AN APPROACH TO INELASTICITY OF CRYSTALS FROM THE KINETICS OF THEIR TRIBOLUMINESCENCE

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The present paper reports on the dependence of the kinetics of triboluminescence (TBL) in sugar crystals on the modes of their mechanical crushing. It has been found that TBL does not appear in sugar crystals at the instant of impact of the load but a certain time lag is required for its appearance which depends on the value of the force applied on the crystal. The value of the decay time of TBL in sugar crystals is found to be $(4.0 \pm 0.3) \times 10^{-3}$ seconds for all the modes of crushing. The area between the TBL intensity and time increases with decrease of delay time between the impact of the load on the crystal and the appearance of TBL. This fact has been discussed on the basis of the inelastic behaviour of the crystals. The value of the mechanical relaxation time of sugar crystals has been determined with the help of the measurements of their TBL and it has been found to be 2.5×10^{-4} second.

1. Introduction

Triboluminescence (TBL) is a phenomenon of emission of light during the fracture of a crystal. Much work has been done on it, but its mechanism is complex upto the recent investigations. The earlier works on TBL were chiefly concerned with the investigation of new triboluminescent substances, triboluminescence spectra and the relation of TBL to other types of luminescence [1–5]. Recently, the works on triboluminescence have become interesting and it has been attempted to correlate TBL with the properties of crystals [6–9]. It has been shown in our earlier papers that TBL is intimately related with the elastic properties of crystals [10–12]. The present paper reports that it is possible to investigate the inelastic behaviour of sugar crystals from their TBL.

2. Experimental

Good crystals of sugar were chosen from the commercial cane sugar (specific rotation 64° at 29°C). To determine the kinetics of TBL, the crystal was placed on a clean transparent glass plate mounted on a wooden platform with a slit. Below the slit, a separately

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mounted IP28 photomultiplier tube (applied voltage 1000 V) was placed and it was coupled to a pre-amplifier. The output of the pre-amplifier was connected across a resistance of 200 Ω and fed to an HP181A storage oscilloscope. An impluse technique was employed for the crushing of a crystal, in which a fixed load can be dropped on the crystal from different heights with the help of a pulley of negligible friction.

A thin aluminium foil was placed on the crystal. A resistance and a battery were connected in series between the load (conducting) and the aluminium foil. As soon as the dropped load touched the aluminium foil, a signal was triggered to the oscilloscope. After a certain interval of time after the impact of the load on the crystal, it got fractured and light was emitted due to TBL. As soon as the photomultiplier received the light, another signal was obtained on the screen of the oscilloscope in the vertical direction. Thus, the kinetics of rise and decay of triboluminescence could be investigated.

In the present investigation, the sugar crystals were always crushed into crumbled masses along the direction of the crystallographic c axis. The size of the crystals used was $5 \times 4 \times 3$ mm^3.

3. *Results and discussion*

The dependence of the kinetics of TBL in sugar crystals on the modes of mechanical crushing has been shown in figure 1. It is seen that TBL does not appear at the instant of impact of the load but a certain time lag is required for its appearance. The delay time

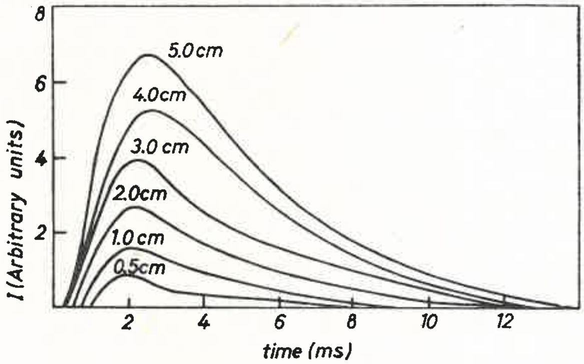

Fig. 1. Dependence of the kinetics of TBL in sugar crystals on the height, h, through which the load is dropped (h is equal to 0.5, 1, 2, 3, 4 and 5 cm)

between the impact of the dropped load and the appearance of TBL is shorter in the case of higher crushing heights while it is higher for the lower values of the crushing height. The rise of TBL is faster in the case of higher crushing heights while it is slower for the lower values of the crushig height.

The TBL intensity reaches its maximum for a particular value of time after the impact. The peak of the TBL curve is higher for higher values of the crushing height. It shifts toward the higher time values for higher values of crushing height. The area under the curve between TBL intensity and time increases with an increase in the crushing height.

The kinetics of decay has been shown in figure 2. It is seen that graph the between log I and t is a straight line with a negative slope which suggests the exponential decay of TBL, that is,

$$I = I_0 \exp(-t/\tau), \qquad (1)$$

where, I is the TBL intensity at the time t, I_0 is the maximum value of TBL intensity for a particular mode of crushing and τ, is the decay time of TBL. The value of the decay

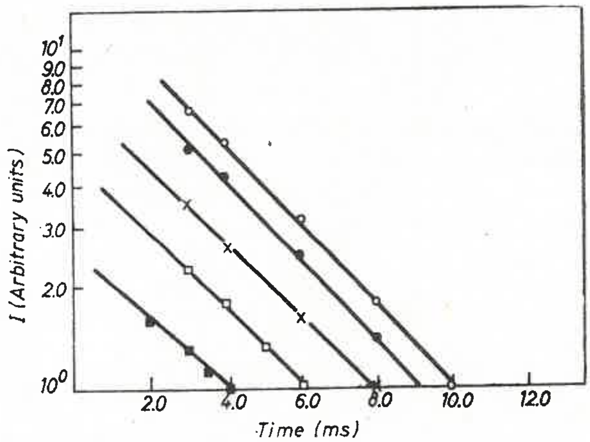

Fig. 2. Dependence of the decay of TBL in sugar crystals on the modes of mechanical crushing (h is equal to 0.5, 1, 2, 3, 4 and 5 cm)

time of suagr crystals, calculated with the help of equation (1) is found to be $(4.0 \pm 0.3) \times 10^{-3}$ seconds for all the modes of the crushing height.

The area under the curve between TBL intensity and time corresponds to the total number of photons emitted in the process of TBL. Thus, figure 1 indicates that the total number N_h, of photons emitted at the crushing height, h, increases with a decrease in delay time, t_h, between the impact and the appearance of TBL at the crushing height h. Figure 3 shows that the dependence of, N_h on t_h can be expressed by a relation

$$N = N_0 \exp(-t_h/\tau_m), \qquad (2)$$

where, τ_m, is the mechanical relaxation time of the crystal and N_0 is a constant. The value of the mechanical relaxation time calculated with the help of equation (2) is found to be 2.5×10^{-4} second.

It has been said that the area under the curve between TBL intensity, I, and time t, corresponds to the total number, N, of photons emitted in the process of TBL. Therefore, N, may be written as

$$N \propto \int I dt. \qquad (3)$$

The phenomenon of TBL is due to the creation of new surfaces at the instant of fracture of a crystal. Thus, its intensity will depend on the rate of creation of new surfaces which will depend on the rate of change of elastic energy. Hence, equation (3) may be written as

$$N \propto \int \frac{d}{dt}(\sigma^2/2E)dt, \quad \text{or} \quad N = C\sigma^2/2E + C_1, \tag{4}$$

where, σ, is the stress applied to the crystal, E is Young's modulus of elasticity of the crystal and C and C_1 are constants.

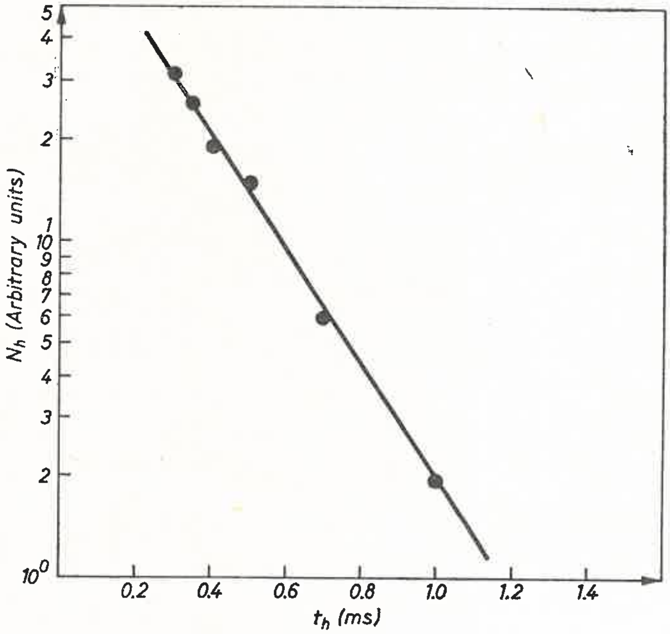

Fig. 3. Dependence of the number, N_h, of photons emitted in TBL process on the time to fracture the crystals

The TBL is zero below the critical value of the stress, σ_k, therefore

$$C_1 = -\frac{C\sigma_k^2}{2E}.$$

Thus, N_h, may be written as

$$N_h = \frac{C(\sigma^2 - \sigma_k^2)}{2E}.$$

When the stress, σ, is much greater than the critical value of the stress, σ_k, then the above equation may be written as

$$N_h = \frac{C\sigma^2}{2E} \quad \text{or} \quad N_h = \tfrac{1}{2} CE\varepsilon^2, \tag{5}$$

where, ε, is the strain in the crystal at the instant of its fracture.

Now, let the dependence of, N_h, on the mode of mechanical crushing of the crystal be taken into consideration. If it is supposed that the strain at the instant of fracture of the crystal is nearly the same for all modes of mechanical crushing, then equation (5) may be written as

$$N_h = C_2E, \tag{6}$$

where

$$C_2 = \tfrac{1}{2}C \cdot \varepsilon^2.$$

Due to the inelastic behaviour of a crystal, the value of E is not a constant but it depends on the modes of straining the crystal. It has been shown that the modulus of elasticity as a function of the time, t_f, required to fracture a crystal may be written in the form [13].

$$E = E_0 \exp(-t_f/\tau_m), \tag{7}$$

where, E and E_0 are Young's modulus of elasticity when the fracture times are t_f and zero, respectively, and τ_m is the mechanical relaxation time of the crystal.

The TBL appears in sugar crystals only when they get fractured. Therefore, the delay time, t_h, between the impact and the appearance of TBL may be taken as the time, t_f, required by the stress to fracture the crystal.

Thus, N_h, may be written in the following form with the help of equations (6) and (7)

$$N_h = C_2E_0 \exp(-t_h/\tau_m), \quad \text{or} \quad N_h = N_0 \exp(-t_h/\tau_m), \tag{8}$$

where,

$$N_0 = C_2E_0.$$

The empirical relation (2) is the same as equation (8). Further, the value of the mechanical relaxation time, τ_m, of the sugar crystals, obtained with the help of equation (2) is of the same order as that obtained by another method for other crystals [14].

Thus, it may be concluded on the basis of the present investigation that the inelastic behaviour of crystals may be studied with the help of their TBL.

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