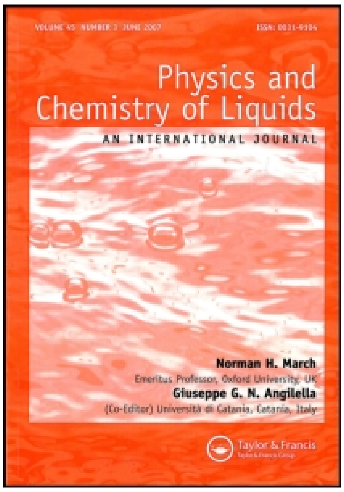

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An Experimental Study of Phase Transition in Water and Nitrobenzene Using Light Scattering from a Helium Neon Laser*

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AN EXPERIMENTAL STUDY OF PHASE TRANSITION IN WATER AND NITROBENZENE USING LIGHT SCATTERING FROM A HELIUM NEON LASER*

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A light scattering experiment was conducted in water and nitrobenzene to test the behavior of these two materials as they were made to undergo phase transition. A helium-neon laser was used as the radiation source. The coefficient of the optical absorption and contribution of scattered and absorbed light are computed from the measured transmitted light intensity at different temperatures. These measurements show that the creation and collapse of bubbles due to the laser heating cause more discontinuities in water than in nitrobenzene. Thus, there is indication of a higher order transition in water than in nitrobenzene.

From this study it is concluded that low power density laser irradiation can be used to gain an understanding of bubble dynamics in a liquid.

KEY WORDS: Bubble dynamics, laser irradiation.

1 INTRODUCTION

The spectrum of light scattered from crystals and fluids with frequency shift and width of the scattered spectral components has undergone detailed theoretical and experimental study[1]. Laser light scattering experiments can demonstrate changes of phase in a dynamical fashion by transforming significant amounts of matter from one state to another. The interaction of laser light with an absorbing medium can be used to distinguish two kinds of physical phenomena, namely the condition when the substance has practically no ionization and secondly when the substance is ionized to such a high level that it takes on the characteristics of a plasma. These two situations arise, respectively, with no radiation (or low power density radiation) and high power density radiation in the laser beam. The phenomenon of gas breakdown at optical frequencies in which a high power laser beam is used to produce electrical breakdown in a gas was first described by Meyerand and Haught[2]. The subject of the present work is the study of phase transitions at relatively lower temperatures and with weak laser light sources.

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The purpose of this paper is to report a phase transition study of water and nitrobenzene by using a He–Ne laser interacting with these polar liquids. The temperature dependency of the transmitted light intensity was used to calculate the scattered light and the optical absorption in the samples.

2 EXPERIMENTAL DETAILS

The experimental arrangement used to conduct the present experiment is shown in Figure 1. Laser light of 6328 A from a He Ne laser (model 125 Spectra Physics) of 60 mW was shone normally into the optical sample holders which contained the samples to be tested. Each optical cell had optic quality parallel faces separated by 10 mm path length. Each cell was sealed with a polyethylene cap. The focal zone of the laser beam was confined to a cross sectional area of about one square millimeter. The emergent beam of light from the optical cell was allowed to pass through a monochromater (Model 02000, Jarrel Ash, Division of Fisher Scientific Co.). The monochromator output is detected by a suitable photomultiplier tube for electronic conversion of the photons from the laser. The output signals were monitored in two ways. The photomultiplier output was connected to an oscilloscope (Tektronics Model 561B) for direct observation and then to a single pen continuous chart recorder (Heathkit Corporation, model EV-208) for a permanent record of the spectral scan.

The amplitude of the signal profile obtained by scanning in the neighborhood of 6328 Å wavelength was determined in the absence of the sample in the cell and then with the samples in place in the optical cells. The water was frozen in the cell and the light from the laser monitored by the monochromator as the temperature of the sample changed. Readings of amplitude and frequency were made for increments of 1 deg C. The absorption coefficient was then calculated using the relation,

$$\alpha = \frac{\lambda}{d}\,[\ln(I_0/I)] \tag{1}$$

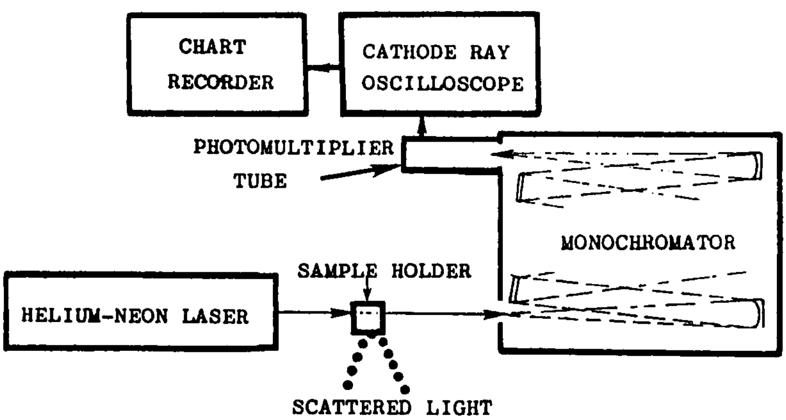

Figure 1 A schematic diagram of the basic apparatus used to make the measurements given in this work.

Where λ is the wavelength of the incident radiation, d is the thickness of the sample, I_0 is the light intensity before interacting with the sample and I is the intensity of the light after it has passed through the scattering material.

A similar procedure to that used for water was followed for the nitrobenzene sample. The ratio of $(I_0 - I)/I_0$ gives the contribution of the scattered and absorbed light to the total light intensity at different temperatures for both samples studied.

3 DISCUSSION OF RESULTS

The variations of the coefficient of optical absorption as a function of temperature for water and nitrobenzene are shown in Figure 2. The transition temperatures from one equilibrium state to another are marked by arrows in the figure. Figure 3

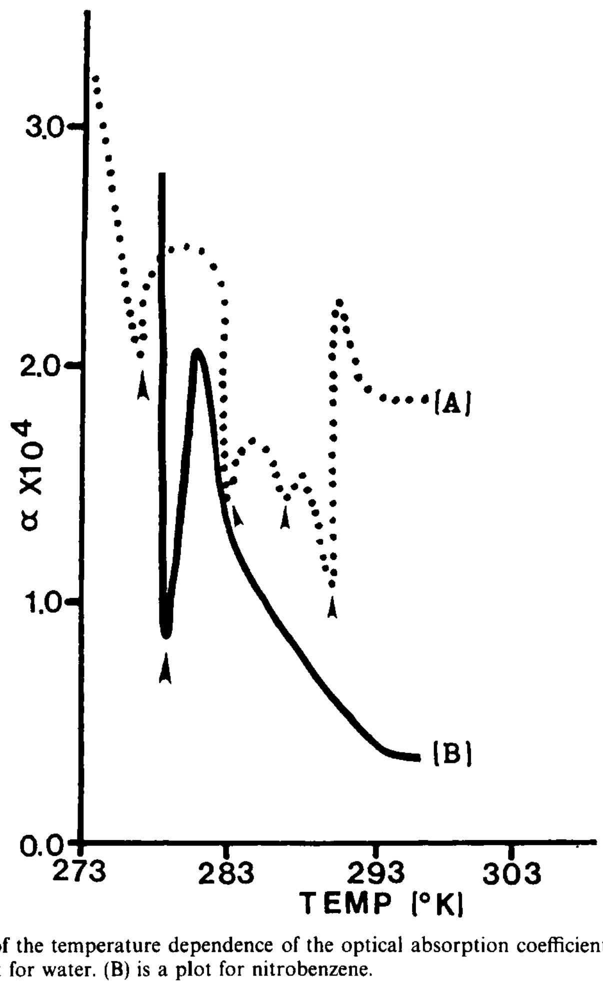

Figure 2 A plot of the temperature dependence of the optical absorption coefficient for two samples of liquid. (A) is a plot for water. (B) is a plot for nitrobenzene.

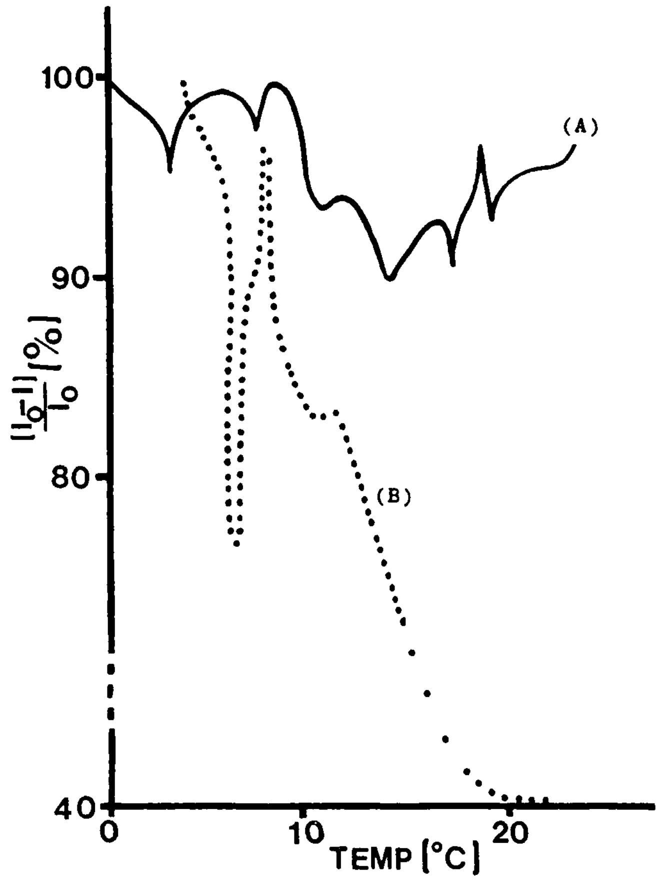

Figure 3 A plot of the temperature dependence of scattered and incident light from a helium-neon laser. The vertical axis shows the intensity of scattered and absorbed light relative to the incident light from the laser. Plot (A) shows the trend for water and plot (B) shows the trend for nitrobenzene.

demonstrates the temperature dependence of the absorbed and scattered light percentages of the total intensity of the incident beam from the He–Ne laser.

When a laser beam interacts with matter in the fluid state two mechanisms are possible, namely, bulk and surface vaporization. Matter in the condensed form is heated and in turn vaporization takes place. This process of vaporization created centers in the form of bubbles with an excess energy storage of $4\pi r^2\sigma$ due to the coefficient of surface tension (σ), where r is the radius of the formed bubbles. As excess heating proceeds, the extra energy storage increases in accordance with the increase in the radius of the bubbles. A maximum energy per bubble is reached at an optimum radius given by $r = r_1$. The equilibrium concentration (N_B) of such bubbles is given by Boltzmann's theorem (3).

$$N_B = N_0 \exp[-4\pi r_1^2\sigma/3kT] \tag{2}$$

Where N_0 is the number density of atoms in the condensed phase, k is Boltzmann's constant and T is the absolute temperature. The radius r_1 is equivalent to several atomic distances. In such small bubbles there is an excess vapor pressure of $2\sigma/r_1$ over the pressure (p) in the medium. Volmer[4] and Frankel[3] have given a relation for the excess pressure and temperature.

The interaction of the laser light with the liquid maintains a vapor pressure of $p + (2\sigma/r_1)$ by heating the liquid. The bubbles form increase in size and collapse in a systematic way with the process continuing during the period of heating of the substance by the light source. This bubble activity serves to modify the laser light in accordance with the degree and size of bubble formation, thus enabling the phase to be monitored by monitoring the transmitted light.

When the laser light is incident on a frozen liquid, there was no transmitted light observed. The transmission of laser light was monitored as the temperature was allowed to cycle over the phase temperature (273 deg K) for water and 279 deg K for nitrobenzene. An overheating created bubbles with different concentrations at different temperatures and thus varied the amount of attenuation of light through the samples. This change in concentration appears to be more temperature sensitive in water than in nitrobenzene, as can be seen in Figure 2.

In the temperature range 273 deg K (frozen state) and 297 deg K (room temperature) there appear to be discontinuities at 273, 277, 283, 286.3 and 290.5 deg K in the curve shown in Figure 2 for water. However, there appears to be only one transition temperature in the nitrobenzene at 279 deg K. This difference in behavior of these two polar liquids arise due to bubble dynamics. Moreover, the hydrogen bonding and variation in the degree of association of molecules in the water distinguishes this substance from nitrobenzene. Thus, one may argue that the NO_2 group is less associative than the OH group.

The larger number of discontinuities in the water sample indicates higher order transitions in water as was shown earlier by Johri *et al.*[5] in the temperature dependence of surface tension and by Johri and Roberts[6] on the study of the dielectric response of water.

From the results of this study, it appears that laser light scattering is a good method to monitor phase changes and such studies may lead to a better understanding of bubble dynamics in liquids.

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