THE THEORY OF THE PHOTOGRAPHIC PROCESS.

By C. E. KENNETH MEES, D.Sc.

In the course of a number of investigations of the behaviour of a photographic plate to light, it seemed to be desirable to extend them with a view to finding out the effect of Röntgen Rays on a plate, and how that effect compared with that produced by light.

It was suggested to me that these investigations would be suitably published at

the Röntgen Society, and it was intended so to do; unfortunately, owing partly to press of other work, and partly to the investigations into the theory of emulsion-making necessitated, the work on the actual effect of X-rays has been delayed, and I therefore agreed to give this paper as a preliminary, so that before discussing the effect of X-rays your Society might have an opportunity of understanding my views on the action of light on a plate. The substance of this paper has already been published, but the difficulty of applying general results to special cases may warrant a further handling.

The most important work on the laws which govern the behaviour of a photographic plate was done by Messrs. Hurter and Driffeld, and published in "The Journal of the Society of Chemical Industry," in 1890. They there laid down certain general principles which have formed the basis of much further work by other investigators.

In the first place, they defined the law of light transmission:—

If T is the transparency of a deposit, then they define the opacity O , as $\frac{1}{T}$, that is the inverse of the transparency.

Now imagine a number n of layers, each layer transmitting $\frac{1}{r}$ of the incident light then two layers will transmit $\frac{1}{r^2}$, three layers $\frac{1}{r^3}$, and n layers

$\frac{1}{r^n}$ The Transparency then of the n layers is $\frac{1}{r^n}$, the opacity will therefore be r^n , and the density which Hurter & Driffield defined as the logarithm, will be n , that is, will be proportional to the number of the layers. Consequently, the density or the logarithm of the opacity is proportional to the mass of the substance present; this has been confirmed by direct measurements made by Hurter & Driffield, and by later and more accurate ones by Eder, and by S. E. Sheppard and myself.

Since in a chemical re-action we measure the effect of the re-action as the mass of product formed, the density will be the measure of the effect of a photo-chemical reaction.

In order to find the law which connected the density of a photographic plate with the exposure, Hurter & Driffield exposed the plate to a standard candle at one metre distance for a number of times in geometrical progression, and they found the relation which holds between the exposure and density obtained. The first slide shows the result in a diagrammatic form. They found that if the density were plotted against the logarithm of the exposure then over a large portion of the curve we should get a straight line.

Fig. 1.

The diagram (Fig 1) shows the actual measurement of a plate curve, and the crosses represent the points which are measured for different exposures.

It will be noticed that the curve is in the form of an integral sign. In the lower portion the density is rapidly increasing as the exposure progresses. Then, throughout a large portion of the curve, the density is proportional to the logarithm of the exposure. Finally, there comes a point at which it falls off. The portions are known as "under," "correct," and "normal" exposures. In order correctly to represent the tones of the original the density must be proportional to the logarithm of the exposure. The "correct" portion is the portion represented by the straight line. The point where the straight line meets the exposure axis was termed the logarithm of the inertia, and the exposure corresponding to it the inertia. They therefore made an attempt to give a theoretical equation for the plate-curve giving the reason for this integral-shaped curve; the basis on which they worked this out was as follows:—

If one considers an infinitely thin layer of a substance under the action of light, then, according to the Bunsen-Roscoe law the light-product is proportional to the exposure, that is to the light-intensity multiplied by the time. It may be pointed out that in the case of X-rays a plate to some extent acts as if it had no thickness of coating, or in other words, as if it were infinitely thin, so that for X-rays the density is approximately proportional to the exposure. If, however, we consider a plate film not as a thin surface, but as a thick layer, then as the light goes through, some of it will act on the top layer, some will get through and act on the layer below, and some will not get through but be wasted, so that we have a different state of affairs, from which by calculation, Hurter & Driffield derived an equation which approximately represented the shape of the plate-curve.

We must next consider the relation which holds for a plate between the density and the time of development. If we develop a plate, the curve swings round the inertia point the slope getting greater as the

development progresses. This slope which is measured by the tangent of the angle made by the straight line portion of the curve with the exposure axis, was termed by Hurter & Driffeld γ .

Fig. 2.

In Fig 2 we see the effect on the slope of developing a plate for equal intervals separated from each other for one minute. At first the plate increases in density rapidly, but this rapid increase falls off until finally further development produces no greater density, and the plate reaches its limit, which is termed γ_{∞} .

Fig. 3.

In Fig. 3 γ is plotted against the time of development, and shows the same effect in another form. γ_{∞} , the limiting slope, is a measure of the density-giving power of the plate.

We see then that the four main Constants of a plate are:—

(1) The inertia. This is the inverse of the speed—in a word, the insensitiveness of a plate.

(2) γ_{∞} . This is the density-giving power of a plate.

(3) "K" or the velocity constant of development, which means the speed of development. This is not of any great importance. "K" can be altered, of course, by the developer used. For instance if the developer be warmed "K" becomes greater.

(4) "O," or the opacity of the plate, which is proportional to the latitude. "O" settles the length of the straight line portion of the plate curve.

We may briefly describe the apparatus used in determining these various constants. In the first place exposures are given by means of a rotating sector wheel, so cut that each progressive sector halves the exposure. This sector is revolved on a spindle in front of a plate held in a darkslide, and the plates are exposed to a standard acetylene burner at the other end of the box containing the sector wheel.

The plates are developed in a thermostat, care being taken to avoid possible causes of fog, the most dangerous being stagnant water.

The measuring photometer is a differential spectra-photometer. The plate to be measured is placed in front of the top-half of a spectroscop slit, the lower half being covered by a polarising nicol. On rotating the analysing nicol in the telescope, the polarising beam in the lower half can be darkened until the two parts of the field are equal in intensity with the angle of rotation, and can be read off, and gives the measure of the density.

In order to investigate the effect of X-rays on plates I have employed a large Tudsbury Machine, working under pressure. This machine has given very satisfactory results except for difficulty with external sparking. The wires have been connected to a large

water-cooled tube especially made by Mr. Isenthal, which has given satisfaction, and is extremely steady in running. The machine gives a very equable current, and the tube does not flicker, but emits a steady glow during the whole of the time it is running. The chief difficulty has been the great length of exposure necessary to reach the bottom angles of the sector wheel. It has been necessary to cover both the sector wheel and the dark slides used, with lead, in order to prevent penetration of the brass by the rays. The few results we have obtained must be taken as preliminary experiments.

First I made a comparison of the speed of X-ray plates, and the conclusion at which I have arrived is, that for plates with an equal thickness of coating, the X-ray speed is proportional to the light speed, and that special X-ray plates as such, have no advantage; the curve, however, is not the same as the light curve, but is of the shape which would be obtained for a plate without any thickness of coating; this indeed might have been anticipated from the fact that a gelatino-bromide film is almost perfectly transparent to X-rays.

I have succeeded in measuring $\gamma \infty$ and the velocity constant of the plate under X-rays, although it is very difficult to tell what the γ is. The only method is to draw a tangent and make comparisons with an ordinary light plate. The results are more consistent than one would expect. The "K" gives a very steady measurement, viz. :—

'0275 for 4 mins.

'0246 „ 8 mins.

'0248 „ 16 mins.

$\gamma \infty$ is 1.50 for the X-rays, and 1.53 for light. $\gamma \infty$ is thus practically the same for X-rays as for light, and this is very important if $\gamma \infty$ has any relation to the chemical constitution of the reaction. That is, it is important to know that the reaction products of X-rays and of light are of the same type.

To sum up, the speed of a plate to X-rays is proportional to its daylight speed; the

velocity constant and the development law are the same, and the shape of the curve is different, the X-ray curve resembling that of a plate which has no opacity to the light action, or in other words is transparent.

The obvious object of importance is to increase $\gamma \infty$. It is to that end that I should direct any investigations in emulsion-making. Unfortunately the fast plate has almost always a low $\gamma \infty$ so that there are practical difficulties in the way.

DISCUSSION.

Mr. GARDINER: One would like a little further information as to the kind of light used in the experiments. Mention was made both of a standard candle and an acetylene burner, there must be very considerable difference in the results according to the kind of light used, luminous radiation of short wave length for instance is absorbed so readily that it will not pass below the surface of the film, while that of longer wave length will of course penetrate easily. The actual result produced must bear some proportion to the amount of energy which the film absorbs. I was not surprised to learn that the shape of the daylight and of the X-ray curve differed, because we know that the disturbances recognised as X-rays are very dissimilar from the disturbances we class under the heading of light. It is fairly obvious why it is that an X-ray effect is similar to the light effect produced on an infinitely thin photographic film.

The difficulty Dr. Mees has had with the connections of the Wimshurst machine recalls my first visit to the laboratory of our late member, Mr. Wimshurst. He avoided as far as possible wire terminals, and his tubes were fitted with highly polished brass balls, into which the indiarubber-covered lead was placed, this entirely stopped outside sparking. No doubt in back numbers of the "Archives" Dr. Mees would get some useful information on that point.

I can only congratulate Dr. Mees; it has been a great pleasure to us to see some real

foundation work, of a kind which radiographers in general do not have the opportunity of seeing.

Mr. A. W. ISENTHAL : The paper before us requires a little digestion before it can be adequately discussed. Dr. Mees at the end of his paper does not hold out much hope of his arriving at any results of great importance with regard to emulsions in X-ray work. I may say, however, what Dr. Mees in his modesty would not say, that since in a very short time he has succeeded by applying scientific principles to orthochromatic plates, in making considerable advances in colour work possible, if anyone can produce any improvement in our X-ray plates he is the man to do it.

It would be interesting to know whether he has taken into consideration the fact that when X-rays traverse a film, particularly an absorbing film, their penetrative power is not weakened in anything like the proportion in which light is weakened, owing to the secondary generation of X-rays. If the rays on the first plane have a certain strength, a little further down that strength may be rather increased than diminished, because when the rays strike the film or any solid, secondary rays are produced. This phenomenon might very well be taken into consideration in theorising about the shape of the curves.

We have had a great many papers read before this Society on the physical and medical side of our work, but only one or two on its purely photographic aspect. Dr. Mees' paper has therefore certainly whetted our appetite for the further discussion which he has promised us.

Dr. E. S. WORRALL : I should like to add my thanks to Dr. Mees for his paper, which I have done my best to follow. On the question of the relation of density to X light received, Dr. Mees says that $D = EK$; the density is fixed by a constant and the amount of exposure, but this is not so in the case of light

where we have a much more complicated formula. Dr. Mees' remarks would seem to indicate that if we were to increase the thickness of the coating of the plate we should better our results from the point of view of speed.

With regard to the determination of the inertia point, is that determined by the time at which the high lights first appear, or how is it obtained?

If the X-ray curve is different from the curve representing the action of ordinary light, where would be the inertia point in that case?

I was hoping to hear something about the admixture of the fluorescing substances in the production of emulsions.

Dr. G. B. BATTEN : Even if we do not pretend to understand the more elaborate formulæ, the whole of Dr. Mees' paper is extremely interesting.

I should like to emphasize the question Dr. Worrall has asked, as to whether by increasing the thickness of a fast emulsion we can get better results from a plate.

In the use of big coils I am aware of the practice of earthing one end of the secondary to save sparking, and I think that would possibly get over some of Dr. Mees' difficulties, though I am not sure if this applies to static machines.

Mr. R. S. WRIGHT : Has Dr. Mees made any experiments with regard to the quality and thickness of the glass on which the emulsion is made? I believe it is a fact that X-ray work with films is not very satisfactory, the reason presumably being that the film is so transparent that the rays pass right through it. But when backed by glass the rays may be scattered or irregularly reflected back into the film. If this is the case, it must be remembered that glass varies enormously, some kinds being almost transparent to the rays, and others almost opaque. Would it make any difference if the plate were backed by a sheet of thin

English plate glass, or by a glass of a greater opacity to the rays? I do not know whether Dr. Mees has made any experiments in that direction.

One word about the difficulty with the machine. For years I have been making experiments with static machines, and the late Mr. James Wimshurst also very kindly gave us any suggestions he could make. Practically we always found that the best results were got by bringing the wires up to terminate in a couple of polished brass balls, and letting these balls spark to the electrodes of the tube. If we keep everything polished, and make all our connections by means of balls, the difficulty of sparking and spitting is to a great extent overcome.

Mr. F. H. GLEW: With regard to the top portion of the curve obtained with the X-rays, I may say that some years ago I tried to get reversal, and kept my tube working for thirteen hours continuously, without getting any sign of reversal at all. It would be interesting to follow the matter out beyond that.

There is one point I might mention in connection with photographic emulsions. I should very much like to see the effect of splitting up the large grains much in the same way that is now done in treating milk. The fat globules are split up until they are so small, and take such an infinite time in rising, that practically they do not rise at all. The method employed is to force the milk with great pressure through a minute orifice. Some such method might perhaps be used with regard to emulsions. In that way a much larger surface area would be obtained for the sensitive material. I should very much like to know what the effect of that would be. From the theoretical point of view, one would expect to get, for light, a very considerably greater sensitiveness, but for X-rays there would probably be less advantage.

Secondary radiation from X-rays is comparatively small, but from radium it is

considerable, because the penetration of radium rays corresponds to a very hard X-ray tube, and the tendency with secondary radiation is always of a retrograde character, that is to say, secondary X-rays are always softer than the primary rays which caused them, they are, therefore, more energetic, photographically, because they are more easily absorbed by the sensitive salts.

Mr. E. PAYNE: With reference to Dr. Mees' remarks that he found "the sensitiveness of plates to X-rays varied with their sensitiveness to ordinary light," in 1896 I made some experiments with some Lumière plates, known as A, B and C plates; I found that the B plates, which are sensitive to red and yellow light and not sensitive to green, were more sensitive to X-rays than either of the others. Are the B plates more sensitive to ordinary light than the A and C plates? I do not think they are. I compared the B plates with "lightning Cadett" plates but found the B plates the more sensitive of the two. I do not know what the makers do to the plates to make them sensitive to red and yellow and not sensitive to green, but it seems to make them more sensitive to the X-rays. I should be glad to know whether Dr. Mees has tried any of these plates, or whether he can explain the result in any way.

Dr. MEES: I thank Mr. Gardiner and others who have brought forward suggestions with regard to the Wimshurst machine. I knew that I should get all the assistance I wanted from this Society. I spent some time in trying to stop the sparking, and the sparking got so serious that I could not get anything through the tube at all. Now I know what to do.

With regard to the point made by Mr. Isenthal, the reason why the X-ray curve differs from the light curve is because the film behaves to X-rays like an infinitely thin plate. If you consider an infinitely thin,

transparent plate, the ordinary plate behaves like that to X-rays. The curve I obtained with X-rays, however, is not what it should be on this hypotheses. If it were perfectly transparent the difference between it and the light curve should be still more pronounced. I am going to experiment by coating some plates on waxed glass, stripping the films and measuring the inertia of a plate behind them, thus getting the opacity of the plate to X-rays. That will settle the matter.

I have a question down as to the quality of the light. Plate curves differ through practically the whole spectrum, both for ordinary and orthochromatic plates. Plates—even the best orthochromatic plates—are much more opaque to the shorter wavelengths than to the longer. In measuring the plate curves in actual sensitometric work acetylene standard light has generally been used. The thickness of the coating is the final thing, but not because it affects the stopping power. γ_{∞} is exactly proportional to the amount of silver in the film, therefore the thickness of coating affects γ_{∞} .

We cannot really determine the inertia point for X-rays. The inertia is the prolongation of the straight line portion to the axis. For an X-ray plate there is no inertia point at all, because there is no straight line. There is, however, one way of determining approximately the inertia, even of an X-ray plate. We can develop two plates, one being exposed to light and the other to X-rays. The γ will be the same in each case, as we have already seen, so that a line can be drawn on the X-ray plate curve parallel to the straight line on the other, and the tangent line, which follows the direction of the straight line instead of taking the usual course of the curve, will give us something akin to the inertia point.

I have made no emulsion experiments with regard to fluorescent substances. I do not think there is any reason to believe that a red sensitive plate is specially sensitive to the X-rays.

Mr. PAYNE suggested that it was possible that the dye was luminescent, giving a secondary effect.

Dr. MEES, continuing, said: It would be easy to make experiments in the way Mr. Wright suggested if I could get glass that is flat. I always understood—all papers tell us so—that X-rays could not be reflected. I do not, therefore, see how they could be scattered.

Mr. ISENTHAL: In the beginnings of X-ray work the plates were coated on iron without any advantage whatever.

Mr. WRIGHT: There is no real reflection, but a sort of white paper reflection; not a reflection you can focus or see, but a reflection that, if the object is near enough to it, would give you good definition of the sort you would get on a white screen.

Dr. BATTEN: I have found a difficulty in getting lead glass flat and in very small squares. I have found the best material to be supplied by the Whitefriars Glass Works.

Dr. MEES: With regard to the suggestion about the crushing of the grains of the plate, the result in my opinion would simply be fog. If you do "anything rude" to an emulsion it always fogs at once.

In reply to Dr. Rodman, my opinion is that there is no appreciable difference between the ratio of speeds to X-rays and to light. The additional density-giving power of certain plates makes up for lack of speed. A high gamma infinity is equivalent to increased speed. A double coated plate is four times as fast as a single-coated plate to X-rays.

The CHAIRMAN: Our Society must be congratulated upon the most excellent paper we have had to-night. We have seen photometric observations and working, which outside the laboratory of the plate-maker

we have no chance of witnessing. It used to be taught that all plates were of the same susceptibility to X-rays, but it was soon found how misleading this teaching was, the results obtained with slow lantern plates showing them undoubtedly to be much slower to X-rays than other faster emulsions.

Our Society will look forward in the future to seeing Dr. Mees here again, when he may give us still more useful information about the right plate to use. Possibly, also, he may be able to tell us something about the advantage of certain developers in reducing or bringing out the latent image.

On the motion of the CHAIRMAN a vote of thanks was passed to Dr. Mees by acclamation.

The CHAIRMAN announced that at the next meeting on June 6th, Mr. Campbell Swinton would read a paper on "Some Recent Investigations in connection with Crookes' Tubes."

The meeting then adjourned.