Photographic Plates *for use in* Spectroscopy *and* Astronomy

Second Edition

EASTMAN KODAK COMPANY
ROCHESTER NEW YORK

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for use in
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1935

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PRINTED IN THE U. S. A.

INTRODUCTION

Modern spectroscopic and astronomical observation is carried on almost entirely by means of photography. The efficiency of such work is therefore dependent to a very large extent upon the quality of the photographic plates which are used and upon their suitability for the work to which they are applied. Photographic plates can be of many kinds, and a choice of the correct plate for each purpose involves a considerable amount of knowledge and careful consideration of the plates available.

This booklet has been prepared for the purpose of giving specific information as to the characteristics of the plates made by the Eastman Kodak Company and especially of the Eastman Spectroscopic plates, which are made in the research laboratory. These plates are made strictly to order, and their preparation has been so systematized that orders can be filled with a minimum of delay. They are known as "Eastman Spectroscopic plates" and *should be ordered under this name* with the necessary information as to the type required.

The characteristics of the plates given in this booklet *are intended only as a guide to the choice of a plate for a specific purpose;* under no circumstances should they be assumed to apply quantitatively to a given box of plates. Not only will different lots of plates vary somewhat in properties, but the study of these new types of plate is very active at the present time, and it is hoped that improvements and therefore changes will be made from time to time. New editions of this booklet will be issued as required. In them the data will be changed to correspond with the latest developments.

If there is any doubt as to the choice of plates for a given purpose, it is suggested that inquiry be made by letter addressed to the Kodak Research Laboratories.

Any suggestions for the improvement of this booklet which will make it of greater value to scientific workers will be welcomed.

EASTMAN KODAK COMPANY,
ROCHESTER, NEW YORK.

March, 1935.

LIST OF ILLUSTRATIONS

PHOTOGRAPHIC PLATES
FOR USE IN SPECTROSCOPY AND ASTRONOMY

The Sensitometric Characteristics of Photographic Plates

Photographic materials are generally said to differ in speed, in contrast, and in color sensitivity. The first two qualities are determined by means of the *characteristic curve.* This curve, first suggested by Hurter and Driffield in 1890, is obtained by giving the material a series of exposures and then, after development, measuring the optical densities (D) of the silver deposits, and plotting them against the logarithms of the exposures (E). Such a curve is shown in Figure 1. A considerable portion of the curve lies approximately along a straight line, and if this straight line be produced to cut the exposure axis at a point corresponding to the exposure i, the equation of the straight line will be

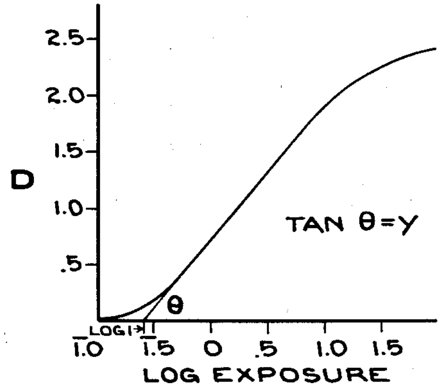

Fig. 1.—*Characteristic curve of a photographic plate.*

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

where γ is the slope of the line.

The value i was termed by Hurter and Driffield the *inertia.* The numerical value found for the inertia depends, of course, upon the quality of the light used for exposure. Hurter and Driffield used at first a standard candle and later a pentane lamp, so that their exposures are stated as *seconds of exposure to one candle power of radiation of low temperature (about 1900° K.) at one meter distance.* The so-called "H. and D. speeds" were then determined by dividing the value for the inertia found as above into 34; i.e., $34/i = $ H. and D. speed.

Recently, the International Congress of Photography[1] has agreed to define the photographic unit of intensity as *one visual candle power of light of approximately sunlight quality* (defined as obtained by a filter of specified composition and corresponding to a light source of approximately 5000° K.). This unit has a photographic intensity on ordinary high-speed plates about six times that of the low temperature unit used originally by Hurter and Driffield and gives inertia values which are correspondingly lower.

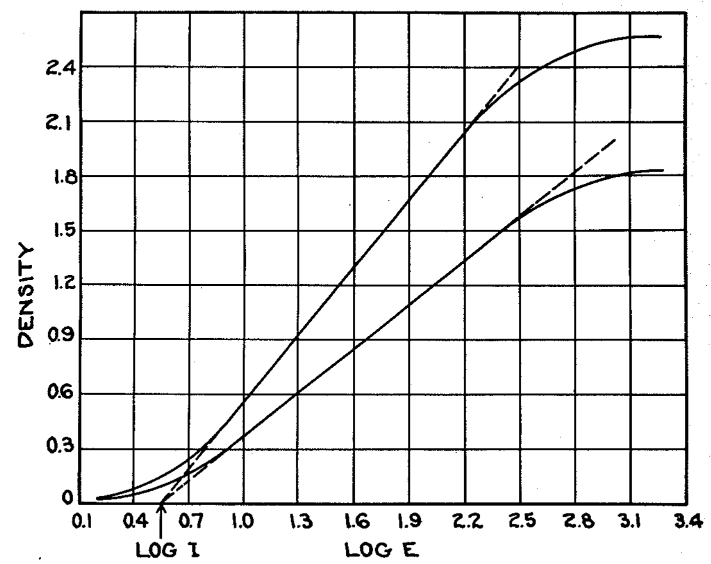

Fig. 2.—*Intersection of characteristic curves.*

Convenient speed numbers can be obtained by dividing these inertia values into 10. Manufacturers of photographic materials have used various light sources and various numerical constants for the conversion of inertias into speed numbers. Unfortunately, this practice has made it impossible to compare the speed numbers assigned by different makers.

In Germany the system used for the marking of plate speeds is a modification of that due originally to Scheiner, the plates being exposed behind a rotating sector wheel and the speed expressed as the smallest

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[1] *Bericht über den VIII International Kongress für Photographie, Dresden*, 1931, pp. 84 and 424.

angular opening to leave a visible trace after development, the reading thus being that of the "Schwellenwert" or threshold speed. This system has also been subject to difficulties involved in the choice of light source used, and often the numbers given have little scientific value.

When plates having sensitometric exposures impressed on them are developed for various lengths of time, the straight-line portions of the characteristic curves usually intersect approximately at the inertia point (see Fig. 2), so that the differences between them can be expressed simply in terms of the numerical value of γ. If, now, the value of γ be plotted against the time of development, an exponential curve is obtained, of which an example is shown in Figure 3. The equation of this curve may

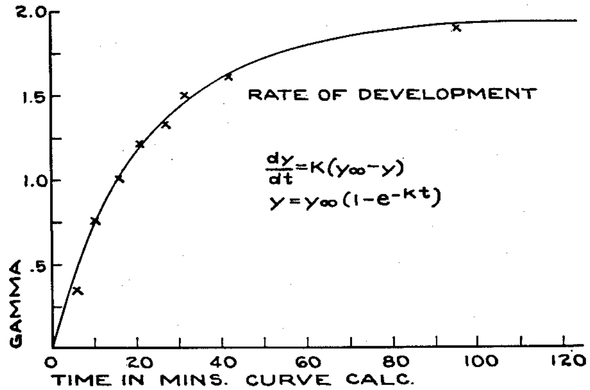

Fig. 3.—*Curve showing relation of development factor to time of development.*

be approximately represented by that of a chemical reaction of the first order, i.e., $\gamma = \gamma_\infty\ (1 - e^{-kt})$ where γ_∞ is the value of γ obtained if development be indefinitely prolonged; i.e., it is the maximum value of γ available for that material, while k is the velocity constant of development and is dependent upon the constitution and temperature of the developer used, and t is the time of development for the value of γ under consideration. In practice, it is convenient to express the contrast of a given material in terms of γ_∞ and of the γ obtained by a fixed time of development in a given developing solution.

The effective sensitivity of a photographic material depends to a large extent upon the exact way in which it is used. Where correct tone reproduction is required, the system involving the determination of the inertia point is certainly valuable, but in astronomical photography a quite different method of expression seems more suitable.

Consider the characteristic curves of two materials, A and B, shown in Figure 4. If the speed is measured in terms of inertia, A is a faster plate than B. This is true also if we judge sensitivity by the exposure required to produce a minimum deposit. If, therefore, our object is to obtain a faint image with the shortest possible exposure, we should select material A. If, on the other hand, we require in the image a certain minimum density in order to make satisfactory readings on the plate and suppose this density to be a value above that of the intersection point of the two curves—then, *for that purpose*, B is a faster material than A.

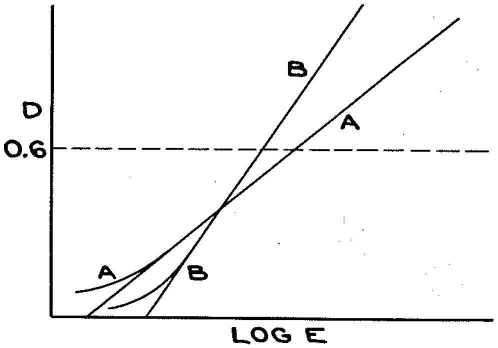

Fig. 4.—*Characteristic curves illustrating the relative speeds of two materials.*

According to T. Dunham, Jr.,[2] "In photographing stellar spectra what is required is a certain minimum density of about 0.6, which is adequate for the detection and measurement of weak absorption lines." Naturally, the determination of the exposure required to produce a given density involves a decision as to the γ which it is practicable to reach in development. Consideration of this question seems to indicate that in practice the maximum γ to which plates can be developed as a routine with a minimum of fog may be taken as 80 per cent of γ_∞. Accepting Dunham's criterion, then, the astronomical sensitivity, S_A, might be defined as inversely proportional to the exposure expressed in seconds at one meter to one candle power of the international high temperature standard light source which will produce a density of 0.6 when the material is developed until γ reaches a value $0.8\gamma_\infty$.

The relative sensitivity of photographic materials, however, depends upon the intensity level at which the measurements are made, since all photographic materials show to some extent the phenomenon known as the "failure of the reciprocity law." The reciprocity law as

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[2] "Die Anwendung der Photographie in der Astrophysik," ibid., p. 287.

enunciated for photochemical reactions by Bunsen and Roscoe states that the product of a photochemical reaction is dependent simply on the total energy employed; that is to say, on the product of Intensity and Time, and is independent of the two factors separately. This was shown by Abney not to be true for photographic materials and the matter was investigated quantitatively by Schwarzschild and others. With the long exposures necessary in astronomy, the failure of the reciprocity law assumes very large proportions and is, therefore, an important factor in controlling the choice of materials, especially in photographic photometry.

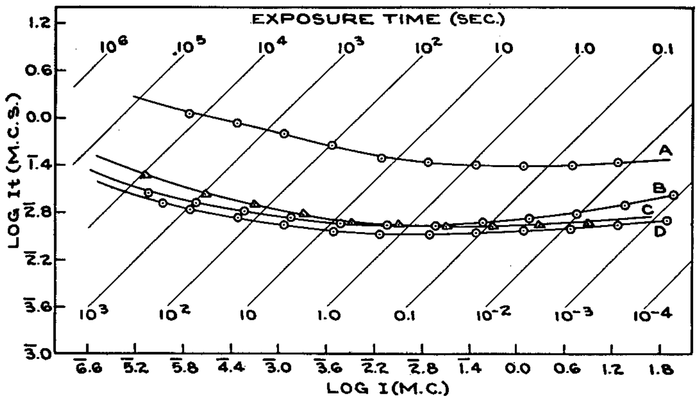

Fig. 5.—*Reciprocity law failure on Eastman plates. A, Eastman Process; B, Eastman 33; C, Eastman 50; D, Eastman 40.*

According to Schwarzschild, the effect of a photographic exposure (E_{ef}) can be expressed approximately in terms of the equation

$$E_{ef} = It^p$$

where I is the intensity and t the time of exposure and p is a constant. The matter was investigated later by Kron,[3] who found an equation of a catenary type to hold, the value of p not being constant but varying continuously with the intensity, and this result has been confirmed by Huse, Jones, and Hall,[4] and others. The reason that Schwarzschild obtained his result is that he was an astronomer working in the region on the low side of optimum intensity with exposures varying from a few minutes to several hours, so that Schwarzschild's simple expression could be applied throughout a limited range.

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[3] *Eder's Jahrbuch der Photographie*, p. 6, 1914; *Publikationen Astrophys. Obs. Potsdam*, **22,** No. 67, 1913.

[4] Huse, E., Jones, L. A., and Hall, V. C., "On the Relation between Time and Intensity in Photographic Exposure," *J. Opt. Soc. Amer.*, **7:** 1107, 1923; **11:** 319, 1925; **12:** 321, 1926; **13:** 443, 1926.

Reciprocity curves for a few materials are given in Figures 5 and 6, which show the effective exposure required to obtain a density of 0.6 plotted against the intensity. It will be seen that these are distinguished by a minimum corresponding to an optimum value of the intensity, this being the intensity at which the greatest effect is produced for a given product of *It*.

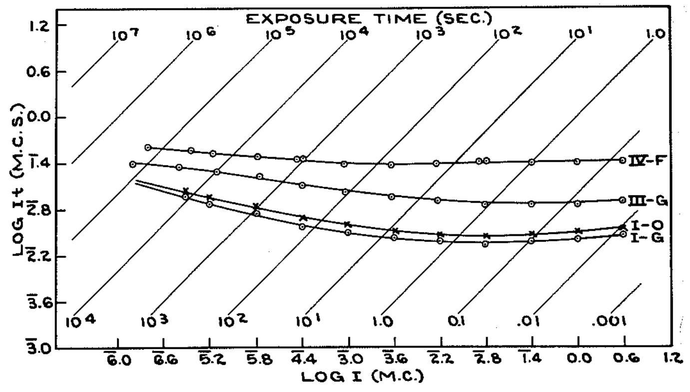

Fig. 6.—*Reciprocity law failure on Eastman Spectroscopic plates.*

The variation of the relative effective speeds with the intensity is of the utmost practical importance, and this is illustrated in Table I, in which are given the $10/i$ speeds and the S_A values calculated according to Dunham's criterion for four commercial plates and for the five standard Spectroscopic Type plates.

TABLE I

Speeds (10/i and S_A) at Different Levels of Intensity*

	Camera Level		Spectroscopic Level		Astronomical Level		
	I=20 M.C.		I=0.1 M.C.		I=0.0001 M.C.		
	10/i	S_A	10/i	S_A	10/i	S_A	γ_∞
Eastman 50	850	22	900	22	200	8	1.1
Eastman 40	700	20	850	28	300	10	1.5
Eastman 33	300	15	320	20	70	8	1.9
Eastman Process	30	3	40	3	20	1	3.7
Type I-O	500	30	650	35	200	10	2.4
Type II-O	350	20	300	20	140	7	3.2
Type III-O	160	10	140	9	30	2.5	3.6
Type IV-O	60	5	50	4	20	1.5	4.4
Type V-O	10	0.6	10	0.6	—	—	4.7

*$S_A = 1/E$ where E = exposure in m.c.s. of light of sunlight quality required to produce a density of 0.6 above fog when developed in D-19 at 65° F. to a contrast equal to $0.8\gamma_\infty$.

Another phenomenon which until recently was considered to pendent of the reciprocity law failure is what is known as the "i tency" effect, also discovered originally by Abney, who founc continuous exposure level of energy I for a time t does not in produce the same photographic density as a second exposure energy given in a number of discrete installments. Since inte exposures are often used in absorption spectrophotometry, this of considerable importance. Fortunately, however, it has recen shown that an intermittent exposure produces the same effect a tinuous exposure provided that the total time of exposure in cases is the same and that the frequency of interruption is above critical level which varies with I. This critical level of frequency order of 100 flashes per second for a one-second exposure, and it c to a value of one flash per second for a one-hour exposure.[5]

For photometric work, the reciprocity failure makes it desir almost necessary that the comparison exposure should be for t time as that of the object to be measured, so that the unknown can be interpolated on a scale of known intensities, the times of being the same. For a complete discussion of the practical me photographic photometry and of the precautions which must in that work, the reader is referred to the paper by Harrison; tains a bibliography of the subject.[6]

In addition to their sensitometric characteristics, photograpl rials differ in two important physical properties—their resolvir and their graininess. The resolving power of a photographic m conditioned by two factors—the turbidity of the emulsion and trast. The turbidity is dependent also upon two factors—tl scattering power and the absorption of the emulsion. The spre image with increase of exposure is a direct measure of the turl is well known that if the geometric image of a point or an e narrow line upon a photographic plate be given an increasing exposures, the diameter, d, of the image will increase in accorda the equation

$$d = a + b \log E$$

where a and b are constants.

This property is, of course, used for the photometry of stell tudes by the measurement of the diameter of the star im

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[5] Webb, J. H., "The Relationship between Reciprocity Law Failure and mittency Effect in Photographic Exposure," *J. Opt. Soc. Amer.*, **23:** 157, 193

[6] Harrison, G. R., "Instruments and Methods Used for Measuring Spe Intensities," *J. Opt. Soc. Amer.*, **19:** 267, 1929.

whereas the equation given holds in the laboratory through a considerable range of exposures, astronomical observations in general appear to be better satisfied by modifications of this formula.[7]

The constant b may be taken as a measure of the turbidity of the emulsion and has been termed by Ross the "astrogamma." The contrast of the image is measured by the development factor, γ, although it must be remembered that the development factor at the edge of an image is very different from that which is obtained by direct sensitometric measurement of comparatively large areas owing to the diffusion and chemical effects produced by the rapid variation in concentration of the developing solution.

In addition to the factors dependent directly upon the structure of the photographic material itself, the resolving power will vary with the contrast of the optical image and with the density produced, as well as with the quality of the exposing radiation.

In practice, the resolving power is best measured by a series of photographs of line gratings, the numerical value of resolving power being the number of equal width black and white lines per mm. resolvable. The average resolving powers of the materials under consideration are given below for an optical image contrast of 20 and for the density for which the resolving power is a maximum when the development γ is $0.8\gamma_\infty$:

TABLE II

Resolving Power to White Light

Material	R. P.
Eastman 50	38
Eastman 40	40
Eastman 33	60
Eastman Process	80
Type I	45
Type II	50
Type III	70
Type IV	85
Type 144	80
Type V	160

Dunham has suggested that the relative graininess of plates can be shown very easily by microphotometer tracings of regions uniformly blackened to a density of 0.3. These are shown in Figure 7 for the plates mentioned, the slit of the microphotometer being 0.5 mm. in length and 5 microns wide, a customary setting in astronomical work.

In addition to these effects, due to the photographic material itself,

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[7] Ross, F. E., "The Physics of the Developed Photographic Image," Monograph on the Theory of Photography, from the Research Laboratory of the Eastman Kodak Company published by the D. Van Nostrand Company, New York, 1924.

one of the most troublesome factors in photometric work is the Eberhard effect, especially when large variations in intensity occur within the small part of a millimeter, as is the case in stellar spectra. The Eberhard effect is undoubtedly due to local differences in the concentration of the developer, the developer becoming exhausted locally where development is most active and accumulating reaction products which restrain its action.

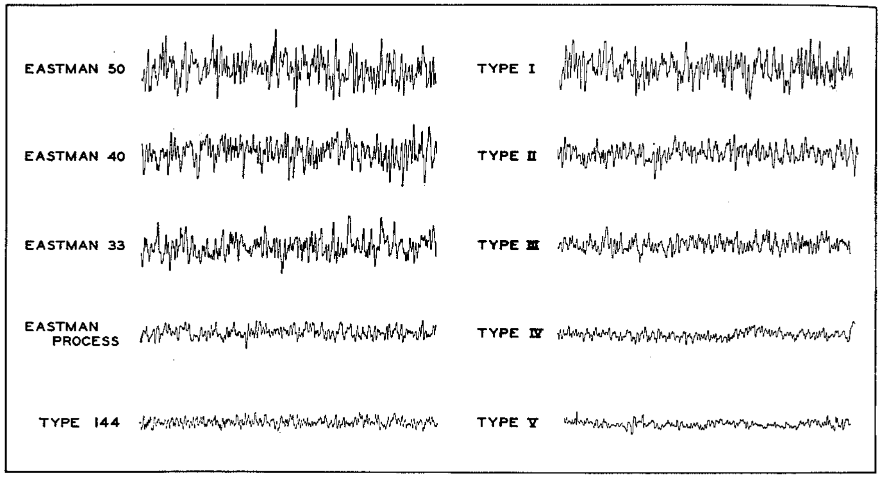


Fig. 7.—*Microdensitometer tracings showing the graininess of materials.*

Figure 8, due to Dunham, shows at the left how an artificial spectral line which should descend only as far as the dotted line drops too far.

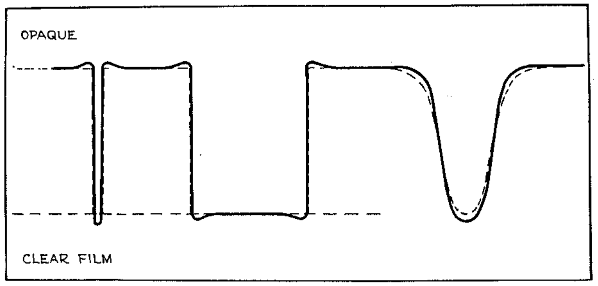


Fig. 8.—*Influence of Eberhard effect on contours of spectral lines.*

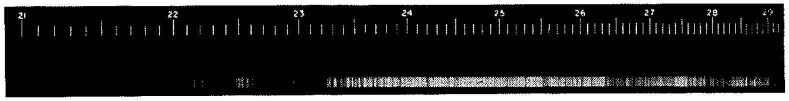
A wider band of rectangular contour has dips near the end, while the background density rises too high as it approaches the band. At the right, the effect is shown on a stellar line whose true intensity curve is represented by the dotted line. Professor Eberhard states that this effect disappears when ferrous oxalate developer is used, but workers in our research laboratory have been unable to confirm his conclusion. The effect diminishes, of course, as development is prolonged and approaches γ_∞, vanishing altogether at γ_∞, since then the whole image is developed and the retarded portions catch up to the rest. The effect is greater in proportion to $(\gamma_\infty - \gamma)$, so that it is much less with high-speed materials which have to be developed to high γ's relative to the value of γ_∞ than with more contrasty materials, for which too high a γ may be disadvantageous for other reasons. The effect can undoubtedly be diminished considerably by brushing the image during development with a soft camel's hair brush, a procedure which is advantageous in many other ways, notably in assuring uniformity of development. For all photometric work, brush development should be employed.

Description of the Various Types of Materials Suitable for Spectroscopic and Astronomical Photography

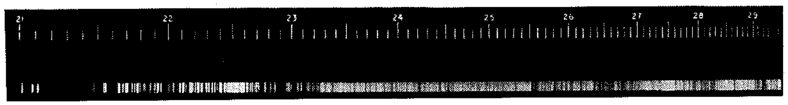
SECTION I

MATERIALS SENSITIVE TO THE ULTRA-VIOLET, VIOLET, AND BLUE

Ultra-Violet Sensitive Materials.—When the ultra-violet region of the spectrum below λ2500A. is photographed, the absorption by the gelatin becomes important, gelatin having a strong absorption for ultra-violet light below λ2800A. and absorbing practically all radiation below λ2000A., even in very thin layers. Figure 9 shows the way in which the ultra-violet spectrum falls off in intensity when photographed on an ordinary plate owing to absorption of the gelatin.



A—ORDINARY PLATE



B—ULTRA-VIOLET SENSITIZED PLATE

Fig. 9.—*Photograph of the ultra-violet spectrum on ordinary and sensitized plates.*

Schumann, when studying the extreme ultra-violet spectrum, worked out a method of making plates which would be sensitive to the very short waves. These plates were either entirely free from gelatin or contained only a small trace of gelatin to bind the silver bromide together.[8] They are difficult to make and have to be prepared individually by hand. They are, consequently, very expensive.

Duclaux and Jeantet[9] described two other means of photographing the extreme ultra-violet—one, by treating an ordinary plate with sulfuric acid so as to dissolve the gelatin; and the second, by bathing the plate with fluorescent materials, such as mineral oils, which transform the short waves into longer ones that can penetrate the gelatin. In the last few years, this method has been applied generally with success, Lyman having used plates treated in this way down to λ580A. in the extreme ultra-violet. Various oils give results which differ somewhat in different workers' hands, and this aspect of the subject, together with the use of a fluorescent oil for photometry, has been investigated by Harrison.[10]

As a result of an investigation of the fluorescence of a large number of organic substances when exposed to ultra-violet light, R. E. Burroughs of our research laboratory found that the ethyl carboxylic ester of dihydrocollidine was particularly satisfactory. This substance is insoluble in water but can be dissolved in certain organic solvents, and if a plate is bathed in a solution of the material and allowed to dry, the surface of the plate is covered with a microcrystalline deposit which fluoresces strongly under ultra-violet light and gives very good photographic images throughout the whole of the ultra-violet region so far investigated, which includes not only the region transmitted by quartz but the Schumann region, and even the shorter wave lengths available only in the vacuum spectrograph (compare Fig. 9). For the very shortest wave lengths, plates prepared with this material have a sensitivity somewhat less than those made by the Schumann method, while in the near ultra-violet their sensitivity is very much greater. The plates are far more convenient in use than Schumann plates. The fluorescent material can either be removed by washing the plate over with acetone before development or, more conveniently, by brushing the plate with a soft camel's hair brush as soon as it is in the developer, when the crystals become detached from the surface of the gelatin and can be brushed off. Plates sensitized with this material, as well as the U.V. sensitizing solution itself, can be supplied by the research laboratory.

Violet and Blue-Sensitive Materials.—For wave lengths in excess

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[8] For a description of Schumann's method, see Baly, "Spectroscopy," Vol. II, p. 380, published by Longmans, Green & Co., London, 1927.

[9] Duclaux, J., and Jeantet, P., "Plaques Photographiques pour l'Ultraviolet Extrême," *J. de Phys. et le Radium*, **2:** 156, 1921.

[10] Harrison, G. R., "Photographic Sensitometry with Fluorescent Oils," *J. Opt. Soc. Amer.*, **11:** 113, 1925.

of λ3000A., that is, for the whole spectral region transmitted by the atmosphere and available for astronomy, no special preparation of photographic materials is necessary. For spectroscopic purposes the plates which will give the maximum sensitivity in this region are of the type of the Eastman 40, the blue sensitivity of panchromatic plates being somewhat depressed. In practical spectroscopy, where sufficient light is available, however, it is often convenient to use a panchromatic plate in order that the longer wave lengths may be recorded at the same time as the violet and ultra-violet. The plates chiefly used for spectroscopy where sensitivity to the longer wave lengths is not required are the Eastman Process, Eastman 33 and Eastman 40, and the Eastman DC Ortho, the last-named plate being of a very suitable contrast and quality for use in absorption spectrophotometry.

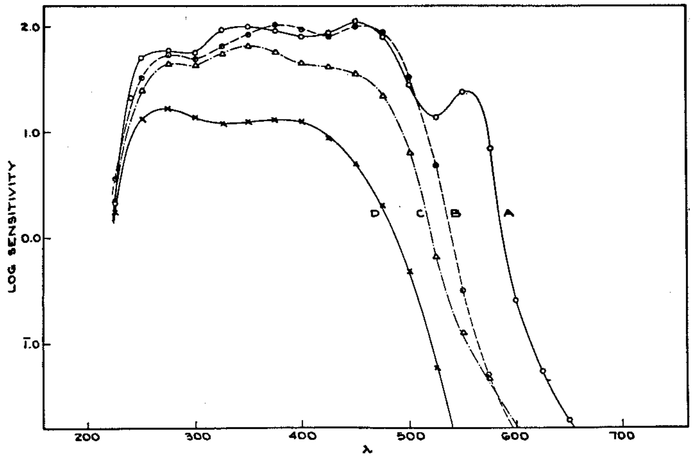


Fig. 10.—*Spectral sensitivity curves of Eastman plates. A, Eastman 50; B, Eastman 40; C, Eastman 33; D, Eastman Process.*

For astronomical photography, it is necessary to use a plate of high speed at low levels of intensity. For many years the plate most widely used in American observatories was the Seed 27, to which the Eastman 40 plate corresponds though the latter is of appreciably higher speed. The fastest plates of this type at present are the Eastman 50 and the Eastman Hyper-Press, which are of somewhat lower contrast than the Eastman 40 and also have a small amount of sensitivity in the green. The Hyper-Press plate is the faster of the two.

The spectral sensitivity curves measured in terms of the absolute energy required to give a density of 0.6 when developed to a γ of 0.8 of γ_∞ are shown in Figure 10. It will be noticed that the Eastman 50 plates have a secondary maximum of sensitivity in the yellow-green, which must be taken into account, of course, in astronomical work. The general sensitometric properties of these plates are shown in Table I (p. 12), their resolving power is shown in Table II (p. 14), and the graininess in Figure 7 (p. 15).

For the photography of the corona during solar eclipses, it has been the custom of experts for many years to use double-coated plates, made by superimposing an emulsion of the highest speed on the top of one of medium speed, e.g., Eastman 40 overcoated on Eastman 33.

Section II

Panchromatic and Other Color-Sensitive Materials

Eastman Spectroscopic Plates.—In order to provide the wide range of materials required for spectroscopy, we have made special arrangements in an experimental department of the research laboratory by which small quantities of plates can be coated, and any kind of plate can be supplied with little delay. It is, of course, impossible for dealers or even for the factory to carry a stock of the wide range of plates now available.

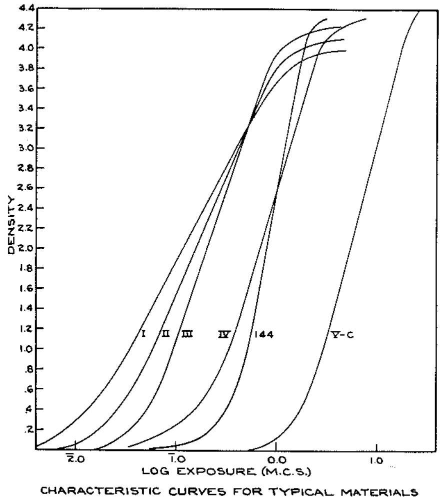


Fig. 11.—*Characteristic curves of typical materials developed to* $\gamma = 0.8\gamma_\infty$.

The spectroscopic plates result generally from a combination of methods of optical sensitizing with certain basic emulsions, and since any method of optical sensitizing can be combined with several basic emulsions, the subject can be understood most easily by treating the two components separately.

Six basic emulsions are used in the laboratory:

Type I. A very high-speed emulsion of medium contrast, giving the utmost sensitivity with a reasonable amount of graininess.

Type II. An emulsion of high speed and somewhat higher contrast and less graininess than Type I.

Type III. An emulsion of moderate speed and of great contrast and very low graininess.

Type IV. An emulsion of low sensitivity, very high contrast, and very low graininess.

Type V. An emulsion of low sensitivity even when sensitized, of very high contrast, and of negligible graininess.

Type 144. An emulsion of high sensitivity when sensitized to the infra-red, of high contrast and of low graininess.

It will be seen that the three characteristics of each emulsion change systematically in the same direction as we pass from Type I to Type V: The sensitivity decreases, the contrast increases, and the graininess decreases.

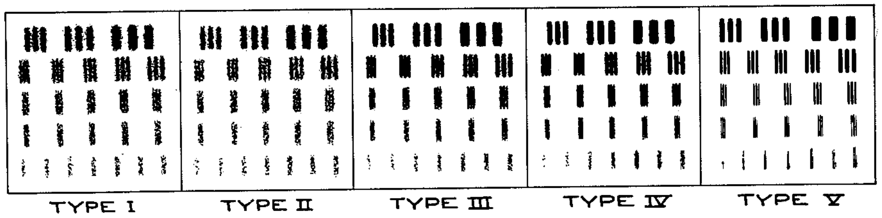


Fig. 12.—*Resolution tests, x22 diameters enlargement.*

Type 144, however, has contrast and graininess equal to Type IV, but when sensitized with dyes, it gives a higher degree of sensitivity than Type IV, approaching or equaling that of the Type I emulsions when sensitized for the infra-red.

The designation 144 may be taken as meaning that the emulsion has the sensitivity of Type I but contrast and graininess corresponding to Type IV. While the new type of emulsion 144 only deserves that designation when used with infra-red sensitizing, in practice it is more convenient to call the emulsion by the same type number whatever type of sensitizing is used with it. Of these emulsions, three are available with all types of sensitizing. These are Types I, III, and IV. Type II emulsion has very limited use but is retained because one of the important commercial plates is made with it. Type V emulsion has very limited use. When unsensitized, it is extremely slow—too slow to be of any use for ordinary scientific work. When sensitized with a few of the special panchromatic sensitizings, it acquires appreciable speed. Its resolving power is very high—higher than that of any other emulsion available. The image appears almost as a stain with practically no graininess. It is believed, therefore, that the material may be useful in spectroscopic instruments whose dispersion is small, resolving power high, and intensity relatively high. The very high resolving power and freedom from graininess of the Type V emulsion make it possible to get results corresponding to those which could be obtained on instruments of much higher dispersion.

Type 144, when unsensitized or sensitized for the green, has the characteristics of an ordinary Type IV emulsion. When sensitized with the panchromatic sensitizers, it has a sensitivity corresponding to Type III, with the graininess and contrast of Type IV. With the extreme red sensitizings, Classes *S* and *U*, its sensitivity corresponds to Type II; and when sensitized for the infra-red, it has sensitivity equal to the Type I emulsions.

The characteristic curves of these materials developed to $\gamma = 0.8\gamma_\infty$ are shown in Figure 11 and their sensitometric properties are given in Table I (p. 12); Figure 12 shows the appearance of the resolution tests, and Table II (p. 14) gives the resolving powers found. Figure 7 (p. 15) shows the microphotometric tracings showing graininess, but in this figure the deviations shown for Type V emulsion are probably due rather to accidental errors, dust, etc., than to graininess, the actual graininess being less than the resolving power of the optical system employed.

All of the spectroscopic emulsions except Type V can be supplied without color sensitizing, these being known as the O plates—I-O, III-O, IV-O, etc. Such plates are sensitive to a maximum wave length of approximately λ5000A. For work in the ultra-violet below λ2500A., these plates can be treated with the U.V. sensitizing solution mentioned previously. Such plates are referred to, for example, as Type I-O, U.V. Sensitive.

The color sensitizings available may be divided into four general types:

1. Sensitizing for the Green

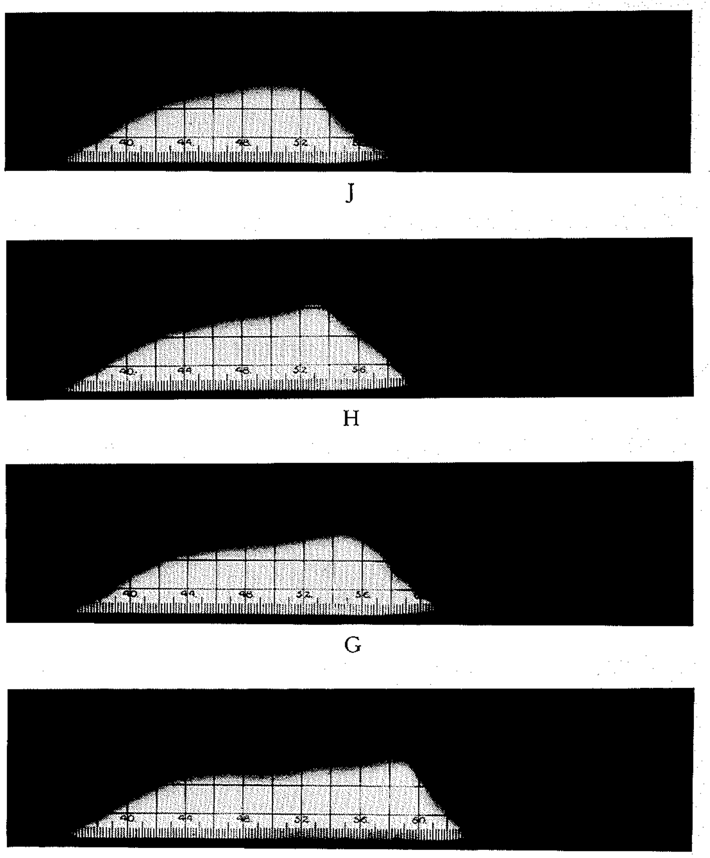
Four sensitizings for the green are available (see Fig. 13).

Class J gives very even sensitivity from λ4800A. to λ5200A., after which the sensitivity falls off rapidly.

Class H has a maximum of sensitivity at λ5300A., the sensitivity being strong to λ5500A.

Class G has a maximum of sensitivity at λ5500A., the sensitivity extending in full strength to λ5700A. This class of sensitizing corresponds most closely to the so-called *isochromatic* or *orthochromatic* plates, and plates of Type I-G will be found to be of very high sensitivity through the green.

Class T has a maximum of sensitivity at λ5900A. and is the most powerful sensitizing available for the D lines of sodium. When it is required, however, to photograph the green and yellow up to λ6000A., it is better on the whole to use one of the panchromatic classes of sensitizings referred to later.



J

H

G

T

Fig. 13.—*Wedge spectrograms* of green sensitizings.*

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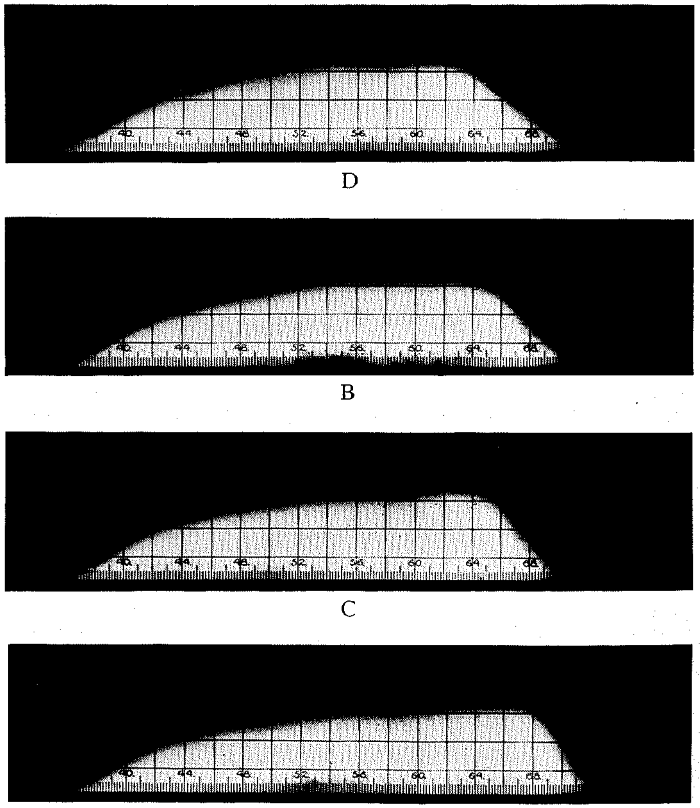
*Wedge spectrograms are made in the spectrograph using as light source an incandescent tungsten filament lamp opened at a color temperature of approximately 3000° K., and a neutral absorbing wedge in front of the spectrograph slit, producing an intensity range of 1 to 10,000 along the slit. Each horizontal line in the scale impressed on the wedge spectrogram corresponds to an intensity decrease of one-tenth as compared with the intensity at the line below it. The shape of the wedge spectrogram is determined by the energy distribution in the radiation from the light source and the spectral sensitivity of the plate. It does not show the sensitivity of the material below about λ4000A., owing mainly to absorption by the wedge in this region.

2. Sensitizing throughout the Red and Green

In this group will be found the plates of the greatest speed for the visible spectrum. They must not be exposed, of course, to red light and must be handled, therefore, in total darkness or by a very faint green light, such as that given by the Wratten Series III safelight. The various classes of sensitizing are mentioned in the order of their extension towards the red (see Fig. 14).



D

B

C

F

Fig. 14.—*Wedge spectrograms of panchromatic sensitizings.*

Class D is the sensitizing which gives the highest sensitivity through the visible green and up to about λ6200A. Except for the high sensitivity of the special green-sensitive plates near their maxima, this is the most generally useful sensitizer for the whole of the green of the spectrum.

Class B sensitivity extends to λ6400A. It is very even and a useful class of sensitizing.

Class C has higher sensitivity in the red than D or B, its sensitivity extending strongly to λ6600A. It will photograph the H-alpha line with ease, but its sensitivity falls off rather rapidly on the red side of the H-alpha line and it is, therefore, inferior to Class F sensitizing for photometric work on H-alpha. It is, however, the best general sensitizing for work in the red.

Class F sensitizing is recommended for use through the whole visible spectrum and especially for the red up to λ6800A.

Several of these panchromatic plates are supplied commercially for ordinary photographic use and can be obtained from the stock of photographic dealers. These are Wratten Hypersensitive Panchromatic plates, Type I-C; Wratten Panchromatic plates, Type II-B; Wratten Process Panchromatic plates and Wratten M plates, Type III-B.

3. Sensitizing for the Extreme Red

In this classification may be placed some special classes of sensitizing (see Fig. 15).

Class S has a very sharp maximum of sensitivity at λ6900A. This plate has several special applications; it is being used in a study of the atmospheric oxygen band B; it is also being used with an appropriate filter for the isolation of a monochromatic region in the extreme red for stellar photometry.

Class U has very high sensitivity at λ7100A., its useful region extending from λ6600A. to λ7400A., thus covering a region of the spectrum which was previously difficult of access.

Class L sensitizing may conveniently be mentioned here. This has been worked out in response to a request for a material sensitive to the whole spectrum, from the ultra-violet to the infra-red. The sensitivity of the Class L plates is not very high, and it falls off appreciably in the infra-red, but these plates are very useful in certain preliminary observations and on instruments of small dispersion, especially on prism type instruments. They offer no advantages for use on instruments of high dispersion.

4. Sensitizing for the Infra-Red

These sensitizings are shown in Figure 16.

Class N covers the gap between the visible and the infra-red, its sensitizing extending from λ6800A. to λ8400A. There is a slight drop in sensitivity at λ7600A., but on the whole the Class N sensitizing is very useful.

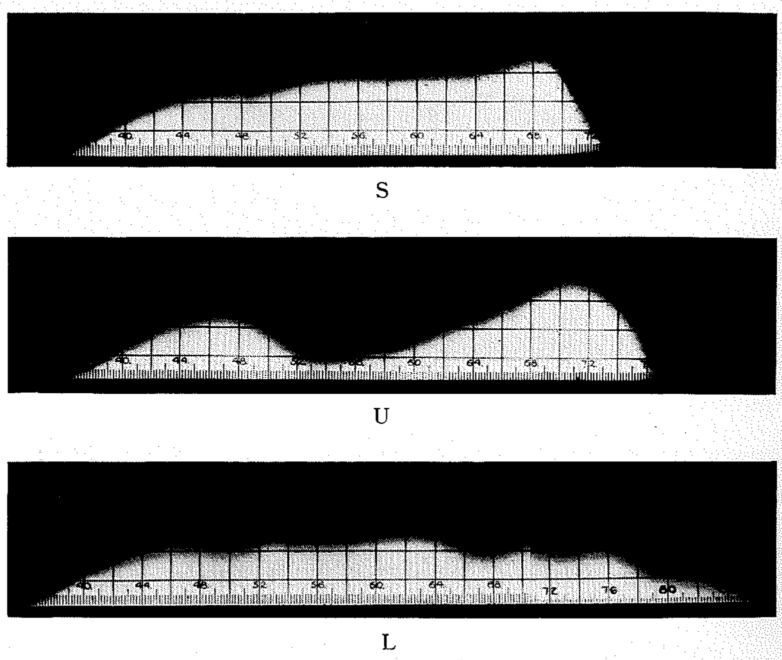


Fig. 15.—*Wedge spectrograms of extreme red sensitizings.*

Class K is available in order to get maximum sensitivity from λ7200A. to λ7700A.

Class R gives far higher sensitivity for the region from λ7600A. to λ8400A. than Class N and should always be used when this region is the important one and where the extension of the Class N towards the visible is not important.

Class P is by far the best for the region from λ8000A. to λ9000A., and Class P plates are very satisfactory for practical use, being free from fog and giving very high sensitivity.

Class M has its maximum at λ9300A. and is valuable from λ8600A. to λ10,000A.; it becomes superior to Class P at about λ9000A.

Class Q has recently been much improved, the plates being cleaner and having more contrast than formerly. The maximum of

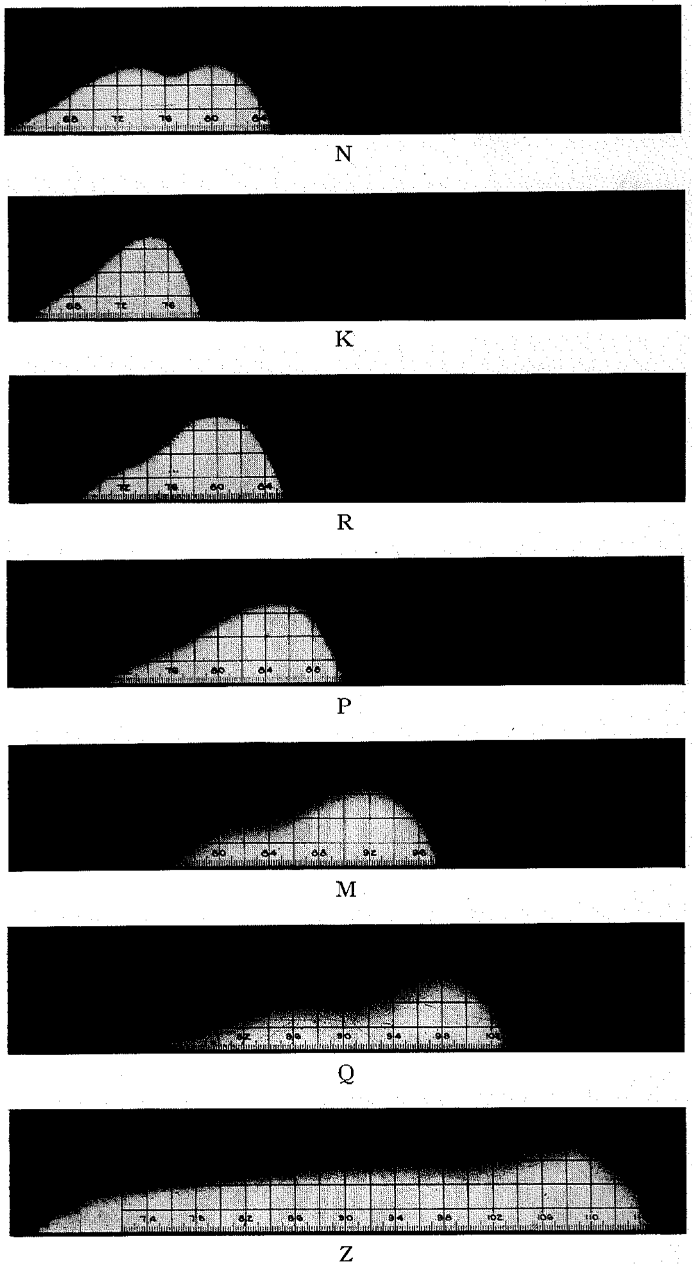


Fig. 16.—*Wedge spectrograms of infra-red sensitizings.*

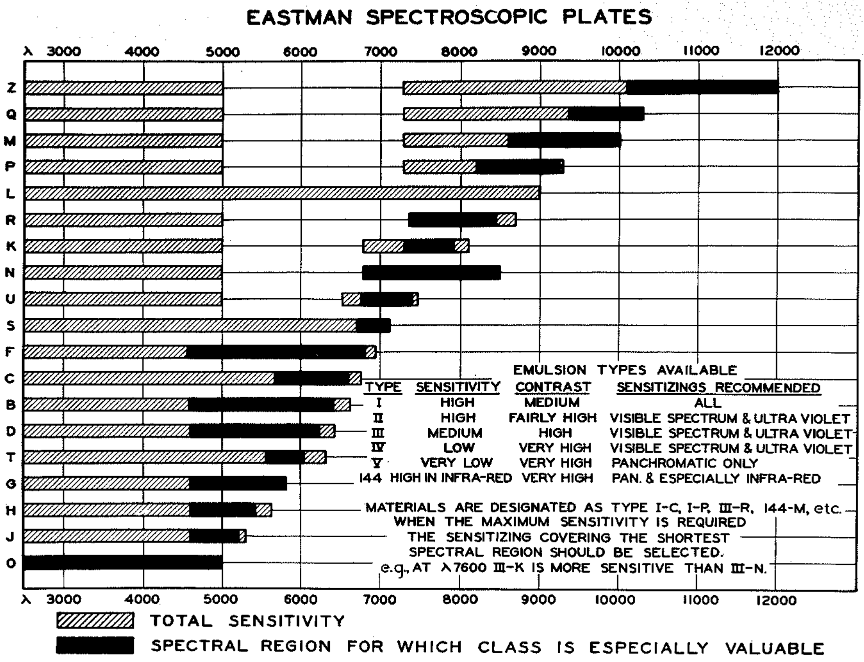
sensitivity is at λ9600A. and it is useful from λ9400A. to λ10,300A., at which point the Class Z sensitizing is superior.

Class Z is an entirely new sensitizing, extending to an extraordinary extent into the infra-red. Its maximum of sensitivity is at λ10,900A., and with it, the spectrum to λ12,000A. is easily accessible.

Class M, Q, and Z plates should be hypersensitized before use.

Summary and Practical Suggestions

The various classes of material available have been summarized in Figure 17. A loose copy of this chart is enclosed because many scientific workers may like to have the chart hanging on the wall of their workrooms for reference. All the different classes of sensitizing are shown, the region of total sensitivity being shown hatched and the region for which the type is valuable being shown as a solid black area. In using the chart, it should be remembered that in most cases the sensitizing covering the shortest spectral region on the chart is that which will give the maximum sensitivity through its own region; for example, the region from λ4800A. to λ5200A. can be photographed on the Class H, G, D, B, or F sensitizings, all of which are shown as a solid black area on the chart, but the highest sensitivity will be obtained by the use of the Class J. Proceeding through the spectrum, we may say that:


EASTMAN SPECTROSCOPIC PLATES

EMULSION TYPES AVAILABLE

TYPE	SENSITIVITY	CONTRAST	SENSITIZINGS RECOMMENDED
I	HIGH	MEDIUM	ALL
II	HIGH	FAIRLY HIGH	VISIBLE SPECTRUM & ULTRA VIOLET
III	MEDIUM	HIGH	VISIBLE SPECTRUM & ULTRA VIOLET
IV	LOW	VERY HIGH	VISIBLE SPECTRUM & ULTRA VIOLET
V	VERY LOW	VERY HIGH	PANCHROMATIC ONLY
144	HIGH IN INFRA-RED	VERY HIGH	PAN. & ESPECIALLY INFRA-RED

MATERIALS ARE DESIGNATED AS TYPE I-C, I-P, III-R, 144-M, etc.
WHEN THE MAXIMUM SENSITIVITY IS REQUIRED
THE SENSITIZING COVERING THE SHORTEST
SPECTRAL REGION SHOULD BE SELECTED.
e.g., AT λ7600 III-K IS MORE SENSITIVE THAN III-N.

Fig. 17.—*Diagram of spectral sensitivity regions of Spectroscopic plates.*

The highest sensitivity at λ5100A. will be obtained by the Class J
" " " " λ5300A. " " " " " Class H
" " " " λ5500A. " " " " " Class G
" " " " λ5900A. " " " " " Class T
" " " " λ6100A. " " " " " Class D
" " " " λ6300A. " " " " " Class B
" " " " λ6400A. " " " " " Class C
" " " " λ6700A. " " " " " Class F
" " " " λ6900A. " " " " " Class S
" " " " λ7100A. " " " " " Class U
" " " " λ7500A. " " " " " Class K
" " " " λ8000A. " " " " " Class R.

For general spectroscopic work, where extreme sensitivity at one point is not the criterion, it is best to use the Class D plates for the whole spectrum from λ5000A. to λ6000A., the Class F plates from λ6000A. to λ6800A., the Class N plates from λ6800A. to λ8400A., and, thereafter, the Class P, M, Q and Z plates.

It may be desirable at this point to make some suggestions as to the best plate for use in certain types of astronomical work. For general stellar photography with reflectors where the shortest possible exposures are required, Shapley has found the plates of Type I-C to be advantageous. They have very high general sensitivity, and their special sensitivity in the red permits shorter exposures than can be attained with other plates. They are, of course, not so sensitive for A and B type stars as the best blue-sensitive materials, but, on the other hand, they are more sensitive for the M type stars. These plates are also valuable for the determination of color indices using widely separated wave lengths, the magnitude in the red, using a red filter over the plate, being compared with the magnitudes derived from images obtained on blue-sensitive plates.

Another possible application for plates of this type is for the direct photography of stars in moonlight or in the vicinity of city lights. The exposure of a blue-sensitive plate is limited[11] even on a dark night far from any city by the diffuse light from the sky. After a number of hours the plate begins to fog, but in moonlight or near city lights this occurs much more quickly. The scattered moonlight responsible for the fogging is principally blue light. When a red filter and red-sensitive panchromatic plates are used, exposures of five hours are possible with the full moon in the sky, and no more fog results during this period than in five minutes on blue-sensitive plates without a filter. The advantage of using this combination when photographs must be taken in the vicinity of lights of a large

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[11] Extract from Dunham, loc. cit.

city would, of course, be less because city lights are redder than moonlight.

Very important instruments in astronomical observatories are the visual refractors which are generally used by photographing in the visual maximum through a yellow filter. For this purpose it has been customary to use so-called "Iso" or "Ortho" plates sensitized to give a maximum in the yellow-green. The best plate from the point of view of focus depends, of course, upon the focal curve of the objective. Our thanks are due to Dr. Aitkin for Figure 18, showing the curve of the Lick 36-inch refractor, from which it will be seen that a panchromatic plate of Class B or Class D sensitizing would be at least as satisfactory as the older "ortho" materials, while the general sensitivity of these plates for wave lengths transmitted by the filter is much higher than that of the older materials. For use with refractors, therefore, our recommendations are to use a yellow filter (the Wratten filter No. 12 has been adopted by most of the important observatories) together with a plate sensitized with the Class B sensitizing.

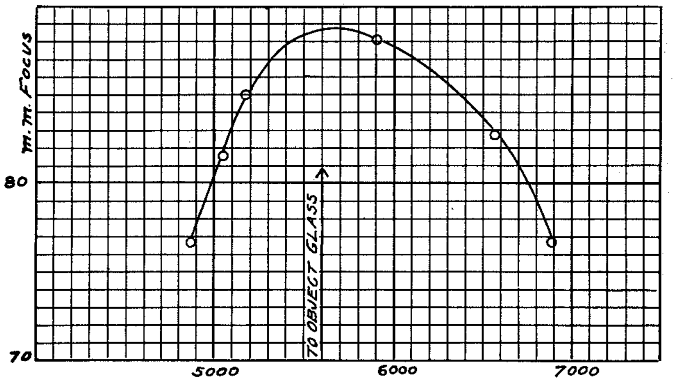

Fig. 18.—*Focal curve of the objective of the Lick Observatory refractor.*

For most work where greater contrast is not a disadvantage, the lower graininess of the Wratten M plate will be an advantage, while where maximum sensitivity is required and low contrast is not a disadvantage, emulsion Type I with Class B sensitizing can be supplied.

Applications for the new types of plates sensitive to the infra-red are rapidly increasing. A number of years ago, Dr. W. H. Wright applied plates sensitized with kryptocyanine to the photography of terrestrial objects in the presence of haze and photographed the Yosemite Valley from the Lick Observatory. Captain A. W. Stevens has employed an extreme red sensitive film in his well-known, long-distance photographs from airplanes, one of which, photographing the Andes range at a distance of 310 miles, shows the haze over the Pampas silhouetted against the mountains in such a way as to demonstrate very clearly the curvature of the earth. Another photograph by Captain Stevens showed Mount Shasta at a distance of 331 miles. Wright, Slipher, Adams, Dunham and others have applied infra-red sensitive plates to the photography of the planets and the study of their atmospheres. An interesting application of infra-red photography has been made by Professor Trumpler of the Lick Observatory in photographing the Orion nebula.[12] A long exposure on an ordinary plate cannot show faint stars within the nebular region because the light of the nebula soon blackens the plates and masks their images, but the nebular light is almost entirely blue-green and visible red, and a photograph on an infra-red sensitive plate with a filter transmitting only infra-red radiation showed many faint stars with very little nebulosity. For this work, the Class R plates are recommended, as for all other cases where general high sensitivity in the infra-red is desired.

For spectra where maximum sensitivity at $\lambda 5300$A. is essential, the Class H sensitizing is recommended.

For the mercury green line and the auroral line in the green, the Class G sensitizing is recommended; for H-alpha and the photography of prominences, the Class C or Class F sensitizing.

Hypersensitizing

Most panchromatic and infra-red sensitive plates are increased in sensitivity by hypersensitizing with ammonia, the best procedure being to bathe the plate for one minute in a 4 per cent solution of 28 per cent ammonia (i.e., 4 parts of 28 per cent ammonia to 100 parts with water) at a temperature not above 55° F. and to dry the plate as rapidly as possible in a blast of dust-free air from a fan. This approximately doubles the red sensitivity of plates of the B and C Classes of sensitizing and increases many times the sensitivity of the extreme red sensitive and especially of the infra-red sensitive plates. For purposes requiring high sensitivity to the infra-red, hypersensitizing is essential.

Hypersensitized plates should be used within a few days of hypersensitizing. They can in most cases be kept for a month or two if maintained in a refrigerator or ice box.

Glass for Plates

The glass on which plates are coated is often of considerable importance in scientific work. Photographic glass is selected from the glass made for use in windows, about 25 per cent of the best window glass being considered suitable for photographic use. Until about ten years ago such

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[12] Dunham, loc. cit.

glass was made by blowing a large cylinder; the ends were cut off and it was opened down its axis, the glass then being allowed to flatten out under heat. Such glass always had a definite concave side, and the concave face was coated with the photographic emulsion, which gave a plate having a coating thicker in the middle than at the edges. Modern glass, however, is made on machines which produce glass showing no definite concavity, the surface being somewhat wavy and sometimes having two or three waves in an 8 by 10 plate. On the whole, this glass gives plates superior in uniformity to those coated on the older glass. Where uniform thickness of the coating is of paramount importance, it is necessary to use plate glass as the support. This, unfortunately, is very expensive.

In many spectrographs it is necessary to bend the plates, and it is customary, therefore, to coat such plates on glass which averages not more than 1 mm. in thickness, plates of this thickness being available in lengths up to 22 inches. Recently, a demand has arisen for even thinner plates owing to the use of grating spectrographs of short focal length, and ultra-thin glass is now available of an average thickness of 0.7 mm.; this glass, however, is somewhat inferior in flatness and gives a good deal of trouble from breakage. This ultra-thin glass cannot be supplied in sizes larger than 8 by 10 inches.

Storage of Plates

Since the slow changes which occur in photographic materials are of a chemical nature and have a high temperature coefficient, it is strongly recommended that materials intended for scientific work be kept in a refrigerator. This will insure their keeping without change for a long time; it is particularly necessary where it is desired to make comparative exposures over a considerable period.

An electric refrigerator, in which the materials are dry, is much to be preferred to one in which the humidity is higher.

It must be remembered that materials should be removed from the refrigerator at least twenty-four hours before use in order to avoid the condensation of moisture upon them.

Instructions for Ordering

When ordering special plates for scientific work, it is suggested that the orders should be marked "Refer to Research Laboratory." The order should state the *quantity*, *size*, and *type* of plates required, preferably in the nomenclature used in this booklet; e.g., "6 dozen Eastman Spectroscopic plates Type III-F, 4 by 10 inches."

If it is desired to order plates sensitized with the ultra-violet sensitizer, the type of plate should be specified, followed by "U.V. Sensitive," e.g., "Type I-F, U.V. Sensitive."

Prices of Eastman Spectroscopic Plates

In the following table, column A gives the prices of Wratten Panchromatic, Wratten Process Panchromatic, Wratten "M," and all Eastman Spectroscopic plates, with the exception of those referred to under column B. Column B gives the prices of plates having Class Q and Class Z sensitizing, and Wratten Hypersensitive Panchromatic plates. Eastman Spectroscopic plates, U.V. Sensitive, are sold at a price 50 per cent above that of the plates of the same size in column A.

If any of the above plates are required coated on ultra-thin glass (X-thin), an additional charge of 50 per cent is made.

The emulsions can be coated specially on film base in cut sheet form instead of glass. This involves some difficulty and a considerable amount of expense, so that promptness of delivery cannot be assured and the price of films is twice that of the corresponding plates.

In order to make the Eastman Spectroscopic plates available to European spectroscopists, Adam Hilger, Ltd., 98 Kings Road, Camden Road, London, N.W.1, England, are prepared to accept orders for Great Britain, Europe, and other countries of the Eastern Hemisphere.

TABLE III

Sizes	Price per Dozen	
	A	B
1¼ x 10 inches	$ .75	$ .85
2 x 7	1.00	1.10
2 x 10	1.10	1.25
2 x 18	4.30	4.75
2¾ x 10	1.95	2.15
4 x 10	2.20	2.45
3¼ x 4¼	.80	.90
3¼ x 18	8.45	9.30
4 x 5	1.10	1.20
5 x 7	1.80	2.00
8 x 10	4.00	4.40
5 x 25 cm.	1.10	1.25
65 x 180 mm.	1.00	1.10

Research Laboratory, Eastman Kodak Company,
Rochester, New York.

March, 1935.

The Following Books Published by the Eastman Kodak Company Will Be of Interest

"The Photography of Colored Objects" (50¢ postpaid). Deals with the use of color-sensitive materials and light filters.

"Wratten Light Filters" (50¢ postpaid). Contains a list of about one hundred light filters, giving their spectrophotometric absorption curves and other data.

"The Fundamentals of Photography" by C. E. K. Mees ($1.00 postpaid). Provides an elementary account of the theoretical foundations of photography.

"Elementary Photographic Chemistry" ($1.00 postpaid). Deals with the chemistry of photography, with a description of the preparation and properties of many of the chemical compounds used.

"Photographic Sensitometry" by Loyd A. Jones (75¢ postpaid). A book dealing fully with sensitometry, including methods of exposure, development, density measurement, interpretation of results and spectral sensitivity.

"Photomicrography" (50¢ postpaid). An introduction to photography with the microscope including a section on motion photomicrography.

Monographs on the Theory of Photography ($2.50 each postpaid):

I. "The Silver Bromide Grain of Photographic Emulsions" by
    A. P. H. Trivelli and S. E. Sheppard.
III. "Gelatin in Photography" by S. E. Sheppard.
IV. "Aerial Haze and its Effect on Photography from the Air."
V. "The Physics of the Developed Photographic Image" by F. E. Ross.
VI. "Chemical Reactions of the Photographic Latent Image" by
    E. R. Bullock.

This is a series of scientific monographs concerning the theory of photography, each monograph being complete in itself and covering the work done in the Kodak Research Laboratories and available literature on the subject. Much of the material has not been published elsewhere.