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Triboluminescence Produced during Motion of Mercury on Glass Coated with Luminescent Materials

Seminar Paper*

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Abstract: Triboluminescence (TBL) is a type of luminescence produced during the rubbing of two dissimilar materials together or separation of two materials in contact. When mercury moves on the glass tube filled with inert gases such as He, Ne, Ar, etc, then TBL appears. The results combined with studies of static electrification and solid-state luminescent processes provide some possible schemes. The process of contacting mercury with glass causes the mercury to become positively charged and the glass negatively charged as a result of the transfer of electrons from the mercury moving into unfilled surface states of the glass. The separation of the mercury and glass surfaces initiates a discharge, which is based on the fact that the emission from He is observed. In case of the movement of the mercury, the discharge process could lead to highly energetic electrons and the interaction of these "soft rays" with scintillator could produce emission.

Keywords: Triboluminescence, Luminescent Materials.

1. Introduction

The appearance of electrification upon rubbing together dissimilar substances is a familiar phenomenon, which is commonly referred to as frictional electrification or tribo-electrification. The source of this electrification is the separation of electrical charges caused by contact potential differences. The friction serves merely to bring about intimate surface contact; polished disks of steel and glass when pressed firmly together and then separated show charge separation.

This type of charging between metal and glass also occurs when the metal is liquid such as mercury. Triboelectrification and triboluminescence of solids, in particular, have been investigated by many workers. Triboluminescence (TBL) is produced due to the contact phenomenon like triboelectricity,tribo-chemical reaction, tribo-thermal generation, etc. induced during the contact or seperation of two dissimilar materials in contact. The triboluminescence depends upon the nature of the material under deformation and the material used for producing deformation. Hence, the triboluminescence arises due to contact phenomena.

The study was concerned with the electrification i.e. the separation of electrical charges, which occurs upon rubbing together dissimilar materials, a process termed 'triboelectrification' or sometimes 'static electrification'. The related optical phenomenon is called triboluminescence [1]. The present paper reports triboluminescence excited by mercury movement on luminescent coatings.

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2. Mechanism of Triboluminescence

Whereas the ion transfer mechanism leads to charge separation, other competing processes lead to charge recombination or electrical discharge of ionic electrets. These processes include tunneling of electrons or field emission of electrons and dielectric breakdown of the surrounding gas [2]. The final charge on an ionic electret following contact and macroscopic separation depends on both charging and discharging processes. These discharging processes can discharge any charged object; they are not specific to ionic electrets.

We can estimate the magnitude of electric field which is produced during separation of charges. Consider the process of separating two flat, parallel surfaces, in which one has positive charge and the other has equal and opposite negative charge. If n of the mobile anions are transferred per unit area from the one surface to another surface, then the charge densities on the surfaces are +ne and -ne, respectively, where e is the magnitude of charge on a single ion. Under these conditions, the electrostatic work W required to transfer an anion from one surface to another surface is given by

$$W = n^2 e^2 .d/\varepsilon_0 \tag{1}$$

where d is distance between two surfaces, and ε_0 is permittivity of space. The potential V is given by

$$V = ned/\varepsilon_0 \tag{2}$$

Now, the field is given by

$$E = ne/\varepsilon_0 \tag{3}$$

It is to be noted that Equation (3) assumes a uniform distribution of charges on each surface. At equilibrium, the number of anions per unit area on the two surfaces is given by

$$n/(N-n) = \exp(-nde^2/\varepsilon_0 kT). \tag{4}$$

Equations (3) and (4) yield the magnitude of field. Given some reasonable assumptions about the number of ionic functional groups per unit area (N) and the distance at which ion transfer becomes kinetically prohibited , we can solve Equation (4) numerically for n, the number of ions that will be transferred at equilibrium.

3. TBL Excited by Mercury Movement on Luminescent Coatings

The conversion of mechanical energy into electrical energy and light (TBE and TBL). Due to the movement of mercury over luminescent coating materials has been investigated. The motion of mercury over the coated glass causes mercury positive charged and glass surfaces to be negative charged. Due to this process of charging mercury and glass surfaces involves the build-up of potential differences in excess of 20 V. The nature of these triboelectric potentials differs significantly from those observed in the absence of scintillator coating. For a preliminary investigation of the TBL, Keszthelyi and Bard [1] used hermetically sealed cell arrangements shown in Fig. 1. These were coated tubes containing a small amount of mercury sealed under vacuum which produced light emission upon moving or shaking the mercury. These closed cells worked essentially without change over a period of several months when used intermittently.

For a continuous test, a glass wheel, scintillator coated, and containing mercury, was rotated by connection to a motor revolving at 0.5-5 rpm; in which emission was observed for 48 hr in this arrangement before the test was terminated. In such cells, even the slightest movement of the Hg in the coated tube produced the characteristic luminescence

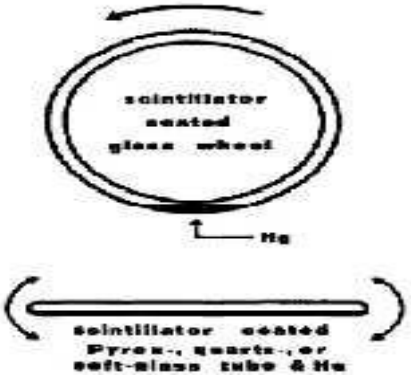

Fig. 1. Appearance of triboluminescence for prolonged periods of time in hermetically sealed cells. The 9 inch diameter evacuated hollow wheel was rotated by using on electric stirrer motor equipped with speed control (after . Keszthelyi and Bard, ref. [1]). Keszthelyi and Bard [1] have made quantitative measurements of the triboelectric potentials generated at the luminescent coating materials by the movement of the mercury using the arrangement shown in Fig. 2.

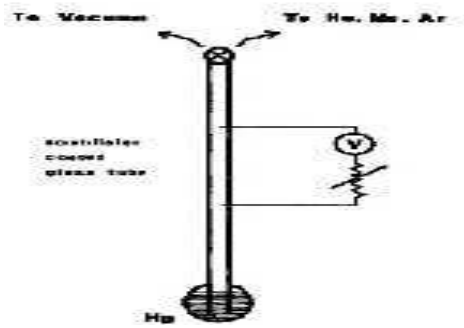

Fig. 2. Measurement of tribeelectric potentials (total length of the 6 mm OD tube was 34 in., separation of the imbedded electrodes was 10 in.)(after Keszthelyi and Bard, ref. [1]). Fig. 3 shows the potential-time behavior (termed here a "potentiogram") between the platinum contacts taken at various ohmic resistance settings of the electrometer [1]. The two electrodes remain shorted by the descending Hg column, whereby the reading on the electrometer (or from the operational amplifier in the voltage follower arrangement) was zero. A sudden increase in potential was observed when the Hg level moves below the top platinum lead (with the lead contacting the mercury positive with respect to the upper glass lead). The subsequent variations and the detailed shape of the "*potentiogram*" were highly reproducible for a given coating, but varied from coating to coating. Such result allowed "*finger-printing*" a coating surface, and also checking for any bald spots, striations, etc.

The maximum voltage generated by the tribo-electrification process could not be determined in these experiments, but it was found to be in excess of the amplifier limiting voltage of about 20V when the high impedance solid-state operational amplifier was substituted in place of the electrometer in Fig. 3. With the electrometer, the highest resistance setting corresponding to the vacuum tube impedance of the electrometer itself could not be applied for fear of damaging the instrument. Debeu [3] measured maximum voltages in excess of 100V on contact electrification using nickel as the stationary phase, and NaCI or quartz particles as the moving phase.

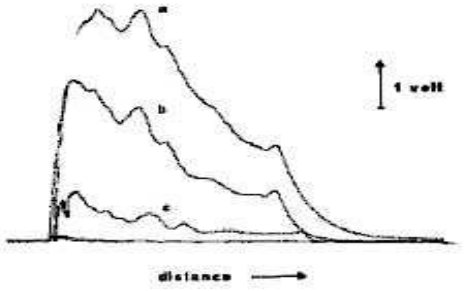

Fig. 3. Potentiogram of the triboelectrically generated voltages with apparatus of Fig. 2. The constant recorder sensitivity is indicated by the "1 volt" scaler. The resistance settings of the electrometer were (a) 10^{11}, (b) 10^{10}, (c) 10^{9} ohms, The rate of fall of the Hg column was 3 in./min. (after Keszthelyi and Bard, ref. [1]). Significantly different results were obtained in the same cells under similar conditions when the luminescent coating was removed [1]. As shown in Fig. 4 , complete discharges occur, involving breakdown of the gas in the bulk volume. When a large number of potentiograms were examined, it was unmistakable that the voltage build-up and discharge pattern was quite random, in sharp contrast with the potentiograms taken in the presence of a luminescent coating where the potentiograms were highly reproducible.

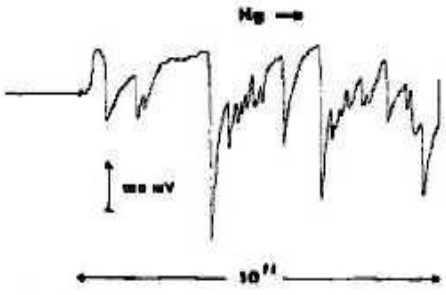

Fig. 4. Potentiogram of the triboelectrically generated voltages under the same conditions as Fig. 3,except that the coating was completely removed; the resistance setting of the electrometer was10^{11} ohms (after Keszthelyi and Bard, ref. [1]).

4. Conclusion

The mechanism for the triboluminescence of the luminescent coating may involve energy transfer from excited state species of the mercury or inert gas to the luminescent coating. However, the lack of luminescence of certain fluorescent dyes and the relative independence of the emission on the type or pressure of inert gas indicates the possibilities of the other mechanisms. The discharge process could lead to highly energetic electrons and the interaction of these "*soft β rays*" with luminescent coating could produce emission. Furthermore, a third mechanism can also be suggested by experiments on charge injection into aromatic crystals.

References

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