

# Infrared light interaction with impurity gels in superfluid helium

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The quick cooling of impurity–helium mixture into superfluid helium formats a distinctive soft matter — impurity–helium gel, clusters of which conglutinate into nanoparticles. The sizes of the particles and its mutual interaction depend on the nature of impurity atoms and impurity–helium coupling. In the paper we describe an experimental setup and preliminary results of experimental investigation of infrared absorption by water–helium gel. The comparison of the infrared spectra of gel absorption with water and ice indicates on some peculiarity of interaction in water molecules in water–helium gel.

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## Introduction

The problem of store from free atoms and radicals in cryogenic fluids appeared as a possibility to increase energetic effectiveness of rocket fuel [1]. Liquid helium rendered most convenient and safety medium for experimental study of atom holding and processes of recombination. It is well known that only its own isotope dilutes in liquid helium in enough quantities:  $^4\text{He}$  in  $^3\text{He}$  and vice versa. All another atoms and molecules (impurity atoms or impurity molecules) do not dilute in liquid helium in appreciable amount. The situation is changed as one initially prepares helium–impurity clusters, which may dilute in helium in considerable concentration. Atoms and molecules of majority of matters introduced in helium format clusters with attractive impurity core covered by helium atoms. Calculation [2] indicated that the interaction between any introduced atoms and the helium atoms gives some energy gain, except in the case of some alkali metals. The rapid cooling of a dilute impurity–helium mixture down to superfluid temperatures formats a soft matter, shaken at any force.

The method was used with some variation in different set of experimental investigations. It was studied the possibility to store free atoms and radials in superfluid helium [3–5]. There were x-ray [6,7] and neutron investigations [8,9] of sizes of these gel nanoparticles. The intensive scattering of short waves length of x-ray and neutrons indicates that the sizes of gel particles were the order of nanometers [7,9]. One of the application of the impurity–helium gels is

to explore a new mechanism of neutron thermalization [10,11] allowing us to obtain a Maxwell distribution with a lower mean energy. The proposed moderator is a gel of low-absorption weakly-bound nanoparticles with effective diameters  $\leq 10$  nm. The existence of some soft vibrating modes in the gel structure gives an additional mechanism of neutron thermalization. In the present work we report about the preliminary results of an interaction of low-energy waves (infrared light) with water–helium gel. The purpose of the experiments was to identify changes in the interatomic interaction in water molecules (like O–H or hydrogen bands) in helium surrounding.

## Method of gel preparation and experimental cell

Some methods for the introduction of atoms or molecule-helium clusters into superfluid helium have been developed in recent years. There are two approaches for technical solution of manufactures of the impurity–helium gels with different rates of mixture input into superfluid helium. One method implies to inject different concentrations of impurity–helium mixture with high velocity through a small orifice [4]. A cooling of the mixture jet to the low temperatures occurs mainly at the liquid surface. Another method uses a cooling of a gel mixture in a wide filling tube. The low-temperature end of the tube is sunk under the helium level [12,13]. A laminar flow of the mixture slow cools by cold helium vapour at temperature gradient along the tube length.

In our experiments we formed the gel by using the method of slow sample filling through a wide tube. A helium cryostat was used similar to one used for neutron investigations [14]. An advantage of the cryostat construction is the possibility to separate the area of a sample preparation and measuring tail of the cryostat. The gel samples were prepared in a quartz bucket at a middle part of the cryostat (Fig. 1, region 1). A helium level in the bucket was held above the end of filling tube by superleak cryopump. The process of sample preparation was visually controlled through windows. The process of sample preparation lasted at least one hour. The sample volume was the order of the  $2 \text{ cm}^3$ . After finishing the sample preparation the bucket was lowered to the bottom part of the cryostat (Fig. 1, region 2) for measuring the infrared absorption. The tail of cryostat was supplied by optical windows, too. The tail may be altered to suit the purpose of the experiments, for example, by aluminium one for neutron measurements or tail may be fitted up by additional windows for light radiation. The cryostat was maintained at least 10 hours a temperature of the order of 1.5 K.

In our experiments the optical investigations were done in the near infrared from 700 to 3500 nm. Light from a halogen lamp focused on the sample through the windows and ultimately through chopper and spectrograph recorded by cooled Ge photo resistor. In the experiments we used two gratings for different frequency regions (300 and 600 lines per mm), which allowed us to measure infrared light in region 700–4000 nm. The lenses, windows and bucket were made from quartz. Calibration of the transmission function of the apparatus was done by measurement of the radiation from a variable temperature black body source. Typical recording time of one frequency scan was of the order of thirty minutes.

### Light absorption by water, ice, and gel

The first step of the experimental investigation of light interaction with water molecules in water–helium gel was to study absorption spectrum of pure water and ice for the succeeding comparison of the results with results from the literature and the following measurements of gel samples. All measurements were conducted inside the cryostat by adding into the sample container water or ice (at room temperature or slightly below  $0^\circ \text{C}$  for ice), liquid helium or liquid helium with gel (at liquid helium temperatures) as appropriate. We suggest that absorption in these experiments is defined as an addition to the measured transmission. The results of the measured coefficient of light absorption,  $\alpha$ , plotted hereafter were calculated as the ratio between the light absorption of a sample,  $\alpha_\lambda$ , to the absolute value of the corresponding signal from an empty cell,  $I_{\text{cell}}$ . The light scattering from a sample is thus the difference of the recorded signal from an empty cell and the cell containing a sample,  $I_{\text{cell}} - I_{\text{cell+sample}}$ . Therefore, the value of  $\alpha$  may be written as

$$\alpha_\lambda = I_{\text{cell}} - I_{\text{cell+sample}} / I_{\text{cell}} \quad (1)$$

The results of the first experiments of infrared absorption of water consisted samples are shown in Fig. 2.

The upper thin (dark blue) line corresponds to the infrared absorption by ice, the lower thin (light blue) line is that from a water sample, the thick (green) line is light absorption by a water–helium gel sample. The downward pointing (light-blue) dashed arrows and upward pointing (dark blue) dashed arrows indicate, respectively, some peculiarities of the corresponding absorption spectra for water and Ih ice samples. The infrared absorption lines of the water sample

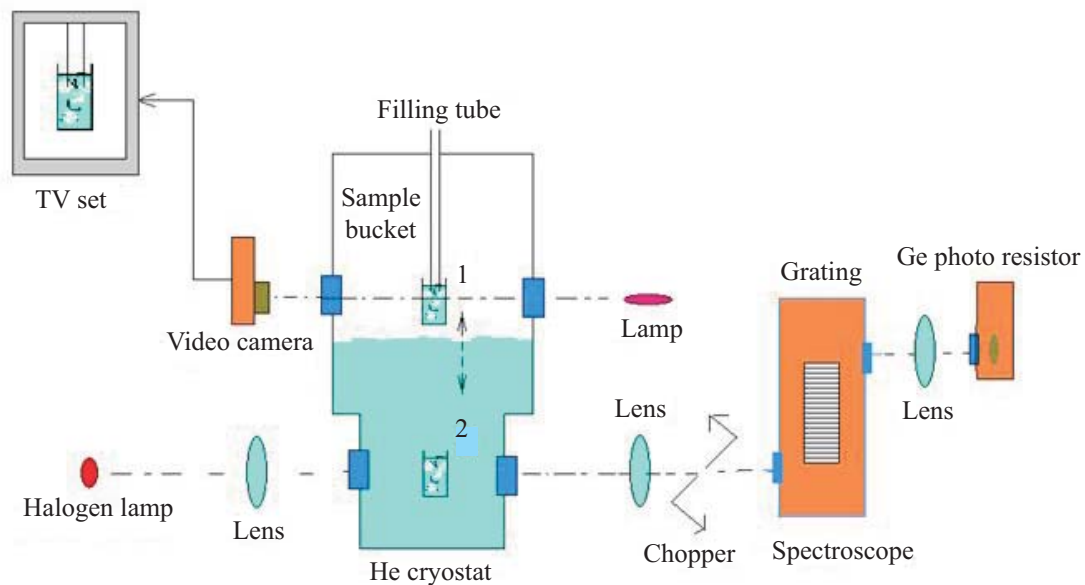


Fig. 1. (Colour online) Scheme of the experimental assembling. Numbers 1 and 2 on the scheme indicate regions of a sample preparation and measurement, respectively.

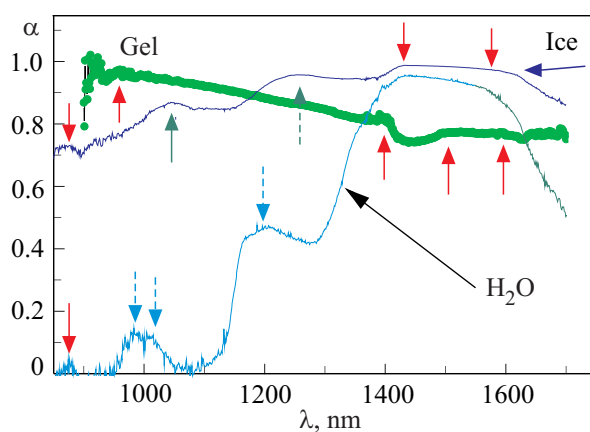


Fig. 2. (Colour online) Results of experimental investigation of infrared light absorption by water, ice, and water–helium gel.

were used for calibration of experimental setup by comparison with the tabulated results for water transmission at near infrared frequencies [15]. The down solid (red) arrows show the same picks for water and ice specimens. The wide peak at  $\sim 1400$ – $1600$  nm corresponds to an overtone of the vibrational mode components of the hydrogen-bonded O–H [16].

The preliminary results of absorption spectrum of gel sample are plotted in Fig. 1 as a thick (green) line. The thickness of the sample was sufficiently big and we observed very large light scattering (and small light transmission) across the whole wavelength range. The wide peak corresponding to stretching of the hydrogen-bonded O–H is significantly reduced in the gel sample. This may indicate that this interaction and the resonance frequency corresponding to it are altered by surrounding the water molecule with helium atoms. The effect of influence of water–helium interaction at the O–H band is visible at frequencies  $\sim 1450$  nm, where we observed a small translucence instead of strong absorption for ice and water samples.

### Conclusion

The first experiments of IR light absorption by water–helium gels demonstrate the effectiveness of the experimental setup. The idea of separation of the regions of sample preparation (above main bath helium level) and measuring the environment in bottom part of cryostat was very productive. The same idea was utilized in neutron investigation of impurity–helium gels.

The preliminary results of infrared transmit through water–helium gel indicated an existence of new absorption lines in spectrum different from the lines found in liquid

water and in ice. This implies some transformation of the atomic interactions in water molecules when they are surrounded by helium.

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