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TEMPERATURE DEPENDENCE OF GAMMA RAY INDUCED LUMINESCENCE IN TOLUENE BASED LIQUID SCINTILLATOR BETWEEN 220 AND 290 K

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The fluorescence of toulene based liquid scintillator (toulene + 6 g/l butyl-PBD + 0.1 g/l POPOP) has been studied as a function of temperature in the range 220 to 290 K. It has been observed that under gamma excitation the light output increases with decrease in temperature by a factor of 1.43. The data are well encompassed by an Arrhenius relation, in which the activation energy of rate process (0.21 eV) is compatible with thermally-activated diffusion mechanism.

1. Introduction

The organic scintillation counter has proved to be an extremely versatile and useful instrument for the detection and study of nuclear radiations. A lot of work has been done to explore the influence of various factors, e.g. solvent–solute composition, oxygen dissolved in the solution, addition of wavelength shifter, magnetic field and temperature, etc. on the luminescence properties of organic scintillators under excitation by radiations of different wavelengths [1–13]. However, literature survey shows that data pertaining to the effect of temperature on the fluorescence efficiency of organic liquid scintillators are very scanty. Furst et al [1] investigated the effects of temperature above ambient (300–550 K) on energy transfer from the bulk material (solvent) to the emitting substance (solute) in a number of organic solutions under gamma rays and ultraviolet excitation. They found that, in general, fluorescence reduces with a rise in temperature by a factor which ranges from 1.3 to 20, depending on the nature of both the organic solution and radiation causing excitation. For low temperatures Seliger and Ziegler [2,3] reported an increase by a factor of 1.20 in the scintillation pulse height of two efficient de-oxygenated liquid scintillators (8 g/l PBD + 2 g/l POPOP in xylene and 3.2 g/l alpha NPO in xylene) on reducing the temperature from 303 to 243 K. Later, Laustrait and Coche [4,5] studied the temperature dependence of the scintillation pulse height of three scintillation solutions (3 g/l PPO, 5 g/l PBD or 3 g/l alpha NPO in toluene) with and without dissolved oxygen, from 313 to 243 K. However, the temperature effects observed by them were much less than those reported by Seliger and Ziegler [3]. Recently, Faizan-Ul-Haq et al [6] have reported that the scintillation response of liquid scintillator NE 213 (purified xylene + naphthalene + POPOP) increases by a factor of 1.34 on cooling from 300 to 225 K. The primary concern of this communication is to report (i) the effect of low temperature on the fluorescence efficiency of toluene based liquid scintillator containing 6 g/l butyl – PBD and 0.1 g/l POPOP, and (ii) the mechanism responsible for quenching of the luminescence when temperature increases from 220 to 290 K.

2. Materials and measurements

To study the effect of low temperature on the fluorescence response of the liquid scintillator referred to, a vacuum-flask type cylindrical chamber of copper was constructed in order to keep the liquid scintillator at a desired temperature below ambient. It had four coaxial walls having space between them. A vacuum of the order of 10^{-3} mmHg ($\approx 10^{-2}$ Pa) was maintained between the two outer walls, whereas the space between the two inner walls contained liquid nitrogen. This copper cylinder was housed in a light tight hardboard chamber along with an EMI photomultiplier tube 6255 and a long light guide, the latter being covered with aluminium foil.

Argon was passed through the liquid scintillator to eliminate and bubble out the dissolved oxygen, if any. A small pyrex glass bottle, covered with aluminium foil excluding its base, and containing liquid scintillator as well as thermocouple of digital thermometer, was first dipped in liquid nitrogen for some time to attain a temperature of about 220 K. Then it was taken out and placed at the centre of the copper cylinder along its axis. By this arrangement the temperature of the liquid scintillator went on increasing very slowly, and for a particular reading, i.e. counts per minute (regarded as index of light output) under gamma excitation, it remained constant for a few minutes. The purpose of interposing a long light guide between the base of the liquid scintillator bottle and the photomultiplier was to eliminate any cooling effect on the latter.

For inducing luminescence in the liquid scintillator gamma rays from Ra^{226} source were used, while the integral counting circuit comprised a quartz photomultiplier tube (EMI 6255), preamplifiers, linear amplifier, discriminator of energy analyser, stabilised power supply and a digital scalar (all ORTEC design). Measurements of light output (counts/minute) were made by keeping the gain of amplifier, operating voltage of photomultiplier, and discriminator bias of energy analyser constant while temperature was increased from 220 to 290 K.

3. Results and discussion

The points in Fig. 1 represent the measured values of the light of deoxygenated toluene based liquid scintillator under gamma excitation as a function of temperature T in the range 220 to 290 K. It is evident that scintillation response increases 1.43 times when temperature falls by a factor of 0.76. Figure 2 refers to the fluorescence data given in Fig. 1 as a function of T^{-1} in log-linear coordinates; it is well encompassed by the relation

$$I_{low} - I = I_0 \exp(-E/kT), \tag{1}$$

where I is the count rate (index of light output) at temperature T, I_{low} is the saturation value equal to 1200 counts/minute, I_0 is the pre-exponential factor equal to 2×10^6 counts/minute, k is the Boltzmann constant and E is the activation energy of the rate process. The latter parameter is evaluated from the slope $d\ln(I_{low} - I)/d(1/T)$ of the straight line drawn through the data points in Fig. 2, using the expression $E = kd\ln(I_{low} - I)/d(1/T)$ which is readily derivable from Eq. (1), and is found to be equal to 0.21 eV.

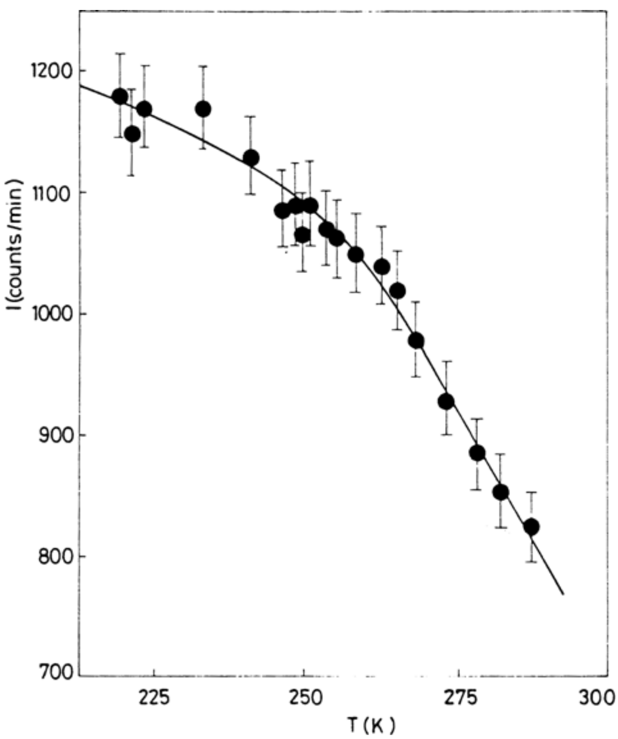

Fig. 1. Temperature dependence of the light output I for liquid scintillator: toluene + 6 g/l butyl – PBD + 0.1 g/l POPOP under gamma excitation. The error bars represent statistical error $\pm\sqrt{I}$

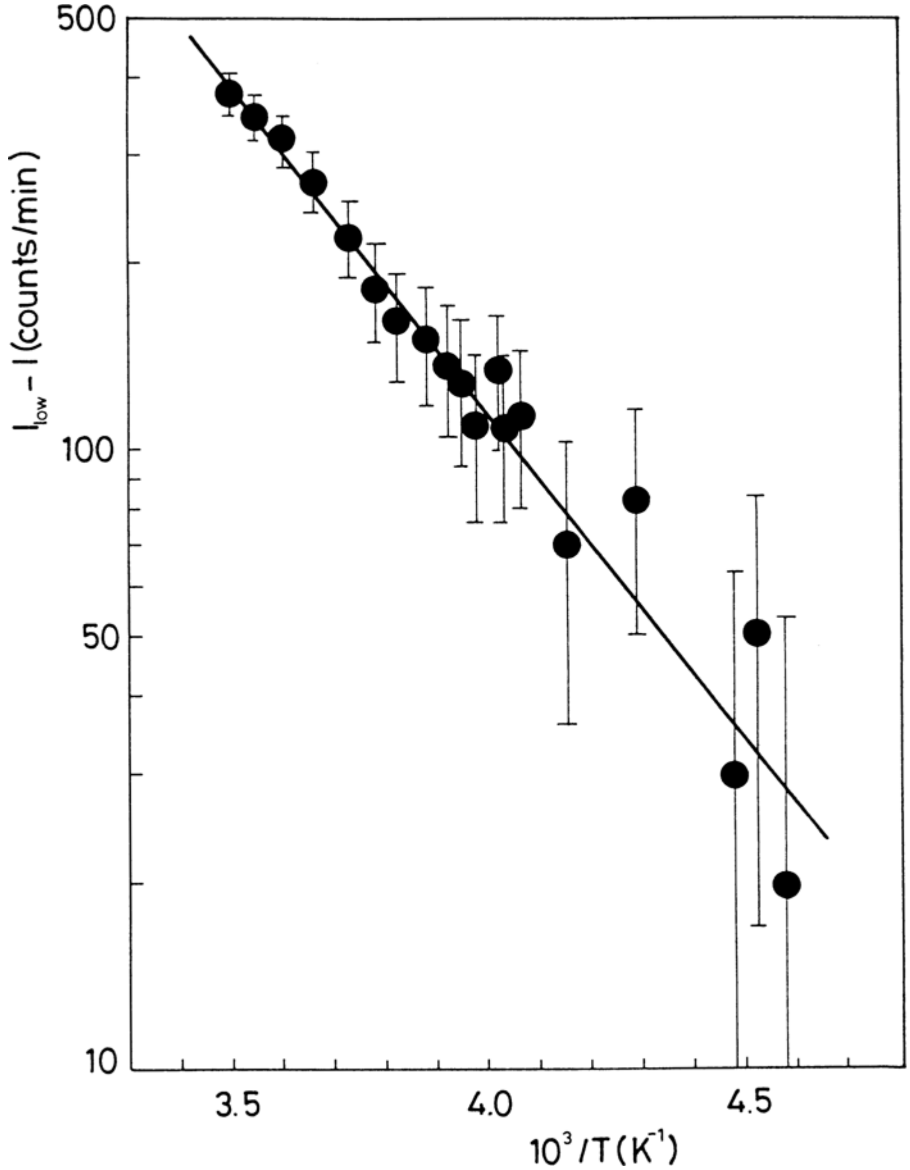

Fig. 2. Arrhenius plot of the light output parameter $I_{low} - I$ versus $1/T$, where $I_{low} = 1200$ counts/minute and values of I have been taken from Fig. 1

The decrease in the light output of liquid scintillator consisting of toluene + 6 g/l butyl - PBD + 0.1 g/l POPOP with increase in temperature from 220 to 290 K under gamma excitation can be attributed to the change in the mean free path of a gamma ray excited ion or electron with temperature; thermally-activated diffusion seems to cause quenching of the luminescence, as in the case of xylene based liquid scintillator NE 213 [6]. The value of the activation energy ($E = 0.21$ eV) obtained from the data given in Fig. 2 and compatible with Eq. (1), is typical for a diffusion controlled process in the temperature range investigated, and strongly supports this view. However, this may not be the unique interpretation of the observations referred to above. One may also seek the origin of the observed effects in intramolecular quenching due to internal conversion and/or inter-system crossing.

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