

## THE TESTING OF PHOTOGRAPHIC DRY PLATES.\*

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

WHILE there are but few scientific workers who are not more or less expert photographers, few of these possess an adequate knowledge of the laws which define the reactions of the photographic dry plate. This is especially unfortunate in view of the fact that, provided these laws are understood, the photographic plate can be used as an extremely satisfactory instrument

In theoretical work these logarithms are taken to base  $e$ ; in practical work to base 10, as usual.

Thus, in order to measure the product of reaction in a photographic plate, we must measure the transparency, and from this calculate the density. By multiplying the density by a factor termed the "photometric constant," we can obtain the number of grammes of silver per square centimeter.

A density of 0.303 then, will mean that the plate transmits half the light; a density of 1 corresponds to

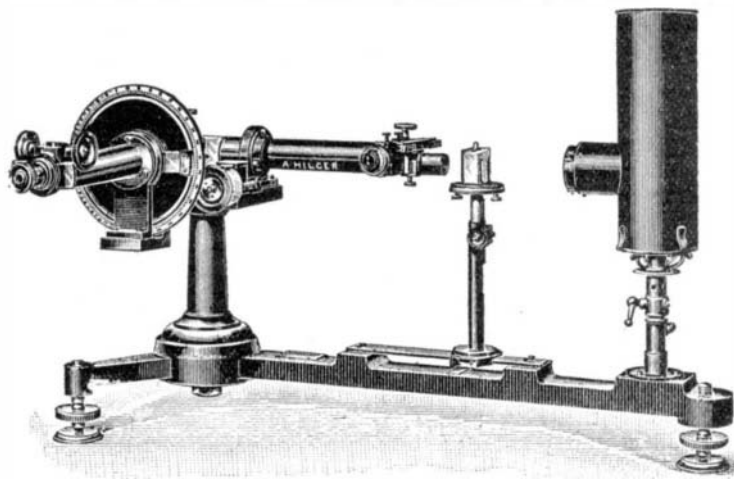


FIG. 1.—HÜFNER SPECTRO-PHOTOMETER.

for the quantitative investigation of many forms of radiant energy.

The blackness of a developed photographic plate is due to the deposition of large numbers of small grains of metallic silver within a thin film of gelatine. Consequently, the product of the reaction will be expressed in terms of the mass of silver deposited.

There are various methods of obtaining measurements of this mass of silver. One, for instance, is to dissolve out the silver with nitric acid, and, after destroying the gelatine, to titrate the silver with potassium thiocyanate, thus volumetrically estimating the mass of silver per unit area. This method is, of course, tedious, and is quite inapplicable to small surfaces of plate; the mass of silver which gives an ordinary intermediate density, such as stops nine-tenths of the light for instance, being about one milligramme per square centimeter.

On the other hand, it is quite possible to measure the amount of light which the plate stops, and it is clear that this amount will have some relation to the mass of silver present in the plate. This relation, in the form in which it is adopted at present, was originally worked out by Dr. F. Hurter and Mr. V. C. Driffield, and published in May, 1890, in a paper read before the Society of Chemical Industry, entitled "Photochemical Investigations."

The relation is as follows:

If  $I_0$  = the intensity of the incident light,  
and  $I_A$  = the intensity of the transmitted light:

Then,  $\frac{I_A}{I_0}$  = transparency =  $T$

$$\frac{I_0}{I_A} = \text{opacity } O = \frac{1}{T}$$

It has been proved experimentally, by Messrs. Hurter

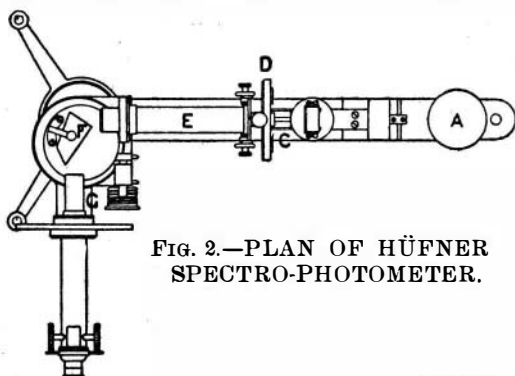


FIG. 2.—PLAN OF HÜFNER SPECTRO-PHOTOMETER.

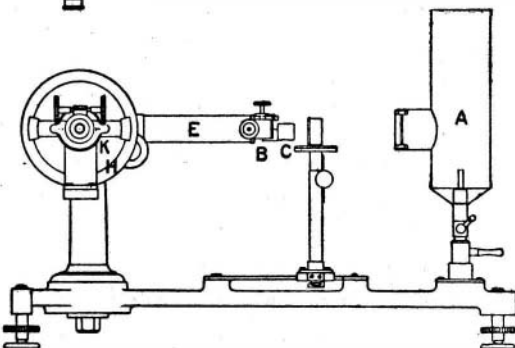


FIG. 3.—ELEVATION OF HÜFNER SPECTRO-PHOTOMETER.

References, Figs. 2 and 3.

A, burner; B, Albrecht rhomb; C, polarizing Nicol; D, Compensating wedge; E, collimator; F, prism; G, analyzing Nicol; H, circle; K, ocular slit.

and Driffield, and by Dr. Eder in Vienna, that the mass of silver per unit area is proportional to the value termed the "density," and defined by

$$D = \log O = -\log T.$$

\* Technics.

a transmission of one-tenth of the light; a density of 2, to a transmission of 1-100 of the light, and so on. With some of the improved photometers, densities as high as 5.7 have been measured, corresponding with a transparency of 1-500,000 of the incident light.

The instruments used for measuring the density are of several types. Modified bench-photometers, of a type originally designed for measuring the relative brightness of two light sources, have generally been used in England. The Germans, on the other hand, have adopted the "absorption photometer," developed by Vierordt, Glan, König, Martens, and other continental workers, for physiological and physico-chemical purposes.

One of the most efficient of these photometers is the Hüfner spectro-photometer, which is supplied in England by Messrs. Hilger & Co., in an exceedingly prac-

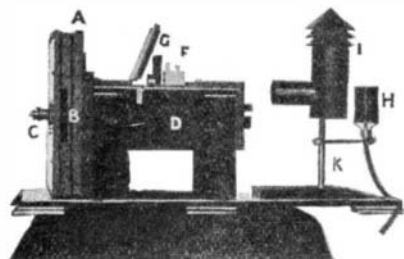


FIG. 4.—EXPOSURE INSTRUMENT.

tical form. Figs. 1, 2, and 3 show the general appearance of the instrument, and also its elevation and plan.

The method adopted is to obtain two fields, which are spread out into spectra, in juxtaposition in the eyepiece, small patches being isolated by shutters. The top one of these fields is diminished by the density to be measured; the lower one is undiminished, but is plane-polarized by the Nicol's prism, marked C.

If, then, the analyzing Nicol G (Fig. 2) be rotated, the lower field will be darkened, while the upper field will be unaffected. When equal illumination of the two fields is obtained, the angle through which the analyzer has been turned is read upon the divided circle H. Now the intensity of the light transmitted by crossed Nicols is equal to  $I_0 \cos^2 \theta$ , where  $I_0$  is the original intensity, and  $\theta$  is the angle between the polarization planes of the Nicols.

Consequently, as the intensity of the light in the lower field is  $\cos^2 \theta$  times the original intensity, and this is equal to the intensity of the light in the upper field, the transparency of the plate placed in front of the upper field is equal to  $\cos^2 \theta$ , i.e.,

$$I = \cos^2 \theta, \text{ and } O = \frac{1}{\cos^2 \theta};$$

$$D = \log O = -\log (\cos^2 \theta).$$

For instance, if the angle read is 45 deg.,

$$\cos \theta = \frac{1}{\sqrt{2}},$$

$$\cos^2 \theta = T = \frac{1}{2},$$

$$O = 2, \text{ and } D = \log_{10} O = 0.303.$$

The first result which it would appear desirable to obtain is the relation between the density produced upon any plate, and the exposure which that plate has received.

Occasionally some most peculiar mistakes are made in regard to this relation. It has more than once been assumed, for instance, that the mass of silver produced is directly proportional to the exposure received.

The most satisfactory relation appears to be that given by Messrs. Hurter and Driffield; and the method of sensitometry introduced by them is the basis of a very useful system of expressing the working properties of different plates.

This method is as follows:

A series of graduated exposures are made, in an exposing machine, upon a slip of the plate to be tested; these exposures being obtained by means of a standard light source and some method of graduating the intensity falling upon different parts of the plate in a known manner.

The plate is then developed in a thermostat maintained at a fixed temperature by means of a regulator. The development is effected for a fixed time, by the action of a standard developer. After fixing and washing, the plate is tested by means of the photometer, and the relation of the density to the logarithm of the exposure is plotted upon squared paper.

From the curves thus obtained, the various constants which define the behavior of the plate are calculated.

The procedure is as follows:

The exposure instrument (Figs. 4, 5, and 6) consists of a camera, at one end of which is placed a standard acetylene burner, consisting of an acetylene flame burning at constant pressure, and fitted with a Methven screen in order to insure constancy in the light emitted. This screen consists of a metallic plate pierced with a small hole, so that only that light which proceeds from a small central portion of the flame is used. At the other end of the camera a strip of the plate to be measured ( $4\frac{1}{4}$  inches x 1 inch is a convenient size) is placed in a dark slide behind a sector-wheel, which is shown separately in Fig. 7. In this sector-wheel the sectors cut out, proceeding from the middle, are 180 deg., 90 deg., 45 deg. . . . for nine sectors. Each piece of the plate, therefore, receives twice the exposure of the piece immediately preceding it when it is exposed behind this rotating wheel.

A small hot-air engine serves excellently to drive this wheel, and can also be used to stir the thermostat, which is used for development.

The camera is fitted with a flap shutter at E, and

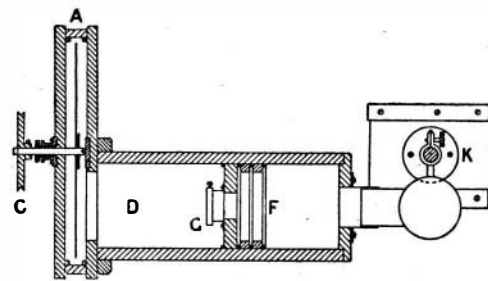


FIG. 5.—PLAN OF EXPOSURE INSTRUMENT.

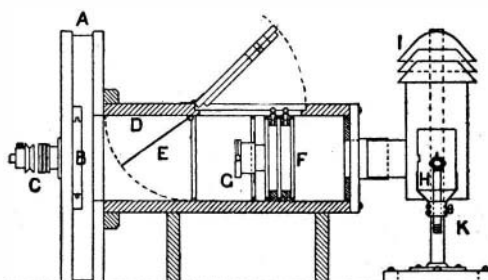


FIG. 6.—ELEVATION OF EXPOSURE INSTRUMENT.

References, Figs. 4, 5, and 6.

A, Guard box for sector; B, open grooves for dark slide; C, driving pulley; D, camera; E, flap shutter; G, removable diaphragm, with iris diaphragm and ground glass for altering intensities, not used at all in practice; H, screened acetylene burner; I, hood for burner; K, stand and slide for burner.

with cells for containing colored fluids at F. In sensitometric experiments, this cell at F contains a fluid which is calculated to exactly reduce the spectral composition of acetylene light to that of June daylight. This is very necessary in the case of orthochromatic plates, as otherwise the great excess of yellow and green, as compared with blue-violet, in the acetylene flame, would unduly favor the color-sensitized plate. The iris diaphragm shown at G is only used for special experimental work, and not for plate testing.

The plate is exposed in this instrument in a dark slide, so arranged that only a little strip, 9 centimeters by 1 centimeter, is exposed; thus after development, there is a series of little 1-centimeter-square patches on the plate, each of which has had twice the exposure of that below it.

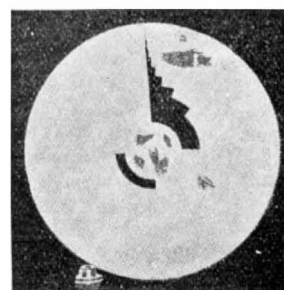


FIG. 7.—SECTOR WHEEL.

This exposed plate is then developed, as subsequently described, and, after fixation, washing, and drying, is placed in the carrier shown in Fig. 8, which fits in front of the spectro-photometer; this enables one to isolate the little patch to be measured, in front of the upper half of the spectro-photometer front, while the lower beam for the photometer passes through the un-

exposed part of the plate below. Thus the difference in density between the exposed and unexposed portions of the plate is measured. This compensates for any general fog of the plate not due to the exposure.

The carrier is fitted with a spring catch, so that each density is placed in position in the photometer by simply pushing the carrier forward one place.

The development of the plate is effected at a constant temperature by means of a thermostat of the type shown in Figs. 9 and 10. This appliance consists of a large copper tank A (Fig. 9), tinned inside, and holding about 10 gallons of water. The water is kept in motion by means of a four-bladed stirrer, driven by a pulley, E, from shafting.

Underneath the tank is a flue-box, B, through which passes a current of hot air from a Bunsen burner, which is controlled by means of a thermo-regulator (B, Fig. 10). The plates are placed in holders, one of which is shown in Fig. 11. This consists of a xylonite sheath, E, into which the plate F slides. The sheath wedges into the split spindle C, which passes through the bearing B, and is rotated by means of the pulley D. The vulcanite cover, A, is the top of the brass developing tubes. Inside these brass developing tubes are stoppered glass tubes, in which is placed the developer. The developer used consists of a decinormal solution of potassium ferro-oxalate, obtained by dissolving 184 grammes of potassium oxalate to make 900 cubic centimeters of solution, and also 27.4 grammes of ferrous sulphate to make 100 cubic centimeters of solution. Ninety cubic centimeters of the oxalate solution, added to 10 cubic centimeters of the ferrous sulphate solution, will then make 100 cubic centimeters of standard developer.

In this way we may obtain a series of densities corresponding with a series of exposures. Now, if we plot the density against the logarithm of the exposure, we shall get a curve of the type shown in Fig. 12. The equation of this curve has been shown by Hurter and Driffield to be of the form:

$$D = \gamma \log (p - (p-1) e^{-\frac{E}{i}})$$

Here D is the density of the plate, and E the exposure received, and p is the optical opacity (O) of the

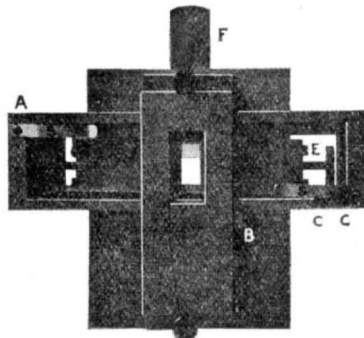


FIG. 8.—CARRIER.

A, Plate carrier; B, spring clicker; C, clicks; E, adjusting screw for side plates; F, top plate; S, springs.

unexposed plate to blue-violet light, I is a constant expressed in the same units as E, and  $\gamma$  is a constant depending on the development.

Now, throughout a considerable number of the points on this curve, a straight line may be drawn, as is shown in Fig. 12.

This straight line will have the equation, of the form  $y = mx + l$ , which may be written  $D = \gamma (\log E - \log i)$ , where i is expressed in exposure units.

It is found, experimentally, that for most plates the value of i is independent of the development, provided that the developer does not contain free alkaline bromide. This value i is called the "inertia," and is taken as fixing the speed of the plate; that is, the greater

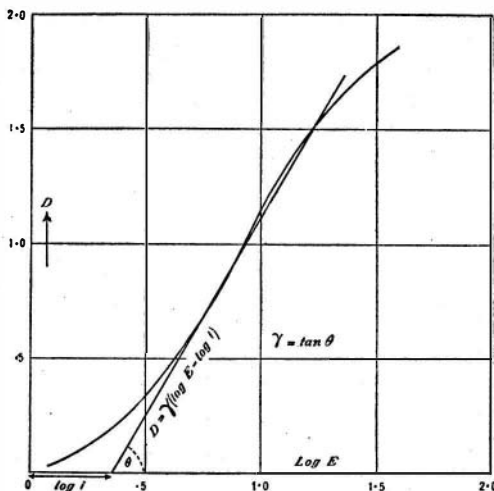


FIG. 12.—CURVE SHOWING RELATION BETWEEN THE DENSITY (D) AND THE LOGARITHM OF THE EXPOSURE (E).

the value of i, the less the density for any exposure E, and consequently the less the sensitiveness of the plate. Therefore, the sensitiveness of a plate is inversely proportional to the value of the inertia.

There are various current methods of expressing this inverse of the inertia. Hurter and Driffield found their "actinograph number" by dividing the number 34 by the number expressing the inertia. Mr. Watkins, for his meters, uses a higher number of about 68,

while Mr. Wynne has adopted an inverse method of expressing the sensitiveness in terms of the diaphragm which will give an exposure of one second, under specified conditions of light intensity. Possibly it is most convenient to express the sensitiveness by divid-

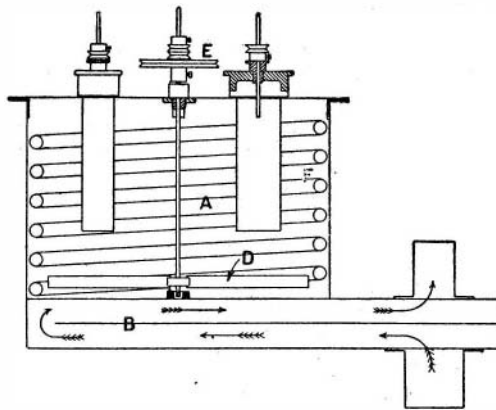


FIG. 9.—THERMOSTAT.

A, Thermostat box; B, flue box; D, central stirrer; E, central pulley; F, cooling coil.

ing the inertia into 50. The results so obtained for particular batches of plates might be:

For a lantern plate .....	1
For a process plate .....	5
For a Wratten Ordinary .....	15
For an Ilford Ordinary .....	40
For a Barnet Ordinary .....	80
For a Imperial Sovereign .....	120
For an Extra Rapid .....	200
For a Monarch, Flashlight, etc....	250 to 400

These figures are merely illustrative; most plates vary in speed from batch to batch.

Besides the sensitiveness of a plate, however, there exists the very important difference which plates ex-

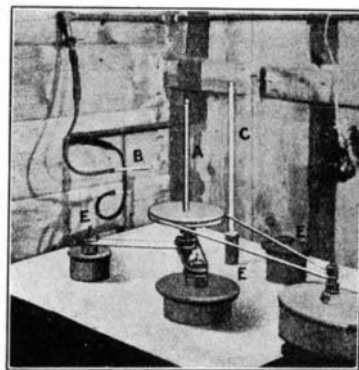


FIG. 10.—TOP OF THERMOSTAT.

A, Central stirrer; B, thermo-regulator; C, thermometer; E, top of developing pots.

hibit with regard to their behavior in the process of development. We have seen that we can express a portion of the plate curve by the straight line equation:

$$D = \gamma (\log E - \log i)$$

where  $\gamma$  was stated to be a factor dependent on development. This  $\gamma$  is clearly  $\tan \theta$ , where  $\theta$  is the angle which the straight line (see Fig. 12) makes with the log E axis.

If a plate be developed for various times, and measured at intervals, it will be found that at first the reaction progresses rapidly, but that after a short time the amount of density gained each minute becomes less and less, until finally a limit is reached, beyond which no further development is possible, however long the plate be immersed in the developer. On investigation, the reaction of development proves to be a simple heterogeneous one, with the surface of the silver bromide as the variable factor, and to conform

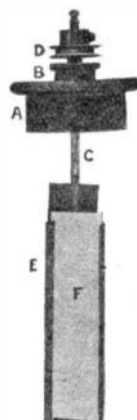


FIG. 11.—PLATE HOLDER.

A, Vulcanite top; B, bearing; C, split spindle; D, pulley; E, plate holder; F, plate.

to the equation for the first order of chemical reaction; in physico-chemical terminology

$$K = \frac{1}{t} \log_e \frac{\gamma_\infty}{\gamma_\infty - \gamma}$$

where  $\gamma$  is the development factor ( $\tan \theta$ ) at any time t,  $\gamma_\infty$  is the final factor attained by infinite development, and K is the velocity constant of development.

These facts are set out in the curves shown in Figs.

13 and 14. Fig. 13 shows the slope of the straight line for a plate whose  $\gamma_\infty = 2.0$ , and  $K = 0.2$ , for each minute of development from 0 to 13. The gradual approach to  $\gamma_\infty$  will be clearly noticed. Fig. 14 shows the curve obtained by plotting  $\gamma$  against t.

The equation for this curve derived from the above equation will be

$$\gamma = \gamma_\infty (1 - e^{-Kt})$$

There is a very simple way of calculating  $\gamma_\infty$  and K from two plates which have been developed, the one for double the time of the other. It can easily be worked out by solving the simultaneous exponential equations; the formula is

$$K = \frac{1}{t_1} \log_e \frac{\gamma_1}{\gamma_2 - \gamma_1},$$

where  $\gamma_1$  is the development factor attained after  $t_1$  minutes development, and  $\gamma_2$  is the development factor attained after twice  $t_1$  minutes development. The values of  $\gamma_\infty$  and K are of great importance in fixing the development properties of a plate. Thus, in a plate which has:

High  $\gamma_\infty$  and high K, the image will appear quickly and gain density quickly.

Low  $\gamma_\infty$  and high K, the image will appear quickly, but fail to gain density.

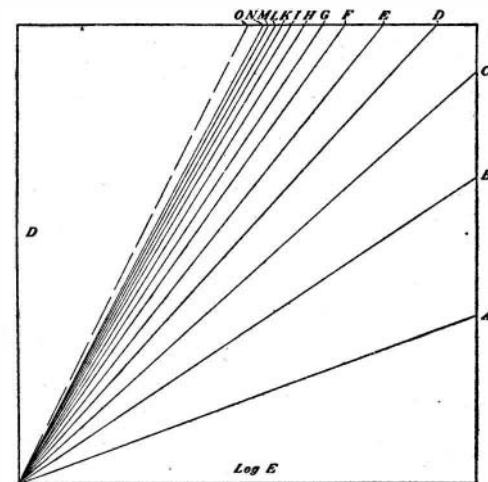


FIG. 13.—DIAGRAM SHOWING RELATION BETWEEN D AND LOG E, FOR VARIOUS CONDITIONS OF DEVELOPMENT.

A. Development, 1 min., $\gamma = 0.36$
B. " 2 " " $\gamma = 0.66$
C. " 3 " " $\gamma = 0.90$
D. " 4 " " $\gamma = 1.10$
E. " 5 " " $\gamma = 1.26$
F. " 6 " " $\gamma = 1.40$
G. " 7 " " $\gamma = 1.51$
H. " 8 " " $\gamma = 1.60$
I. " 9 " " $\gamma = 1.67$
K. " 10 " " $\gamma = 1.73$
L. " 11 " " $\gamma = 1.78$
M. " 12 " " $\gamma = 1.83$
N. " 13 " " $\gamma = 1.85$
O. " $\infty$ " " $\gamma = 2.0$

Inertia = 1 K = 0.200

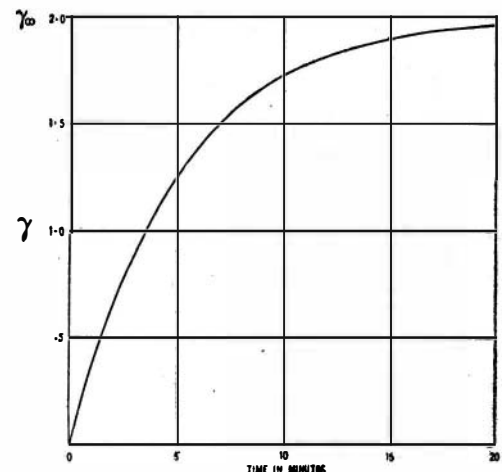


FIG. 14.—CURVE SHOWING RELATION BETWEEN THE VALUE OF  $\gamma$  AND THE TIME.

High  $\gamma_\infty$  and low K, the image will appear slowly, but gain density easily.

Low  $\gamma_\infty$  and low K, the image will appear slowly and fail to gain density.

Since the ordinary printing processes require a  $\gamma$  from 1 to 1.4, the following may be taken as average value of  $\gamma_\infty$ :

Low value .....	1.0
Fair value .....	1.8 to 2.0
High .....	2.5 to 3.0
Very high .....	above 3.0

Process plates and plates used for very short exposures should always give values above 2.5 for  $\gamma_\infty$ . In the same way for K, with decinormal ferrous oxalate developer at 20 deg. C., we may expect to get:

For slow plates .....	about 0.25 to 0.35
For medium plates .....	about 0.10 to 0.25
For very fast plates .....	about 0.05 to 0.20

In this way it will be seen that  $\gamma_\infty$  represents the density-giving power of a plate, while K represents the speed of development. Thus, when a maker claims,

in advertisements, for his plates, that they are easy to develop, and have great density-giving power, he means that  $\gamma^\infty$  and  $K$  are both high; of course, it does not follow that it is true, any more than that all plates are the "fastest in the world."

Another factor of importance in plates is their "latitude," that is to say, the range of exposures which they can render in approximately correct gradation. This really means the length of that part of the plate-curve which approximates to a straight line.

It can easily be shown that this latitude is strictly proportional to the optical opacity of the plate to blue-violet light, and, consequently, a measure of this may be included in the sensitometric estimation of a plate.

A high value for the latitude is what a plate-maker means when he states that his plates give good gradation, though the eye-judgment of gradation is usually biased by the value of  $\gamma$  to which the plate has been developed.

In the case of orthochromatic plates, it is necessary to devise some method of measuring their color sensitiveness. This can be done by a series of exposures to the spectrum, but it is by no means easy to deduce any accurate conclusions from spectra, and the method has not the very desirable property of expressing the result as a numerical constant. A much better method is that introduced by Dr. Eder, who exposes two plates, in the exposure instrument, behind two screens, one of which cuts off all the blue-violet, while the other cuts off all the green, yellow, and red; so that the plate sensitiveness is divided into the two parts, blue sensitiveness and chromatic sensitiveness, and the effects of each of these can be compared.

Thus, if the blue inertia is 0.15, and that of the yellow screen is 0.75, then we can express the color sensitiveness by the ratio:

$$\frac{\text{blue sens.}}{\text{yellow sens.}} = \frac{5}{1},$$

remembering that the sensitiveness is the inverse of the inertia. The results for this ratio which may be expected are:

Ordinary plate .....	100
Erythrosin "orthochromatic," "isochromatic," etc., plate .....	15 to 20
Panchromatic and orthochrome T plates .....	5 to 10
Plates with subdued blue sensitiveness .....	2 to 5
Plates bathed in isocyanines .....	1.0 to 2.0

Even the best orthochromatic plates are about twice as sensitive toward blue as toward yellow, except one or two comparatively unknown but very useful makes, which are very slow, owing to the almost complete annihilation of the blue sensitiveness by means of yellow dyes, picric acid, etc.

No attempt is made in this article to describe systems of sensitometry other than that employed by the author. For these the reader must be referred to the literature on the subject.

The system employed by Dr. Eder is described in his papers, of which a French translation by M. Belin is published by MM. Gauthier-Villars, under the title of "Système de Sensitométrie des Plaques Photographiques." The system employed by Mr. Chapman Jones will be found in his "Science and Practice of Photography."

The actual practice of sensitometry by the author is as follows: If possible, the plate to be tested is obtained coated on thin "patent plate" glass, and cut into 4 inch x 1 inch and 4 inch x 1½ inch strips, cut in each case from the middle of plates, the edges (where the coating is usually very uneven) being thrown away. If the plates cannot be obtained in this form the strips must be cut from the center of ordinary large-sized plates. Two 4¼ inch x 1 inch plates are then exposed together in the exposure instrument, for a sufficient amount to get all the sectors registered. This amount will vary with the plates. Exposures are measured in candle-meter-seconds—that is to say, the unit is the light of one candle (British standard) at one meter distance for one second. The acetylene standard has been calibrated by repeated careful measurements, so that the exact exposure per second received by a plate at the dark slide is known. In the case of the standard burner used for sensitometry in the author's instrument, the plate receives, 3.52 candle-meter-seconds exposure per second, when the sector wheel is removed.

The two plates are next inserted in the holders (shown at *E* in Fig. 11), and two of these are placed back to back in the split spindle. The developer is mixed and placed in one of the stoppered glass tubes in the thermostat, and the whole is left for twenty minutes until the developer has attained the standard temperature.

The plates are rotated in distilled water in the thermostat for one minute, and then placed in the developer, where they are slowly rotated by means of the pulley at the top of the spindle.

After five minutes one is removed, washed for thirty seconds in distilled water and fixed, and after ten minutes the other is also removed, washed for one minute, and fixed. After washing, the plates are measured in the spectrophotometer, and the numbers obtained are plotted as is shown in the curve given in Fig. 12. The inertia,  $\gamma_\infty$ , and  $K$  are then calculated from the values for  $\log i$ ,  $\gamma_1$ , and  $\gamma_2$  obtained from the curves.

The opacity of the unexposed plate is then measured in the spectrophotometer for blue-violet light.

After the ordinary sensitometry has been performed for a plate, and the inertia,  $\gamma_\infty$  and  $K$  have been cal-

culated, together with the expressions of inverse inertias as the "sensitiveness" in various systems, and the calculation of the time of development for a factor of 1, which is of use in comparing the developing rate of plates, the color sensitometry of the plate can be proceeded with by means of the 1½-inch plates, as has already been described. Since it is possible in this way to express the properties of a plate in definite symbols, there seems to be no reason (if the common hypothesis, that emulsion making is presided over by the Prince of Evil, be rejected), why much greater uniformity in the manufacture of plates should not be attained.

It would, for instance, be by no means a difficult matter to work out the relation between the value of  $\gamma_\infty$  and the amount of "cooking" that the emulsion has undergone; or between  $K$  and the viscosity of the gelatine. And that done, a sudden drop or rise in  $\gamma_\infty$  or  $K$  should bring instant inquiry into the cause.

In conclusion, the author would express the hope that he has succeeded in making clear the fact that, provided the numerical constants,  $i$ ,  $\gamma_\infty$ , and  $K$ , and the exact curves for a plate are known, and that the plate has been developed in a standard manner, then any one density corresponds with a definite exposure, and can be used as a simple and accurate quantitative measure of that exposure. If this were once generally realized, it is probable that the photographic dry plate would prove an even more efficient scientific instrument than has hitherto been the case.

#### HIGH SPEED ON STEAM AND ELECTRIC RAILWAYS.\*

By ROBERT H. SMITH.

DURING the last two or three years much has been said and written on the subject of increased railway speeds, and the popular vague idea that electricity is to make practicable hitherto unimaginable traveling speeds, since it has actually already produced many things that were unimaginable only a few years back, has infected not a few of our leading electrical engineers. Just recently there has, however, been a lull in the discussion of the main railway problem, as is well illustrated by the particularly cautious reticence in Col. Crompton's reference to it in his James Forrest lecture. He expressed three opinions in reference to this matter, namely, that single-phase current is the only form of electric energy that may have a main-railway future before it, that goods traffic cannot be worked electrically in economic competition with steam traction, and that steam locomotive engineers are likely to greatly improve their machines as soon as there is any serious probability of electric rivalry.

Meantime electrical enthusiasts are gradually learning the general conditions and difficulties of the main-line problem which they propose to attack. A study of these, of which tramway and urban railway work has given them no experience, is necessary for success. A good deal may be already definitely and usefully said as regards the comparison between steam and electric power for high railway speeds.

It must obviously be conceded by all that electric traction has actually raised mean traveling speed upon tramways and upon city passenger railways, and in a very marked degree. Of course, electric traction on such lines has brought with it many other superior conveniences, besides higher speed, which have very largely contributed to their popularity and financial success; but the increase in speed is undoubted and important. But the increased speed is still quite a low speed. On tramways no high speed could be permitted for reasons of public safety. On city railways doubling the present maximum speed would raise the mean speed by only so small a percentage as would yield no profit on the extra cost. The success of the electrification of such lines, in so far as speed is concerned, depends (1) on the density of the traffic; (2) on the uniformity of the service demanded, it being all local passenger traffic and there being no passing of trains devoted to ordinary, express, and goods services; (3) on the very regular and short distances between stops; and (4) upon the regular and very small time interval between trains.

None of these conditions apply to long distance express traveling. Hence it has long since been recognized that this latter problem is an entirely new one absolutely distinct from that already successfully solved on numberless short distance lines. Although Col. Crompton did not actually say so, it is to be presumed that his remarks applied only to long distance runs with either high express speed or at least mixed traffic.

It is important to note that it is only when stations are separated by long distances that very high maximum (as distinguished from mean) speed is of any practical utility, and that in these circumstances very rapid acceleration and retardation become of quite minor importance.

It is not yet certain whether very high express speed between stations far apart is or is not necessarily accompanied by long time-intervals between trains. The determination of this question is of great importance in the solution of the problem. Its determination seems to depend on two things. If it is eventually found that to work a very high-speed service it is essential to set apart isolated lines for this service alone, then this would clear the way for single-coach or two-coach express trains running at small time-intervals. The other plan of clearing the whole line of all other traffic at the times of running the flying expresses naturally leads to the opposite conclusion of making the

express time-intervals long and the express trains heavy. Without arguing the matter in detail, it is obvious that the former condition of very frequent and very light express trains is favorable to electric traction, while the other is more favorable to steam traction. Thus the question of long or short time-interval depends largely upon how other conditions will determine the choice of kind of driving power, steam or electric.

Except on the basis of the idea that electricity is capable of doing for us everything that has hitherto been found impossible without its aid, it is difficult to account for the popular expectation of very high speeds resulting from electric traction. Because one of the most remarkable historical facts of the development of electric engineering is that no high traveling speeds have been attempted commercially. The Zossen trials have no flavor of commercial economy about them. If for the sake of pure scientific experiment as much money, trouble and time had been spent upon steam high-speed trials, we would by this time have learned whether 150 miles per hour is possible with steam locomotion. The extreme maximum speeds upon commercial electric lines actually running are only half those on steam lines. So far as historic inference goes, therefore, one should not expect very high electric speeds. This, of course, is not in the least degree conclusive, since steam traction took half a century to grow up to the speeds now reached by electric traction in a life of only a quarter of a century.

The problem of very high speed is, like all truly technical problems, a complex one. It depends on certainly not less than seven factors.

The first of these is, without any doubt, the construction of the roadway. The present high steam speeds have only been reached slowly as the result of rebuilding the road-beds in doubly solid fashion, bedding the sleepers deeper and more compactly, much heavier chairs and rails, and fishplates very much stiffer and better secured. Without this reconstruction the present over-all speed of fifty miles per hour would be impossible, and it is perfectly safe to say that it could not be doubled, or, indeed, raised by any very large percentage (given the same time lost in stops) without entirely new and very expensive reconstruction.

At this first point steam and electric traction seem to be on a par: the question of kind of driving power is simply irrelevant. It may be that electric motors deal more gently with weak rails and a bad road-bed than do steam engines; but to run either at the speeds suggested would equally require rebuilding of the roadway.

This is a very important fact, because it makes it probable that for the introduction of such an entirely new kind of service the building of new and separate lines will be preferred to reconstruction of existing lines, leaving these latter for the ever-increasing local traffic. This is the more likely because for the first ten or twenty years of the new high-speed service, single track would in all probability suffice. Especially would this be so for what may be called single section lines; that is, lines with no intermediate stations between the two termini. Single track express lines between London and Brighton, between Liverpool and Manchester, between Edinburgh and Glasgow, and between Birmingham and London seem already to offer fair chances of remunerative working. Twenty years hence very likely a dozen, or even two dozen, other similar single-section lengths might be profitably suggested. And eventually these would become, linked together, the sections of longer journeys, such as London to Aberdeen, worked upon a rigid block system.

If these considerations be correct, there is little risk in prophesying the adoption of electric in preference to steam traction on such lines. This conclusion is reached, it will be observed, without entering upon the comparative merits of the two kinds of traction *per se* beyond the characteristics already discovered and proved in tramway and city practice. It results directly from these and from the road-bed limit to speed.

The second difficulty in attaining very high speed is the air-resistance to be overcome. At slow speeds this is a small proportion of the total, and through a long range of medium speeds the air-resistance seems to rise as the square of the velocity. Above fifty or sixty miles it probably rises still more rapidly up to some critical speed not yet experimentally investigated, and not revealed distinctly by the published Zossen results. In any case, at extra high express speeds of 100 miles or over, it certainly forms the great bulk of the total resistance. In this second difficulty, again, electric traction appears to offer no direct advantages over its steam rival. With electric motors it may be easier to mold the shape of the car to that of least air resistance than with steam locomotives, but this seems the extent of the superiority that may be claimed on either side.

The hindrance to high speed which is, in the opinion of the writer, third in degree of importance, arises through the spring suspension of the cars and their under frames upon the wheels. Under given conditions of the track, the danger of derailment at high speed depends in a very great and critical degree upon success in insulating the heavy masses lying over the wheels from the shocks arising at the rail surface, and confining these shocks to the comparatively small masses of wheel and axle. The wheels run less risk of riding over the rails in proportion to the quickness with which they are thrust down upon the rails after each such shock. This quickness is inversely proportional to the mass that must be thrust down along with the wheels. The ideal design is to have the tires and wheel rims alone forced to follow the irregularities

\* Engineering Review.