THE BEHAVIOUR OF PHOTOGRAPHIC PLATES TO X-RAYS.

By O. BLOCH, F.I.C., and F. F. RENWICK, A.C.G.I., F.I.C.

The following note contains a brief account of part of the work done during the past few years in the Research Laboratories of Ilford, Limited, on the action of X-rays upon gelatine dry plates.

For the purpose of to-day's discussion it was thought best to omit all description of the working methods adopted and to include only such data as are necessary for the understanding of our results.

When the mixed radiation from an excited X-ray bulb is allowed to act for various lengths of time on a photographic plate, the relations between the masses of silver reduced by subsequent development and the quantities of radiation received by the plate are represented by a curve of the kind shown in Fig. 1A. The silver deposits are measured

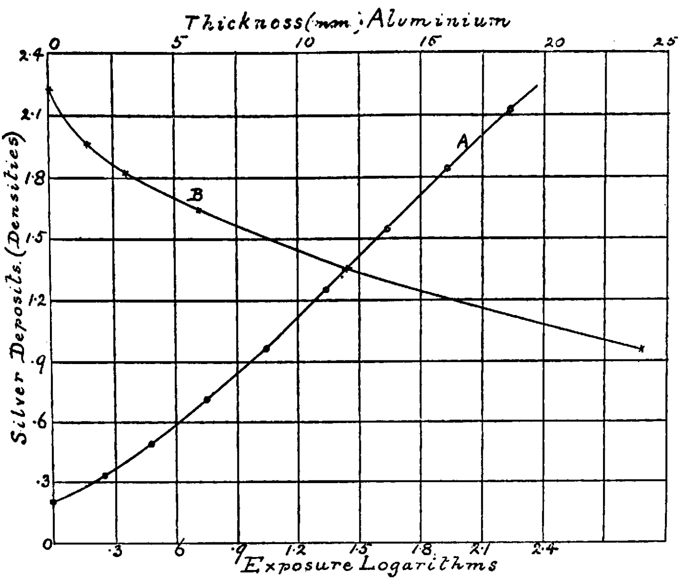

FIG. 1.

photometrically by determining their opacity-logarithms or " densities " ($\log_{10} O = D$), which are plotted against logarithms of the times of exposure to a constant radiation.

Such curves closely resemble the well known " characteristic curves " representing the action of light on photographic plates but differ by having a more pronounced " foot " or strongly curved lower portion than is found in the curves characteristic of light action. Moreover, within this lower range of exposures, densities are not proportional to the exposures received, as is the case with light in the so-called "period of under-exposure." The great importance in practical radiography of this part of the X-ray characteristic curve will be dealt with more fully later. No satisfactory formula, which is independent of time of development, has yet been evolved for expressing the sensitiveness of a plate to X-rays, such as Hurter and Driffield gave us for the light effect, and therefore at present no scientific criterion of X-ray plate speed exists. Moreover, any classification of plates which relies only on the straight line portion and ignores the important region comprised within the very pronounced foot of the characteristic curve is undesirable because it would bear little relation to practice. In fact, a speed number

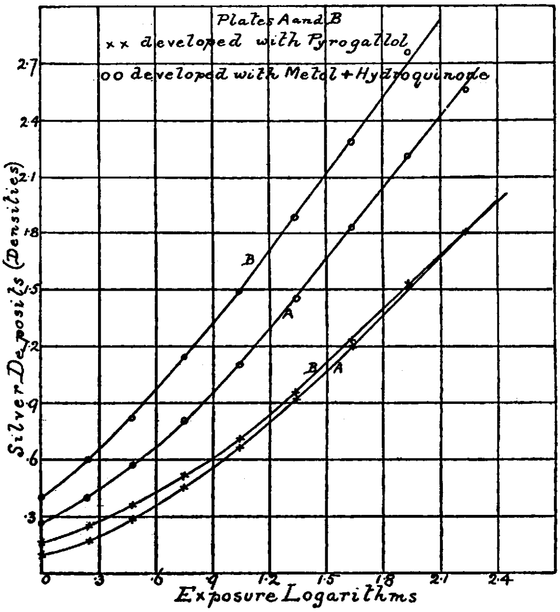

FIG. 2.

which depended entirely upon the foot of the curve would possess a real value denied to figures derived from the straight portion. Incidentally we may remark that for the estimation of the intensity of X-radiation, methods dependent on the effects it produces on a photographic plate have been adopted by several workers without a proper appreciation of the bearing upon this problem of the shape of the X-ray characteristic curve and its divergences from the curve characteristic of light action.

When, however, X-rays pass through a series of increasing thicknesses of some material before acting on the plate, selective absorption of the longer wave lengths takes place, so that the radiation affecting the plate is of shorter average wave length the greater the thickness of material penetrated. In addition to this, part of the radiation is scattered in all directions, and part is transformed into other X-rays characteristic of the material penetrated. The curve connecting the masses of silver reduced by subsequent development with the thicknesses of material penetrated is therefore different in form from that found for varying time of exposure to the same radiation. Fig. 1B shows such a curve for a series of aluminium steps. After a fair thickness has been penetrated, the silver deposit becomes nearly inversely proportional to the increase of thickness, but we shall see that in order to reach this stage early, *i.e.*, with moderate thicknesses of different materials, the incident radiation must be made more penetrating in character (shorter in wave length) the higher the atomic weight of the material under examination.

Our next diagram (Fig. 2) demonstrates the great influence which the nature of the developing agent employed can exert on the result.

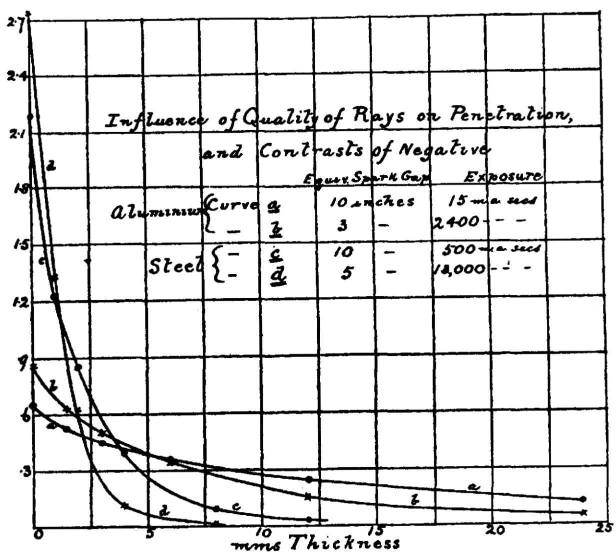

FIG. 3.

In this experiment, two plates of different types were simultaneously exposed to X-rays for a series of accurately known periods with no intervening absorbing material. After cutting both plates in half, one portion of each was developed for three minutes at 65° F. in a Pyro-Soda Developer, the remaining portions being developed in a Metol-Hydroquinone Sodium-Carbonate Developer. Whereas with Pyro-Soda the two plates gave very similar results, in Metol-Hydroquinone one of the plates proved to be considerably faster than the other.

We find that mere variations in the length of time of development do not alter the general form but only the steepness of the characteristic curve to X-rays; the growth of each individual density by prolongation of development conforms to the rule which holds for light-affected plates, viz., $D = D_{\infty} (1 - e^{-Kt})$.

Fig. 3 shows a set of curves expressing quantitatively the well known influence of the wave length of the radiation employed on its penetrating power and on the steepness of gradation of the resulting negative. Curves *a* and *b* show the effects of "hard" and "soft" radiation respectively after passage through a series of aluminium steps; while curves *c* and *d* afford a similar comparison for various thicknesses of steel, development being the same for both pairs.

A far larger section of the characteristic curve is required to include the wide range of intensities acting on the plates in the case of the steel-steps, and hence we get a far greater range of densities in these negatives than in the records under the aluminium scale. Moreover, the exposures given in this experiment were only sufficient to give records through the greatest thicknesses of steel by utilising the shallow part of the "foot" of the characteristic curve of the plate, and therefore the contrasts representing differences of thickness at this end of the scale are very small.

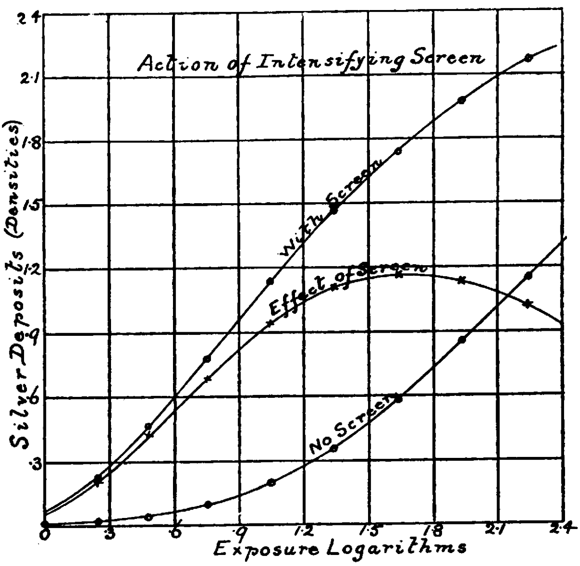

FIG. 4.

The differences in gradation resulting from variations in the penetrating power of the radiation acting on the plate are small in comparison with those dependent on length of exposure (which governs the portion of the characteristic curve used to portray the subject) and conditions of development. It will be evident therefore that the longest practicable exposure and development will be required to secure maximum contrasts where there is a considerable thickness of a dense metal to be penetrated. It is, of course, essential to use the most penetrating radiation possible in such cases in order to secure a sufficient transmission of X-rays to act on the plate, the transparency of all materials to X-rays increasing rapidly as the wave length of the rays employed becomes shorter.

Even with the hardest practicable radiation, such as is generated by a Coolidge tube regulated to an equivalent spark gap of 13 to 15 inches between points, apparently $1\frac{1}{2}$ to 2 inches of steel is the limit that can be critically examined, and very great exposures are then necessary.

Our chief hope of improving upon this state of affairs lies in improved sensitive materials. With this object one naturally turns first to fluorescent (intensifying) screens for aid.

Figs. 4 and 5 are examples of the effects obtained by using one of the commercial calcium tungstate screens in contact with a plate when exposing it to geometrically increasing doses of a constant quality of radiation.

Fig. 6 shows the results obtained when various thicknesses of steel were radiographed with and without an intensifying screen,

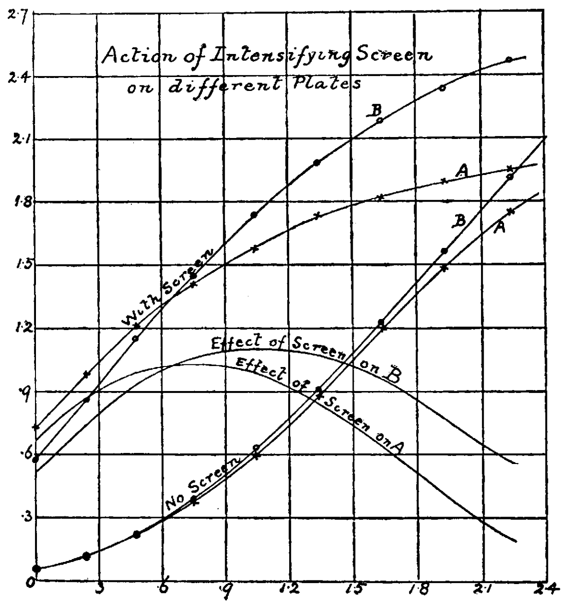

FIG. 5.

on three different kinds of plate. As might be expected, the effect of the screen on the gradation of the negatives varies with the qualities of the photographic plate employed. The shape of the curves varies with the ratio:—

$$\frac{\text{Sensitiveness to light}}{\text{sensitiveness to X-rays.}}$$

In this experiment (Fig. 6), plate A, possessing the lowest ratio, gives a curve which is still convex to the coordinate axes throughout its length, the next in order is represented by a straight line over its median region, while plate C, with the highest ratio, gives a curve which is concave to the axes for a considerable part of its range.

The use of fluorescent materials as " intensifiers " of the action of X-rays offers advantages in that not only do they permit of great reduction of exposure but also the resulting negatives display somewhat stronger contrasts between the lower densities than the unaided plate will yield. This is brought out in Fig. 7, where curve D represents

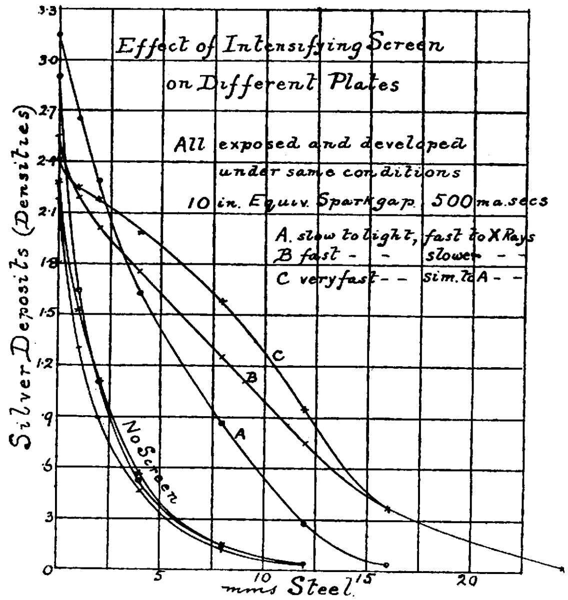
Effect of Intensifying Screen
on Different Plates
All exposed and developed
under same conditions
10 in. Equiv. Sparkgap. 500 ma.secs
A. slow to light, fast to X Rays
B fast - - slower - -
C very fast - - sim. to A - -
Silver Deposits (Densities)
mms Steel
No Screen
A
B
C
3·3
3·0
2·7
2·4
2·1
1·8
1·5
1·2
·9
·6
·3
0
5
10
15
20

FIG. 6.

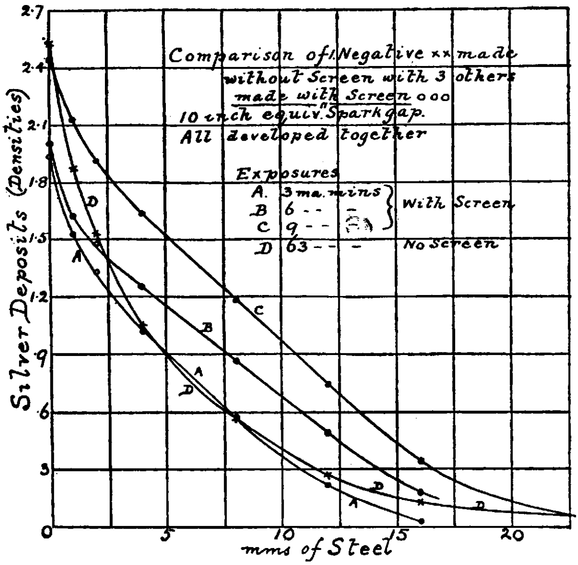
Comparison of Negative xx made
without Screen with 3 others
made with Screen ooo
10 inch equiv. Sparkgap.
All developed together
Exposures
A. 3 ma. mins
B 6 - -
C 9 - -
D 63 - - -
With Screen
No Screen
Silver Deposits (Densities)
mms of Steel
A
B
C
D
2·7
2·4
2·1
1·8
1·5
1·2
·9
·6
·3
0
5
10
15
20

FIG. 7.

the effect on the plate when used without a screen and the other three curves show the effects of three different exposures with a calcium tungstate screen in contact with the plate's surface.

In normal X-ray exposures, and to a less degree when intensifying screens are used, the silver deposits obtained under the thicker parts of a dense subject will usually represent exposures falling within the region comprised by the foot of the characteristic curve of the plate. Now the value of the tangent to this curve at any point is the measure of the degree of contrast. It will be obvious therefore that it is not possible to secure good contrasts throughout a negative unless the quantities of radiation which have affected the plate were all sufficiently great to be well above those comprised within the shallower part of the foot of the above curve in which region the tangents have small values.

Failure to comply with this requirement is the chief reason why, for example, it is usually found so difficult to bring out very shallow defects in a thick piece of steel.

It is unfortunate that even the best commercial intensifying screens, so far, at least, as our experience goes, are sufficiently granular to mask the fine details in a radiogram. There is also the difficulty, and it is a very great one, of securing perfect contact between plate and screen. Consequently we are disposed to doubt the advisability of using separate fluorescent screens in the radiography of metals, where fine definition is usually essential.

It is of interest to record that silver bromide itself is feebly fluorescent to X-rays, but there does not appear to be any relation between the intensity of the fluorescence and its X-ray sensitiveness. At present there seems to be little prospect of making ordinary silver bromide dry plates much more sensitive to X-rays than those now available. Some of the existing X-ray plates contain other substances which are either fluorescent or assist by reason of the secondary X-radiation they emit when acted on by very penetrating X-rays. Hitherto, however, no striking success along either of these lines has been achieved, most of the materials that have been found to enhance the X-ray effect being either injurious to the silver bromide emulsion or too difficult to incorporate with it. It seems, nevertheless, probable that success will sooner or later reward those at work on this aspect of the subject.