

*Citation:*

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**Physics.** — “*A difference between the action of light and of X-rays on the photographic plate*”. By Prof. I. K. A. WERTHEIM SALOMONSON.

(Communicated in the meeting of September 25, 1915).

In a series of experiments on the quantitative action of X-rays and light on photographic plates, I found a characteristic difference between the two kinds of rays.

In these experiments so-called exposure-scales were made by exposing one half of a plate to regularly increasing light-quantities and the other half in the same way to Röntgen-rays. Both halves were developed at the same time in one developing tray and also fixed simultaneously in one tray.

On each of the negatives we find a series of small fields, which have been exposed to the action of light or of x-rays of intensities increasing in the ratio of 1, 2, 4, 8, 16 etc., and which show an increasing density. On the half exposed to the X-rays the time of exposure and the hardness of the rays are also recorded. The transparency of each of the small fields is photometrically measured. The reciprocals of the figures obtained in this way give the *absorption-factor*, the logarithm of which is the optical *density*. From the figures for the density curves are drawn, the densities being plotted as ordinates to the logarithms of the exposures as ordinates, In this way we get the “characteristic curves” of the plates as used by HURTER and DRIFFIELD, EDER and others.

The different precautions taken in these experiments need not be described: sufficient be it that the exposures, once started, were automatically carried out, and that any irregularities in the intensity of the light and the X-radiation either could bear no influence on the result or could be immediately detected

Curves like these always show a curvature convex to the X-axis corresponding to the underexposed part. The “correct exposures” give a straight line. This part generally commences at a density of roughly 0.5. The straight line prolonged to the axis of abscissae meets it in the “point of inertia” (Beharrungspunkt) which is used by HURTER and DRIFFIELD to indicate the “speed” of the plate. It is almost entirely independent of the time of development, the kind of developer used and its temperature, which influence only the slope of the curve in the straight part. We also know that the quantity of silver in a negative increases proportionally to the logarithm of the exposure.

T A B L E · I.					
Negative 5 A and 5 B.					
<i>I</i>	$\varphi$	$2 \log \operatorname{ctg} \varphi$	<i>R</i>	$\varphi'$	$2 \log \operatorname{ctg} \varphi'$
1	43°24'	0.049	1	38°19'30"	0.204
2	39.55 30"	0.155	2	33 34 30	0.356
4	33.45	0.350	4	26.24	0.615
8	23.12	0.736	8	17.37 30	0.996
16	14.30	1.175	16	10.52 30	1.433
32	8 0	1.704			
64	4 16 30	2.253			
Negative 6 A and 6 B.					
1	43°42'	0.039	1	40°49'30"	0.127
2	40. 4 30"	0.150	2	36.12	0.271
4	35 15	0.301	4	29.31 30	0.494
8	24.54	0.667	8	22. 6	0.783
16	16.13 30	1.072	16	15.27	1.117
32	10. 1 30	1.505			
64	8. 4 30	1.696			
Negative 7 A and 7 B.					
1	43°51'	0.035	1	41° 6'30"	0.118
2	42. 3	0.090	2	38.18	0.205
4	37.51	0.219	4	33.25 30	0.361
8	30.13 30"	0.469	8	26.19 30	0.611
16	20.12	0.868	16	18.19 30	0.960
32	12	1.355			
64	7. 9	1.803			
Negative 8 A and 8 B					
1	44°	0.030	1	39°45'	0.160
2	40.48'	0.128	2	34.33	0.324
4	33.16 30"	0.366	4	26.43 30"	0.596
8	22.12	0.778	8	18.13 30	0.965
16	13.22 30	1.248	16	11.18	1.399
32	8. 7 30	1.691			
64	4.22 30	2.236			

In the next table I give the result of the measurement of 4 pair of negatives. (See p. 672)

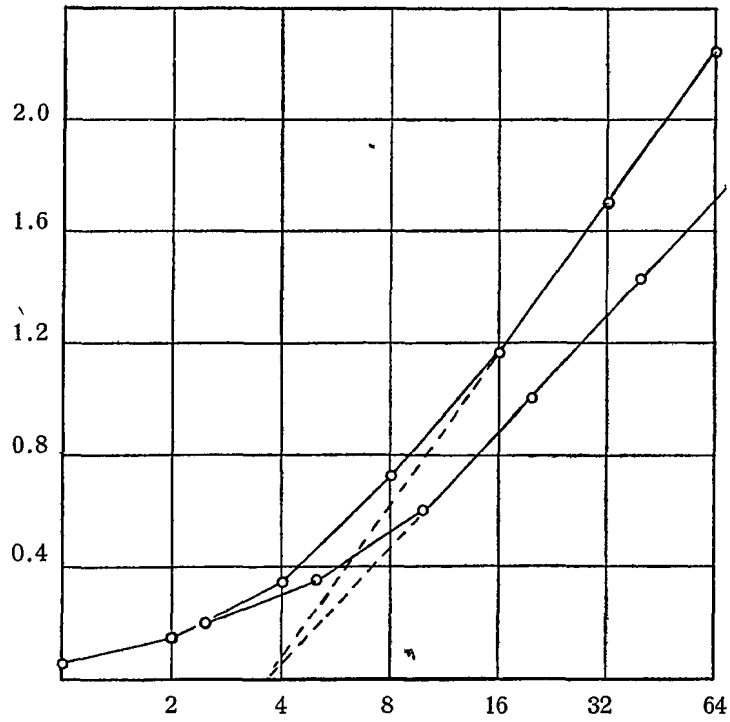


Fig. 1.

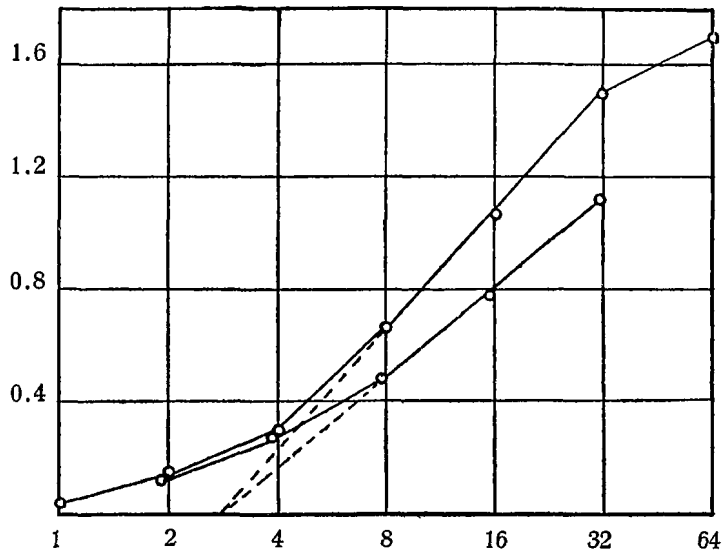


Fig. 2.

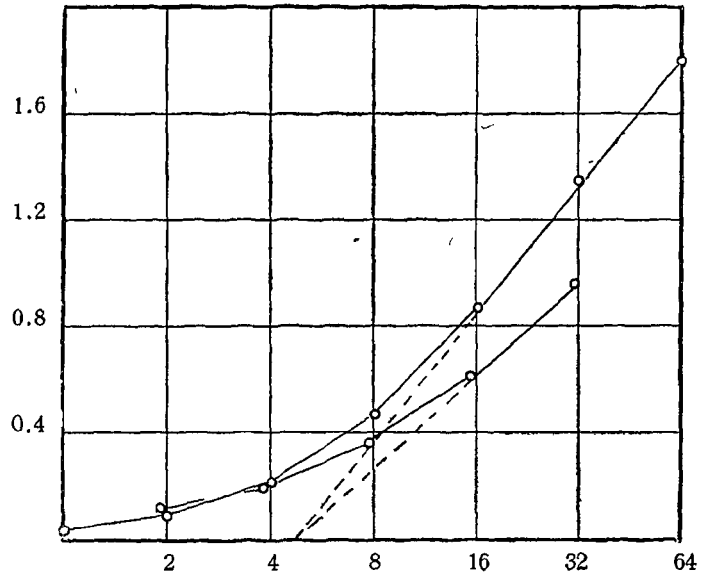


Fig. 3.

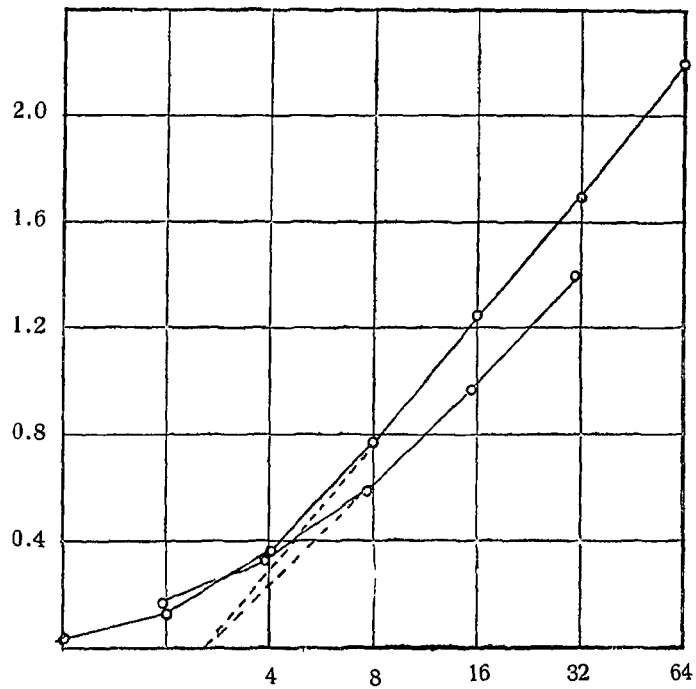


Fig. 4.

The fact to which I wish to draw attention is, that for every pair of negatives the characteristic curve for light slopes considerably more than the one for X-rays. This is clearly shown in fig. 1—4. Each of them contains two curves, the upper one showing the action of light, the lower one the X-ray curve. The slope of these curves always proved to be different in the manner indicated and to be independent of the development if only both halves of the plate were developed in the same tray for the same length of time without undue restriction of the time. Changes in the development merely caused changes in the slope of both curves at the same time and in the same way.

We may expect a physical difference in the action of light and of X-rays on the photographic plate. The sensitive layer strongly absorbs light, whereas X-rays are only slightly absorbed. As we know that the action of both kinds of rays increases with the intensity, we may in the case of light look for a strong action at the surface of the sensitive layer and for a markedly diminished action in the lower strata of the emulsion. In the case of X-rays which are not notably weakened after passing through the silver-bromide-emulsion we may reasonably expect that the action in the deeper layers is not less than the action on the surface. After development the reduced silver should be nearly equally deposited in every part of the gelatine layer if the negative had been obtained with X-rays. In light-negatives the silver would probably be accumulated on the surface and only a slight amount would be present in the deeper strata. Any one who has developed many light- and X-ray-negatives knows, that with the former only the parts exposed to the strongest lights are visible at the back after development but before fixing, whereas properly developed unfixed RÖNTGEN-negatives present nearly the same appearance at the back as on the front surface.

We may ask if this difference might be responsible for the difference in the slope of the characteristic curves. It seems to me that this is possible and even quite probable, if we consider the question in the following way.

Let us first consider how the reduced silver is deposited in light- and RÖNTGEN-negatives. After this we shall see how this effects their transparency.

We may represent the absorption of light and RÖNTGEN-rays in the gelatinobromide-emulsion by the well-known formula

$$I_l = I_0 e^{-\mu l} \dots \dots \dots (1)$$

in which  $I_l$  is the intensity of the radiation after passing a layer

of thickness  $l$ ,  $I_0$  being the intensity of the radiation at the surface,  $\mu$  the absorption coefficient of the absorbing medium for the incident rays.

By multiplication by  $t$ , the time, and equating  $I_l t = Q_l$  and  $I_0 t = Q_0$  we get;

$$Q_l = Q_0 \epsilon^{-\mu l} . . . . . (2)$$

a formula for the quantity of radiating energy at a distance of  $l$  below the surface. Differentiating 2 gives:

$$-d Q_l = Q_0 \mu \epsilon^{-\mu l} dl . . . . . (3)$$

an expression for the light absorbed in a stratum of thickness  $dl$  at a distance  $l$  below the surface. As the quantity of silver reduced by development in this stratum is proportional to  $-dQ_l$  we may put:

$$d Ag = k Q_0 \mu \epsilon^{-\mu l} dl . . . . . (4)$$

which integrated gives:

$$Ag = K Q_0 (1 - \epsilon^{-\mu l}) . . . . . (5)$$

as a formula for the total quantity of reduced silver between the surface and a layer at a distance  $l$  below it.

From (5) we deduce:

$$\frac{dAg}{dQ} = K(1 - \epsilon^{-\mu l}) . . . . . (6)$$

i.e. the increase of silver caused by an increase of exposure depends on the absorption coefficient  $\mu$ . If  $\mu$  is large the differential quotient is also large.

In order to calculate the density of the negative, we suppose that the absorption in an infinitely thin layer is proportional to the amount of silver in it and also with the intensity of the light falling on it. Using (4) for the quantity of silver we get the equation:

$$-d I_l = c I_l . K Q \mu \epsilon^{-\mu l} dl . . . . . (7)$$

or after integration

$$D = \log \frac{I_0}{I_l} = c K Q (1 - \epsilon^{-\mu l}) . . . . . (8)$$

in which  $D$  is the density,  $I_0$  the intensity of the light before, and  $I_l$  the same after passing through the negative.

From (8) we find:

$$\frac{dD}{dl} = c K (1 - \epsilon^{-\mu l}). . . . . (9)$$

This last equation shows that the increase of density also depends on the absorption coefficient  $\mu$  of the rays used in producing the negative.

These formulae are only available in cases of underexposure. For correct exposure we can get an expression by applying the empirical formula given by HURTER and DRIFFIELD. This formula (10) "represents the necessary relation between the density and the exposure which must be fulfilled if photography is true to nature" (HURTER).

This formula slightly modified is:

$$D = \log \frac{I_0}{I_t} = a + b Ag = a_1 + b_1 \log Q. \quad (10)$$

in which  $a$ ,  $a_1$ ,  $b$  and  $b_1$  are numerical constants,  $Ag$  the total quantity of reduced silver,  $Q$  the total energy of the light. If we use the expression for  $Ag$  from (5) in this formula we get:

$$D = \log \frac{I_0}{I_t} = a + b Ag (1 - \varepsilon^{-\mu l}) = a_1 + b_1 \log Q (1 - \varepsilon^{-\mu l}). \quad (11)$$

in which we have also corrected the value for  $Q$  by using (8) and putting in it only that part of  $Q$  which really has been absorbed.

If the results of this discussion represent the facts with sufficient accuracy, we may draw the conclusion, that between light- and Röntgen-negatives still another point of difference should exist.

We may expect that in cases of the same density a light-negative contains considerably less silver than a Röntgen-negative; in cases of light- and Röntgen-negatives containing the same quantity of reduced silver, the transparency of the latter will invariably be greater.

In order to test the truth of these conclusions I asked my assistant Dr. KATZ to make a careful quantitative analysis of the amount of silver in a set of larger plates forming together an exposure-scale. The 10 plates measuring nearly  $10 \times 15$  cm. were cut from one plate  $30 \times 40$  cm. Five of them were used for the lightscale, the other 5 for the Röntgen-exposure scale. The results of all the measurements are given in table II. (See p. 678),

The vertical columns contain: Under Plate 42 the number of each plate; under  $Q$  the relative quantities of light; under  $\varphi$  we find the reading of the polarisation photometer; under  $2 \log ctg \varphi$  the measured density, whereas the next column contains the most probable value for the calculated density, supposing a linear relation between  $\log I$  and  $\log ctg \varphi$ . The following vertical columns contain: the measured quantity of silver on the whole surface of each plate, the exact measured surface, the quantity of silver per square centimeter. In the last column the most probable quantity of silver is given, calculated on the supposition of a linear relation between  $\log Q$  and



TABLE II.								
Plate 42	Q	$\varphi$	$2 \log \operatorname{ctg} \varphi$ meas.	$2 \log \operatorname{ctg} \varphi$ calc.	mgr silver	Surface	Ag p. cm <sup>2</sup> meas.	Ag p. cm <sup>2</sup> calc.
$L_1$	1	25°0'	0.663	0.6654	19.4	96.7	0.201	0.1954
$L_2$	2	14.34½'	1.170	1.1590	28.6	93.7	0.306	0.3202
$L_3$	4	8.50½'	1.617	1.6526	39.9	88.4	0.452	0.4451
$L_4$	8	4.34½'	2.194	2.1462	57.7	99.7	0.578	0.5700
$L_5$	16	2.48½'	2.619	2.6398	69.1	100.7	0.689	0.6948
$R_1$	1	37°33'	0.228		15.1	93.6	0.161	0.1582
$R_2$	2	32.21	0.397		21.0	97.3	0.216	0.2190
$R_3$	4	26.3	0.622	0.6272	26.4	94.6	0.279	0.2798
$R_4$	8	17.0	1.029	1.0187	32.4	96.1	0.338	0.3406
$R_5$	16	11.13½'	1.405	1.4102	39.9	98.6	0.405	0.4014

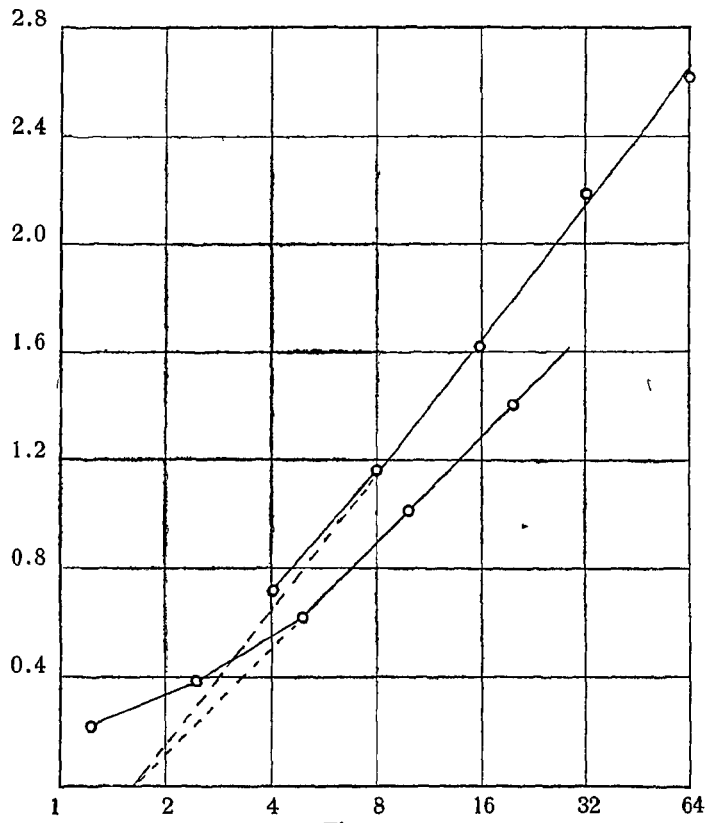


Fig. 5.

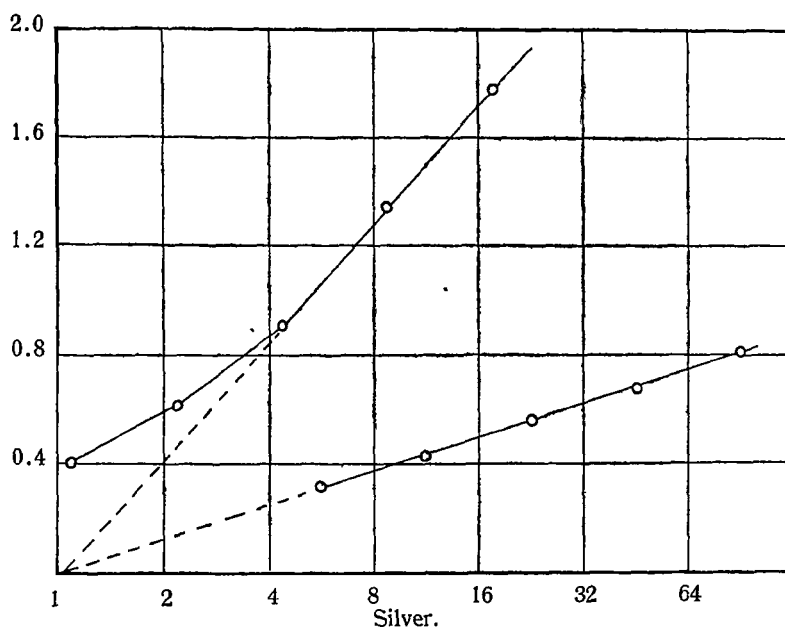


Fig. 6.

the quantity of silver per unit surface. The formulae used for the calculation of the figures on the 5<sup>th</sup> column were

$$D_L = 0.1708 + 0.4138 \log_{(2)} Q \quad \text{and} \quad D_R = 0.5473 + 0.3915 \log_{(2)} Q.$$

The second formula was calculated from 3 figures only.

For the last column I used the formulae:

$$100 Ag_L = 7.055 + 12.485 \log_{(2)} Q \quad \text{and} \quad 100 Ag_R = 9.74 + 6.08 \log_{(2)} Q$$

We see immediately from the table, that the conclusion as to the difference in the amount of silver contained in the film after exposure to light and to X-rays seems to be true. We find that  $L_1$  and  $R_1$  show only a slight difference in density viz. 0.663 and 0.622, the Röntgennegative being the more transparent one. Yet this contains 0.279 mgr. of silver per unit whereas the denser light negative contains only 0.201 mgr. The same thing is found for  $L_2$  and  $R_2$ .

If two negatives with nearly the same quantity of silver be compared, for instance  $L_1$  and  $R_2$ , containing 0.201 and 0.216 mgr. of silver, we find the light-negative about 50 percent denser than the Röntgennegative, which, however, contains more silver.

I must advance still another argument in favour of my theoretical deductions. If these be true we ought also to expect differences in the slope of the characteristic curves when ordinary light waves of different length are used, the absorption-coefficients of which in bromide-silver-gelatine is different. In EDWARDS' Handbook of Photo-

graphy, Part III, we find on plate II a series of characteristic curves pertaining to light of different wavelength between 4100 and 5100. The curve for 4600 shows maximal action and also maximal slope. Experiments by EDER on orthochromatic plates, the curves of which are given on other plates, also prove the fact that stronger absorption or a large value for  $\mu$  concurs with stronger slope in the curve.

Another fact mentioned by EDER (l.c. p. 223) is the greater density of collodion negatives as compared with gelatine-negatives containing the same amount of silver. As the former are notably thinner than gelatinefilms this is equivalent to a larger absorption in the thinner films. If, finally, the thickness of a layer containing a certain amount of silver is so far reduced that the conditions, present in a silver-mirror are approached, EDER finds that only 0,039 mgr. of silver per

TABLE III.					
Number	$\frac{dS}{dL}$	$\frac{dS}{dR}$	Quotient	Hardness	Quotient Calc.
5 <i>A</i> and <i>B</i>	.505	.409	1.232	7.2 BENOIST	1.250
6 <i>A</i> and <i>B</i>	.419	.311	1.349	6.1 "	1.336
7 <i>A</i> and <i>B</i>	.445	.300	1.482	4.2 "	1.483
8 <i>A</i> and <i>B</i>	.468	.401	1.167	8.4 "	1.157
42	.489	.391	1.250		

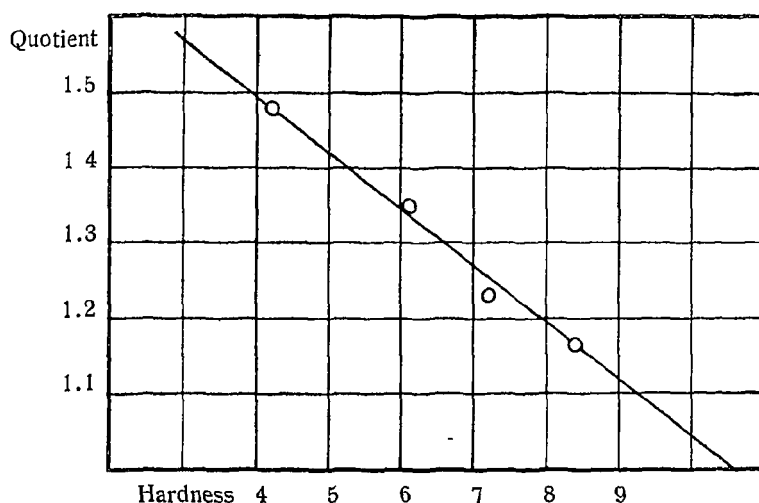


Fig. 7.

square centimeter is sufficient to produce a density of 1.5 and 0.052 mgr. of silver a density of 2.0.

On the other hand I found in my experiments one fact that at first sight did not agree with my deductions. If from the different series of experiments given in table I and II we calculate the increase of density with the increase of the action of the light and of the Röntgenrays, we find the figures given in table III, graphically represented in fig. 7. (See p. 680).

The first column gives the number of the experiment, the second one the increase of density when the action of light is doubled; the third one the increase of density on doubling the action of the Röntgenrays.

In the fourth column the quotient of the figures in the former columns is given. The 5<sup>th</sup> column contains the penetrating power of the X-rays expressed in degrees BENOIST.

The figures in the 4<sup>th</sup> column are useful to indicate the amount of difference in slope of the characteristic curves. If these be compared with those for the hardness of the rays, we find the remarkable fact, that the difference in slope is less for penetrating rays than for rays from a lower-vacuum tube. This is best seen in the curve of fig. 7 which shows an absolutely unexpected linear relation between the quotient and the penetrating power. The figures in the last column of table III are calculated with the linear equation:

$$\text{Quot.} = 1.809 - 0.0776 \text{ Degrees BENOIST.}$$

Though this seemingly anomalous behaviour of the harder rays might be caused in different ways, we cannot reasonably suspect a secondary radiation originated in the gelatine bromide layer itself, as this would occur in every part of the layer. We can only suppose that the more penetrating rays are mixed with an exceedingly absorbable radiation which is present to a far less extent in the radiation of medium hardness. Perhaps a very absorbable radiation might be generated by the harder X-rays by impact on the glass support after their passage through the sensitive layer. If the primary rays already contain a certain amount of soft rays, these may be derived from the anticathode (as a soft characteristic platinum or tungsten-radiation) or from the glass-bulb, or perhaps from the envelope in which the plate was exposed to the rays. Between the first and the last of these possibilities we must have the difference, that in the first case the deepest parts of the gelatine layer contain more silver than the surface, whereas in other cases the surface of the gelatine will be richest in silver. In order to decide in this question I asked Dr. KLESSENS to make a few microscopic slides from transverse sections of the gelatine layer of different negatives.

Microphotographs of these, enlarged about 500 times show immediately that the theoretical deductions in my paper are confirmed. In fig. 8 a transverse section through a light-negative shows a strong deposit of silver in the upper part of the gelatinelayer and hardly any silverparticles in the deeper strata. A section through a Röntgen-film made with soft rays ( $3^\circ$  BENOIST) is shown in fig. 9. The silverparticles are almost equally distributed in the layer. From a negative with hard X-rays ( $8^\circ$  BENOIST) I got the photograph shown in fig. 10,



Fig. 8.

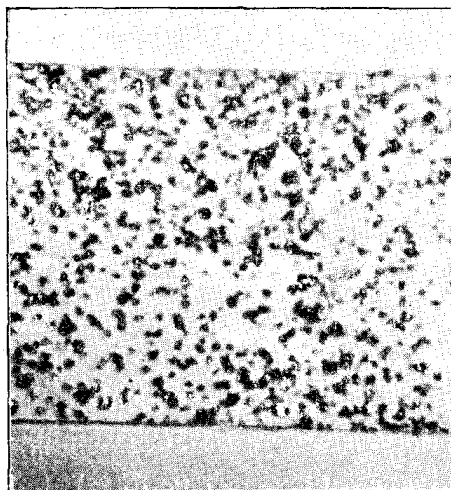


Fig. 9.

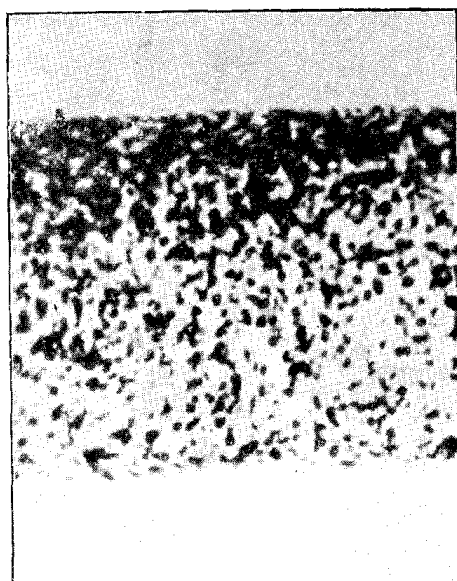


Fig. 10.

in which the surface of the gelatine contains more silverparticles than the deeper strata. With rays of medium hardness I found a more even distribution of the silver particles, showing that these rays contained only a limited amount of extremely soft rays.