

Letters to the Editor

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Viscosity of Gaseous He³ and He⁴ between 1.3°K and 4.2°K

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WE have recently shown¹ that the symmetry effects calculated by Halpern and Gwathmey² which should occur with the gaskinetic collisions of *ortho-para*-H₂ and *ortho-para*-D₂ cannot be observed with even an approximately right order of magnitude. The reliability of the calculations, however, is not very high, because they are based on the hard-elastic-sphere model which is not suitable for the nonspherical potential of H₂ and D₂. Halpern³ has therefore suggested that the influence of the statistics on the gaskinetic cross sections be reinvestigated by measuring the viscosity-difference of gaseous He³ and He⁴ at very low temperatures. In the case of He no difficulties with respect to the potential are to be expected. Since He³ obeys Fermi statistics while He⁴ obeys Bose statistics, the viscosity of gaseous He³ should appreciably exceed the viscosity of He⁴ at low temperatures. Somewhat later, de Boer and Cohen⁴ have explicitly calculated the temperature-dependence of the viscosities between 0 and 5°K using a Lennard-Jones potential of the form $4e[(\sigma/r)^{12} - (\sigma/r)^6]$.

To investigate the extremely small viscosities, we have developed a measuring device based on the principle of the oscillating cylinder. The amplitudes of the oscillations are recorded by

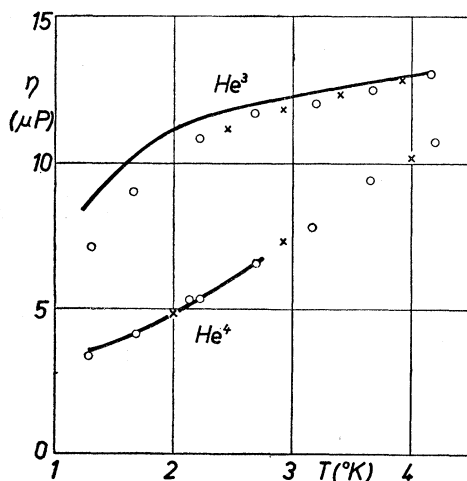


FIG. 1. The temperature dependence of the viscosity coefficient η (micropoise) of gaseous He³ and He⁴. Circles and crosses represent the experimental results obtained with decreasing and increasing temperature, respectively. Continuous lines represent theoretical curves of de Boer and Cohen.

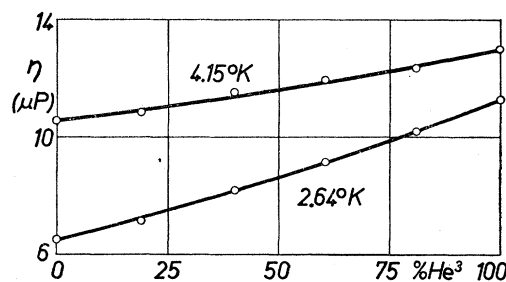


FIG. 2. Concentration dependence of the viscosity coefficient η (micropoise) of gaseous He³-He⁴ mixtures at temperatures 4.15°K and 2.64°K.

high-frequency circuits using a change in capacity connected with the oscillation. At 4.2°K the relaxation time of the oscillating system filled with He⁴ amounts to 2.7 min while it exceeds 3 hr with the highest obtainable vacuum. The period of the oscillating cylinder is 1.3 sec. At a viscosity of 5 micropoise the accuracy of the measurements was better than ± 1 percent.

The viscosities of pure He³ and He⁴ were measured between 1.3° and 4.2°K (Fig. 1). The results for pure He⁴ agree perfectly with the calculations of de Boer and Cohen. For He³ the figure shows a small deviation between theory and experiment at low temperatures. In any case, we may presume that the results obtained confirm the predicted symmetry effect of the helium isotopes.

Furthermore, the concentration dependence of the viscosity of gaseous He³-He⁴ mixtures was determined at 4.2° and 2.6°K as shown in Fig. 2. The absolute values of η are derived from the well-known viscosity of He⁴ at 77.3°K (83.68 micropoise).⁵ The pure He³ was supplied by the U. S. Atomic Energy Commission. Details will be published in the *Zeitschrift für Physik*.

¹ E. W. Becker and O. Stehl, Phys. Rev. **87**, 525 (1952); Z. Physik **133**, 615 (1952); Becker, Misenta, and Stehl, Phys. Rev. **91**, 414 (1953); Z. Physik (to be published).

² O. Halpern and E. Gwathmey, Phys. Rev. **52**, 944 (1937).

³ O. Halpern, Phys. Rev. **82**, 561 (1951).

⁴ J. de Boer and E. G. D. Cohen, Physica **17**, 993 (1951).

⁵ W. H. Keesom, *Helium* (Elsevier Publishing Company, Amsterdam, 1942), p. 107.

F-Center Wave Functions in Alkali Halides*

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IN recent publications¹⁻³ Hutchison, Kittel, and co-workers have presented important new information based on paramagnetic resonance absorption measurements capable of giving insight into the charge distributions of *F*-center electrons in KCl. From the measured¹ shift in the *g* factor, -0.007 , Kahn and Kittel² have shown that the spin of the *F*-center electron is strongly coupled with orbital angular momentum; if its wave function is written as an atomic function, they have concluded, it must be of almost pure *g* character ($l=4$) to explain the shift in the splitting factor. Seitz has presented arguments,³ based on the inclusion of the interaction of the electron with its surroundings, to show that a ground state described by about half *s*-like and half *g*-like behavior is a reasonable one. Secondly, Kittel *et al.* have shown the width of the resonance absorption peak, 56 oersteds in KCl, to be a result of hyperfine interactions of the electron with the nuclear magnetic moments of the neighboring ions. Knowledge of these breadths and of the magnetic moments involved in samples of KCl containing two isotopes of K has enabled them to calculate the probability density of the *F*-center electron at the surrounding nuclei.⁴ From these two results Kittel and co-workers have concluded that the natural model for the