

The Magnetic Susceptibilities of Some Common Gases

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The Faraday test body method, which had been developed and used by the author for finding the magnetic susceptibility of NO_2 , has been applied to the measurement of the magnetic susceptibilities of several common gases at room and at liquid air temperatures. The following values $\times 10^6$ were obtained for the molecular susceptibilities: $\chi(\text{H}_2) = -4.0051$, $\chi(\text{He}) = -1.906$, $\chi(\text{Ne}) = -7.651$, $\chi(\text{A}) = -19.23$, $\chi(\text{CO}_2) = -20.88$, $\chi(\text{N}_2) = -11.938$ at room temperatures, and $\chi(\text{H}_2) = -3.98$, $\chi(\text{He}) = -1.91$, $\chi(\text{Ne})$

$= -7.64$, $\chi(\text{A}) = -19.8$, $\chi(\text{O}_2) = 11830$ at liquid air temperatures. These values are based on the provisional value of $\chi(\text{O}_2) = 3335 \times 10^{-6}$ at 20°C . The results show that the diamagnetic susceptibilities do not vary, within the experimental error, in going from room to liquid air temperatures. This is contrary to the 40 percent change observed for hydrogen by Bitter. The susceptibility of oxygen was found to follow Curie's law to within 2 percent.

INTRODUCTION

THIS series of experiments was undertaken with the hope of furnishing more accurate values for the magnetic susceptibilities of some of the more common gases which could be used for comparison with existing and future theoretical calculations. At present the agreement between the theoretical and experimental results is none too satisfactory, mainly because of the large variations among the results of different experimental observers. For example, the results of several observers for the molecular susceptibility of hydrogen range from -3.3×10^{-6} to -5.8×10^{-6} ; similar differences exist for other gases. In many cases it is hard to select the experimental result which is the most reliable. It seemed necessary, in order to obtain results which could be fully relied upon, to measure susceptibilities far more accurately than had hitherto been done. The apparatus used by the writer¹ had the merits of high sensitivity, freedom from troublesome electrostatic effects, of being very little affected by external changes of conditions, and it could be used for work at liquid air temperatures.

Several theoretical values are now available for comparison with experiment. Wang's² theoretical calculation, as later corrected by Van Vleck,³ indicates that $\chi(\text{H}_2) = -4.20 \times 10^{-6}$ should be correct to within 5 percent for the molecular sus-

ceptibility of hydrogen. Mrowka's⁴ recent calculation indicates nearly the same theoretical value. Slater⁵ and Stoner⁶ have calculated the susceptibility of helium, obtaining $\chi(\text{He}) = -1.85$ and -1.90×10^{-6} , respectively. A recent, but probably less accurate calculation has been made by Vinti,⁷ who obtains $\chi(\text{He}) = -2.09 \times 10^{-6}$. Vinti⁷ also obtains a value of $\chi(\text{Ne}) = -7.5 \times 10^{-6}$ for neon.

APPARATUS AND PROCEDURE

If a solid is suspended in a nonhomogeneous magnetic field, a torque is exerted by the field on each element of volume of the solid, which is proportional to the magnetic field strength, its directional derivative, and the difference between the volume susceptibility of the solid and that of the surrounding medium. Based on these facts, a method, known as the Faraday test body method, has been used and developed by Glaser,⁸ Hammar,⁹ Vaidyanathan,¹⁰ Bitter,¹¹ and others whereby the torque on the solid due to changing the surrounding medium is measured. In a previous article¹ the writer describes several improvements he had made in the measuring ap-

⁴ Mrowka, *Zeits. f. Physik* **80**, 495 (1933).

⁵ Slater, *Phys. Rev.* **32**, 349 (1928).

⁶ Stoner, *Proc. Leeds Phil. Soc.* **1**, 484 (1929).

⁷ Vinti, *Phys. Rev.* **41**, 813 (1932).

⁸ Glaser, *Ann. d. Physik* **75**, 459 (1924).

⁹ Hammar, *Proc. Nat. Acad. Sci.* **12**, 594 (1926).

¹⁰ Vaidyanathan, *Phil. Mag.* **5**, 380 (1928); *Ind. J. Phys.* **1**, 183 (1926-27).

¹¹ Bitter, *Phys. Rev.* **35**, 1572 (1930).

¹ Glenn G. Havens, *Phys. Rev.* **41**, 337 (1932).

² Wang, *Nat. Acad. Sci. Proc.* **13**, 798 (1927).

³ Van Vleck, *Nat. Acad. Sci. Proc.* **15**, 539 (1929).

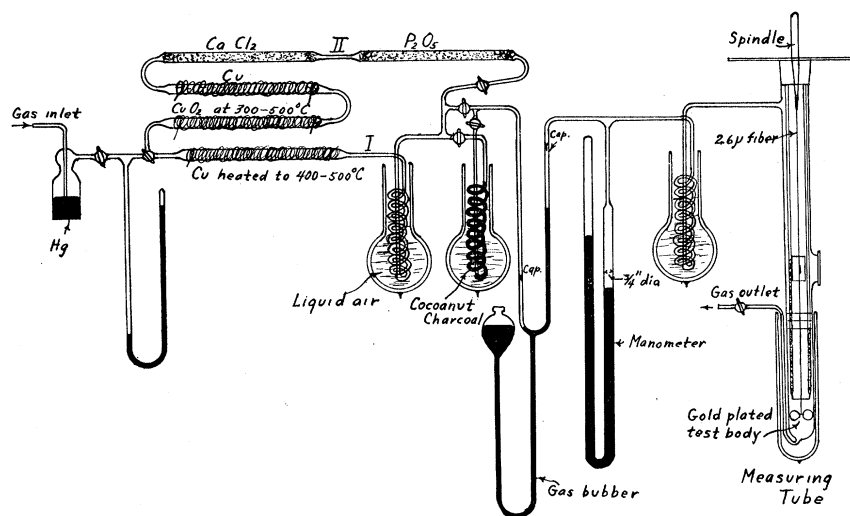


FIG. 1. Purifying and measuring apparatus.

paratus employed in the above method. The measuring apparatus has since been modified for liquid air measurements by surrounding the lower part of the tube with a Dewar flask. The flask also served to reduce the temperature variations around the test body at room temperatures.

The gas purifying apparatus is shown in Fig. 1. Hydrogen, helium, neon, and argon were all purified by being passed through arrangement I, the coil containing coconut charcoal, the mercury bubbler, and finally through a long spiral coil surrounded by liquid air. The bubbler was constructed to facilitate the accurate control of the rate of flow of gas into the measuring chamber and for maintaining a pressure slightly in excess of one atmosphere in the purifying tubes. This eliminated any chance of contamination of the gas by the development of small leaks in the stopcocks or glassware. The gas which entered the measuring chamber was freed from mercury and other vapors by the final coil in liquid air. Nitrogen was purified by the same procedure, except that it was not sent through the coconut charcoal. Carbon dioxide, which could be passed through neither the coconut charcoal nor the liquid air because of its high freezing point, was passed over P_2O_5 for the removal of water vapor. Oxygen was passed through the arrangement II and the coils in liquid air but not through the coconut charcoal.

The temperature of the measuring tube was

maintained constant for measurements at room temperatures by controlling the temperature of the magnet and surrounding room. A mercury thermostat connected to the grid of a Thyatron tube controlled the heat input into the room, while a fan circulated the air. The temperature of the distilled water, which was used for cooling the magnet, was controlled by a similar Thyatron arrangement. Temperatures could be maintained constant, by these arrangements, to within a tenth of a degree.

Preliminary to starting a series of measurements, the entire system was evacuated to a pressure less than 0.1 mm of Hg and the charcoal baked out at temperatures between 400 and 500°C for a period of about twenty minutes, and while still hot, the gas to be measured was flushed through it. The coil containing the charcoal was then surrounded by liquid air, the measuring instrument was reevacuated and flushed out with the gas going through the cold charcoal. Finally, the purifying system was filled, as far as the bubbler, to a pressure slightly in excess of one atmosphere. The magnetic field was then excited and the temperature controls were allowed to operate about two hours before any measurements were begun so as to allow the system to come to a steady condition. Most of the susceptibility determinations were taken with a magnetic field strength of about 7500 gauss, although some were made with weaker fields.

After steady conditions were obtained, the torsion fiber was twisted by turning the torsion head until the test body was in the position of required sensitivity. The position of the test body was observed by means of an optical lever having a ten meter light path. For the most accurate measurements, sensitivities were used such that one mm change in pressure of hydrogen would produce a deflection of from 2 to 5 cm of the light spot on the scale of the optical lever. After gas was let into the tube the fiber was twisted until the light beam of the optical lever returned to its original position.

The torque on a test body placed in a magnetic field and surrounded by a vacuum is given by¹²

$$T = (k_s/2)(1 + 4\pi k_s) \int [\nabla H^2, r] d\tau,$$

where k_s is the volume susceptibility of the solid, H is the magnetic field strength, r is the radius vector about the axis for which the torque is taken, and the integration is to be taken over the entire volume of the test body. If the test body is surrounded by a gas of volume susceptibility k_g , k_s is replaced in this formula by $k_s - k_g$. The k 's used in this experiment were always less than 10^{-5} , we can therefore neglect the squared terms in k and write:

$$T = (k_s - k_g)A,$$

where A is a constant for a given test body in a given position in the magnetic field. If the pressure of the gas is changed we have:

$$\Delta T = -\Delta k_g A.$$

If k_x is the volume susceptibility of an unknown gas and k_s refers to the known gas:

$$k_x = (\Delta T_x / \Delta T_s) k_s = [(dT_x / dp) / (dT_s / dp)] \cdot k_s.$$

Thus the volume susceptibilities are proportional to the change in torques which are in turn proportional to the angles through which the suspending fiber is twisted.

Errors due to inaccurate centering

The torque on a test body due to a nonhomogeneous magnetic field varies linearly with the

¹² M. Mason and W. Weaver, *The Electromagnetic Field*, p. 218.

pressure of the surrounding gas, if the test body remains fixed relative to the field. However, unless the suspending fiber is perfectly centered at its upper end, this condition is never satisfied experimentally. If, as in the present experiment, a null method is used, as the torsion head is turned the test body will be translated around the circumference of a circle, the radius of which will depend on the accuracy of the centering; a torque will be introduced by this translation which varies, to a good approximation for small circles, as a sine function of the position of the torsion head. As an example of the magnitude of this torque, for the case of a 2.6μ fiber centered to within a radius of 10μ the test body has been observed to rotate in a direction opposite to that of the twisted fiber showing that the torque introduced by translation was larger and opposite to that produced by the twisting of the fiber.

If the fiber used is so large that the total change in the torque obtained for the gas under investigation, corresponds to only a small fraction of a revolution of the fiber (for example, A to B or A' to B' in Fig. 2, b), the sine characteristic will

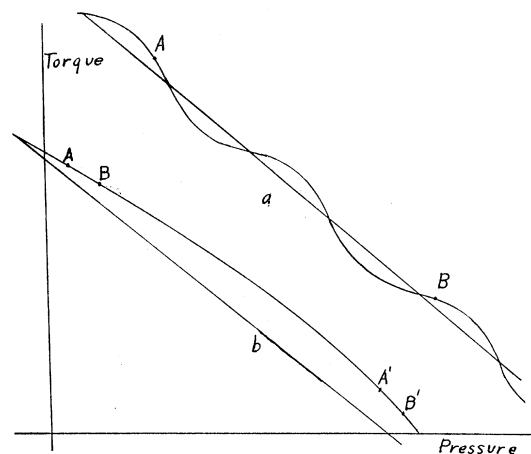


FIG. 2. The effect of inaccurate centering of small and large fibers is shown by a and b .

most likely not be recognized; however, the slope of the curve, which is proportional to the susceptibility of the gas, will depend on the portion of the sine curve for which the data are taken. For example, if one-fiftieth of a turn of the torsion head is used for one atmosphere of hydrogen it would still require sixteen turns for an atmosphere

of oxygen, and it is possible for the centering to produce a variation of a factor of two in the slope for hydrogen depending on the portion of the sine curve used, and yet not appreciably affect the slope of the oxygen curve. In case a sufficiently small fiber is used, so that the torque changes by several revolutions of the fiber (*A* to *B* in Fig. 2, *a*), this sine variation can be recognized and corrected for.

In the present experiment the torque due to inaccuracy of centering has been reduced to less than 1 percent of the torque caused by one atmosphere of hydrogen by finding a favorable position for the test body in the magnetic field and by centering the fiber to within a radius of 5μ .

Low pressure effects

If one observes the torque required to keep the test body in a given position, with zero magnetic field, as a function of the pressure, it is found to be constant down to a pressure of about 1 to 5 cm, below which it deviates, the sign of the deviation depending on whether the temperature of the magnet is below or above that of the room. Fig. 3. The effect increases at least down

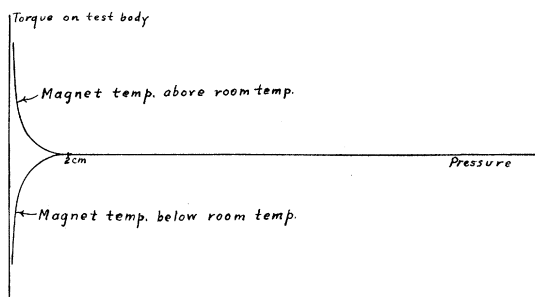


FIG. 3. An effect at low pressures.

to a pressure of 10^{-3} mm of Hg. That the effect does not enter above 5 cm is shown by the fact that the curve in Fig. 3 is horizontal above that pressure. The effect is present both with and without the liquid air flask surrounding the lower part of the tube. The behavior suggests that it is of the nature of a radiometer disturbance.

Liquid air measurements

The liquid air measurements could not be made as accurately as those at room temperatures be-

cause of convection currents around the test body. These convection currents increased with pressure and with the time after which the Dewar flask was initially filled with liquid air. This may be accounted for by assuming that the nitrogen near the surface of the liquid air boils away first thereby leaving a warmer layer richer in oxygen, this temperature difference in turn causes convection currents inside the tube. The magnitude of the disturbances depended on the gas that was being measured; hydrogen behaved the best with helium, neon, argon, and nitrogen behaving progressively worse, in fact the susceptibilities of the latter two could not be determined to within 10 percent and 50 percent respectively at liquid air temperatures.

The following reasons argue for the superiority of the present apparatus and the reliability of the results over those of previous observers:

(1) Extremely high sensitivities bring out and indicate means for the elimination of systematic errors such as constant drifts in the apparatus and centering errors.

(2) The fact that the measured susceptibilities check within the limit of error those made at room temperatures, as they should from theoretical considerations, argues for the reliability of the results.

(3) The results are reproducible from day to day.

(4) The torque on the test body in a vacuum due to the magnetic field remains very nearly the same from day to day. Other observers using the test body method have found relatively large variations from day to day.

(5) The torque on the test body in a vacuum due to the magnetic field does not vary appreciably in going from room to liquid air temperatures, showing that the torque on the test body is only slightly effected by changes in temperature. Therefore the small temperature changes at room temperatures affect the results only insofar as they affect the pressure of the gas.

(6) The torque on the test body does not vary rapidly with the change in the magnetic field. This has been brought about by reducing the resultant torque on the test body by means of compensators.

(7) The apparatus is free from electrostatic effects.

(8) The materials used in the construction of the measuring apparatus were Pyrex glass, fused quartz, platinum and gold all of which are practically inert chemically.

DISCUSSION OF RESULTS

Hydrogen

Hydrogen has been the subject of controversy for some time. The results of recent observers have tended to increase the uncertainty of the value for the susceptibility of this gas. The author has obtained over one hundred curves for this gas, using four different types of test bodies, the recent ones had a coat of platinum or gold evaporated on them the others did not. Although many of the one hundred curves were not calibrated accurately and were used mainly to test the effect of alterations of the instrument none of them either at room or liquid air temperatures have indicated a molecular susceptibility which varied by more than a few percent from -4.0×10^{-6} . The accuracy and consistency of the results are illustrated by curves 156 and 159 in Fig. 4, and by the Tables I, III and IV. All observations were taken with increasing pressures and then decreasing pressures in the measuring

TABLE I. H_2 , curve 139.

| Pressure (cm Hg) | Torque (Rev. of fiber) | Pressure (cm Hg) | Torque (Rev. of fiber) |
|------------------|------------------------|------------------|------------------------|
| 5.500 | 15.2566 | 37.860 | 12.3348 |
| 6.537 | 15.1708 | 42.010 | 11.9606 |
| 8.486 | 14.9967 | 46.177 | 11.5859 |
| 10.519 | 14.8114 | 49.888 | 11.2551 |
| 12.536 | 14.6345 | 54.078 | 10.8662 |
| 14.647 | 14.4388 | 57.152 | 10.5893 |
| 16.583 | 14.2689 | 59.813 | 10.3520 |
| 18.500 | 14.0919 | 61.865 | 10.1640 |
| 20.499 | 13.9089 | 63.572 | 10.0125 |
| 24.297 | 13.5616 | 53.144 | 10.9588 |
| 26.336 | 13.3775 | 44.363 | 11.7476 |
| 28.364 | 13.1987 | 34.576 | 12.6347 |
| 30.372 | 13.0152 | 24.840 | 13.5186 |
| 32.299 | 12.8405 | 15.450 | 14.3696 |
| 34.151 | 12.6703 | 5.010 | 15.4848 |
| 36.409 | 12.4733 | | |

tube in order that any constant drifts in the apparatus would be detected.

The results for hydrogen of Soné,¹³ and Wills and Hector¹⁴ agree within their limits of error with those obtained by the author in Table V. The results of the author for hydrogen at liquid air temperatures disagrees with the low result of 3.3×10^{-6} for the molecular susceptibility as found by Bitter¹⁵ who averaged two determina-

¹³ Soné, *Phil. Mag.* **39**, 305 (1920).

¹⁴ Wills and Hector, *Phys. Rev.* **23**, 209 (1924).

¹⁵ Bitter, *Phys. Rev.* **36**, 1648 (1930).

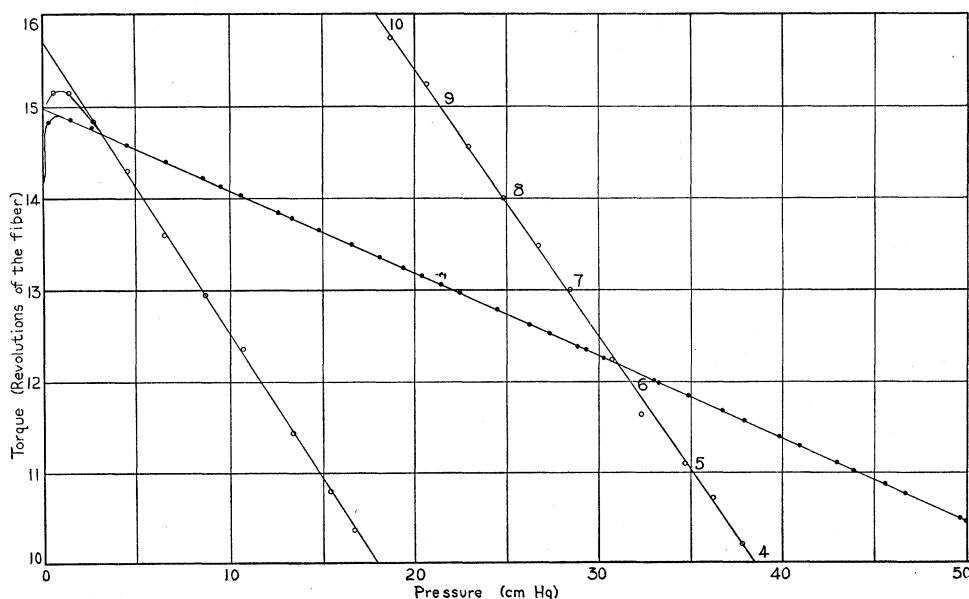


FIG. 4. Dots, hydrogen at room temperatures, curve 156; circles, hydrogen at liquid air temperatures, curve 159.

TABLE II. O₂, curve 140.

| Pressure (cm Hg) | Torque (Rev. of fiber) | Pressure (cm Hg) | Torque (Rev. of fiber) |
|---------------------|---------------------------|---------------------|---------------------------|
| 0.240 | 34.167 | 2.519 | 202.178 |
| 0.509 | 53.680 | 3.047 | 241.214 |
| 0.982 | 88.422 | 4.078 | 316.649 |
| 1.482 | 125.916 | 5.486 | 421.111 |
| 2.014 | 164.722 | 3.486 | 274.417 |
| | | 1.675 | 141.564 |

tions at liquid air temperatures. The author's result agrees with Van Vleck's theoretical calculation within the theoretical uncertainty.

Oxygen

The accurate determination of the slope for oxygen was difficult because of its high molecular susceptibility which, unless an enormous number of turns of the fiber were used, limited the pres-

sure to a few centimeters. This required the use of a mercury manometer having a large cross-sectional area and the aid of a cathotometer for the accurate measurements of the difference of level. This gas was used as a standard for the measurements of the other gases. The provisional value of 3335×10^{-6} for the molecular susceptibility at 20°C was used; should this value be found to be in error, the results for the other gases will have to be changed proportionally. The results for oxygen at liquid air temperatures show that Curie's law is satisfied to within 2 percent. The results are given in Tables II, III and IV.

Helium

The results for helium are surprisingly close to the theoretical calculation made by Stoner,⁶ and agree with the experimental results of Wills

TABLE III.

| Curve No. | Gas | Date of obs. | Sloz of curve in rev. of fiber/cm Hg Pres. | Obs. temp. |
|-----------|------------------------|--------------|--|------------|
| 138 | H ₂ | 8/12/32 | -0.09050 ±0.00015 | 24.3 |
| 139 | H ₂ | 8/14/32 | -0.090531 ±0.000021 | 24.45 |
| 140 | O ₂ +0.4% A | 8/14/32 | 73.64 ±0.03 | 24.9 |
| 141 | N ₂ | 8/18/32 | -0.2702 ±0.0005 | 23.9 |
| 142 | CO ₂ | 9/20/32 | -0.4734 ±0.0020 | 21.90 |
| 145 | H ₂ | 10/ 2/32 | -0.0901 ±0.0002 | 23.3 |
| 148 | He | 10/ 3/32 | -0.0432 ±0.0002 | 21.95 |
| 151 | He | 10/ 8/32 | -0.146 ±0.004 | (-189.4)* |
| 152 | H ₂ | 10/ 8/32 | -0.306 ±0.010 | (-189.4)* |
| 153 | H ₂ | 10/24/32 | -0.316 ±0.004 | (-189.4)* |
| 155 | H ₂ | 10/28/32 | -0.3316 ±0.003 | -189.4 |
| 156 | H ₂ | 10/29/32 | -0.090946 ±0.000021 | 21.8 |
| 159 | H ₂ | 11/ 2/32 | -0.3193 ±0.0008 | -189.4 |
| 160 | H ₂ | 11/ 3/32 | -0.09073 ±0.00030 | 21.5 |
| 164 | Ne | 11/13/32 | -0.17299 ±0.00006 | 21.8 |
| 168 | Ne | 11/16/32 | -0.609 ±0.004 | -189.5 |
| 169 | O ₂ +0.4% A | 11/17/32 | 75.46 ±0.06 | 20.82 |
| 170 | O ₂ +0.4% A | 11/17/32 | 945.0 ±6.0 | -189.7 |
| 172 | H ₂ | 11/18/32 | -0.09107 ±0.00060 | 20.8 |
| 177 | H ₂ | 12/22/32 | -0.09017 ±0.00017 | 22.88 |
| 180 | H ₂ | 12/28/32 | -0.09010 ±0.00010 | 22.60 |
| 181 | O ₂ Elect | 12/28/32 | 74.401 ±0.07 | 22.66 |
| 185 | H ₂ | 1/11/33 | -0.0891 ±0.0006 | 22.72 |
| 186 | O ₂ Elect | 1/11/33 | 73.34 ±0.15 | 22.23 |
| 187 | H ₂ | 1/19/33 | > -0.0889 ±0.0003 | 22.14 |
| 189 | O ₂ Elect | 1/19/33 | 74.50 ±0.15 | 22.30 |
| 190 | H ₂ | 1/26/33 | -0.09013 ±0.00050 | 22.16 |
| 191 | N ₂ | 1/26/33 | -0.26849 ±0.00013 | 22.42 |
| 192 | He | 1/26/33 | -0.04260 ±0.0003 | 22.47 |
| 193 | H ₂ | 2/13/33 | -0.09035 ±0.0006 | 22.06 |
| 194 | H ₂ | 3/20/33 | -0.0645 ±0.0010 | 22.57 |
| 195 | H ₂ | 3/20/33 | -0.2304 ±0.0025 | -192.2 |
| 197 | He | 3/22/33 | -0.03125 ±0.00020 | 22.02 |
| 199 | He | 3/23/33 | -0.03075 ±0.00020 | 22.04 |
| 201 | A | 3/24/33 | -0.3098 ±0.0010 | 22.57 |
| 202 | A | 3/24/33 | -1.16 ±0.10 | -191.9 |

* These temperatures were estimated from later temperature determinations under practically the same conditions.

TABLE IV.

| Curve No. | No. of standardizing curve | $\chi \times 10^6$ | Assigned weights |
|-----------|----------------------------|--|------------------|
| | | H ₂ (Room temperatures) | |
| 139 | 140 | -4.008 ±0.004 | 12 |
| 180 | 181 | -4.002 ± .005 | 8 |
| 138 | 140 | -4.009 ± .006 | 6 |
| 172 | 169 | -3.998 ± .006 | 6 |
| 177 | 181 | -4.008 ± .008 | 3 |
| | | Weighted ave. val. -4.0051 ±0.0016 | |
| | | H ₂ (Room temperatures) | |
| 160 | 169 | -4.009 ±0.014 | 8 |
| 190 | 189 | -4.001 ± .020 | 4 |
| 185 | 186 | -4.024 ± .025 | 3 |
| 193 | 189 | -4.01 ± .03 | 2 |
| 187 | 189 | -3.97 ± .04 | 1 |
| | | Weighted ave. val. -4.008 ±0.005 | |
| | | H ₂ (Liquid air temperatures) | |
| 159 | 160 | -4.01 ±0.04 | 25 |
| 153 | 156 | -3.95 ± .06 | 11 |
| 195 | 194 | -3.92 ± .07 | 8 |
| 155 | 156 | -4.14 ± .20 | 1 |
| | | Weighted ave. val. -3.982 ±0.019 | |
| | | He (Room temperatures) | |
| 148 | 145 | -1.910 ±0.010 | 16 |
| 192 | 189 | -1.892 ± .013 | 10 |
| 197 | 195 | -1.94 ± .03 | 2 |
| 199 | 195 | -1.91 ± .04 | 1 |
| | | Weighted ave. val. -1.906 ±0.006 | |
| | | He (Liquid air temperatures) | |
| 151 | 152 | 1.91 ±0.08 | |
| | | Ne (Room temperatures) | |
| 164 | 169 | -7.651 ±0.008 | |
| | | Ne (Liquid air temperatures) | |
| 168 | 169 | -7.64 ±0.08 | |
| | | A (Room temperatures) | |
| 201 | 194 | -19.23 ±0.20 | |
| | | A (Liquid air temperatures) | |
| 202 | 201 | -19.8 ±1.4 | |
| | | N ₂ (Room temperatures) | |
| 141 | 140 | -11.950 ±0.026 | 2 |
| 191 | 189 | -11.930 ±0.020 | 3 |
| | | Weighted ave. val. -11.938 ±0.017 | |
| | | CO ₂ (Room temperatures) | |
| 142 | 145 | -20.94 ±0.09 | 5 |
| 142 | 140 | -20.79 ± .12 | 3 |
| | | Weighted ave. val. -20.88 ±0.08 | |
| | | O ₂ (Liquid air temperatures) | |
| 170 | 169 | 11830 ±80 at -189.7°C | |

TABLE V. Comparison of the results of various observers molecular susceptibilities $\times 10^6$.*

| Observer | H ₂ | He | Ne | A | N ₂ | CO ₂ |
|--------------------------------------|--|-------------------------|--|-------------------------|--|--------------------------------------|
| Author ¹ | -4.0051 ±0.0016 | -1.906 ±0.006 | -7.651 ±0.008 | -19.23 ±0.20 | -11.938 ±0.017 | -20.88 ±0.08 |
| | -3.982 ±0.019 | -1.91 ±0.08 | -7.64 ±0.08 | -19.8 ±1.4 | Liquid air measurements | |
| Wills and Hector ¹⁴ | -3.84 -4.04 -3.94 | -1.94 | | | | |
| Hector ¹⁶ | | -1.84 -1.91 -1.88 | -7.70 -6.97 -5.63 -6.75 -6.85 -6.62 -6.03 -6.57 -6.52 ±0.21 | -18.3 -17.8 -18.1 | -11.96 -11.50 -11.94 -11.80 | |
| Soné ^{13†} | -4.13 -3.92 -3.98 -3.84 -3.89 -4.02 -4.11 -3.85 -4.04 -4.09 -4.10 -3.96 -3.996 ±0.029 | | | | -7.22 -7.62 -7.42 -7.42 -8.04 -8.06 -8.05 -10.2 -10.0 -10.1 | -18.61 -18.88 -18.30 -18.60 |
| Lehrer ¹⁷ | -5.08 ±0.18 | | | -20.11 ±0.32 | | -20.86 ±0.16 |
| Bitter ¹⁵ | -5.8 -3.3 | | | | -14.8 -14.2 | -24.2 |
| Hammar ^{9‡} | (-4.0) | | | | -8.0 | -19.3 |
| Glaser ³ | | | | | | |
| Glaser ¹⁸ | | | -6.85 | -20.1 | -7.36 | -18.9 -21.0±.2 |
| Vaidyanathan ¹⁰ | | | | -25.3 | -12.9 | -20.5 |

* The errors given for the author, are the probable errors as calculated by the rule of mean squares, likewise for Soné's results for hydrogen and Hector's results for neon.

† Soné used N₂ purified by three different methods.

‡ Hammar's values are calculated by assuming $\chi(\text{H}_2) = -4.0 \times 10^{-6}$.

¹⁶ Hector, Phys. Rev. 24, 418 (1924).

¹⁷ Lehrer, Ann. d. Physik 81, 229 (1926).

¹⁸ Glaser, Ann. d. Physik 78, 641 (1925); 1, 814 (1929).

and Hector,¹⁴ and Hector.¹⁶ No change in the susceptibility was found in going from room temperatures to liquid air temperatures.

Neon

Only one determination was made for neon at room temperatures and one at liquid air temperatures because of the limited amount available. The curve obtained for room temperatures is one of the most accurate obtained for any of the gases. The results do not agree with either those of Hector¹⁶ or those of Glaser.¹⁸ However these men used neon which contained impurities of helium in excess of 1 percent which partially explains their low results. The neon used by the author was purchased from the Air Reduction Sales Company of New Jersey and was reputed to contain less than 0.1 percent impurity.

Argon

The value obtained for this gas is greater than that obtained by Hector¹⁶ but less than those obtained by Lehrer,¹⁷ Glaser¹⁸ and Vaidyanathan.¹⁰

Nitrogen

The results for nitrogen are in good agreement with those of Hector.¹⁶ Bitter¹¹ found that nitrogen originally containing an impurity of oxygen contained after passage over hot copper a small

amount of NO and this might explain the low results of several observers. Soné¹³ obtains three different values for three different methods of purification. Table V. The highest of these three, obtained from nitrogen purified by the reduction of air, is still below the results of Hector and the author; but he assumes this value to be too high because of the amount of argon in air; however, the amount of argon in air is known and could not account for the large differences among his values.

Carbon dioxide

The results for this gas are probably more consistent for different observers than any other gas. The author's result agrees with that of Lehrer to within 0.1 percent and with that of Glaser to within 0.6 percent.

In conclusion the author desires to express his appreciation to Dr. C. E. Mendenhall for his interest in the work and valuable suggestions, also to his brother, R. Havens for his assistance during the latter part of the work. The author wishes to express his gratitude to the Wisconsin Research foundation for its financial assistance which in a large part made these investigations possible.