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Abstract

Full Text

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PHYSICS

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DEVELOPMENT OF NUCLEAR EMULSIONS

(Presented by Academician A. P. Aleksandrov on 2 IX 1960)

During prolonged development of nuclear emulsions, saturation is observed in the grain density on the tracks of relativistic particles. At the same time, along with the usual fog, a fog consisting of very fine grains appears and very rapidly increases throughout the volume of the emulsion. It is of interest to consider the nature of this fine-grained fog, whose rapid increase limits the development process.

The most natural assumption seems to be that the appearance of fine-grained fog is the beginning of development of the main mass of nonionized microcrystals of the emulsion. Since the development centers in nonionized microcrystals are small, the development of each such crystal begins after a long interval of time following the start of development of the ionized microcrystals. In nonionized microcrystals the development process proceeds very slowly, and the developed silver grains at the beginning of the process are still small. If this assumption is correct, then the sizes of the developed grains of the fine-grained fog should increase during development up to the sizes of the grains in the tracks.

To test this assumption, the following experiments were carried out. P emulsions from the technical-plate factory were poured onto a glass support in the form of very thin layers. Unexposed layers were developed with an amidol developer of ordinary composition for different lengths of time. For the different development times, the following average grain sizes were obtained:

Development time, hours	0.25	1.0	21.0	40.0
Mean diameters of grains of ordinary fog in μ	0.5	0.55	0.55–0.6	0.55–0.6

Development time, hours	0.25	1.0	21.0	40.0
Mean diameters of grains of fine-grained fog in μ	0.1-0.12	0.15-0.20	0.4-0.45	0.5-0.55

These experiments show that the nonionized microcrystals of the emulsion are developed, and that their number and sizes increase with development time.*

Let us consider what causes may lead to the formation of fine-grained fog during prolonged development. If one assumes that in the unexposed microcrystals, on average, each sensitivity center contains several silver atoms, then, owing to statistical fluctuations, in a number of microcrystals the centers will be sufficiently large to serve as development centers. The number of such centers will depend on the development threshold under the given conditions. To illustrate this statement, Fig. 1 gives the Poisson distribution of the number of silver atoms in the sensitivity centers of microcrystals at an average number 2 of atoms per center. $W(\nu)$ is the probability of having ν silver atoms in a sensitivity center

$$W(\nu) = \frac{\lambda^{\nu}}{\nu!} e^{-\lambda}. \quad (\lambda = 2).$$

In the same figure is shown the dependence of the number of microcrystals $f(\nu)$ that have sensitivity centers with a number of atoms greater than or equal to ν, located in a volume of 200 μ^3 of emulsion:

$$f(\nu) = 4 \cdot 10^4 \sum_{\nu'=\nu}^{\infty} W(\nu').$$

As can be seen from the figure, $W(\nu)$ decreases rapidly with increasing ν, and the probability for an individual crystal to have a development center with a number of atoms greater than or equal to, for example, 10 is very small. However, because the total number of microcrystals in the volume of emulsion

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* Here and below we do not consider the ordinary fog that appeared in the first stages of development and that is associated with the presence in the emulsion of some number of microcrystals which, even before irradiation, already had sufficiently large development centers.

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Fig. 1

Figure 1: Fig. 1

is large (in 200 μ^3 of emulsion there are about 8000 microcrystals), in 200 μ^3 in this case there are already 2 microcrystals with such a number of atoms. Here it is assumed that each microcrystal has on average 5 sensitivity centers on its surface. A sensitivity center with 10 silver atoms can apparently already serve as a development center. On going to ν equal to 9, the number of microcrystals capable of development increases by a factor of 5.

Fig. 1

These arguments are fully applicable also under the condition of any number of sensitivity centers on the surface of the microcrystals.

Thus, the graphs presented show that if the development threshold corresponding to the beginning of development of the main mass of microcrystals is reached, the number of developed grains will increase unusually rapidly as development proceeds further.

Comparing the experimental observations with the calculated graphs, one may consider that the appearance of a fine-grained fog during prolonged development is the beginning of development of the main mass of nonionized microcrystals of the emulsion.

Let us consider the question of the probability distribution of silver atoms in the development centers of microcrystals ionized by the action of a relativistic particle that has passed through them. From the known fact (^{1}) that the grain density g on a track depends linearly on the ionization I in the region of prerelativistic ionization, one can obtain that the probability $\varphi(\nu)$ of having surface centers with a number of atoms ν is proportional to $1/\nu^2$. Indeed:

$$g = \int_{\infty}^{\nu_0} \varphi(\nu)\, d\nu = \frac{I_0}{I} \int_{\infty}^{\nu_0} \psi\left(\frac{\nu I_0}{I}\right) d\nu = \int_{\infty}^{\nu_0 I_0/I} \psi(u)\, du = g(u)\Big|_{\infty}^{\nu_0 I_0/I} = g\left(\frac{\nu_0 I_0}{I}\right), \tag{1}$$

where ν_0 is the number of atoms in the development center corresponding to the development boundary; I_0 is the ionization corresponding to the passage of a relativistic particle; $\psi(\nu)$ is the probability distribution of having surface centers with a number of atoms ν for a relativistic particle.

In deriving the formula, the natural assumption was made that when the ionization changes the shape of the atom distribution curve is the same as in the case of ionization by a relativistic particle, but in each sensitivity center the number of silver atoms changes in proportion to the ionization. Many-

developer I_0/I in (1) appears from the normalization condition

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Fig. 2

Figure 2: Fig. 2

Fig. 3

Figure 3: Fig. 3

$$\int_0^\infty \frac{I_0}{I}\,\psi\left(\frac{\nu I_0}{I}\right)\,d\nu$$

for a prescribed number of surface centers. Since the grain density g is proportional to the ionization I over rather wide limits, $g \sim 1/u$, while $\psi(\nu)$ must be proportional to $1/\nu^2$, the probability of having a development center with a number of atoms greater than ν will then be proportional to $1/\nu$.

In order to reconcile the fact that the grain density in the track of a relativistic particle depends only weakly on development time during prolonged development, while the fog simultaneously increases strongly, it is necessary to assume that $\Delta\nu$, corresponding to a sharp increase in fog, must lead to only a small change in the grain density in the track, i.e., $\Delta\nu/\nu_0$ must be much smaller than 1.

Fig. 2

Fig. 3

Figure 2 shows the curve of the dependence $f(\nu)$ and the curve const$/\nu$. From consideration of the curves it is seen that, for $\nu_0 = 10$ and $\Delta\nu = 1$, corresponding to a sharp increase in fog, the inequality $\Delta\nu/\nu_0 \ll 1$ is well satisfied.

In this case, indeed, within the limits of measurement error, no increase in the grain density in the tracks of relativistic particles should be observed.

The question arises whether the chosen parameter $\nu_0 = 10$ is reasonable and whether the required probability distribution $\psi(\nu) \sim 1/\nu^2$ can be obtained from the point of view of the ionization processes produced by a relativistic particle.

If it is assumed that the energy loss of a particle in traversing 1 g/cm^2 of silver bromide is equal to 1.4 MeV (^{2}), and that 7.5 eV is expended in forming one electron, then on the average about 24 electrons arise in a microcrystal, which corresponds to the passage of a particle through 2/3 of the diameter of the microcrystal for an average diameter of $0.305\,\mu$.* Figure 3a shows the Poisson distribution, taking into account the statistical fluctuations in the number of electrons produced and referring to the case in which a relativistic particle traverses 2/3 of the diameter of the microcrystal. When the nonuniformity of the microcrystal sizes and the difference in the path lengths of particles in microcrystals of a given diameter are taken into account, a considerable broadening

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Fig. 4

Figure 4: Fig. 4

of the curve is obtained. Figure 3b shows the distribution that takes into account the main factor—the different path lengths of particles in the crystals. It is evident that the assumption of the presence of a single sensitivity center in a microcrystal leads to the distribution corresponding to curve **b**. Such a distribution is sharply inconsistent with the law $\psi(\nu) \sim 1/\nu^2$.

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[*] Since the probability of collision of a particle with a microcrystal of diameter d is proportional to $d^2F(d)$, where $F(d)$ is the distribution of microcrystals by diameter, then, for an average diameter of $0.28\,\mu$, the most probable value in a collision is $d = 0.305\,\mu$.

Let us suppose that in each microcrystal there are several traps, some of which are located on the surface. In this case the most effective of them are those traps that are situated in the immediate vicinity of the points at which the particle enters and leaves the microcrystal.

Fig. 4

Figure 4 gives the distribution curve $\psi(\nu)$, constructed under the assumption that, not far from the point of entry and exit of the particle, there is on average one trap, and that the selected region of the microcrystal adjacent to the surface contains on average 8 electrons. In calculating the distribution, fluctuations both in the number of traps and in the number of electrons formed in this region were taken into account. It is seen from the figure that the distribution obtained as a result of the calculation is close to the dependence const$/\nu^2$. Similar curves are also obtained for other values of the number of electrons.

Thus, within the simplest assumptions, taking into account the fluctuations arising in the process of ionization and the fluctuations in the number of traps, it is possible to obtain a picture that qualitatively explains the experimental results.

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