# Gouy Magnetic Balance for Use at Low Temperatures

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A magnetic balance of the Gouy type has been constructed in our laboratory for making absolute measurements of the magnetic susceptibility of paramagnetic salts which are to be used as working substances in adiabatic demagnetization experiments; the construction of the balance was very simple, and its performance has proved to be very satisfactory. The paramagnetic susceptibility of potassium chromium alum was measured over the temperature range between room temperature and liquid nitrogen temperatures.

When a cylindrical specimen is suspended between the magnet poles so that the lower end of the specimen is at the center of the magnet, where the field strength, $H$, is strongest, and the other end in a weaker field, the specimen is influenced by a longitudinal force, $f$, with a magnitude[1] in which

$$f=1/2\,\chi A(H_1^2-H_2^2) \qquad (1)$$

$\chi$ is the volume susceptibility of the specimen, $H_1$, $H_2$ are the maximum and minimum values of the field strength respectively, and $A$ is the cross sectional area of the specimen.

## Construction of the Apparatus

A chemical balance of the standard type (as shown in Fig. 1) was used for measuring the body force, $f$. For the measurements in the low temperature region, the magnetic balance was set as a whole in a large, glass bell-jar so as to avoid the condensation of air and vapors on the surface of a quartz tube containing the specimen. The helium which filled the bell-jar served as a heat exchange gas. The balance was placed on the thick aluminum plate (600 mm.×600 mm.×20 mm.) with leveling screws.

The beam arrest of the balance was achieved by pushing an O-ring-sealed metal bar below the pillar of the balance. The compensation[2] of the body force being exerted upon the specimen was adjusted by the electromagnetic force between a needle-shaped permanent magnet suspended from an end of the beam and a solenoid with 2500 turns of copper wire wound on an ebonite pipe (30 mm.×8 mm.$\phi$×5 mm.$\phi$). A storage battery of 2 volts was used as the current source of the solenoid. A "Kovar seal" was used for electrical lead connections from the storage battery to the solenoid set on the aluminum plate.

Powdered potassium chromium alum was filled in a long quartz tube, which was suspended at one end of the beam by a nylon string. This tube was enclosed in a pyrex glass tube in a Dewar flask, as shown in Fig. 1. A number of compression nuts with O-ring seals were used so as to avoid leakage of the helium gas.

The magnet used was a highly homogeneous permanent magnet with a 30 mm. pole gap, a 150 mm. pole diameter and a 5820 gauss field intensity. The homogeneity of this magnet, which has previously been used in nuclear magnetic resonance studies in this laboratory, is very high to the degree that the fluctuation is less than 0.1 gauss in the 2.54 cm. square area at the center of the pole face.

The ball bearing used in the wheels of the truck on which the permanent magnet was mounted was satisfactory enough to free the balance system from vibrations when the permanent magnet slides on the rails. For the determination of the specimen temperature, a copper-constantan thermocouple was used. It was, however, necessary not to set the leads in the suspended specimen, because the leads may influence the smooth swinging of the beam. Three thermocouples, the upper, the middle, and the lower, were set quite near the specimen, as is shown in Fig. 1, so that the temperature gradient could be checked. From this measurement, it was proved that the temperature difference was within 0.3 degree centigrade over the specimen when the liquid nitrogen filled the Dewar flask. These copper-constantan thermocouples have been calibrated by the melting point of several pure liquids (water, carbon tetrachloride, and ethyl alcohol). The sample of potassium chromium alum was

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1) P. W. Selwood, "Magnetochemistry", Interscience publishers, (1943).
2) T. Hirone et al., *Sci. Rept. Research Institute of Tohoku University*, A, 67 (1954).

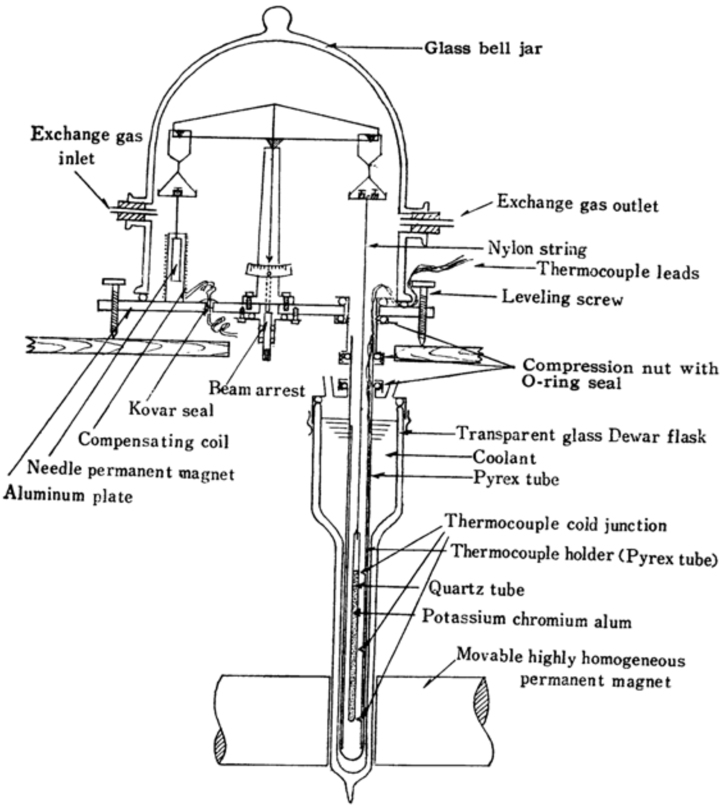


Fig. 1. Sketch of the Gouy magnetic balance.

the same as that which was previously used by us as a cooling substance in adiabatic demagnetization experiments*. The weight of the powdered specimen was approximately 2.77 g. in the present experiments.

## Experimental

After filling the refrigerant into the Dewar flask, the temperature equilibrium of the whole system containing the specimen was attained in 10 min. Then, the pointer of the magnetic balance was adjusted to come to rest at the zero mark. Thereafter, the specimen was subjected to the magnetic field by setting the permanent magnet at the position of the specimen. The force acting on the specimen was measured by the compensating system explained above.

No linear relation was obtained between the force and the compensating current. Therefore, several approximate experimental expressions for the relation between the body force and compensating current were set up. The compensating current was read by a precise milliammeter. The magnetic field measurement was made using a magnetic fluxmeter of Yokogawa Electric Works which had been calibrated by the nuclear magnetic resonance frequency of protons. The field intensity at the lower end of the specimen tube was 5820 gauss, while that at the upper end was 25 gauss. $H_2$ (25 gauss) in Eq. 1, therefore, is negligible as compared with $H_1$ (5820 gauss), and Eq. 1 reduces to this relation:

$$f=1/2\,\chi A H_1^2 \qquad (2)$$

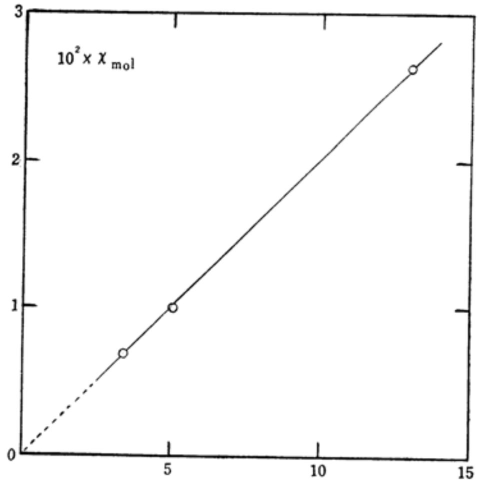


Fig. 2. Plot of susceptibility per mol. vs. reciprocal temperature for potassium chromium alum.

* To be published shortly.

TABLE I. THE MEASURED VALUES OF THE BODY FORCE AND MOLAR SUSCEPTIBILITY OF POTASSIUM CHROMIUM ALUM VS. ABSOLUTE TEMPERATURE

| | $T$°K | | |
|---|---|---|---|
| | 285 | 195 | 77 |
| $f$, dyne | 21.7 | 31.6 | 85.0 |
| $\chi_{mol}\times 10^3$ | 6.73 | 9.76 | 26.4 |

The cross-sectional area of the powdered specimen was determined gravimetrically by assuming that the powder is uniformly filled in the quartz tube. The diamagnetic susceptibility of a quartz tube was measured over the range from room temperature to liquid nitrogen temperature and was found to be suitable for the present work, because its variation with the temperature was very small. The observed susceptibility is the sum of the susceptibility of a quartz tube and the powdered specimen. The diamagnetic fraction of the quartz tube was about 1.5% of the total susceptibility at the liquid nitrogen temperature, and about 6% at room temperature. In Table I, the measured values of the body force and the molar susceptibility of potassium chromium alum are given. The Curie constant of potassium chromium alum, which was determined from the data in Fig. 2, was $C=1.86$. This value is comparable with the theoretical value, $C=1.84$, which is calculated by assuming the "spin only paramagnetism" for the $Cr^{+3}$ ion[3].

3) C. Kittel, "Introduction to Solid State Physics", John wiley (1953).


## Summary

This paper has reported on the performance, in the range between room and liquid nitrogen temperatures, of a Gouy-type magnetic balance, which had been constructed for absolute measurements of the magnetic susceptibility of paramagnetic salts. As a magnetic field, we used a highly homogeneous permanent magnet which was easily movable by hand. Therefore, precise measurement of the susceptibily is possible. With this balance, the susceptibility of $10^{-5}$ c. g. s. units was measurable within a range of error of 5%.


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