The Scattering of Laser Light in Superfluid Helium

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It has been recognized for several years that the observation of light scattering in He II would be an interesting tool for the study of density fluctuations in this quantum liquid. The scattering is expected to be caused in superfluid He^4 mainly by thermally excited first sound[1–4], in He$^3-$He^4 mixtures also by second sound[5] and in pure He^3 by zero and first sound[6]. The only quantitative experiment on liquid He^4 by Lawson and Meyer[7] indicated that within an experimental error of 20% there was no excessive scattering at the λ-point. This large experimental uncertainty can be considerably reduced when a laser is used as a light source: We report here on a measurement of the light scattering in superfluid He^4 as a function of temperature with a relative error of less than 2%. This demonstrates that precise measurements of the light scattering in liquid helium are quite feasible in spite of the small scattering cross section.

The scattering cell which is shown in Fig. 1 contained 30 cm^3 of highly purified liquid He^4 and was cooled by a separate helium bath. A 40 mW light beam from a He$-$Ne laser entered and left the cell through Brewster windows (not shown in Fig. 1). The scattering at right angles was monitored by a photomultiplier within a well defined solid angle. The background signal due to dark current of the photomultiplier and scattering by the empty sample cell did not exceed 15% of the signal due to the liquid.

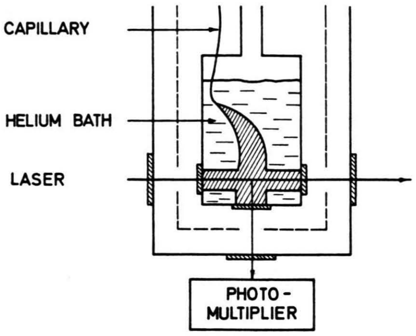

Fig. 1. Schematic diagram showing the scattering cell (hatched) surrounded by a separate helium bath and radiation shield.

Our data are shown in Fig. 2: The photocurrent with liquid helium in the scattering cell minus the photocurrent for the empty cell (6×10^{-9} Amp) is plotted versus temperature. Evidently below the λ-point the scattered light intensity approaches zero with falling temperature. A temperature independent contribution to the light scattering, for example Raman scat-

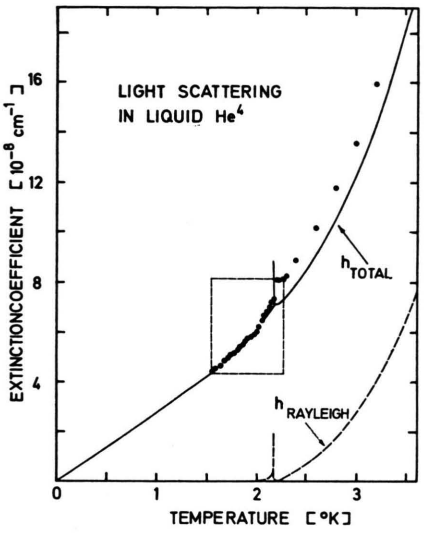

Fig. 2 a. The total light scattering in liquid He^4 and its Rayleigh contribution versus temperature.

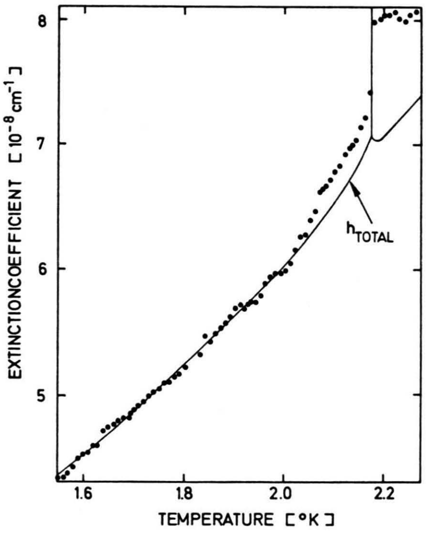

Fig. 2 b. Enlarged section of Fig. 2 a.

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tering, could not be detected in He II. — On warming through the λ-point we observed a sudden increase of the scattering by about 10%.

The extinction coefficient of light due to scattering in liquid helium has been calculated to be

$$h_{\text{total}} = \frac{\omega^4 (\varepsilon - 1)^2}{6 \pi c^4 \varrho u^2} k T \tag{1}$$

where ω and c refer to the frequency and velocity of light, and u is the velocity of (first) sound.

The absolute value of the scattered light intensity measured in our experiments agrees within 15% with the expectation of expression (1) over the whole temperature range. For a more precise comparison of the temperature dependence between our data and expression (1) we have matched in Fig. 2 at $T = 1.5$ °K our points and the solid curve representing the theoretical expectation (1). Below 2.1 °K the light scattering varies with temperature exactly as predicted. However, above the λ-point there is an additional scattering which is not yet understood at present. At the λ-point itself one would expect a maximum of the scattering amplitude but only within an extremely narrow temperature interval: No indication of any maximum was observed in our experiments.

The expected RAYLEIGH contribution

$$((c_{\text{P}} - c_{\text{V}}) / c_{\text{P}}) \cdot h_{\text{total}}$$

to the total scattering h_{total} is also shown in Fig. 2 a by a dotted line. Since it becomes evidently negligible below the λ-point the light scattering in He II reported here is probably caused only by BRILLOUIN scattering on first sound.

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Tracks of Iron Ions in Olivine Crystals

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As FLEISCHER et al. [1, 2] showed, fossil heavy charged-particle tracks in meteoritic minerals can be used to study the elemental abundance of very heavy cosmic rays and the history of meteorites. Recently PRICE et al. [3] have been able to set an upper limit for the rate of space erosion of a meteorite by studying the distribution of charged-particle tracks in minerals of this meteorite.

In many meteorites the very heavy nuclei of the primary cosmic radiation are considered to be the dominant source of the fossil tracks. But no experiments have been made to show directly whether iron nuclei (which is the most abundant element in the VH group of the cosmic radiation) are registered in form of an etchable track for example in olivine as a common meteoritic mineral. The reason is that it is difficult to produce iron ions for acceleration in a heavy ion accelerator. From the known registration characteristics of olivine for artificially accelerated arsenic and iodine ions it cannot be extrapolated whether iron is registered or not [4].

Therefore we used the recoil-method as described by HORN and VON OERTZEN [5]: polished (100)-faces of olivine crystals $[(\text{Mg}, \text{Fe})_2\text{SiO}_4]$ have been exposed at an angle of 45° to an intense beam of 45 MeV ^{32}S ions ($\sim 10^{14}/\text{cm}^2$) from the Heidelberg Tandem VAN DE GRAAFF. The sulphur ions are not registered in olivine [6]. The iron ions of the crystal lattice of olivine are knocked on by elastic scattering. From the kinematics of elastic scattering the energies of the iron nuclei emitted under different angles relative to the primary direction can be derived. By etching the olivine crystals with 48% HF (20 sec, 23°) tracks are revealed (Fig. 1 *) which must be due to iron nuclei. From earlier experiments it was known that the lightest detectable ion that would give an etchable track in olivine must have an atomic number larger $Z = 20$ [6]. Therefore of the elements in olivine only iron should be considered as a source of recoil tracks.

The maximum track length of the recoil nuclei observed at 0° to the beam direction is $(5 \pm 0.5)\ \mu$ — the corresponding energy being 42 MeV. Measuring the maximum track lengths at angles of 20° (36,5 MeV) and 35° (28 MeV) respectively (Fig. 2) the maximum angle has been deduced at which tracks are formed. At large angles corresponding to low recoil energies length and angle measurements are impossible.

The curve shown in Fig. 2 was calculated using for the energy dependence of the energy loss of iron ions in olivine between 0.3 and 0.8 MeV/nucleon (which is the energy range of the iron ions produced in the recoil experiment) the expression

$$\mathrm{d}E/\mathrm{d}X = C \cdot \ln E\,.$$

That this description is quite accurate can be seen in the semilogarithmic plots of $\mathrm{d}E/\mathrm{d}X$ versus E in ref. [4, 7].

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