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Viscosity Difference Measurements for Normal and *Para* Liquid Hydrogen Mixtures

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THE absence of experimental data in the literature concerning a viscosity difference for normal and equilibrium liquid hydrogen may be attributed to the limited reproducibility of "oscillating disk" measurements in a liquid-hydrogen environment. Indeed, there is disagreement over the viscosity values for equilibrium liquid hydrogen even without proton spin considerations.[1]

Measurements presented here represent the first application of the piezoelectric alpha quartz torsional oscillator technique to liquid-hydrogen viscosity measurements. This method was recently employed by Welber and Quimby to obtain the viscosity of liquid helium.[2] The logarithmic decrement of such a torsional right circular cylindrical crystal is related to the viscosity coefficient of a surrounding liquid by the relation

$$\eta \rho = \frac{M^2}{S^2} (\Delta - \Delta_0)^2 \frac{F_R}{\pi},$$

where η is the viscosity coefficient; ρ is the density of surrounding liquid; $\omega = 2\pi F_R$ (resonant frequency); r is the radius of crystal; and M the mass of crystal.

$\Delta = \frac{1}{2}$(energy dissipated/c)/ (energy of vibration); Δ_0 is the logarithmic decrement of crystal in vacuum; and S the total surface area of crystal including end faces; provided that $\lambda = (\rho\omega/2\eta)^{-\frac{1}{2}} \ll r$, where λ is the thickness of the characteristic boundary layer.

The torsional crystal of 0.25 cm radius used for this experiment had a resonant frequency F_R of approximately 39 702 cps providing a λ of about 1.6×10^{-4} cm. The crystal was located in an isothermal copper chamber, which in turn was placed within a double Dewar system. A bath of liquid hydrogen in the inner Dewar served only as a cold reservoir, while the pure normal hydrogen gas was condensed into the vacuumtight copper chamber around the crystal. The latter, highly polished, was suspended at the central strain node so that in vacuum at 14°K it possessed a decrement of 4.7×10^{-7}, as contrasted with 12.5×10^{-5} when immersed in liquid hydrogen. The crystal was electrically connected to one arm of a modified Shearing capacitance bridge, and the decrement was determined from measurement of the crystal resistance at resonance. Suitable filter and preamplification systems of the bridge output signal provided a precision better than 0.2% for relative values of $\eta\rho$.

Values of $\eta\rho$ were measured as a function of temperature (below 14.5°K) within selected time intervals, short compared to the half-life of the conversion process. A number of such "sub runs" were taken at different times, hence at different concentrations during the slow conversion process occurring over a 200-hr "run," of which there were three, of essentially identical results. The *ortho-para* concentration was determined in each "sub run" by measuring the temperature of the triple point; the latter could be determined precisely with reference to a carbon resistance thermometer, since contact of hydrogen ice with the crystal surface resulted in nearly an infinite crystal resistance. The carbon thermometer was calibrated from vapor-pressure measurements using an octoil and mercury manometer system. The absolute temperature measurements are probably correct within
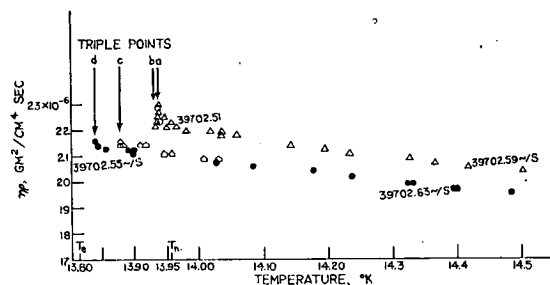

FIG. 1. (a)—Triple point for "sub run" consisting of open circle data points having 69% ($\pm 5\%$) *ortho* composition.

(b)—Triple point for "sub run" consisting of open triangle data points having 67% ($\pm 5\%$) *ortho* composition.
(c)—Triple point for "sub run" consisting of open pentagon data points having 47% ($\pm 5\%$) *ortho* composition.
(d)—Triple point for "sub run" consisting of filled circle data points having 28% ($\pm 6\%$) *ortho* composition. Maximum velocity of a point on rim of crystal was 0.3 cm/sec. Maximum power dissipated by torsional crystal in the liquid H was 2.5×10^{-8} w.

0.01°K, whereas temperature differences of 0.003°K could easily be detected. The results for four typical "sub runs" taken from one experiment are shown in Fig. 1. The resonant frequency, F_R, decreased, as expected, with increasing $\eta\rho$, and these F_R values are indicated in the figure adjacent to their corresponding $\eta\rho$ data points. Examination of the first, second, and last "sub runs" clearly indicates that at 39 702 cps the $\eta\rho$ values below 14.5°K for 69% *ortho* liquid hydrogen are about 4% larger than the corresponding values for 28% *ortho* liquid hydrogen. As a consequence of the uncertainty in absolute temperature, differences in *ortho-para* concentration can be determined more accurately than absolute concentration values. The uncertainty in the absolute values of the concentration is ±5% *ortho*, while the *differences* in concentration are correct within 2%. Since the density of normal liquid hydrogen at 14°K has been reported to be approximately 0.4% higher than the corresponding equilibrium density,[3] we can attribute approximately 3.7% difference in $\eta\rho$ as resulting from differences in η due to *ortho-para* composition. We wish to point out that a theory exists covering the viscosity difference in gaseous hydrogen for temperatures above 70°K in which symmetry effects produce different cross sections for identical-molecule collisions as compared with nonidentical collisions. These calculations predict increasing values of viscosity with increasing *ortho* composition. The same mechanism may also be active in the liquid. It is of interest to note that in the case of gaseous hydrogen Becker and Stehl[4] have investigated viscosity differences between various *ortho-para* concentrations utilizing a static magometric bridge technique. Their results are in disagreement with the theoretical calculations of Halpern and Gwathmey[5] and of Falk and Mann,[6] both in respect to sign and magnitude.

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