Studies in Photographic Sensitivity, Part I. The Effect of Heat on the Sensitivity Curve of Photographic Plates

By

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Abstract

In my paper entitled "Sensitizing Action of Heat on Photographic Plates for Infra-Red Ray,"[1] it was observed that previous heating of a photographic plate sensitizes the plate more for infra-red rays than for violet ones. The present experiments were carried out to find at various wave lengths the amount of sensitization called forth by a previous heating. The following facts were established from experiments carried out with twelve kinds of plates: (1) The contrasts always become steeper for all wave lengths. (2) The inertia of panchromatic plates and other slow plates was decreased, but that of high speed plates was increased. (3) In the former case, the amount of sensitization was greater in the red side of the maximum point of the sensitivity curve than in the violet side, while in the latter case the amount of desensitization was greater in the violet side, and was smaller in the other side. These facts mean that the maximum point in the sensitivity curve always shifts a little towards the red when the plate has been previously heated.

Introduction

In my paper entitled "Sensitizing Action of Heat on Photographic Plates for Infra-Red Ray," it was found that a previous heating of dry plates sensitizes the plate more for infra-red rays than ultra-violet ones. Afterwards, Kellner[2] found that heat did not influence selectively the action of lights of special wave lengths.

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[1] Jap. Jour. of Phys. **11**, 163 (1923)

[2] Zeits. Wiss. Phot. **24**, 63 (1926)

In the present experiments, it was attempted by a more quantitative measurement to examine how the previous heating affects the forms of the characteristic curves corresponding to various wave lengths.

Apparatus and Method of the Experiment

The special plate holder employed in the previous investigation[1] was also used in these experiments. A constant-deviation spectrograph was adopted instead of a grating spectrograph to eliminate the superposition of the second order spectrum and a diffuse light. A small sector wheel was made in our work shop with special care, and it was tested by the method described in the following paragraph. This was placed in front of the slit of the spectograph and was rotated by a motor. This sector, as shown in Fig. 1, has a similar construction to Hurter and Driffield's disc, but instead of its stepped aperture this has two windows of continuously decreasing aperture which was reduced to one half as the radius was increased by one mm.. It was difficult to cut exactly apertures of such dimensions in a brass plate, and so it was constructed by combining two thin plates, one of which has two apertures with correct edges along ABC and A′B′C′ shown in Fig. 1 and the other with correct edges along ADC and A′D′C′.

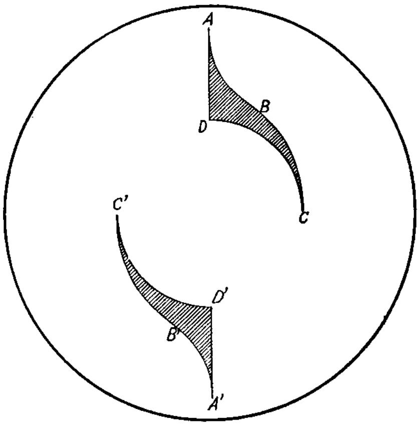

Fig. 1. The Sector.

As the light source, an incandescent lamp with a condensed filament was used, and this was first focussed by a lens on a small circular aperture, and the rays coming from this aperture were sent on to the sector after being made parallel by a photographic lens. For the sake of wave length scale the light from tin sparks was sent on to the slit of the spectrograph reflected by a right-angled prism placed temporarily in front of the sector.

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[1] Loc. Cit.

The lamp current was supplied from a secondary battery which was used for this purpose only. The plate holder was heated to the required temperature in a steam bath before charging a dry plate. After this, both the plate holder and the plate were also kept at this temperature for one hour, and then an exposure was made with it.

All the plates to be investigated were cut out from a single plate and were developed simultaneously in a bath containing metol hydroquinone developer for 5 minutes. In the following experiments all the plates were developed in this way.

The densities of the negatives thus taken were measured by means of a Moll's microphotometer, the light deflected from the galvanometer being plotted on a section paper. A curve obtained by connecting these points represents the relation between the intensity of the light transmitted through the negative plate and log E. From these curves, density-log E curves, i. e. characteristic curves were obtained. The correction for a general fog was made according to the equation given by Wilsey.[1]

Testing of the Sector and the Method of Drawing Characteristic Curves

Although the sector was made with special care, the form of the aperture could not made correct and this error should be taken into account. The correction for this was made in the following way.

Six pieces were cut out from an Ilford Special Rapid Panchromatic Plate, and to each of them a series of exposures were given in the ratio of 2^0, 2^1, 2^2,...............2^5 by opening the shutter placed in front of the sector and timing with a stop watch. All the exposures were given 3 minutes after the lamp had been lighted, as the current flowing in the lamp required 3 minutes to reach its steady state. In order to prevent the errors due to the fatigue of the battery a similar series of exposures were given in a reverse order to another six pieces cut out from another dry plate, and the resultant values of the two series were averaged. The plates thus treated were measured by the microphotometer. Fig. 2, B represents a series of such curves. Curve I shows one corresponding to a 1 minute exposure, curve II, 2 min. exposure, etc.. The horizontal distances of any two adjoining curves must always be equal if the sector has been made correctly but generally this was not the case. The error

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[1] Eastman Kodak Co. Research Lab. Commu. No. 246. Photo. J. **65**. 454 (1925)

due to such incorrectness in the sector was eliminated by the following method :—

A line parallel to the abscissa was drawn from the point a, where the curve I intersects the ordinate corresponding to the maximum exposure, and the points where this line intersected curves II, III,.........lettered a_2, a_3,............ . From a_2, a straight line was drawn parallel to the ordinate and its intersection with the curve I lettered b_1 ; from b_1 a line was drawn parallel to a_1 a_2 and its intersections with the curve II, III,......... lettered b_2, b_3,......... . From b_2 a line was drawn parallel to the ordinate and its intersection with curve I lettered c_1. This process being extended to the curve VI, two systems of cross lines, one being vertical and the other being horizontal were obtained as shown in Fig. 2, B.

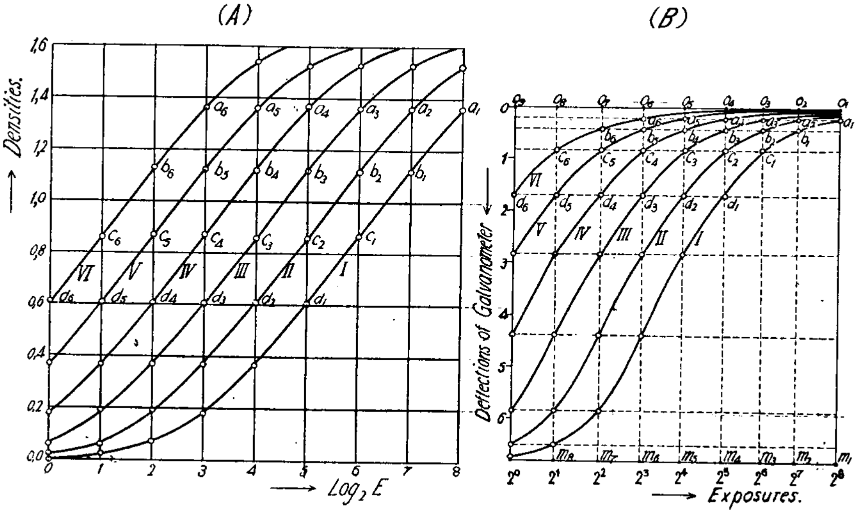


Fig. 2. Testing of the Sector.

If the sector be correctly made the distances between every two adjoining lines parallel to the ordinate must be equal, but in the present case the distances between these lines were not perfectly equal. But in the computation of densities if we use these vertical lines as the ordinates corresponding to the exposures 2^0, 2^1, 2^2...............2^8, the error due to the incorrectness of the sector-aperture may be eliminated. All the characteristic curves given in the following paragraphs were drawn in this way. An example of obtaining a characteristic curve is given here. Let the line o_1o_2......... represent the line of zero deflection of the galvanometer and the line m_1m_2......... be the one of the maximum deflextion, corresponding to an unexposed portion of the plate. Then $\log_{10}$ (o_2m_2/o_2a_2) represents the density of the point a_2, and thus the curves in Fig. 2, A were obtained which represent D-log E diagram i. e. characteristic curves of the plate corresponding to the curves in Fig. 2, B. As seen from the figure all the curves now become parallel and similar in their forms, and are separated by the same distance from one another.

Effects of Heat on the Form of Characteristic Curves for Rays of Various Wave Lengths

Three pieces were cut out from one plate, and to one of these the exposure to the sector spectrum was given at room temperature (15°C.). Next, the plate holder only was heated up to 80°C. in a steam bath, and when its temperature reached the above value the second piece of the plate was placed in it and this was again kept in the bath until the thermometer inserted into the plate holder reached 80° C.. Then the same exposure as the first one was given to this.

Finally, after the plate holder had cooled down to the room temperature, the same was repeated with the third piece of the plate. Figs. A and B in Plate I show the photographs taken in the first and second ways for Wratten and Wainwright Process Panchromatic Plates, and Figs. C and D are the similar photographs for Ilford Process Panchromatic Plates. Characteristic curves of thus treated and untreated plates for rays of the wave lengths of 450, 500, 550, 600, 650, and 700 $\mu\mu$. are given in Fig. 3 from which the sensitivity curves were drawn as shown in Fig. 4, A, the ordinate of this diagram representing the value of log i, where i is the inertia of the plate.

Now let us define the amount of sensitization due to preliminary heating by $\Delta \log i = \log i - \log i'$, where i' is the inertia of the treated plate and i is that of the untreated one. Then the so-called sensitizing curve is drawn with a dashed line taking wave length horizontally and log i vertically as shown in Fig. 4, A. The changes of gamma of characteristic curves for the rays of various wave lengths are represented by a dotted line in the same figure. Fig. 4, B, C, and D also represent the diagrams corresponding to Fig. 4, A for other panchromatic plates. In all these plates, heat always sensitizes the plate for all spectral regions although the form of the sensitizing curve depends upon the nature of plates. The curves for plates having many maxima and minima in their sensitivity curves are very complex. But generally the sensitizing action

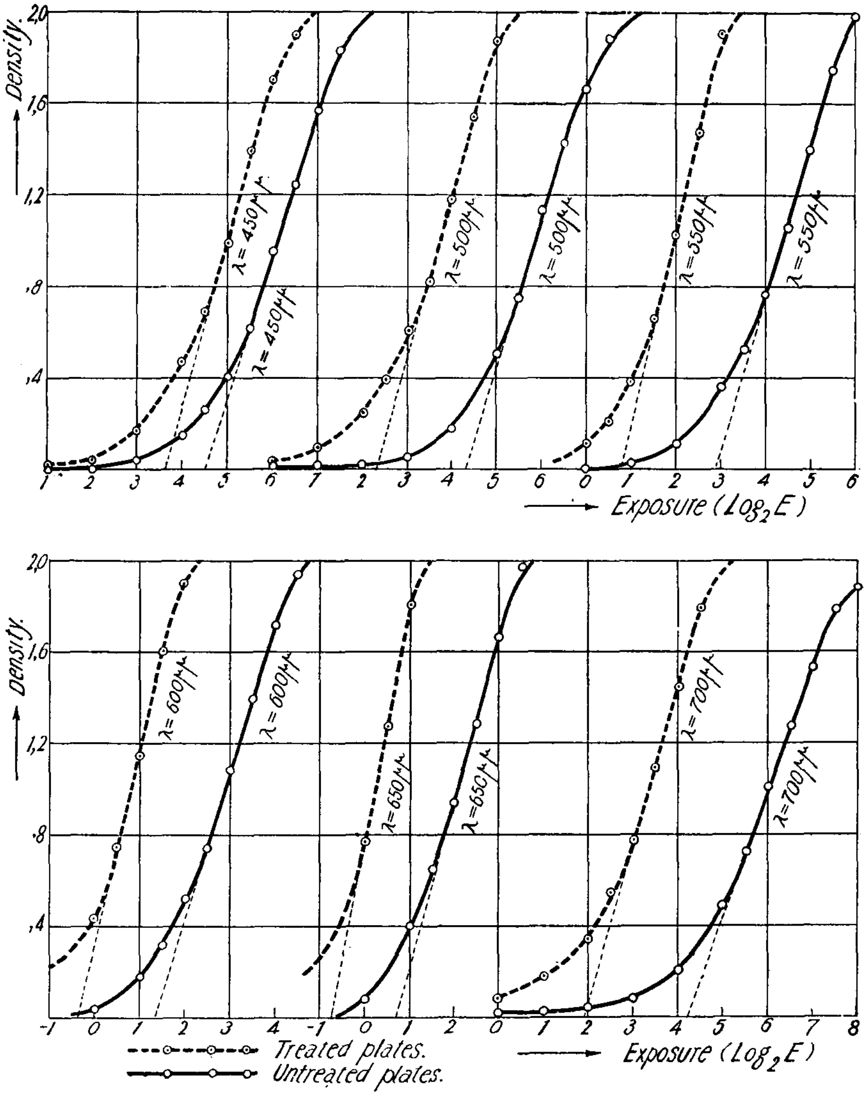
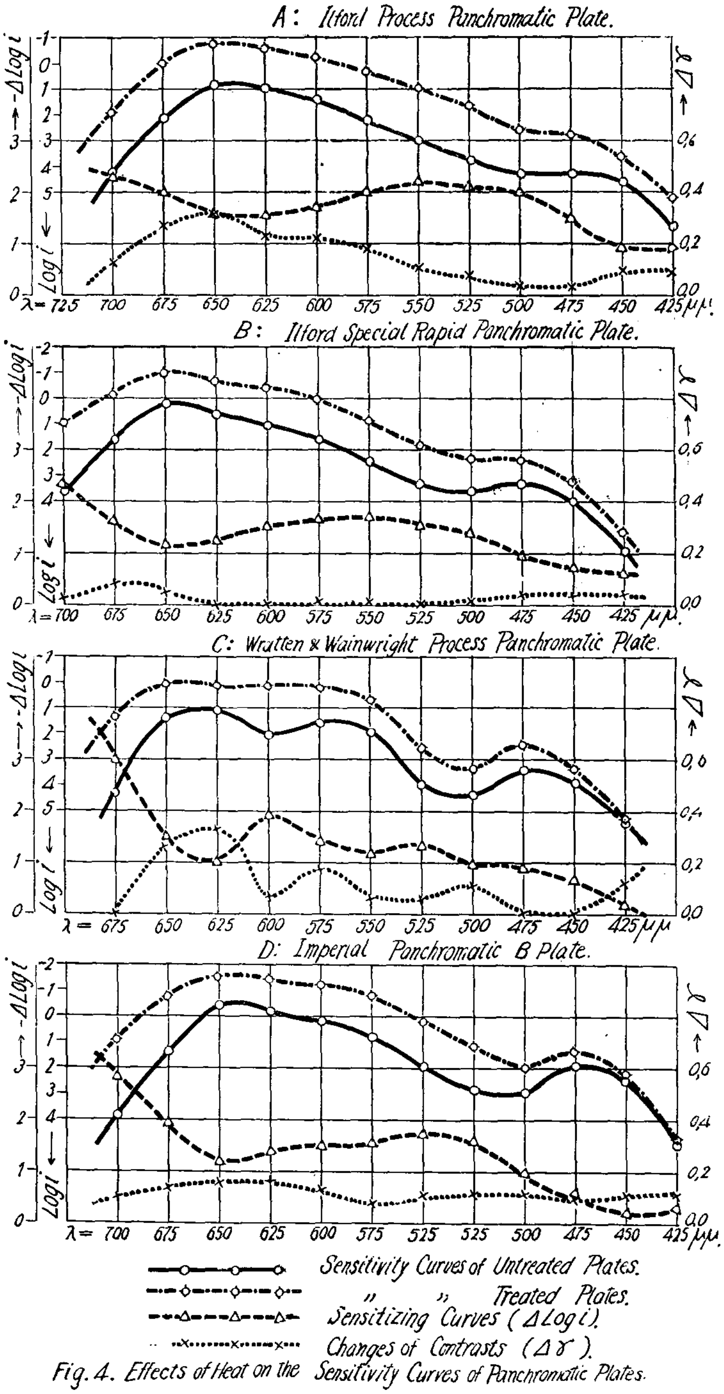


Fig. 3. Effects of Heat on the Characteristic Curves.



A: Ilford Process Panchromatic Plate.

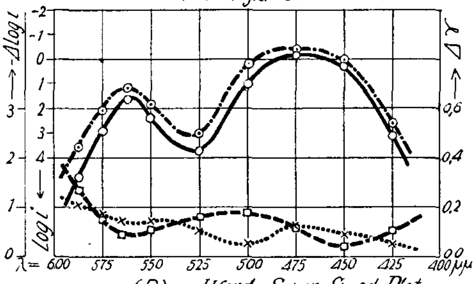
B: Ilford Special Rapid Panchromatic Plate.

C: Wratten & Wainwright Process Panchromatic Plate.

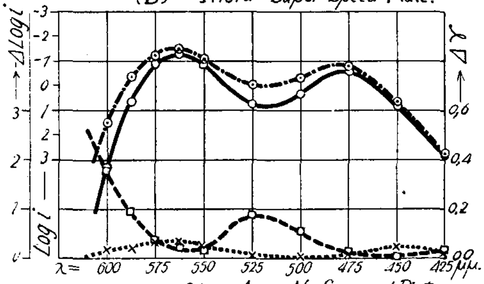
D: Imperial Panchromatic B Plate.

Fig. 4. Effects of Heat on the Sensitivity Curves of Panchromatic Plates.

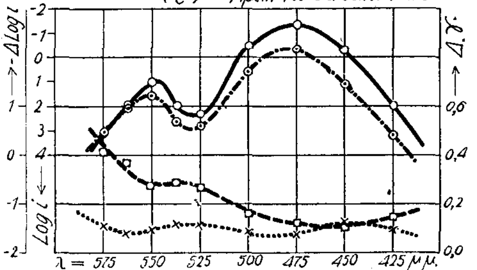
(A) Agfa Chromo Plate



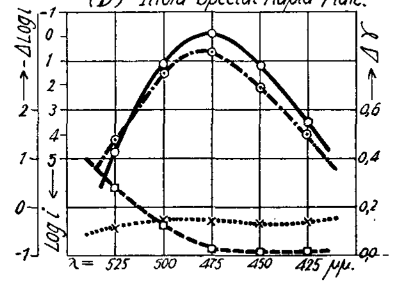
(B) Ilford Super Speed Plate.



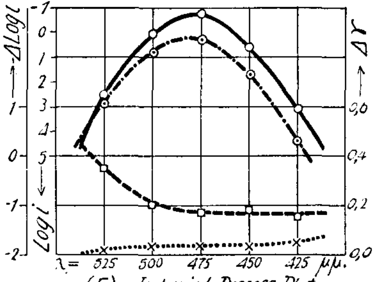
(C) Apem No Screened Plate.



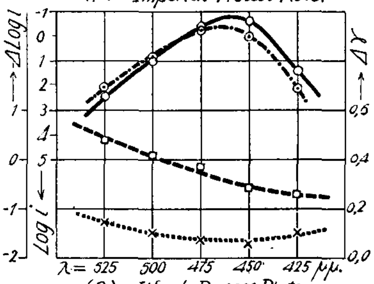
(D) Ilford Special Rapid Plate.



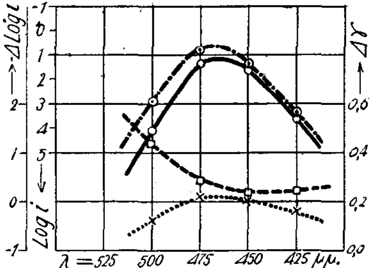
(E) Eastman Universal Plate.



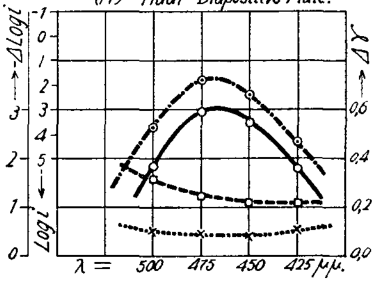
(F) Imperial Process Plate.



(G) Ilford Process Plate.



(H) Haaf Diapositive Plate.



—○—○— Sensitivity Curves of Untreated Plates. (Log i).
-·-⊙-·-⊙-·- " " Treated Plates. (Log i')
-□-□-□- Sensitizing Curves. (ΔLog i).
···×···×··· Changes of Contrasts. (Δγ).

Fig. 5. Effects of Heat on the Sensitivity Curves of Orthochromatic and Ordinary Plates.

is smaller for more refrangible rays and greater for less refrangible rays, i. e., more precisely, the sensitizing action is usually greater in the red side of each maximum point of the sensitive curves than in its violet side.

Fig. 5, A to C also represent the diagrams corresponding to Fig. 4 for some orthochromatic plates, and Fig. 5, D to H those for various ordinary plates.

From these results, it was observed that there are two distinct effects produced by heating plates; one of which is the decrease of the inertia, while the other is increase of it. The inertia of panchromatic and other slow plates is reduced, but that of high speed plates is increased by the preliminary heating. Plates such as the Eastman Universal Plate and the Ilford Super Speed Plate (700° H. D.) are examples of the latter. But even in the cases where heat reduces the sensitivity of the plate, the amount of desensitization is greater in the shorter wave length side of the maximum point of the sensitivity curve and is smaller in its longer wave length side; moreover, in some plates heat sensitizes the plate for less refrangible rays. This is seen in the Ilford Special Rapid Plate and the Imperial Process Plate.

Thus in ordinary plates the sensitizing curve gradually rises towards long wave lengths giving no minimum point, whenever the effect of heat is positive or negative. When the plate has been originally sensitized with dyes as in panchromatic or orthochromatic plates, the sensitizing curve has a minimum point near the maximum point of the sensitivity curve, but the amount of sensitization is remarkably greater in all the cases in the red side of it. These results mean that the maximum point of the sensitivity curve is always shifted without exception towards the longer wave lengths by the action of heat.

The amount of this displacement is small, and is about 50 Å. for a raise of the temperature by 65° C. or 0.8 Å. per degree, therefore it will be difficult to detect this shifting on the negative plate unless adequate care is taken.

The change of contrast (γ) due to previous heating was generally opposite to that of sensitivity, that is, the greater the sensitization, the smaller is the increase of contrast, and the smaller the sensitization, the greater the change of contrast. Generally, the contrast was increased by heating for all kinds of plates and in panchromatic and orthochromatic plates the change of contrast was greater for the rays of long wave lengths, but in ordinary plates this change of contrast was small, and did not seem to be selective to certain wave lengths.

Wallace[1] found that at higher temperatures photographic plates have smaller sensitivity and greater contrast than at lower temperatures indicating that the characteristic curves in the two cases intersect at some point. But in the light of the present experiments it has been ascertained that his statement is correct only for ordinary high speed plates for the rays of short wave length, but not for panchromatic and slow plates.

Life of Plates Sensitized by Heat

The sensitizing action of heat on photographic plate was not reduced immediately to nothing as the temperature fell, but was kept for serveral hours after the plate reached the room temperature. Fig. 6 represents this relation. At the end of the first one hour, it was reduced to 2/3 of the maximum value, after that time the rate of its reduction became very small and approached asymptotically to zero. For the less refrangible rays this effect was kept for a longer time than for the more refrangible rays.

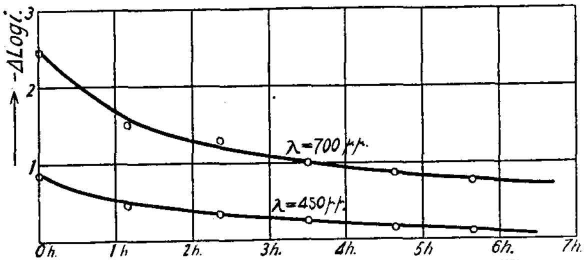


Fig. 6. Life of the Sensitizing Action of Heat.

The Effect of Drying

It is imposible to distinguish the effect of heat from the drying effect that accompanies the raising of the plate temperature. Although the greatest precautions were taken to keep the plates in a dry condition by keeping them in a desiccator, the results of the above experiments may not be free from the objection that the effect of drying the plates enters into them. But in our country the humidity is rather small in autumn and winter, during which seasons the present experiments were carried out. The effect of the latter, if it exists, would therefore be very small.

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[1] Astro. Phys. J. **28**, 39 (1908)

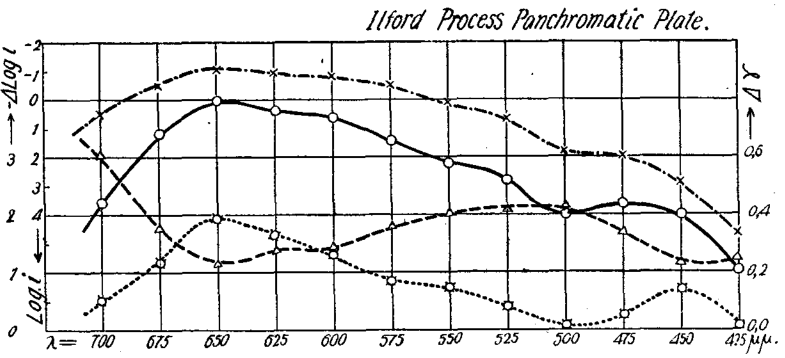

Fig. 7 Effect of Heat on a Perfectly Dried Plate.

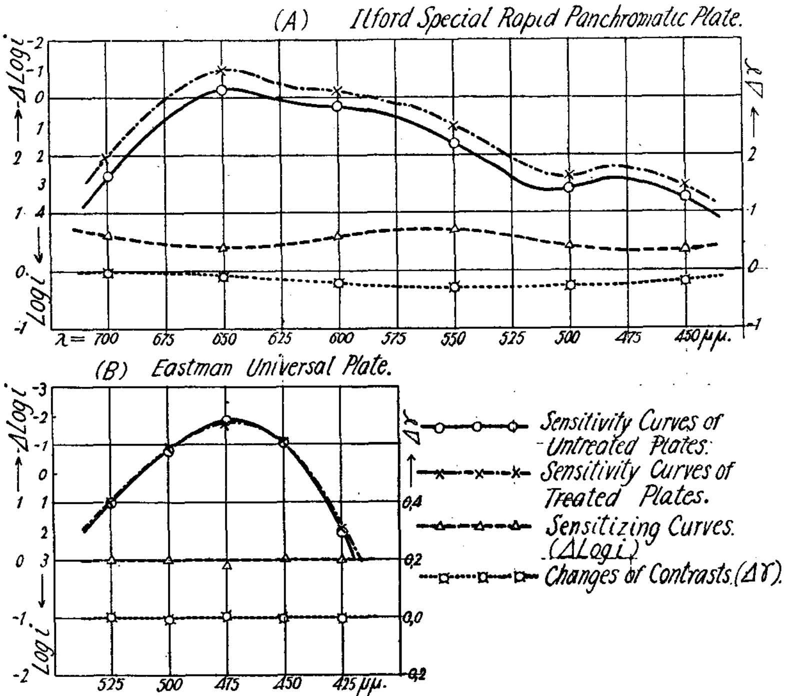

Fig. 8. Effect of Drying.

In order to ascertain this, however, similar experiments to the above were carried out with specially well dried plates. The plates were put film-side downward in a porcelain vessel containing phosphorus pentoxide, and the whole vessel was again kept in a desiccator containing calcium chloride for a few days. On one half of the plate the exposure was given by the above method without heating it, and on the other half the exposure was given after heating.

The result of this experiment will be seen from the curves given in Fig. 7, which is quite similar to the one given in Fig. 4. It may be said from this fact that the effects of heat described in the previous paragraph are probably due to heating the plate only. Moreover in order to obtain only the effect of drying, similar exposures were given to two plates, one of which had been kept in ordinary air while the other had been well dried in the desiccator used in the above experiment. The results obtained with Ilford Special Rapid Panchromatic and Eastman Universal Plates are given in Fig. 8; A and B.

Comparing the above two experiments we may conclude that the effect of drying is not analogous to that of heating. The sensitizing action of drying was generally very much smaller than that of heating and had not much difference in the two sides of the maximum point in the sensitivity curve. Consequently by the process of drying, the spectral sensitivity of photographic plates can not be extended towards the infra-red region. Particularly, in ordinary high speed plates, heat reduced their sensitivity greatly in the violet region and slightly in the red region, but the drying had no such effect.

The result obtained in the present experiments seem more favourable to the photoelectric conductivity theory of latent images than the photoelectric theory.

An experiment is now going on to see how the photoelectric conductivity of silver bromide produced by rays of various wave lengths depends on its temperature.

In conclusion, the author wishes to express his sincere thanks to Prof. M. Kimura for his valuable advice and the great interest he has taken in this investigation, and the author's thanks are also due to President T. Maruyama of the Konan College for his kind offices.

Plate I