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The Photographic Action of Ionizing Particles. I.

THE FORM OF THE BLACKENING CURVE FOR PHOTOGRAPHIC FILM EXPOSED TO RADIATION

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The form of the curve expressing the blackening density of an irradiated photographic film is investigated as a function of the exposure. The data obtained for films of various sensitivity and various types of radiation, as well as the data concerning the effect of supplementary exposure, are used to determine the degree of dispersion of the latent image.

INTRODUCTION

AT the present time there is in the literature a great amount of data concerning the type of dependence between the photographic blackening and the intensity of a beam of ionizing particles. These data cover the action of particles of various types and various energies. However, usually the purpose of obtaining such data was purely utilitarian and, hence, practically no attempts were made to connect the results obtained with the theory of the formation of a latent image due to the action of these particles.

It should be stated that for the case of the photographic action of light, the interpretation of the shape of the blackening curve, in particular, the portion near the origin, has yielded important results[1]. In particular, the curves expressing the optical density of blackening, D, (above the fog) as a function of the exposure, H, i.e., the product of the intensity of radiation and the exposure time*, can have various forms depending on the values of the radiation intensity and the exposure time at which the given curve was obtained. Generally speaking, two types of curves are possible (Fig. 1). The curve of the first type (I) is characteristic for small amounts of irradiation and long exposure times. The curve shows that, under these conditions, large centers of latent image are formed in the emulsion crystals, thus yielding developable crystals. The curve of the second type (II) is characteristic of strong irradiation and short exposure times. These conditions point to the formation of extremely small centers – the so-called subcenters which, in spite of being thermally stable, do not contribute to the developability unless something is added to these latent centers by additional exposure or in some other way. Thus, for the case of the photographic action of light, the analysis of the blackening curves permits us to establish the degree of dispersion of the latent image[2], i.e., its distribution among separate centers. At the same time, the data concerning the dimensions of the centers (even if they are comparable) formed under different conditions may serve as a means of understanding the mechanism of formation of the latent image.

For the case of photgraphic action of ionizing particles, no such analysis is available. However, numerous facts indicate that the degree of dispersion of the latent image created by these particles can vary to a great degree, depending upon the ionizing properties of the particles and the sensitivity of the photographic film[3]. Data which is available in the literature on the blackening curves obtained by particle irradiation point to the fact that they can be evaluated by analogy with Fig. 1. Thus, for α- particles of natural origin, the experimental curves can be very easily described by the equation $D = D_0(1 - e^{-kH})$ which can be obtained theoretically[4] merely by assuming that every crystal which comes into contact with the α- particles can be developed, i.e., it acquires a sufficiently large center of latent image. Therefore, it can be expected that in this case the blackening curve will be of type I. From the equation of the curve, its slope will be a maximum at

* This relation differs from that widely used in the photographic literature, which expresses a dependence between the blackening density and the logarithm of the exposure, and which is represented graphically by the so-called characteristic curve.

[1] P. C. Burton and W. F. Berg, Photograph. J. 86B, 2 (1946).

[2] P. V. Meiklar, Uspekhi Fiz. Nauk **38**, 43 (1949).

[3] A. L. Kartuzhanskii, Uspekhi Fiz. Nauk **52**, 341 (1954).

[4] S. Kinoshita, Proc. Roy. Soc. (London) **83A**, 432 (1910).

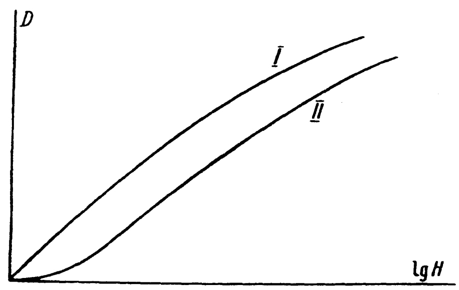

FIG. 1. *I* - the curve characteristic for small intensities and long exposure times; *II* - the curve characteristic for high intensities and short exposure times.

the origin. For protons, which possess smaller ionizing power and form smaller latent image centers, the blackening curves differ considerably from type I, and approach type II[5]. If electrons are used for irradiation, the form of the portion of the curve close to the origin, which is characteristic of the curve of type II, can be observed with an even greater degree of clarity. This becomes more noticeable as the energy of the particles is increased and the sensitivity of the photographic film is decreased[6].

It was deemed necessary to conduct a systematic study of the forms of the blackening curves of various photographic films exposed to irradiation by various ionizing particles, and to correlate the data obtained in this manner with the general scheme of the formation of the latent image under the action of the particles. By comparing these data to the analogous data for the case of light, it is possible to estimate the degree of similarity of the photographic actions of the light and the particles. A study of this kind had also some practical interest for us in connection with the development of a method of quantitative β - radiography from the blackening data[7]. We have not considered the case of high density blackening for which a certain analogy with the action of light has recently been discovered[8].

EXPERIMENTAL METHOD

The following radioactive isotopes were used as particle sources: Po^{210}, possessing monochromatic α - radiation with the energy 5.3 mev; C^{14}, possessing β - radiation with a maximum energy of 0.155 mev, i.e., with a comparatively high ionizing power; P^{32}, possessing β - radiation with a maximum energy of 1.7 mev, i.e., consisting chiefly of particles with the minimum ionizing power, or very close to it. In a number of the other experiments an electron microscope with an accelerating potential of 50 kv was used.

A number of photographic films of widely differing sensitivity were used in the experiments: positive plates of the Plant No. 2 GUKPP, electron sensitive plates of the same manufacturer, and also films of high concentration designed especially for the detection of ionizing particles. To obtain a scale of blackening, each plate was exposed for different times, i.e., blackening for different exposure times was produced on different portions from the same source. This was achieved by displacing the plates (laterally) with respect to the source. The same exposure method was used in the case of the electronmicroscope. The sources used possessed a sufficiently high activity (of the order of 10 - 100 μc on a cm^2 of surface), which permitted us to use exposure times of not more than 20-30 minutes.

The developing process was done in a metol-hydroquinone developer, ID-19, diluted with distilled water in the ratio of 1:2, at a constant temperature (20 ± 0.5) °C, and stirred with a soft rubber brush. If, in a given experiment, it was necessary to compare several plates, they were developed concurrently. Developing time amounted to 20 minutes for the highly concentrated thick films and 8 minutes for the positive plates and the electron sensitive plates. Upon the determination of the developing process, the highly concentrated films were placed in a 1% solution of acetic acid for 10 minutes, after which they were fixed and washed in the usual manner. All other films were rinsed in flowing water and then immediately submerged in the fixing solution.

The measurement of the blackening density was performed on the photoelectric microphotometer MF-2. The weak blackening was of greatest interest to us as it gave the initial portion of the blackening curve.

As the relative error in measuring these blackenings is rather large, each blackening was measured a number of times. Moreover, the results of several experiments were completely eliminated because of the inhomogeneity of the observed blackening. Essential precautions and critical evaluation of the results insured the measurements of small blackening densities with the error ΔD of not more than 0.01. For blackenings induced by

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[5] P. Brix, Z. Physik. 126, 35 (1949).

[6] N. Digby, K. Firth and R. J. Hercock, J. Photograph. Sci. 1, 194 (1953).

[7] I. L. Finagin, A. L. Kartuzhanskii and B. P. Soltitskii, Zh. Tekhn. Fiz. 25, 1276 (1955).

[8] K. S. Bogomolov and V. N. Zharkov, Dokl. Akad. Nauk 92, 1161 (1953).

α - particles in the highly concentrated films, it was possible to increase the precision of measurements of small densities by counting the number of tracks appearing on a unit area of the film and subsequently correlating this number with the optical blackening density of the same area in accordance with a specially constructed scale. The tracks were counted with the aid of a binocular microscope, MBE - 1, equipped with a 90 power immersion objective and 15 power eyepiece. Initially it was thought that the method of counting the tracks could also be applied to blackenings induced by β - particles; however, the lack of monochromaticity of the radiation of the β sources and the fact that the tracks varied in their appearance and lengths, and also because of the density of grains in these tracks, led to inexact results. The error in this case exceeded all the incidental errors incurred in the direct measurements of blackening densities.

All blackening densities in the curves shown below are given after the fog density has been subtracted.

In certain experiments the films, after being irradiated with particles, were subjected to additional exposures by light of varying spectral distribution. The plate was placed in a special plate holder into the opening of which a corresponding colored light filter and also a neutral light filter were inserted. A 300 watt projection lamp was used as a source; the filament of the lamp was placed parallel to the plate. We found that for a plate of dimensions 3 × 4 cm, and a distance between plate and lamp of 15 cm, the variation in uniformity of illumination at various points of the plate did not exceed 5%.

EXPERIMENTAL RESULTS

In Fig. 2, the blackening curves are shown that were obtained by the irradiation of six photographic films with α-particles from the Po^{210} source. The parts of these curves close to the origin are plotted to a larger scale in the insert. Among the four highly concentrated films designated A, B, C, and D, the film A is the least sensitive. The traces of the α - particles on this film consist merely of several points and are very difficult to distinguish, while the blackening is very slight even for exposures several times longer than those used for other films.

From the study of Fig. 2, it can be seen that the blackening curves for all films except A pass through the origin of coordinates and have maximum slope at that point. Although the use of the criterion of Fig. 1 has not been rigorously substantiated, these curves should undoubtedly testify to the formation of sufficiently large latent image centers in every emulsion crystal impinged upon by an α - particle in any of the films. This is also known from other data[3]. The blackening curve of the film A, unlike all the other curves and in contrast to the data concerning the action of α - particles quoted in the literature, does not pass through the coordinate system origin. Its first

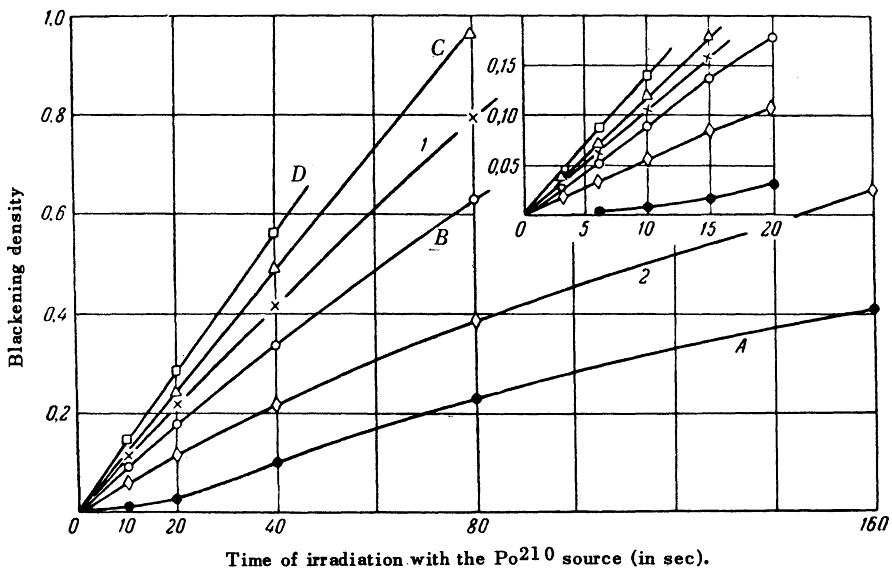

FIG. 2. *1* - the electron sensitive plates; *2* - positive plates, A, B, C, D, highly concentrated films

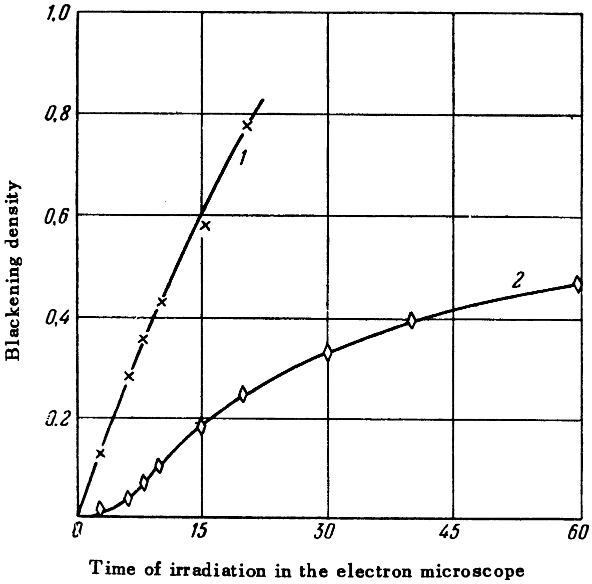

FIG. 3. *1* - electron sensitive plates; *2* - positive plates

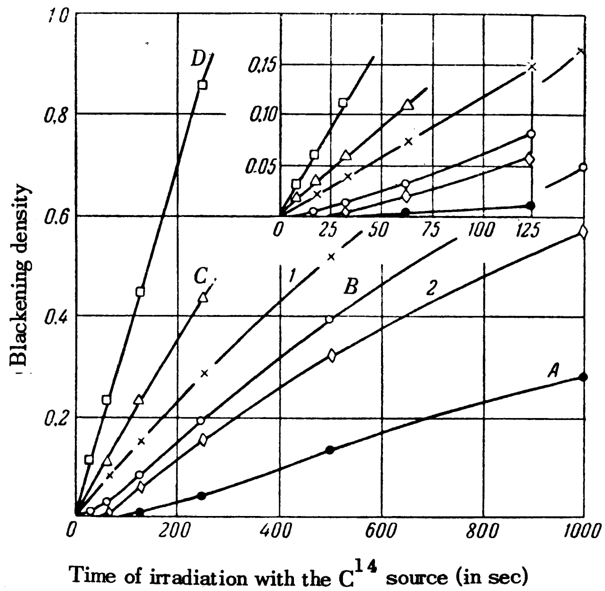

FIG. 4. *1* - electron sensitive plates; *2* - positive plates, *A*, *B*, *C*, *D* - highly concentrated films.

derivative does not have a maximum at the beginning of the curve and it is not a monotonic function as it is the case with all other curves. Since the sensitivity of the film *A* is quite small, relatively few of its crystals impinged upon by α - particles become developable, i.e., acquire latent image centers which are capable of effecting development. This is easily seen from the character of the α - traces in this film. If this is the reason for the behavior of the film *A* , then we are justified in relating the form of the initial portion of the blackening curve with the dimensions of the silver centers in the emulsion crystals (as we have related them for the case of light in Fig. 1), and also with the sensitivity of the film.

In Fig. 3, the blackening curves are given for the electrosensitive and positive plates subjected to the irradiation of 50 kv electrons in the electron microscope. In Fig. 4, the blackening curves are given for all six films for irradiation by C^{14} source. As for the β - spectrum of C^{14}, the maximum energy amounts to 155 kev, and the mean energy is, as usual, smaller by a factor of 3. The results given in Figs. 3 and 4 agree quite well as should have been expected.

The data shown in these diagrams show, in good agreement with data of Fig. 2, that highly sensitive films in whose emulsion crystals large latent image centers are formed, are characterized by blackening curves possessing maximum slope at the origin. The films of small sensitivity, where the emulsion crystals are not in position to make effective use of the conduction electrons, which are formed by the passing of an ionizing particle, are characterized by curves analogous with curve II in Fig. 1. A substantially new fact that is apparent in Figs. 3 and 4, as compared with Fig. 2, is that now among films possessing curves of type II, there are besides the film *A*, also the positive plates and film *B*, the purpose and the sensitivity of which are limited to the recording of α - particles of natural origin. In this fashion, by going to particles with a smaller ionizing power, a further differentiation of the photographic films under investigation takes place (according to their sensitivities). This difference becomes immediately apparent from a study of the form of the initial portions of the blackening curves of these films.

The blackening curves for five of the films (film *A* is excluded because of its insufficient sensitivity) obtained by irradiation from a P^{32} source are shown in Fig. 5. The mean energy of the β - radiation spectrum of this isotope amounts to some 0.7 mev; hence, a considerable portion of the active radiation consists either of particles of minimum ionizing ability, or of particles whose ionizing ability differs from the minimum by a relatively small factor (1.5 - 2.0 times). Under these conditions, a sufficient sensitivity, corresponding to the maximum slope of the blackening curve at the coordinate origin, is evident only in the case of the film *G* , designed for the detection of relativistic particles. The film *B* , intended for the detection of nonrelativistic particles of considerable energies, is found to be

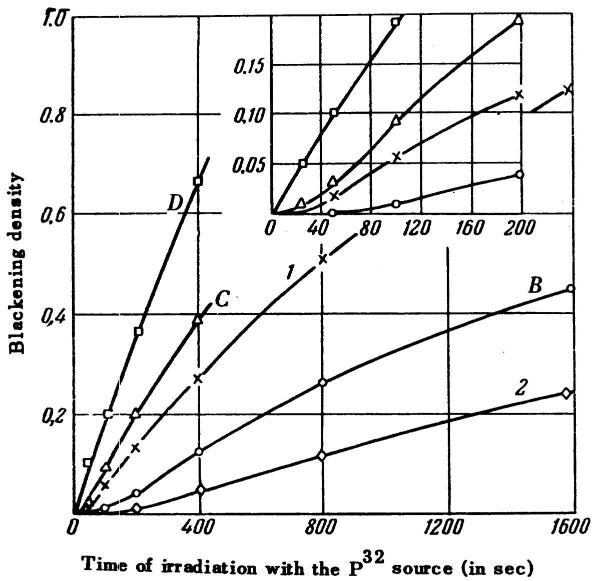

FIG. 5. *1* - electron sensitive plates; *2* - positive plates, *A*, *B*, *C*, *D* - highly concentrated films.

insufficiently sensitive for the detection of the above radiation; the same statement can be made concerning the electron sensitive plates, intended for irradiation in an electron microscope or some similar device, i.e., for irradiation by electrons possessing energies of less than 100 kev. The above conclusions are in full agreement with the shapes of the curves shown in Fig. 5.

From the data presented in Figs. 2 - 5, it is possible to establish a correspondence between the shapes of the initial portions of the blackening curves and the dimensions of the latent image centers in the emulsion crystals. At the same time, we know the dimensions of these centers to be dependent on the relationship between the ionizing capabilities of the impinging particles and the sensitivity of the film. It should be noted that the interpretation of the present experimental data is analogous to that proposed for the case of light, and that no auxiliary concepts have been invoked.

Some of the data available in the literature[9-11] indicate that the sensitivity of a film irradiated by particles can be increased by subjecting the film to a supplementary exposure to light of low intensity; some additional build-up of the latent image centers created through the action of the particles is thus effected. This method had been employed previously[1] to intensify the latent image centers formed by exposure to light. It was found in that case that an intensification took place only if the latent image was highly dispersed, and the blackening curve prior to the secondary exposure to light was of type II (Fig. 1); the secondary exposure then resulted in a type I blackening curve. The experiments described below are designed to demonstrate an analogous change in the shapes of the blackening curves of films first irradiated by particles and then exposed to light.

In making use of secondary exposure, a number of things must be taken into account. Mainly, it should be noted that in thick and highly concentrated layers, the scattering and the absorption of light are so high that the depth of penetration of the secondary exposure effects can be made comparable with that of the particles only by the use of radiation of sufficiently long wavelength. On the other hand, the action of long wave radiation, as contrasted to that of short wave radiation, is to destroy, rather than to build up the latent image (Herschel effect). This fact makes very difficult the selection of the spectral composition of radiation to be used for secondary exposure. It should be mentioned that in the case of thin films of normal concentrations - electron sensitive and positive plates - the use of short wave radiation is permissible; in fact, any wavelength up to the beginning of the ultraviolet region may be employed. It is also essential to select the exposure time correctly; it must be so chosen as to obtain the minimum possible background density due to the supplementary exposure, together with the greatest possible intensification.

An account of the experiments performed is now in order. Among the films subjected to irradiation by α - particles, the film *A* appeared to be the most interesting, because of the properties noted in Fig. 2. In this particular film the length of the α - particle tracks did not exceed 20 μ (in other films where individual tracks could be distinguished, their length was found to be some 25-27μ), and the spectral composition of the light used for the secondary exposure could be varied widely, practically throughout the entire visible range. Figure 6 shows the blackening curves corresponding to secondary irradiation through the ZhS-18 filter, which transmits light with $\lambda > 490$ mμ; the penetration depth in this case amounts to some 20 μ. Similarly, Fig. 7 shows analogous curves corresponding to irradiation through the KS-14 filter ($\lambda > 620$ mμ), with penetration depth of some 35-40 μ. Finally, in Fig. 7 similar curves are shown for the case of irradiation through the KS-19 filter ($\lambda > 700$ mμ), with the penetration depth up to

[9] E. Schopper, S. Magun and W. Braun, Z. Naturforsch. 6a, 338 (1951).

[10] S. G. Grenishin, Zh. Tekhn. Fiz. 22, 33 (1952).

[11] K. Zuber. Nature 170, 669 (1952).

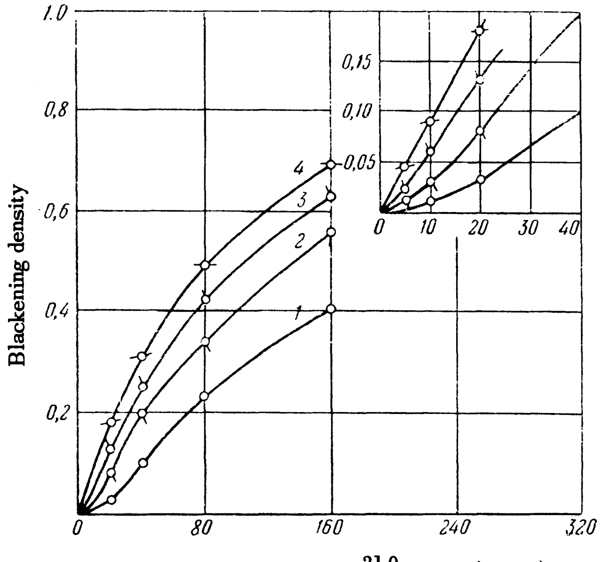

FIG. 6. *1* - no supplementary exposure to light; *2* - supplementary exposure time 3 sec; *3* - supplementary exposure time 6 sec; *4* - supplementary exposure time 12 sec.

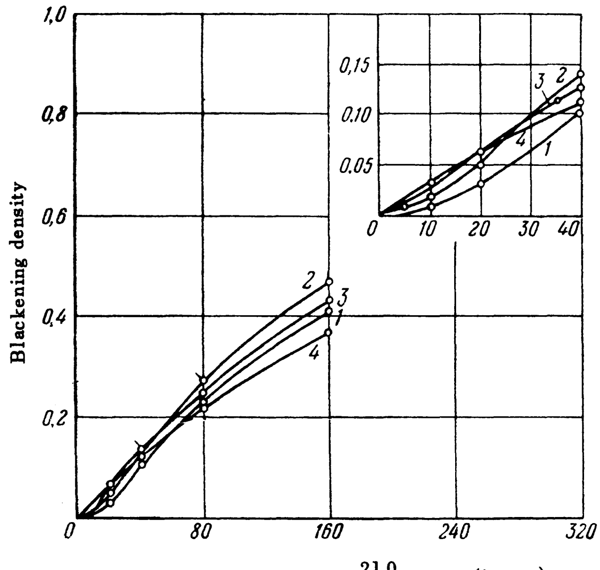

FIG. 8. *1* - no supplementary exposure to light; *2* - supplementary exposure time 30 sec; *3* - supplementary exposure time 100 sec; *4* - supplementary exposure time 300 sec.

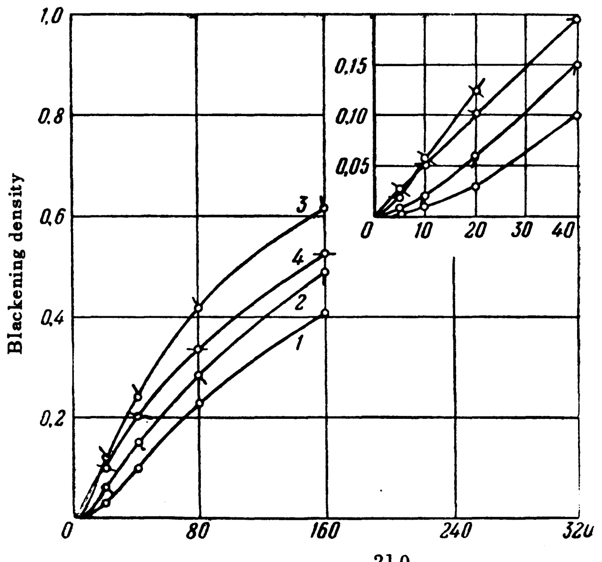

FIG. 7. *1* - no supplementary exposure to light; *2* - supplementary exposure time 15 sec; *3* - supplementary exposure time 50 sec; *4* - Supplementary exposure time 150 sec.

50 mμ. In accordance with convention, the blackening density data for these curves are given after the substraction of the background densities due to the secondary exposure, and of the fog.

A study of Figs. 6-8 permits us to arrive at definite conclusions. First of all, the action of the supplementary exposure brings about not only an increase in blackening, but also a change in the form of the initial portion of the blackening curve; specifically, a gradual transition from type I to type II is observed. It follows that an increase in blackening is connected with an increase in the developability which is brought about by the build-up of the already existing latent image centers. The formation of new centers due to the action of light is excluded from consideration by the act of subtraction of the background density from all blackening densities of regions irradiated by particles. Hence, the curves of Figs. 6-8 demonstrate only the effect of the supplementary exposure on the previously formed centers.

We must also take note of the fact that there exists a definite relationship between the effects of the supplementary exposure and the spectral composition of light used for this purpose. It is found, for example, that the comparatively short wave radiation, transmitted by the ZhS-18 filter, produces an inhomogeneous increase in all blackening densities. On the other hand, the radiation of longer wavelengths transmitted by the KS-14 and KS-19 filters causes the heavy blackenings to disappear, because of the Herschel effect, if the exposure time is sufficiently long; at the same time weak blackenings are intensified. Until the present time, the dual action of the long wave radiation, dependent upon the blackening density, was known mainly for the case when the first exposure was also made by light[12,13]. As far as the action of particles is concerned, the intensification was observed only in one investigation[9] and only for linear density of the developed crystals making up the particle tracks, rather than for the optical density of continuous blackening.

The explanation of the dual action of the supplementary exposure given in the reference can be applied in our case. It is known that long wavelength light is absorbed both by the latent image centers, resulting in their decrease in size, and by the silver halide, effecting the formation of the photolytic silver which subsequently builds up the available centers. The predominance of either of the competing processes depends on the degree of light absorption by both types of absorbinn centers. In the case of small blackenings, where the latent image is not abundant, the absorption by the silver halide matrix predominates and hence the centers are built up.

In the case of heavy blackenings, the predominant process is the absorption by the latent image centers; hence a decrease in size results.

In the group consisting of the emulsion *A*, *B*, *C*, and *D*, the particle sensitivity and the light sensitivity vary identically; hence, under similar conditions of irradiation by particles, the formation and the build-up of centers must predominate over the dissolution in the case of the film *B* to a greater degree than in the case of *A*, for the film *C* to a greater degree than for *B*, etc. This can be directly seen from the results of the experiments with the film *B*, which were conducted analogously to those described above for the film *A*.

For the case of film *B* , Fig. 9a (exposure with the KS-14 filter) and Fig. 9b (exposure with the KS-19 filter) show no noticeable intensification of the latent image and consequently no change of the initial portion of the curve. This is in good agreement with the previously proposed explanation since, as it was mentioned above, the film *B* is sufficiently sensitive to α -particles. At the same time, the Herschel effect in the film *B* can only be observed when the filter KS-19 is used and generally is weaker than for the film *A*. This can be explained by the fact that in the more sensitive film, under the action of exactly the same radiation, the formation or the build-up of latent image centers predominates in resolution for heavy blackening and in the long wavelength portion of the spectrum over that for the less sensitive film.

A number of experiments were conducted in which the primary exposure was made with β - particles from the C^{14} source. It can be seen that in a specially prepared cross section the depth of penetration of these particles in the highly concen-

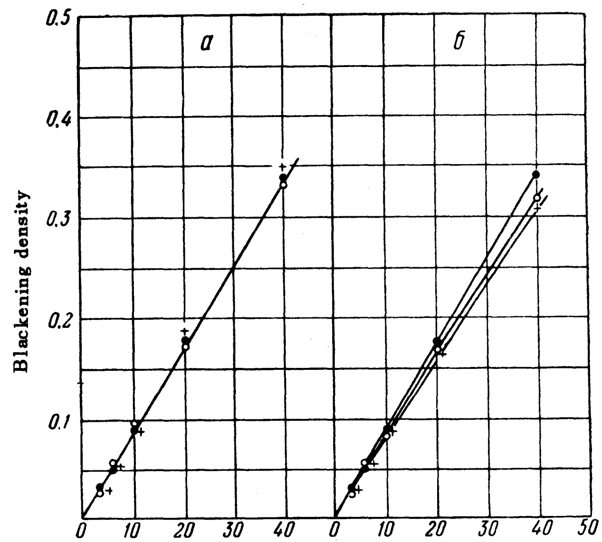

FIG . 9. *a*: ● - no supplementary exposure to light; O - supplementary exposure time 15 sec; + - supplementary exposure time 75 sec; *b*: ● - no supplementary exposure to light; O - supplementary exposure time 100 sec; + - supplementary exposure time 300 sec.

trated films amounts to some 40 μ; this excludes the possibility of using filters with the short wave length cut off greater than that of KS-14. Curves obtained for irradiation by the C^{14} source and a supplementary exposure to light are shown in Fig. 10; the KS-19 filter was used in the case of the films *C* and *D* and the KS-14 filter for the films *A* and *B*. It can easily be seen that in the films *A*, *B*, and *C* some intensification is apparent, whereas there is none at all in the film *D*. If the unexpected appearance of the intensification phenomenon in the film *B* , which is highly sensitive to the β - radiation, is temporarily disregarded (this irregularity will be explained later), then the obtained results are in full agreement with the proposed explanation of the action of supplementary exposure.

It should also be noted that in Fig. 10 (unlike Figs. 8 and 9) the supplementary exposure in the case of the films *A* and *B* did not produce a full intensification, i.e., the disappearance of the inflection in the initial portion of the blackening curve was not observed even for exposures which produced background densities of 1.5 - 2.0. This indicates a definite difference in the degree of dispersion of the latent images produced by the α - and the β - particles. These films of normal concentrations (positive and electron sensitive plates) were also subjected to the consecutive

[12] P. V. Meiklar, Zh. Fiz. Khim. 19, 441 (1945).

[13] Iu. N. Gorokhovskii and S. A. Shestakov, Zh. Fiz. Khim. 11, 356 (1938).

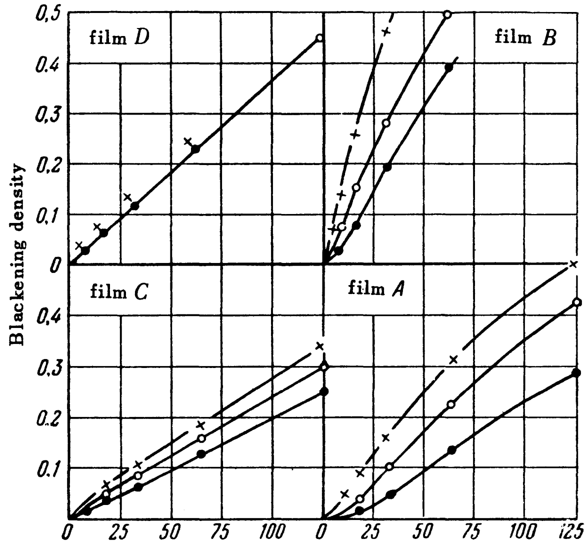

FIG. 10. Film A: ● - no supplementary exposure to light; O - supplementary exposure time 100 sec; + - supplementary exposure time 300 sec; Film B: ● - no supplementary exposure to light; O - supplementary exposure time 50 sec; + - supplementary exposure time 150 sec. Film C: ● - no supplementary exposure to light; O - supplementary exposure time 20 sec; + - supplementary exposure time 60 sec. Film D: ● -no supplementary exposure to light; O - supplementary exposure time 12 sec; + - supplementary exposure time 40 sec.

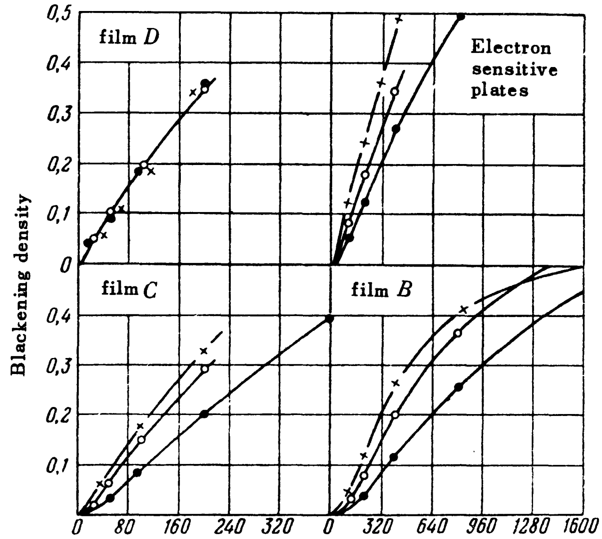

FIG. 11. Film B: ● - no supplementary exposure to light; O - supplementary exposure time 300 sec; + - supplementary exposure time 1000 sec. Film C : ● - no supplementary exposure to light; O - supplementary exposure time 20 sec; + - supplementary exposure time 60 sec. Film D: ● - no supplementary exposure to light; O - supplementary exposure time 12 sec; + - supplementary exposure time 40 sec. Electron sensitive plates: ● - no supplementary exposure to light; O - supplementary exposure time 50 sec; + - supplementary exposure time 150 sec.

action of the β - radiation from C^{14} and the supplementary exposure to light. Here it was possible to use radiation of shorter wavelength for the supplementary exposure; for example, the 365 mμ mercury line, and the 436 mμ mercury line which were separated by means of the UFS-3 filter and a colored gelatin filter, respectively. Although in this case the conditions of exposure could thus be varied to a greater extent than for other films, the results obtained did not yield any new information as compared with the results given above, although they verified these completely.

We would like to present some data from a series of experiments in which the primary exposure was performed by β - particles from a P^{32} source. It should be noted that according to calculations the β-radiation from a P^{32} source is capable of penetrating the emulsion layers to a depth in excess of 1 mm; in any case, this radiation penetrated through all of the films investigated. Films A and B each had an emulsion thickness of 50 μ, the films C and D – a thickness of 100 μ. The two latter films were exposed on both sides with the aid of the KS-19 filter; since the radiation transmitted by this filter penetrates to the depth of nearly 50 μ, this practice permitted us to extend the action of the supplementary exposure to all emulsion crystals, on the surface as well as in the depth of the film. For thinner films the problem was correspondingly simpler.

The blackening curves obtained from these experiments for the films B, C, and D and for the electron sensitive plates are shown in Fig. 11. The absence of any intensification in the case of film D and its presence in all other films should be considered quite normal.

The differences in the degree of dispersion of the latent image created by the action of various particles and in various films are obvious from the data given here. However, it should be remembered that any particle, even one with a comparatively high ionizing capability, invariably forms a highly dispersed latent image – the degree of dispersion never being less than in the case of light; thus, the experiments described above reflect only very small differences in the degree of the image dispersion. The correctness of this assertion can be seen from the following experiment. It is known[1] that a brief exposure to light of high intensity also creates a highly dispersed latent image, which can be intensified by a subsequent exposure to light of small intensity. This process creates large latent image centers. We have subjected the positive and the electron sensitive plates to a uniform exposure of 8 μsec duration. The radiation was supplied by a flash lamp; the UFS-3 and neutral gray filters were used. Conditions were so adjusted that a uniform blackening density of approximately 0.5 was obtained. Instead of subjecting the plates so treated to a secondary exposure to light, we superimposed the usual blackening pattern of the Po^{210} α-source. The intensification effect was not observed in any of the cases, i.e., the α-particles did not produce the effect obtained with the radiation capable of creating coarsely dispersed latent images. At the same time, the reverse order of exposures produced a marked intensification in some cases.

The following modification of the experiment described above is of interest. Instead of using the flash lamp the uniform blackening of the plates was produced by irradiation in the electron microscope. In this case the subsequent irradiation by α-particles gave a distinct intensification, i.e., the resulting blackening density was always greater than the sum of the blackening densities formed by each of the separate exposures. No such effect was observed when the exposures were performed in the reverse order. The obtained results can be understood if one assumes that an intensification will take place only in the case where the radiation used for the primary exposure creates a latent image of a higher degree of dispersion than that used for the secondary one; this statement applies to light as well as to particles. It follows that no particles, ever those of high ionizing power, even form centers larger than those due to exposure to light, even if the latter is highly concentrated and of very short duration.

These data also supply the answer to the question proposed recently by Biberman and Kovner[14] concerning the possibility of build-up of centers created by the action of particles of smaller ionizing power by the subsequent action of particles of higher ionizing power. As these authors consider such an experiment as a conclusive proof of the formation of a highly dispersed latent image due to the action of particles and the possibility of its subsequent build-up, the proposed hypothesis is also supported from this point of view.

CONCLUSIONS

1. The dependence of the blackening density, D, on the exposure, H, has been investigated for six different photographic films irradiated by α- and β-particles of various energies.
2. It has been shown that the shape of the initial portion of the curve, $D = f(H)$ is a characteristic of the degree of dispersion of the latent image.
3. It has been established that the degree of dispersion increases as the energies of the ionizing particles and the sensitivity of the film are decreased.
4. A subsequent exposure to light serves to change the degree of dispersion of the latent image formed by the ionizing particles in a regular fashion; both the build-up and the dissolution (Hershel effect) of the latent image are observed.
5. The latent images due to the action of light and of particles were found to be qualitatively the same for all particles and films.

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[14] L. M. Biberman and I. A. Kovner, J. Exper. Theoret. Phys. USSR 26, 234 (1954).

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ERRATA
(both of our own and of JETP)

Vol.	Page	Column	Line	Reads	Should read
2	434	2	22	27.3 μ	23.7 μ
2	557	Fig. 10			On the right hand side, abscissa values should read 0, 200 400, 600, 800, 1000.
2	591	2	7	$A = \frac{e^2 H_0^{\ 2} \delta_{00}}{mc^2}$	$A = \frac{e^2 H_{00}^{\ \ 2} \delta_{00}^{\ \ 2}}{mc^2}$
2	754	1	3 ff.	————	[14] B. B. Kinsey and G. A. Bartholomew, Phys. Rev. **82**, 380 (1951). [15] B. B. Kinsey and G. A. Bartholomew, Phys. Rev. **83**, 234 (1951).
2	771	1	10	Intermediate State	Intermediate State of Tin
	771	1	19	sphere of lead	sphere of tin
3	145	1	1	$R = 10\ ec$	$R = 1/ec$