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Comments on the number of sensitivity centres in silver halide grains

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Abstract. A comment on the number of sensitivity centres in silver halide grains of nuclear emulsions is made and a theory for its evaluation at different temperatures is presented. The results at room temperature agree satisfactorily with assumptions made by various workers.

Keywords. Photographic sensitivity centres, silver halide grains, nuclear emulsions.

1. Introduction

It is well known (Toy 1922; Mitchell 1957) that the silver halide grains of photographic emulsions contain sensitivity centres which are responsible for the development of the latent images in them. These sensitivity centres are the specks of silver sulphide, some impurities, dislocations and defects in the grains. So far no one has given a suitable quantitative explanation of the number of these centres, their distribution inside the grains and the effects of various physical phenomena in AgBr grains.

It is obvious from the work of Sharma and Gill (1962), Sharma and Gaur (1969) and Mahendra Singh *et al* (1973) that correct information regarding distribution of the sensitivity centres in AgBr grains of emulsions is very helpful in explaining the process of ionization and hence the process of latent image formation in nuclear emulsions due to passage of charged particles.

2. Theory

According to the theories of Gurney and Mott (1938) and Mitchell and Mott (1957) for the formation of latent image, any ionizing particle, while passing through AgBr grain loses energy and ejects electron-hole pairs from its normal state in Br^- ion ($Br^- \rightleftarrows Br + e^-$). The holes so formed can be trapped very rapidly at hole traps forming a recombination centre. The recombination of free holes with free electrons in emulsion is not possible, but there is a possibility of recombination of free electrons and trapped holes at the recombination centre. The possibility of recombination of free holes and trapped electrons is also negligible.

The rate of loss of electrons due to the recombination process is governed by the following relation (Sharma and Singh 1971):

$$(dn/dt) \propto n^2 \tag{1}$$

where n is the number of electrons or holes available for latent image formation in silver bromide crystals of G–5 emulsion. Integrating eq. (1) and applying the boundary condition that at $t = 0$, $n = n_0$ (maximum number of electrons or holes produced by the passage of charged particles), we get the following relation:

$$n = \frac{n_0}{1 + \frac{3n_0\,(ct)\,a^3}{2\pi x_0 d^3} \exp\left(\frac{W_0}{2kT}\right)} \tag{2}$$

where x_0 (≈ 30) is a constant defined by Mott and Gurney (1957); d ($\approx 0 \cdot 27 \mu m$) is the mean diameter of the silver bromide grains of emulsion; a, the lattice constant of AgBr crystal ($\approx 5 \cdot 755$ Å); W_0 ($\approx 0 \cdot 7625$ eV) is the minimum energy required to liberate an interstitial Ag^+ ion; k is the Boltzmann constant; T, the absolute temperature; c, the constant of proportionality and t is the time of recombination respectively. The value of (ct) as calculated by Sharma and Gill (1962) comes out to be $\simeq 4 \cdot 06$. n_0 is related with the specific energy loss and is given by the following relation of Sharma and Gaur (1968):

$$n_0 = 46 \cdot 55\,(dE/dR) \tag{3}$$

dE/dR is expressed in $GeV \cdot m^{-1}$ units.

The probability of development of a grain is given by the following relation of Sharma and Gill (1962)

$$\pi = 1 - \exp\left[-(\theta/g_0\phi) \exp(-\theta)\,(1-\phi)^{-1} \{1 + (\theta-\phi)\,(1-\phi)^{-1} + \cdots\}\right] \tag{4}$$

where $\theta = n/S$, $\phi = B/S$

S = average number of sensitivity centres in a grain.

B = (457), limiting value of effective ionization at an energy loss of several thousands of $GeV \cdot m^{-1}$.

g_0 = (275), average number of grains from 100 μm length of an unprocessed emulsion.

Fowler and Perkings (1951) have given the following dependence of the specific energy loss (dE/dR) on the charge (Z) and the velocity (β) of the particle traversing a G–5 emulsion

$$dE/dR = \frac{0 \cdot 587\, Z^2}{\beta^{1 \cdot 46}}\ GeV \cdot m^{-1} \tag{5}$$

The probability of development π and the mean gap length $\bar{\omega}$ are related by the following relation (Sharma and Gill 1962)

$$\pi = d/\bar{\omega} + d, \tag{6}$$

Now substituting eqs (2), (3), (5) and (6) in eq. (4), we get

$$S = \frac{g_0 B^2 \left[1 + 27\cdot 325 \left\{ \frac{3ca^3}{2\pi x_0 d^3} \exp\left(\frac{W_0}{2kT} \right) \right\} tZ^2 \beta^{-1\cdot 46} \right]}{g_0 B \left[1 + 27\cdot 325 \left\{ \frac{3ca^3}{2\pi x_0 d^3} \exp\left(\frac{W_0}{2kT} \right) \right\} tZ^2 \beta^{-1\cdot 46} \right]} \times \frac{\log\left(1 + \frac{d}{\bar{\omega}}\right)}{\log\left(1 + \frac{d}{\bar{\omega}}\right) - 27\cdot 325\, Z^2 \beta^{-1\cdot 46}} \quad (7)$$

3. Results and discussion

The values of S (average number of sensitivity centres in a grain) can be calculated from eq. (7) as we know the magnitude of all the parameters in the right hand side of this equation.

The experimentally observable parameter in eq. (7) is the mean gap length $\bar{\omega}$. The experimental plot for $\bar{\omega}$ in case of relativistic particle tracks ($\beta \approx 1$) of charge Z is shown in figure 1. On this basis the calculations of S by varying T have

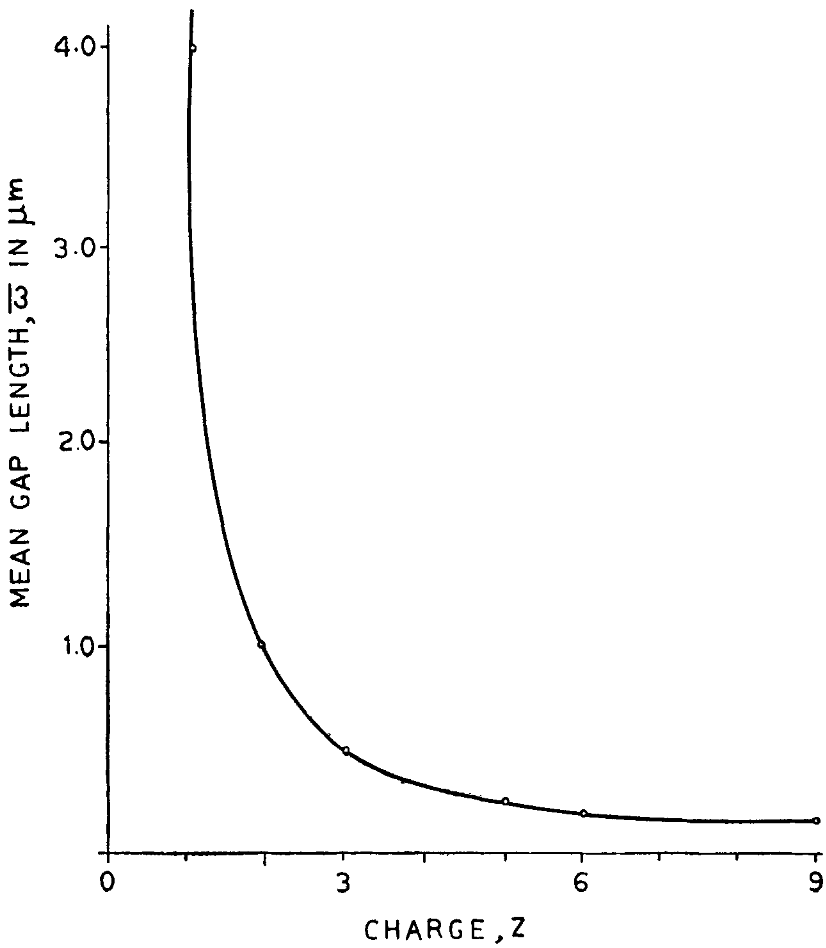

Figure 1. Variation of $\bar{\omega}$ with Z.

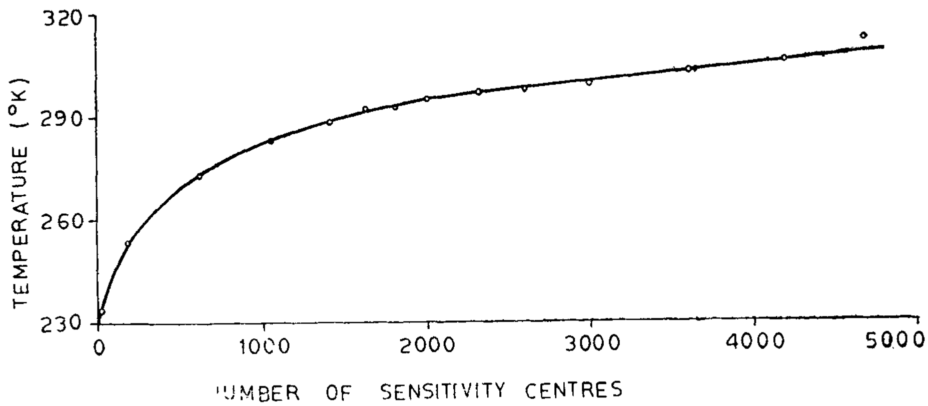

Figure 2. Curve showing a relation between the computed number of sensitivity centres (S) *vs.* temperature (° K).

been made for singly charged relativistic particles (with the observed values of $\bar{\omega}$) and the relation between S and T is shown in figure 2.

At low temperatures the chemical sensitization becomes ineffective and causes a decrease in surface sensitivity to an extent greater than the internal sensitivity (Mitchell 1957). The number of sensitivity centres increases with the temperature but at high temperatures the mobility of Ag^+ ions and electrons also increases to such an extent that they may cross each other but may not be able to combine at the sensitivity centres as they require some optimum time to remain in each other's potential field for combination. The thermal agitations tend to destroy the latent image at high temperatures (Barkas 1963) and, therefore, sensitivity centres at this stage do not contribute to the latent image formation as the sites remain as free centres. This clearly shows that at higher temperatures the probability of their combination at trapping centres decreases.

Mees (1959) has suggested that the number of atoms of light-liberated silver in exposed grain is between 1–500, and the number of molecules of silver sulphide in sensitized grain is between 1,000–50,000. The number of sensitivity centres estimated by us between 233° K–273° K is found nearly as 40–600, while between temperatures 283° K–373° K it comes out approximately as 1,050–46,000 (the calculated value of sensitivity centres equal to 46,000 at a temperature of 373° K is not shown in the graph). It is clear from figure 2 that around room temperature the magnitude of sensitivity centres (*i.e.*, 1,500–2,000 sensitivity centres between 283° K–291° K) is in good agreement with the values used by Sharma and Gill (1962), Sharma and Gaur (1969) and Mahendra Singh *et al* (1973) for their work of mechanism of latent image formation and nuclear track structure.

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