MAINTAINING PHOTOGRAPHIC STANDARDS.*

BY

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PHOTOGRAPHY is so generally practised by technical workers that it is thought a description of the methods employed for the determination and upkeep of the quality of light-sensitive materials may prove interesting. No doubt many workers have seen marked on the packages of photographic plates and films certain numbers that are intended as an indication of the speed of the emulsion. These numbers may be expressed as Hurter and Driffield, Watkins or Wynne values, and I shall endeavor in this paper to describe just how these speed readings are determined and precisely what they mean. Shortly after the introduction of the gelatine dry plate it was customary to express the speed of an emulsion as X-times, which meant that it was X-times the speed of a wet collodion plate. Such speed readings naturally had no real meaning, as they were based upon a variable factor. In the early days of dry-plate photography a well-known photographic worker, Leon Warneke,[1] introduced a sensitometer consisting of a series of numbered squares with increasing quantities of opaque pigment. The plate to be tested was placed in contact with this and an exposure made to the light emanating from a tablet of luminous paint which had previously been excited by exposure to a fixed length of burning magnesium ribbon. After development and fixation the last visible number was taken as expressing the speed of the plate.

The chief objections to this method were that no two numbered plates agreed in density, and the light emitted by the luminous surface varied considerably between its excitation and the exposure of the plate. Furthermore, the pigmented squares possessed selective spectral absorption. It is not uncommon in these days to see plates marked upon the old Warneke system. The

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* Communicated by the Author.
[1] Warneke, *British Journal*, 1881.

Seed plates—23 and 27—are instances of this. It is here implied that for the same standard exposure these two Seed emulsions would show as the last visible squares Numbers 23 and 27 respectively. Later Chapman-Jones [2] introduced a modified Warneke sensitometer with a series of 25 graduated densities, a series of four colored squares and a strip of neutral gray, all five being of the same luminosity, and a series of four colored squares, each passing a definite portion of the spectrum. This plate tester was used with a standard candle as a light-source and is still in use for rough estimations of the speed and color sensitiveness of plates. Various other methods more or less similar in principle have been tried, but none have proved practical.

In 1890, two English scientists, Doctor Hurter and Mr. Driffield, published a paper, entitled " Photochemical investigations," [3] which dealt with the chemical, physical, and mathematical principles underlying a scientific system of testing the speed and other characteristics of photographic emulsions. Since Hurter and Driffield's time many investigators have worked on the system and contributed towards its perfection. In connection with the testing of emulsion speeds there are several terms and definitions which must be thoroughly understood. The most important are opacity, transparency, and density. Opacity is the optical property of a substance (in our case silver) to impede the passage through it of light. In other words, opacity is the supression of light or its absorption by the silver image. Transparency is the inverse of this, and is measured by that fraction of the original light which the silver image transmits. For substances which do not reflect much light, such as a thin layer of India ink or a layer of reduced silver deposited as a black substance in negatives, the relation between the quantity of the substance present and the light absorbed is quite simple. If we hold a screen in the form of a thin layer of dilute India ink between the eye and a light-source the layer of India ink absorbs light and therefore reduces the intensity of the light transmitted. Supposing that such a layer absorbs one-half of the incident light, naturally one-half of the light will be transmitted, and, whatever may be the intensity of the original light, the intensity after passing through the India-ink layer will be one-half of what it originally

[2] Chapman-Jones, *Photographic Journal*, 1901.

[3] Hurter and Driffield, *Jour. Soc. Chem. Ind.*, 1890.

was. Two such layers of ink will reduce the incident light to one-fourth its original intensity, and any number of layers will reduce the intensity of the light to a fraction which is equal to the remnant of light the first layer passes, but raised to a power the index of which is the number of layers employed. Thus if n layers were employed and the first one reduced the intensity of the incident light to a fraction $\frac{1}{m}$, then n layers would reduce it to $\left(\frac{1}{m}\right)^n$. If in place of using several successive layers, the first layer is made to contain as much India ink as the n successive layers contain altogether, we shall find that the one layer has the power of reducing the intensity of the light transmitted by exactly the same amount as the n layers do. The reduction of the intensity of the original light is due to the absorption of light by the black particles, and is governed simply by the number of them which are interposed in a given area. Thus we find that the number of layers can be replaced by the number of particles, and the rule can be stated in this form—the intensity Tx of light after passing A particles of a substance is a fraction of the original intensity T, such that $\frac{Tx}{T} = \left(\frac{1}{C}\right)^A$. For mathematical reasons the fraction $\frac{1}{C}$ is generally expressed as a negative power of the base of the hyperbolic logarithms e, so $\frac{1}{C} = e^{-k}$, and we can write $\frac{Tx}{T} = e^{-kA}$. The symbol k is adopted for the coefficient of absorption, then the fraction $\frac{Tx}{T}$ represents and measures the transparency of the substance, and the inverse of this is $\frac{T}{Tx} = e^{kA}$ and measures the opacity of the substance and indicates the intensity of light that must fall on one side of the substance in order that a given intensity may be transmitted. The letter T is used to denote transparency and O opacity.

Density is frequently confused with opacity. By density is meant the number of particles of a substance spread over a given area. In our case it is the relative quantity of silver deposited per unit area multiplied by the coefficient of absorption; kA is what is termed density, and its symbol is the letter D.

The laws of transmission and absorption in connection with a layer of India ink also hold good for a layer of reduced silver,

such as exists in a negative, hence it will be seen that density as applied to photographic negatives is directly proportional to the amount of silver deposited per unit area and may be used as a measure of that amount. The relations existing between the three terms, opacity, transparency, and density, are as follows:

$$O = e^D$$
$$T = e^{-D}$$
$$D = \log_e O = -\log_e T.$$

In theoretical considerations, such as those dealt with above, Napierian logs are used, but in practical sensitometry common logarithms are used. The full relation existing between opacity, transparency, and density, and also the terminology generally adopted in practical sensitometry, are shown in Fig. 1. By a consideration of these definitions we are in a position to trace the connection between the densities of a theoretically perfect negative and the light intensities which formed them. Density is the logarithm of the opacity, and since, in a theoretically perfect negative, opacities are directly proportional to the intensities of the light which produced them, it follows that each density must be proportional to the logarithm of the light intensity which produced it, or, more correctly, density is a linear function of the logarithm of the intensity of light and time of exposure. Therefore, in a theoretically perfect negative the amounts of silver deposited in the various parts are proportional to the logarithm of the intensities of light proceeding from the corresponding parts of the original object. The practice of a system of emulsion speed measuring is based on the inter-relation of the before-mentioned definitions. To apply these practically in plate-speed measurements four instruments are required:

1. Some form of standard light for making the exposures.

2. An exposing machine used in conjunction with the standard light for impressing the plates with a series of known exposures.

3. A thermostat for maintaining the developing solutions at constant temperature.

4. Some form of photometer for reading the densities of the plates made in the exposing machine.

Standard Lights.—Hurter and Driffield, in their investigations, used the English standard candle. The great objection to this is its spectral composition; candle light is decidedly orange-red; for non-color sensitive plates this may be used, but with yel-

low or red sensitive plates the speed readings obtained would be absolutely wrong. The readings would be five or six times the true speed. In Germany the Hefner amyl-acetate lamp is generally used; in England the Vernon-Harcourt pentane lamp. Un-

F.G. 1.

$$O = \frac{Intensity\ Incident\ Light}{Intensity\ Transmitted\ Light} = \frac{I}{I_t}$$

$$T = \frac{Intensity\ Transmitted}{Intensity\ Incident} = \frac{I_t}{I}$$

$$D = -\log_{10}T = \log_{10}O$$

$$I \div O = I_t\ or\ I \div I_t = O$$

Putting $\frac{I}{I_t}$ into logs gives

$$\log I - \log I_t = \log O = D = Density$$

For instance when a plate transmits half the incident light.

$$I \div I_t = Opacity$$
$$100 \div 50 = 2$$
$$Log\ I - I_t\ log = log = log\ O = Density$$
$$\log 100 = 2.000$$
$$\log 50 = 1.699$$
$$\overline{\quad\quad}$$
$$0.301 = D = Density$$

| I		I_t	T	O	D
100		100	1	0	0
100		10	.1	10	1
100		1	.01	100	2
100		.1	.001	1000	3

$$log\ I - D = log\ I$$
$$log\ I_t + D = log\ I.$$

doubtedly the most satisfactory light-source is acetylene; a special burner is used giving a long, cylindrical flame. The burner is surrounded by a circular metal chimney which has a small, rectangular opening fitted with a cone that extends to within three millimetres of the surface of the flame; thus only a small portion

of the flame is used, and by always keeping the gas pressure constant by means of a manometer, and the height of the flame the same, the intensity of the light does not vary one per cent. This acetylene light is calibrated to a standard candle. In front of the rectangular opening in the metal chimney is placed a special blue-violet filter that reduces the spectral composition of the acetylene to practically the same as daylight.

Exposing Instruments.—Various instruments for impressing a graduated series of exposures on a plate have been proposed, and they may be divided into two classes, depending on whether a time or an intensity scale is used. Intensity scales usually consist of a sheet of glass covered with squares of pigmented gelatine

Fig. 2.
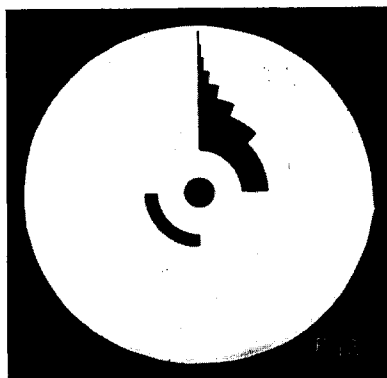
transmitting known amounts of light; thus in the Warneke sensitometer previously described each square transmits one-third less light than the preceding. The Chapman-Jones sensitometer is another example of an intensity scale; in practical sensitometry intensity scales are seldom used. Time scales may be impressed by intermittent or continuous exposure. For many reasons continuous exposures are most to be desired, but in practice it has been found difficult to construct a suitable instrument. A time scale impressed by intermittent exposure is easily obtained with a sector wheel having a series of angular openings of the following values: 180, 90, 45, 22.5, 11.25, 5.625, 2.812, 1.406, and 0.703 degrees; each aperture passes twice as much light as the preceding one and gives double the exposure. The sector wheel

is revolved during the exposure in front of, and as near as possible to, the sensitive plate. For negative emulsions it is usual to expose for 40 candle-metre-seconds, and, as the largest angle on the wheel is 180 degrees, it is obvious that an exposure of 80 c. m. s. must be given to obtain an effective 40 c. m. s. The form of the wheel is shown in Fig. 2. In order to do away with the inconvenience of working in a dark room and to avoid troublesome reflections, the sector wheel is enclosed in a box 12 inches by 12 inches by 2 inches. At the back of the box are fitted grooves to carry the plate-holder. The complete instrument is shown in Fig. 3. A pulley is provided by means of which the wheel can be rotated during the exposure of the plate; a small 1/15-horsepower motor geared down to 50 revolutions a minute is used.

FIG. 3.
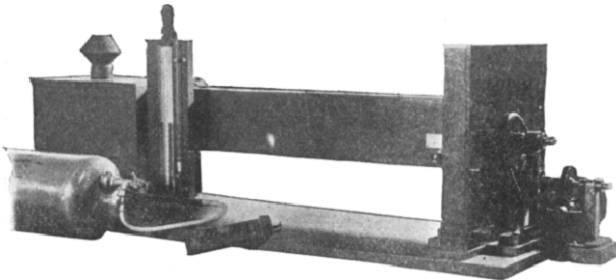
A box 6 inches by 6 inches by 33 inches contains an exposing shutter actuated by a milled head, and grooves are provided for two fluid cells by means of which light of any color can be obtained. The special acetylene burner before described is fitted on a stand having a vertical and horizontal movement by rack and pinion, so that the light itself may be placed at one metre distance from the plate surface and exactly centred. The acetylene tank, manometer, and lamphouse are also shown in the illustration. In practice two plate-holders are used—one for two plates 4¼ inches by 1 inch, the other for one plate 4¼ inches by 1½ inches; this latter holder is arranged so that two series of exposures can be impressed on the same plate. In each plate-holder only a narrow strip of the plate is exposed; the unexposed portion is used as a fog strip.

Thermostats.—The thermostat in use is a modified form of the Freas water thermostat and has proved very satisfactory.[4] The complete installation is shown in Fig. 4. The thermostat tank has a capacity of 340 litres of water and is equipped with a paddle-stirring device and mercury regulator which controls the electric heaters through a thermal relay. Hot point tubes are used as the source of heat. There are devices for maintaining

FIG. 4.

Fig.4
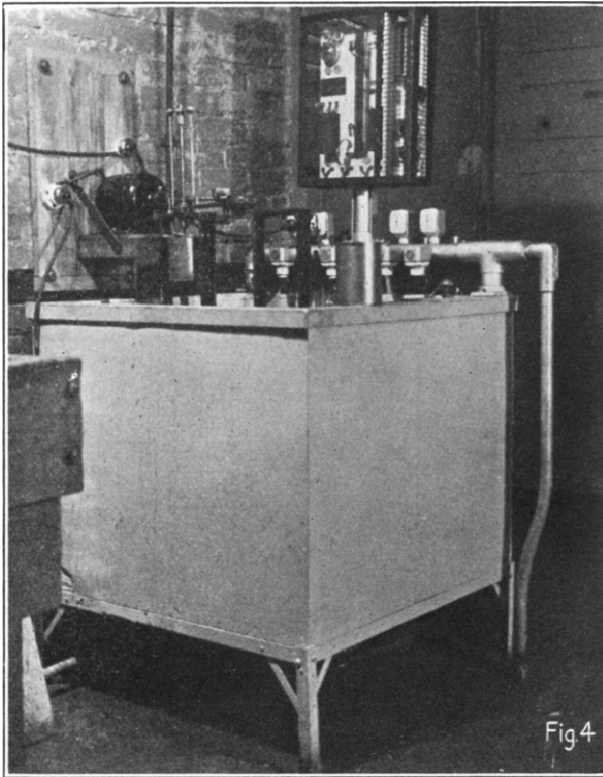
the water at constant level and for cooling the water in the tank when the room temperature is too great. A special top is fitted to the instrument with developing cups set down into the water, and the plate strips to be developed are held in small metal slides

[4] Hitchins and Gilbert, " A Water Thermostat for Maintaining Photographic Developing Solutions at Constant Temperature," *Photo. Jour. of America,* 1917, 139.

which fit around the inner periphery of the cylinder entering into the cup. Housed in an inner cylinder there is a small multiblade paddle which pulls a steady stream of developer from the bottom of the developing cup and discharges it over the top of the cylinder, distributing it evenly over the plate strips. Fig. 4A shows this portion of the thermostat in detail. As the various

FIG. 4A.
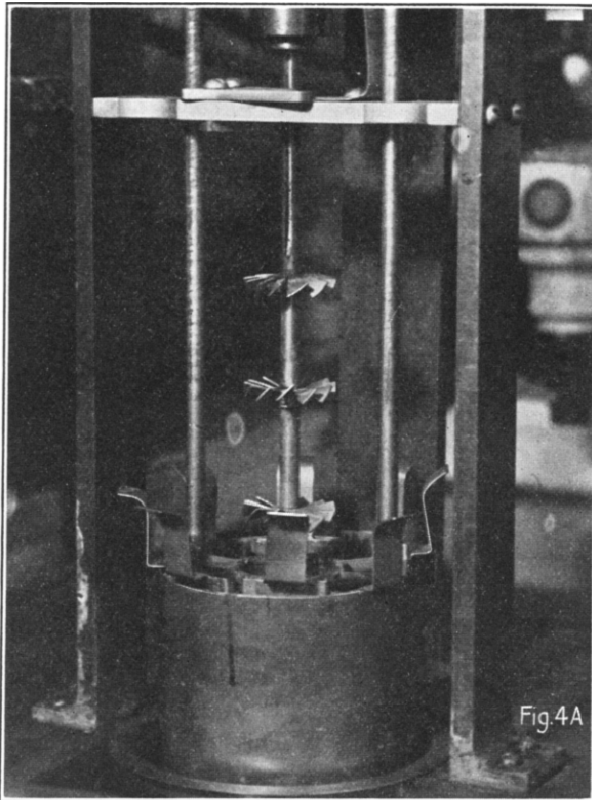
development times are completed the plate strips in their holders can be withdrawn and placed in the fixing bath without being handled with the fingers. The accuracy of this thermostat is within one two-hundredth of a degree plus or minus, and it will run unattended day in and day out. For accurate results in sensitometry it is of vital importance that the temperature of the developer be constant.

Photometers.—A photometer as used in photographic work is an instrument for measuring the absorption of light by various media. Hurter and Driffield, in their original investigation, used the old Bunsen grease-spot photometer, a form not really suitable for photographic measurements. Polarization or spectro-photometers are now generally used in sensitometric work. The Martens polarization photometer is an excellent instrument and gives very accurate readings. In this photometer extinction is obtained

FIG. 5.
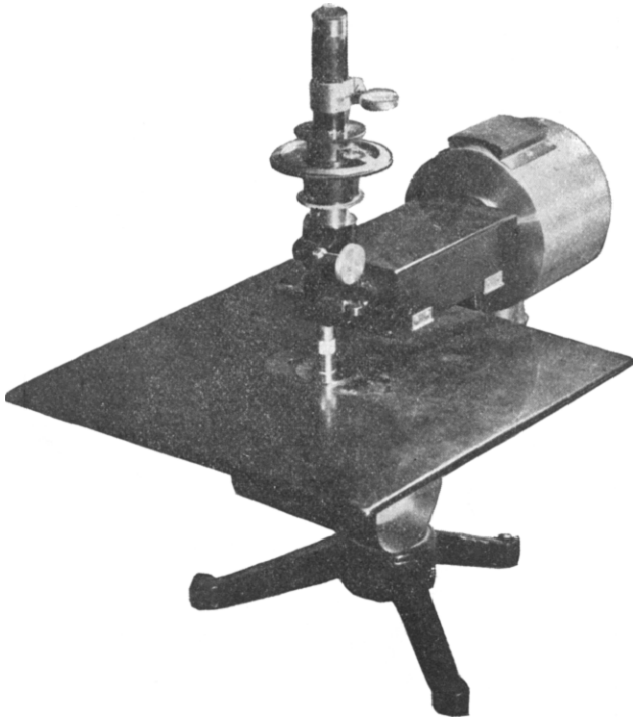
by means of a Wollaston prism. The formula for converting the readings to densities is $\log.\tan.^2\theta^1 - \log.\tan.^2\theta$ in which θ^1 is the angle or degree of rotation with the negative density in position and θ the angle without the negative density or the zero of the instrument. This photometer is illustrated in Fig. 5. Recently a Hüfner spectro-photometer built by Adam Hilger, of London, has been used. This instrument is designed for the accurate measurement of the absorption of liquids or dyes at any

wave-length, and for the determination of the densities of photographic plates or films, for which purpose it is extremely convenient and accurate. Supposing it is desired to compare the intensities of two beams of light, one of which has undergone absorption by passage through a photographic plate, for instance: in the path of the beam which has not undergone absorption is interposed a Nicol prism which polarizes the light perpendicularly. The two beams of light are then thrown on the slit of the spectroscopic portion of the instrument, being brought into close juxtaposition with a sharp dividing line by a prism of special design. The light, after passing through the slit, undergoes collimation and is dispersed into a spectrum by a prism, and after passing through a second Nicol prism is brought to a focus and

FIG. 6.
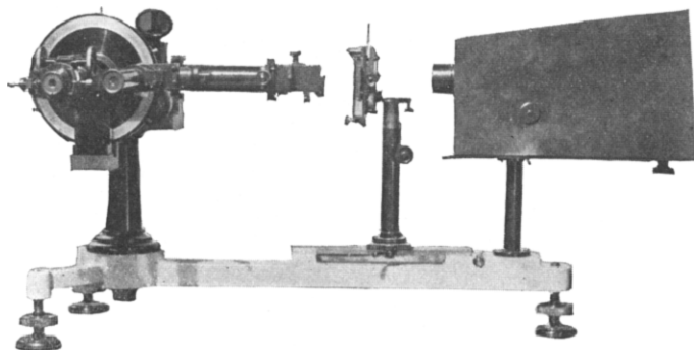
observed by an eye-piece. Two spectra are then seen, one above the other, the one being an absorption spectrum of the substance under observation, the other spectrum being reducible by rotation of the second Nicol prism to any desired intensity. The intensity of this latter spectrum can be deduced from the rotation of the second Nicol, and thus by exact matching of any desired part of the two spectra an exceedingly accurate measurement of the amount of absorption by the material under observation can be obtained. The Hilger instrument is shown in Fig. 6. The intensity of light passing through crossed Nicols is proportional to the square of the cosine of the angle θ between them, and the formula for converting the readings to densities is as follows:

$$\text{Density} = -\log_{10}\cos^2\theta$$

With this instrument transparency $= \cos^2\theta$, and opacity $= \dfrac{1}{\cos^2\theta}$.

In practice the system of plate-speed measuring is carried out as follows: The acetylene light is lit; the height of the flame and gas pressure adjusted; the light should burn at least five minutes before any exposures are made, so that it may have time to settle and burn steadily. The plate-holder is loaded with two strips of the film or plate to be measured. The strips lie side by side and are exposed together in the exposing machine. Then the plate-holder is inserted in the exposing instrument, the sector wheel set revolving, the shutters of the plate-holder drawn, and exposure made by means of the flap shutter. The candle-power of the acetylene light must be known so that an exposure equivalent to 40 c. m. s. can be given, then the strips are developed for times t^1 and t^2 in such ratio that $t^2 = 2t^1$ in the thermostat at 65° F. Practically any developer may be adopted as the standard, but potassium bromide must not be added for plate-speed work. The time of development is merely a matter of convenience; if too short, the densities are thin, and if too long, the

FIG. 7.

higher densities are hard to read. Time of development does not affect the speed readings obtained. As soon as developed the plate strips are plunged in clean hypo, and when completely fixed are well washed and immersed in a 5 per cent. solution of hydrochloric acid for a few minutes to dissolve any lime salts that may be deposited in the film. The strips are then allowed to dry naturally. The negative obtained is shown in Fig. 7. One edge has been left unexposed and is called the fog strip. From this is measured the inherent fog in an emulsion, viz., the density of the gelatine, the glass, or celluloid, and any silver reduced without light action. The series of graduated densities are now measured with the photometer and the results minus fog reading plotted in the form of a curve upon a special chart. Hurter and Driffield called this the "Characteristic Plate Curve," because they found that with all plates under certain conditions of exposure the curves obtained were of the same character. The curve is always of an f shape, and if the plate has been sufficiently exposed may be divided into four regions (see Fig. 8), the concave

part *A-B* corresponding to under-exposure; the straight line period *B-C* corresponding to correct exposure; the convex part *C-D* denoting the over-exposure period; and the last period of the curve, *D-E*, corresponding to reversal. Suppose we compare this typical curve to a flight of stairs: it will be seen that in the under-exposure period the steps show a gradually increasing rise; keeping in mind that each step means growth in density, it will be seen that we have here an absolutely false relationship. In this case proportionality exists between exposure and density instead of between exposure and opacity. A negative, the gradations of which fall within this period, will have strong contrasts and be

FIG. 8.
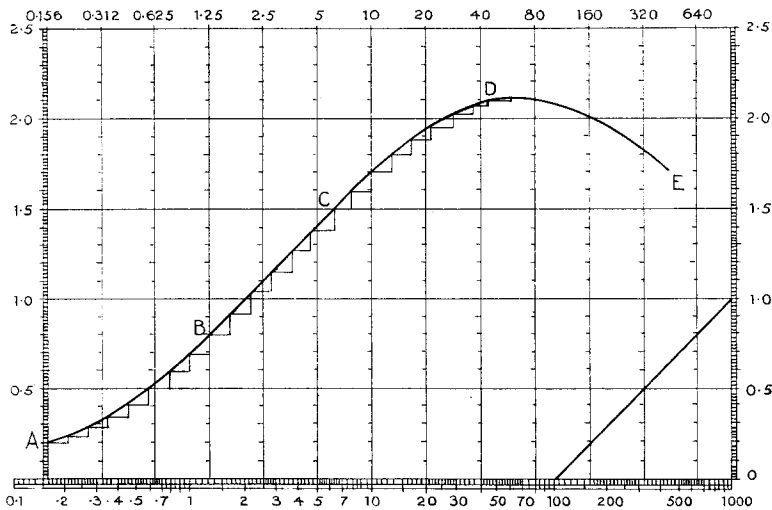
recognized as under-exposed by the practical photographer. The shadows and nearly all half-tones will be represented by almost bare glass, and the high lights will be of relatively extreme density. In the period of correct exposure the steps are all of equal rise; that is to say, each doubling of the exposure is represented by an equal gain in density, so that a negative the gradations of which fall within the period of correct exposure differs as little as possible from that which at the beginning was defined as theoretically perfect. It will be remembered that the definition of a perfect negative was that the densities of the negative should be proportionate to the logarithm of the exposures which produced them, and it is characteristic of the straight-line period of the curve

that the densities are proportionate to the logarithms of the exposures. As the result of many measurements of the densities falling within this period it has been found that the straight line portion conforms to the following simple linear equation: $D = \gamma$ (log. E — log. i), D being the density, γ a constant depending on time of development; E the product of intensity of light and time or the " exposure," and i a constant depending upon the speed of the plate. The over-exposure period is marked by a gradual decrease in rise in the steps, which finally become almost imperceptible. In this period the densities, instead of growing with increase of exposure, steadily decrease. A negative, the

FIG. 9.
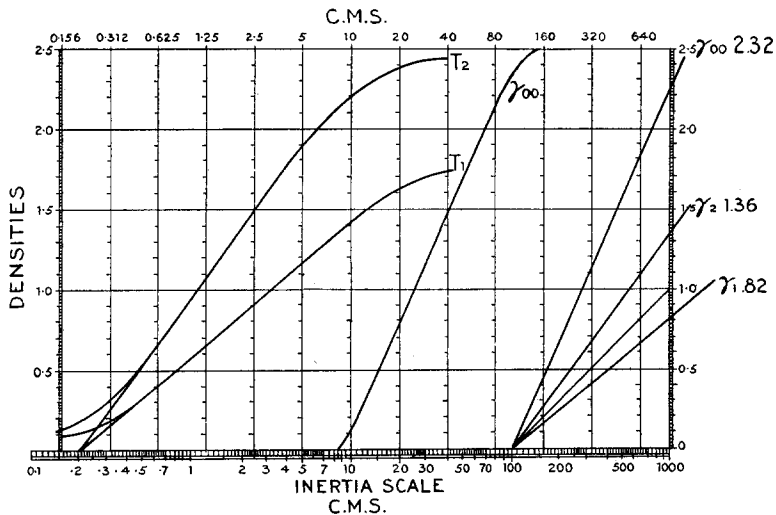
gradations of which fall within this period, will be equally as false as one in the under-exposure period, but in an opposite direction. Under-exposed negatives show too much contrast; over-exposure yields a flat, thin negative. In the last period of the curve D-E there happens the phenomenon reversal; this is the transformation of the negative into the positive. This period is mainly of theoretical interest; such long exposures are required to produce true reversal that in ordinary photographic practice this period is negligible.

Before proceeding further it will be as well to describe the chart on which the curves are plotted. It is shown in detail in

Fig. 9. The top line of figures stand for exposures in c. m. s. The figures at the left-hand side represent densities; the bottom line of figures constitute the inertia scale which is used in determining the plate speeds. The right-hand set of ordinates are gammas and represent actual degrees of contrast in the negative. From 100 on the inertia scale there is a printed line travelling to γ 1.0, which will be explained later. To obtain the speed of a plate the straight-line portion of the curve is prolonged until it cuts the inertia scale; this point is called the inertia; then $34 \div i =$ the speed of the plate. This constant 34 holds good only when the standard light is equivalent to a standard candle. In the example shown in Fig. 9 the inertia is 0.2 and the speed is 170. The inertia is really a measure of the least exposure which will just mark the beginning of the straight line or correct exposure period. The speed of an emulsion is the inverse value: The longer the exposure required to bring a plate to the beginning of the correct exposure period the slower the emulsion. Inertia is really an exposure expressed in c. m. s.

In all plate-speed testing it is essential that two strips of the plate are exposed together; then one strip is developed for t^1 and the other for t^2; that is to say, one strip is developed twice as long as the other. The two series of densities obtained are read on the photometer, and the two curves plotted on the same chart. It will be seen that, although one strip was developed twice as long as the other, the inertiæ coincide, both straight-line portions when prolonged cutting the scale at 0.2. When we have plotted the t^1 and t^2 curves of any plate we can read not only the speed but can obtain in addition a lot of useful data relating to the character of the emulsion. We can show graphically the amount of contrast that any particular emulsion will give for a given time of development. This is done by drawing parallel with the straight-line portions of the curves t^1 and t^2, lines from 100 on the inertia scale until they cut the γ scale. Curve t^1 will then give γ^1 and t^2 will give γ^2. Supposing the times of development for t^1 and t^2 to have been 3 and 6 minutes, it will be seen that γ^1 and γ^2 represent graphically the degrees of contrast and density obtained in 3 and 6 minutes' development. Whenever the γ line of the plate coincides with the printed γ line of the chart the contrasts of the subject photographed are correctly rendered. If the reading is below 1 the contrasts of the

subject are reduced, and if above 1 are increased. Having found γ^1 and γ^2, $\gamma\infty$ is easily determined. $\gamma\infty$ is a very important factor; it measures the ultimate contrast and density obtainable with a given emulsion. $\gamma\infty$ can be determined by direct development; a strip of the plate to be tested is exposed as usual to a graduated series of light intensities and then developed for 45 minutes, the densities read and the curve plotted. A parallel to the straight-line portion of the curve is drawn from 100 on the inertia scale to the γ scale, and where it cuts is taken as $\gamma\infty$. In the example shown (Fig. 9) $\gamma\infty = 2.32$. $\gamma\infty$ can also be calculated mathematically from the figures obtained for γ^1 and γ^2; the formula is as follows:

$$\infty = \frac{\gamma 1^2}{2\gamma 1 - \gamma 2} = \frac{\cdot 82^2}{2(\cdot 82) - 1 \cdot 36} = \frac{6724}{2800} = 2 \cdot 40$$

For $\gamma\infty$ by direct development 2.32 was obtained, and 2.40 by calculation. In connection with the character of photographic emulsions there is another important factor—K, or the velocity constant; this is the speed with which a plate develops. It is arrived at in the following manner:

$$K = \frac{1}{t} \log_e \frac{\gamma^1}{\gamma^2 - \gamma^1} = \frac{1}{3} 2 \cdot 3026 \times \log_{10} \frac{\cdot 82}{1 \cdot 36 - \cdot 82}$$

$$K = \frac{1}{3} 2 \cdot 3026 \times \log_{10} 1 \cdot 52 = \frac{1}{3} 2 \cdot 3026 \times \cdot 1818 = \frac{1}{3} \cdot 43881 = \cdot 1463$$

K depends upon the plate, the developer, and the temperature of the developer. It increases as the concentration of the developer is increased, so that in making measurements of K it is important that the developer be kept constant. K is usually higher in a slow plate than in a fast one, and decreases as the plate ages. For many purposes a plate with a high $\gamma\infty$ is very useful. It means that with under-exposure development can be forced and density piled on easily. In this case density-giving power is equivalent to speed. It has been previously stated that when the plotted γ line coincides with the printed γ line on the chart the contrasts of the subject photographed are truthfully rendered. It is well known that for different classes of work a soft, normal, or contrastive negative may be desirable. It is an easy matter to produce a negative of the degree of contrast judged to be most suitable. This is simply the control of γ. γ is entirely dependent on length of development for a given

plate, and it is easy to determine the time of development necessary to reach a given γ. It has been found that a γ or contrast of 0.80 is most suitable for portraiture where softness and modelling are important, and that for architecture a γ of 1.00 is suitable. For landscape work a γ of 1.30 has been found best. Knowing γ^1 and γ^2 for a given plate, the time of development necessary to reach a chosen γ can be shown graphically. The construction is illustrated in Fig. 10. Supposing γ^1 to be 0.82 and γ^2 1.36, use an ordinary H. & D. chart and call the base-line divisions " Minutes of Development " and the left-hand ordinates " Gammas "; then there are three points through which a curve can be

Fig. 10.
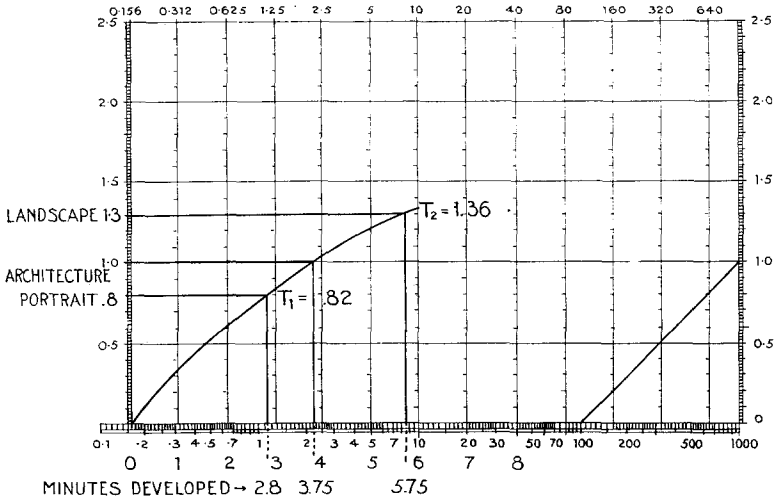
drawn—0, 0.82, and 1.36. γ^1 was obtained with 3 minutes' development and γ^2 with 6 minutes', therefore the density corresponding to γ^1 is plotted on the 3-minute line, and the density of γ^2 on the 6-minute line. To find the time of development for gammas of 0.80, 1.00, and 1.30, horizontal lines are drawn from those points on the left-hand scale, and where they cut the curve a perpendicular is dropped to the base line. In the examples shown a γ of 0.80 is obtained with 2.80 minutes' development, γ 1.00 in 3.75 minutes', and γ 1.30 in 5.75 minutes' development. There is another advantage in exposing two strips of the plate together, because when the two curves are plotted it is at once

seen if free bromide is present in the emulsion or if bromide has been added to the developer. Suppose that on plotting the two curves we find that they run more or less parallel to each other and that the inertiæ do not coincide as shown in Fig. 11 : this proves that there is free bromide in the emulsion, or that bromide has been added to the developer. The presence of bromide actually lowers the speed of a plate for a given time of development, so both the inertiæ obtained are wrong, the influence of the bromide not having been overcome. The way to find the true inertia is to prolong the straight-line portion of t^1 curve below

FIG. 11.
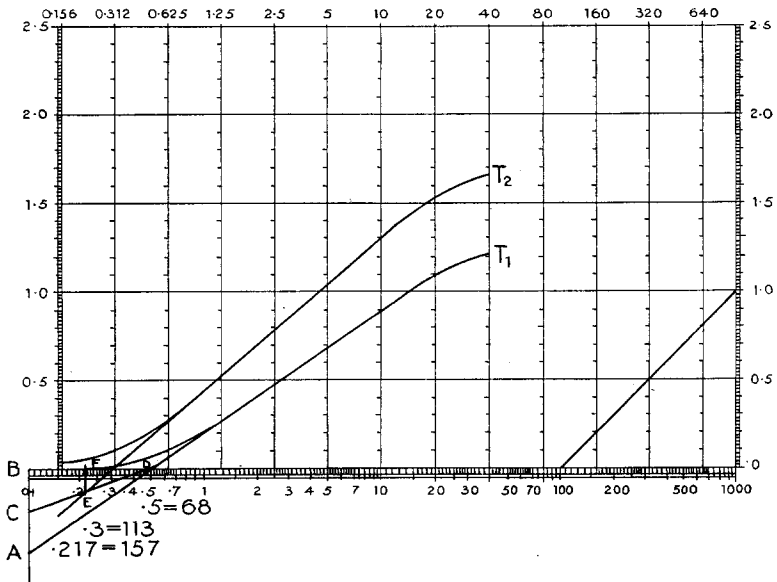
the inertia scale, then from any point A draw the ordinate A-B. Bisect A-B at C and join C-D, the latter being the point where curve t^1 cuts the inertia scale. Continue the straight portion of curve t^2 until it cuts C-D, then from E erect a perpendicular E-F until it cuts the inertia scale, and this point 0.217 is the true inertia of the plate and the speed is 157, whereas the speed obtained from t^1 curve gave 0.5 inertia, equivalent to 68, and t^2 gave 0.3 inertia, equivalent to a speed of 113. It will be seen that this construction is merely a mathematical anticipation of the true speed of the emulsion that will be obtained if develop-

ment is continued sufficiently long to overcome the restraining action of the bromide.

Another very important property of a plate is its latitude. This can be judged fairly well from a straight-line portion of the plate curve. Supposing the straight-line portion extends from 1.25 c. m. s. to 20 c. m. s., then any exposure ranging from 1 to 16 would be in the period of correct exposure. Latitude is really the measure of the opacity of the unexposed plate to blue-violet light and can be determined more accurately as follows: A plate of known speed is exposed behind the plate the latitude of which is to be measured. For instance, suppose a plate with a speed of 150 is exposed behind an Ansco film, and, when the densities are read and plotted, gives a speed of 100, then 150 minus 100 = 50, which is the latitude of the Ansco film, because the Ansco emulsion, being sensitive to blue-violet light, cuts out or absorbs this from the standard light, and that portion of the light which passes through the Ansco film is not absorbed and so cannot do any work but it will act upon the plate behind and the densities and speed obtained under these circumstances are a measure of the non-absorption of the blue-violet by the Ansco film.

The Hurter and Driffield system, if properly carried out, is of the greatest help in maintaining a standard of emulsion quality, and in its wider and deeper applications is almost indispensable to the emulsion maker for graphically recording the effects of various experiments. It will be readily understood how changes in an emulsion during manufacture will be shown in the curves when plotted. What these variations in the plotted curve mean to the emulsion maker would entail a thorough discussion of the theory and practice of emulsion making, which is not possible in an article of this nature. In the various branches of photographic work it is necessary to use emulsions of different character. In process and copying work a slow plate having good latitude and a high $\gamma\infty$ is desirable. It should develop quickly and be capable of giving great density and contrast, and it is important that the inherent fog of the emulsion should be low. An emulsion intended for the general run of hand camera work where most of the results are underexposed should have a high speed, develop rather slowly, and have a reserve density and contrast-giving power. The under-exposure period should be well

defined, and it is desirable that the emulsion be yellow-green sensitive, or, in other words, orthochromatic. An emulsion intended for portraiture should have a very high speed around about 250 H. & D. It should develop slowly, and the $\gamma\infty$ should not be higher than 2.00. It should have good latitude and a well-defined under-exposure period. In the modern practice of portraiture the tendency is to use a rapid orthochromatic or panchromatic emulsion. The inherent or chemical fog of any emulsion must be kept as low as possible. This is one of the problems of emulsion making. The inherent fog of any emulsion should not be higher than 0.20, even when the plate is developed to $\gamma\infty$. The speed readings obtained can be used directly as a basis for the calculation of exposure, because, providing two plates of different kinds are impressed with the same series

FIG. 12.
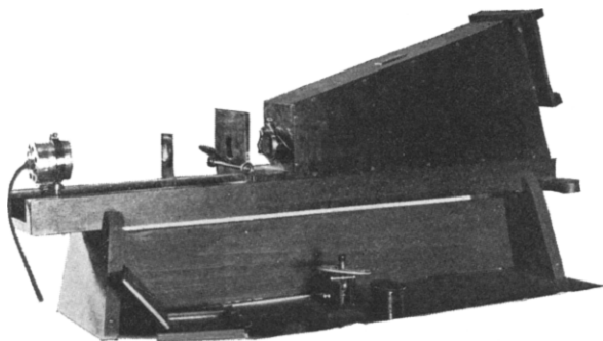
of known exposures by the same light-source, their speeds are inversely proportional to their respective inertiæ; for instance, if strips of plates A and B are impressed with the same series of graduated exposures by the sector wheel, and the inertia of A is found to be 0.2, while the inertia of $B = 0.4$, then the speed of A is twice that of B. If the speed of B is 85 H. & D., then the speed of $A = \frac{85 \times .4}{.2} = 170$ H. & D.

There are one or two other applications of the H. & D. system that are of use in practical photography. For instance, if we have to test a set of developers for their density-giving or reducing properties, a series of strips of the same emulsion are exposed and these strips developed in the different developers or combinations of them. When the strips have been read their

curves will show graphically the performance of the various developing agents. For estimating the action of the various intensifiers and reducers a number of strips are exposed and their curves plotted, then if any of the plate strips are submitted to the action of an intensifier or reducer the difference between the curve obtained after treatment and the first curve is an indication of the action to which the plate has been subjected.

Apart from the determination of the speed, fog, gamma infinity, and velocity constant of emulsions, there is another very

FIG. 13.
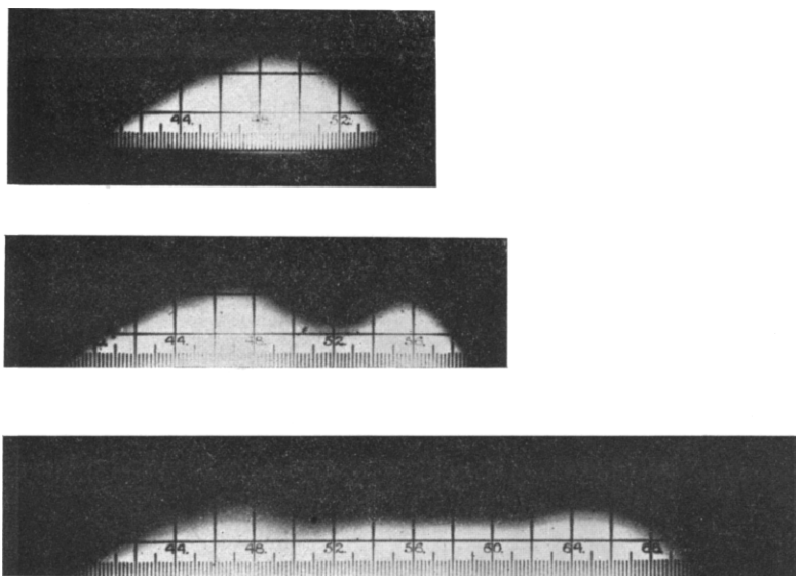
important factor which must be considered: this is color sensitiveness. To determine this, a Hilger diffraction grating spectrograph is used. This instrument is designed so as to project and bring to a focus in the image plane a diffraction spectrum much as any image is brought to a focus on an ordinary camera. The complete instrument is shown in Fig. 12. The plate-holder is 3¼ by 4¼ inches, and has fitted into it an accurately engraved wave-length scale. The plate to be tested is exposed behind the wave-length scale to the action of the spectrum. The spectroscopic slit has in front of it a black glass wedge that produces a

gradient of exposure across the width of the spectrum so that
we obtain a negative that shows graphically the color-sensitive-
ness curve of the emulsion.   This automatic curve plotting is
due to the wedge.   If a plate is very sensitive to a certain color,
that color will stand more damping down by the wedge before
its power to impress the plate is lost than will a color to which
the plate is not so sensitive, and so the maximum or peak of
the curve represents the wave-length to which the plate is most
sensitive. The results obtained are illustrated in Fig. 13; the
top curve is the usual one given by non-color sensitive emulsions.

FIG. 14.
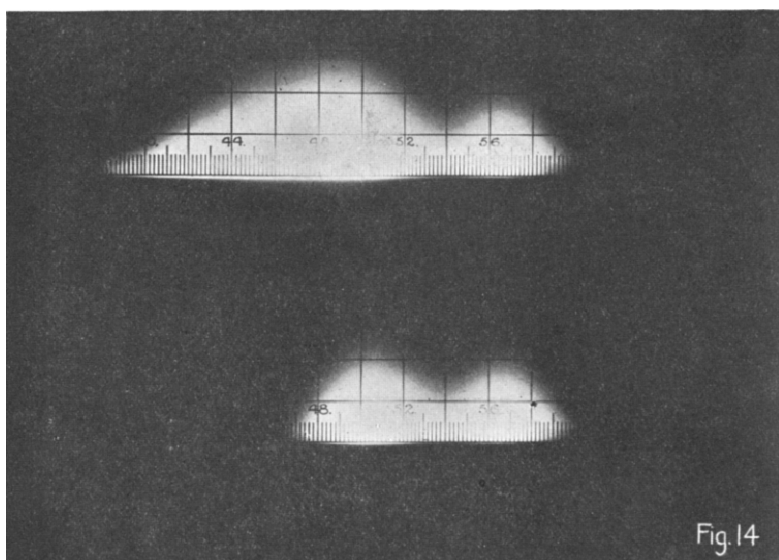
Its maximum is at wave-length 4900 in the blue, and it is quite
insensitive to yellow.   The second curve is characteristic of an
orthochromatic or color-sensitive emulsion.   A maximum still
exists in the blue, but in addition there is a secondary maximum
at 5600 in the yellow.   This additional color-sensitiveness is
obtained by adding a dye—erythrosine—to the emulsion during
manufacture. The presence of the dye gives to the emulsion the
power of absorbing yellow light instead of passing it, and the
light so trapped is used in forming a developable image.   The
third curve is typical of a panchromatic emulsion.

There is an almost equal sensitiveness throughout the spectrum. In panchromatising an emulsion two dyes are usually used—pinachrome and pinacyanol. It is not usual to incorporate these dyes with the emulsion during manufacture, but the finished plates are bathed in a solution of the dyes. The first two curves show the importance of orthochromatism. A non-color sensitive plate will render even dark blue as white and light yellow as black, in absolute contradiction to the visual effect. It cannot well be otherwise, since the greatest sensitiveness of an ordinary plate is in the blue, and there is no record made of anything yellow, so yellow must be rendered as black and blue as white

FIG. 15.

in the final print. An orthochromatic emulsion giving a curve like No. 2, having a secondary maximum in the yellow, will give a better rendering of color luminosity, but not a really true rendering, because the blue sensitiveness is still predominant. How to obtain true color correction by the use of a yellow screen is shown in Fig. 14. The first curve is characteristic of an unscreened orthochromatic emulsion with maximum sensitiveness in the blue. The second curve shows the effect of exposing through a screen having a multiplying factor of five. The action of the blue has been curtailed, and colors will now be rendered in practically their correct values. The maxima have been shifted, so that blue, blue-green, and yellow will be rendered as they appear visually.

All of the foregoing discussion has been in connection with negative emulsions, but recently a modification of the plate-test-

ing system has been applied to the determination of the character of developing-out paper emulsions.

For this work a sector wheel is also used for producing a known series of exposures; the form of the wheel is shown in Fig. 15. There are 16 sectors increasing in value as powers of the square root of 2. Geometric step-up in exposure is not practical for paper emulsions; such steps are too widely separated to reveal the delicate gradation scale. The exposing instrument used in this work is practically the same as that for negative

FIG. 16.
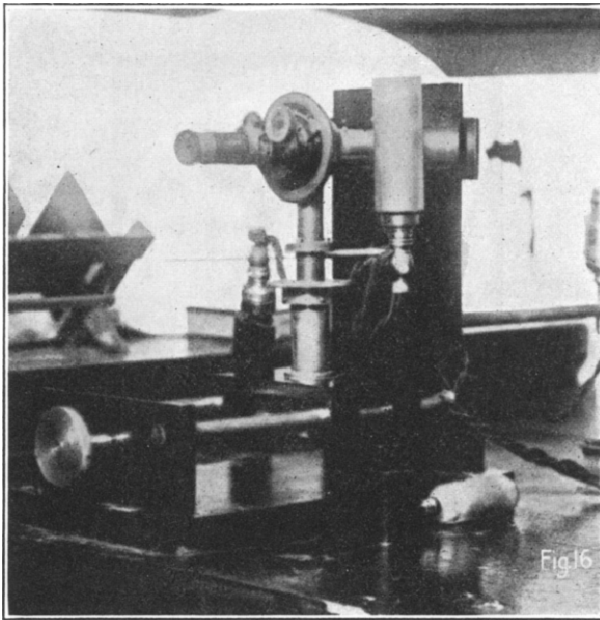
emulsions, but in order to keep exposure within reasonable limits a 15-candle-power electric glow lamp is used, controlled by a potentiometer. The paper strips are developed at standard temperature, and after drying are read in a specially designed photometer. When reading paper deposits we are, of course, dealing with differences in reflecting power, which vary according to the amount of silver reduced. In devising a photometer for reading reflection densities precautions must be taken to avoid specular reflection or polarization of light at the surface of the

paper. The photometer in use for this purpose is illustrated in Fig. 16. The strip of graduated densities is illuminated with 45-degree light, and the tube of the instrument is at right angles to the paper surface. The photometer is a modification of the Martens instrument.

In Fig. 17 the curves obtained with the various grades of Cyko paper are shown. The curve given by Contrast Cyko is characteristic of this emulsion and shows the short scale and steep

FIG. 17.
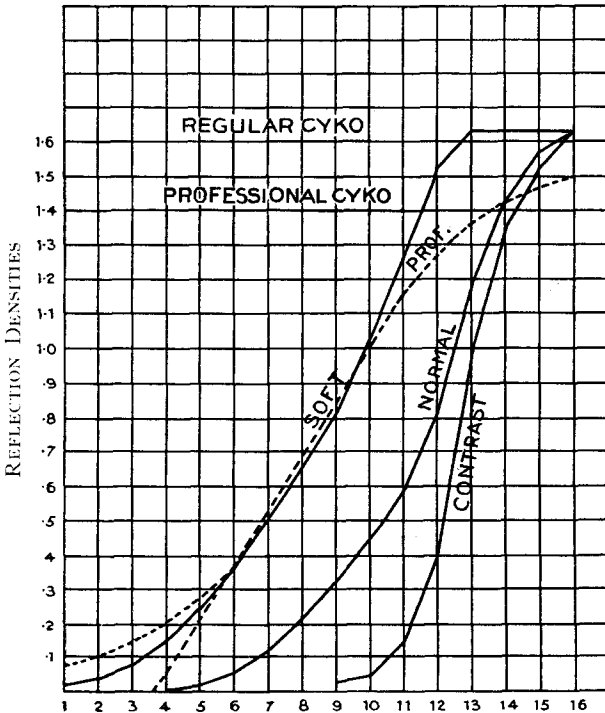
rise of a paper of this type. Normal Cyko has a longer scale and less steep rises in density. Soft Cyko and Professional Cyko give curves that are characteristic of their performance.

The paper-measuring system has been in use only a short while for determining and maintaining a standard of quality in developing-out paper emulsions. There is, however, every indication that it will prove as useful as the system of plate-speed measurements has in the control of negative emulsions.

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