different temperatures. The following results were obtained on two solutions:

Temperature	SOLUTION 1 ($R = 28.676$)		SOLUTION 2 ($R = 12.967$)	
	P	ρ_e	P	ρ_e
285.80°K	2472	1.03002	9729	1.06673
290.10	2464	1.02936	9879	1.06604
293.63	2457	1.02866	9962	1.06532
296.55	2454	1.02798	10048	1.06461

From these data, with the aid of formulas (12) (13) and (14), the results given in Table II were calculated, with the exception of those given in the last column, which were calculated from the value 0.14475×10^{-6} found above for the volume susceptibility of oxygen under a pressure of one atmosphere at the temperature 20° C, it being assumed in this calculation that the susceptibility varies inversely as the square of the absolute temperature in accordance with Langevin's theory for a paramagnetic gas. The symbol κ_1, heading the last two columns denotes volume susceptibility at a pressure of one atmosphere.

TABLE II

Temperature	$\Delta\rho_1/\Delta P \times 10^6$	R_0	$R_0\theta$	$\kappa_1(obs.) \times 10^6$	$\kappa_1(calc.) \times 10^6$
285.80°K	5.0586	48.602	13890	0.1530	0.1522
290.10	4.9467	47.775	13860	0.1472	0.1478
293.63	4.8848	47.320	13890	0.1439	0.1442
296.55	4.8235	46.914	13910	0.1409	0.1414

The rather large differences between corresponding values of κ_1 (obs.) and κ_1 (calc.) are probably to be accounted for by small errors in the determinations of the temperatures of the gas.

The constancy of the numbers under the caption $R_0\theta$ justify, to within the errors of the present series of experiments, the assumption of the validity of Curie's law for paramagnetism in the case of nickel chloride for the temperature range of the present experiments.

HYDROGEN

Hydrogen gas is diamagnetic and, moreover, its susceptibility even under high pressure is very small. In magnetic quality, therefore, it differs little from a vacuum, and it is evident that a liquid which is magnetically neutral against hydrogen will have a value for the quantity R which differs little from R_0. It is difficult, therefore, to make, at a given temperature, a solution of a paramagnetic salt in water which can

be magnetically balanced against hydrogen gas, unless the gas can be subjected to very great pressure. It is easier to make a solution which has somewhere near the susceptibility of the gas and then to bring liquid and gas to magnetic neutrality through the variation of temperature, this procedure being possible since the rates of variation of susceptibility with temperature are very different for the liquid and the gas.

The temperature variations necessary are not great, in fact, in the experiments described below they were always less than 1° C.

The appropriate formula for the calculation of the volume susceptibility of hydrogen under standard pressure and at standard temperature is formula (19). In this formula the quantity R may be replaced by R_0 without introducing appreciable error, since hydrogen differs little from a vacuum in magnetic quality. The values of R_0 and of $dR_0/d\theta$ for the temperatures at which the experiments on hydrogen and helium were performed are found on the assumption that $R_0\theta = $ constant, the value of the constant being taken as 13890 which is the mean of the values under $R_0\theta$ in Table 2. The values of R_0 and of $dR_0/d\theta$ so found are given later in the collected data for hydrogen and for helium.

The experiments on hydrogen have therefore to furnish only the value of the quantity $\Delta\theta/\Delta P$.

To determine this quantity two similar series of experiments were carried out.

An approximately neutral solution of nickel chloride in pure water was made up. This solution could be made slightly magnetic, or diamagnetic, through decrease, or increase, of the temperature by a few degrees. In the series of experiments under consideration the actual procedure was as follows.

The temperature of the room was raised until, by means of the magnetic balance, it was found that the gas under a given pressure was magnetically neutral against the solution; then the pressure of the gas was changed by a considerable amount and the temperature of the room varied until the gas was again neutral against the solution under the new pressure. The increases of pressure and temperature here mentioned are what we have denoted above by ΔP and $\Delta\theta$ respectively. The value of the quotient $\Delta\theta/\Delta P$ required for the calculation of κ_0 by formula (19) was thus determined.

In each of the two series, four observations were made at slightly different temperatures of the pressure and temperature corresponding to magnetic neutrality of gas and solution. The results are given in Table III. The temperature variations were measured by a thermocouple one of whose junctions was in contact with the tube of the magnetic balance

containing the meniscus separating the gas and liquid, the other junction being in melting ice. By calibration against an air thermometer the galvanometer through which the current from the thermocouple passed was found to give a deflection of one scale division for a change in temperature of 0.858°C.

In the first column of the table are found the galvanometer readings corresponding to magnetic neutrality of the gas against the solution; in the second, the corresponding temperatures computed from the data of the first column with the aid of the galvanometer constant; in the third, the readings in pounds of a pressure gauge connected to the supply tank of hydrogen; in the fourth, the actual pressures of the gas expressed in millimeters of mercury, obtained from the data of the third column after calibration of the pressure gauge against a mercury manometer.

TABLE III

Series 1	Gal. defl.	Temperature	Pressure	
1	54.470	303.570°K	28lb	1946 mm
2	.230	.776	80	4600
3	53.880	304.077	145	7980
4	.530	.378	210	11330
Series 2				
5	54.363	304.441	65	3840
6	.098	.668	110	6130
7	53.830	.898	160	8750
8	.570	305.121	210	11330

Mean temperature $=304.36°$K

From the data of series 1 six values for $\Delta\theta/\Delta P$ are obtained and weighted, the weight 1 being assigned the values obtained from 1 and 2, 2 and 3, 3 and 4; and the weight 2 to those obtained from 1 and 3, 2 and 4; and the weight 3 to the value obtained from 1 and 4. The same procedure was followed with the observations for series 2.

The weighted mean values so found are:

$$\Delta\theta/\Delta P = 86.2 \times 10^{-5} \text{ for series 1,}$$
$$\Delta\theta/\Delta P = 90.7 \times 10^{-5} \text{ for series 2.}$$

Taking the mean of these two results we find:

$$\Delta\theta/\Delta P = 88.5 \times 10^{-5}$$

The necessary data for the calculation of the volume susceptibility of hydrogen from (19) are collected below:

$p_0 = 760$ $dR_0/d\theta = 0.1505$

$\theta_0 = 293.1$ $\theta = 304.36$

$\rho_w = 0.99528$ $\Delta\theta/\Delta P = 8.85 \times 10^{-5}$

$R_0 = 45.814$ $\chi_w = 0.720 \times 10^{-6}$

After inserting these values in the above formula for κ_o it is found that:

$$\kappa_o = -1.64 \times 10^{-10}$$

for hydrogen under a pressure of one atmosphere at the temperature 20°C.

Soné[2] using an entirely different method arrived at the value -1.659×10^{-10} for the same standard conditions.

HELIUM

Some preliminary experiments were made on helium, but circumstances compelled the discontinuance for a time of the experiments on this gas before data which could be considered quite satisfactory were obtained. The results given below are therefore to be considered in a measure as tentative.

The helium as furnished contained about 8 per cent of nitrogen. This impurity was removed by passing the gas over hot magnesium which at the same time served to remove any traces of oxygen.

Before the introduction of the helium gas into the measuring apparatus, the latter was flushed out with hydrogen, which was allowed to flow through the apparatus for about four hours to ensure that every trace of air was removed. Then the helium gas was allowed to flow through the apparatus for about one hour before the measurements were begun.

The data obtained for helium in one series of experiments are contained in Table IV which is quite analogous to Table III for hydrogen and the explanation given above for Table III applies equally well to Table IV.

TABLE IV

	Gal. defl.	Temperature	Pressure	
1	52.030	302.200°K	20lb	1420 mm
2	51.783	.412	115	6380
3	.520	.638	213	11500
		Mean temperature = 302.42°K		

Treating these observations in a manner quite analogous to that used in the case of hydrogen we obtain three values for $\Delta\theta/\Delta P$ from which after weighting and taking the mean value we find:

$$\Delta\theta/\Delta P = 4.35 \times 10^{-5},$$

with a mean deviation for the three values of 0.05×10^{-5}.

The data required for the calculation of the volume susceptibility of helium from formula (19) are collected below:

$p_0 = 760$ $dR_0/d\theta = 0.1524$
$\theta_0 = 293.10°K$ $\theta = 302.42°K$
$\rho_w = 0.99600$ $\Delta\theta/\Delta P = 4.35 \times 10^{-5}$
$R_0 = 46.110$ $\chi_w = 0.720 \times 10^{-6}$

Inserting the values here given in formula (19) we obtain:

$$\kappa_0 = -0.807 \times 10^{-10}$$

for helium under a pressure of one atmosphere at a temperature of 20°C.

[2] Také Soné, Phil. Mag. **39**, 305, 1920

The susceptibility of helium thus appears to be almost exactly one-half of that of hydrogen under the same standard conditions.

The only other determination for the susceptibility of helium known to the writers is that made by Tänzler.[3] The measurements of Tänzler were relative. Assuming the susceptibility of oxygen to be $+0.123 \times 10^{-6}$ at $0°$ C under a pressure of one atmosphere, he found the volume susceptibility of helium under these conditions to be -17.5×10^{-10}. Using the value for oxygen found by us above, the susceptibility of oxygen at $0°$ C under a pressure of one atmosphere is found to be $+0.167 \times 10^{-6}$ and on the basis of this value Tänzler's result for helium would be -23.7×10^{-10} at $0°$ C or -22.1×10^{-10} at $20°$ C under a pressure of one atmosphere. This result is about 27 times the value found by us for the susceptibility of helium under the same standard conditions. The discrepancy between Tänzler's results and our own is certainly very great.

In this connection a paper by W. Pauli, Jr.[4] is of considerable interest. In accordance with the theory of Pauli for a diamagnetic monatomic gas, if R denote the distance of an electron in an atom from the nucleus and if $\Theta = \Sigma e R^2$, where the summation is over all the electrons in the atom, then:

$$\Theta = 1.68 \times 10^{-20} \chi_A,$$

where χ_A denotes the atomic susceptibility obtained from the volume susceptibility at $0°$ C and 760 mm pressure through multiplication by the mol-volume (22.4×10^3).

From the value of the volume susceptibility for helium found by us above we obtain for the volume susceptibility at $0°$ C and 760 mm pressure the value 0.866×10^{-10}; hence

$$\chi_A = 0.866 \times 10^{-10} \times 22.4 \times 10^3 = 1.94 \times 10^{-6},$$
$$\Theta = 1.68 \times 10^{-20} \chi_A = 3.26 \times 10^{-26}.$$

From our knowledge of the order of magnitude of atomic dimensions from other sources, this value for Θ is reasonable. Tänzler's value for the susceptibility of helium leads, on the other hand, to a value of Θ which is far too great.

DEPARTMENT OF PHYSICS,
    COLUMBIA UNIVERSITY,
        June 27, 1923.

[3] Tänzler, Ann. der Phys. **24,** 931, 1907
[4] W. Pauli, Jr., Zeit. f. Phys. **2,** 201, 1920