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Calibration Levels of Films and Exposure Devices

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ABSTRACT. This paper attempts to analyse the conditions at present considered necessary for the correct determination of exposure for monochrome and reversal colour film, as made by exposure meters and the exposure control devices of automatic cameras. It takes into consideration the factors on which calibration of films, exposure meters and automatic cameras is based, and gives the presently accepted values for various photographic constants, for both the arithmetic and logarithmic methods of specification of film speed.

1. INTRODUCTION

THE factors of primary significance in the determination of the exposure required in a camera, in order to obtain an acceptable photograph are:—

(i) the illumination on the light sensitive material (the image illumination [E]).

(ii) the time for which the light sensitive material (the film) is exposed to the image illumination (the effective exposure time [t]).

(iii) that characteristic of the film known as film speed (S).

Exposure H is defined as the product of image illumination and effective exposure time

$$H = Et \qquad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (1)$$

and the exposure determination problem is to establish the measurements of these and other quantities which must be made in order to find the exposure required for acceptable photographs, to classify the light sensitive material according to its suitability for photography and to determine the relationship between the various parameters involved, which will permit calibration of exposure devices whether they be integral with, coupled to, or separate from a camera.

2. THE PHOTOGRAPHIC PARAMETERS

In addition to the photographic parameters of image illumination, exposure time and film speed already mentioned it is necessary to consider also the scene luminance and its relationship to image illumination and also the camera aperture. These items will be discussed in the following sections, together with their mutual relationships.

2.1 The Assessment of Image Illumination

Image illumination within the camera is dependent upon a number of factors, the most important of which are the scene luminance and the f-number (A) of the camera. For a scene of uniform luminance L the relationship between them can be expressed by the equation

$$E = \frac{qL}{A^2} \qquad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (2)$$

in which q is a factor which takes into account the light transmission characteristics of the lens system. Before the introduction of the exposure device incorporated within the camera, direct measurement of image illumination was not practicable and in consequence exposure determination techniques have used a measurement of scene luminance to determine exposure.

The value of luminance which is used in order to obtain correct exposure for an average scene will be

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denoted by the single valued symbol L_g, and its corresponding image illumination by E_g, so that for an average scene

$$E_g = q\left(\frac{L_g}{A^2}\right) \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (3)$$

and the significance of these symbols will now be discussed.

It has been shown[1,2,3] that the image illumination E within a camera is related to the scene luminance L by the equation

$$E = \frac{L}{A^2} \cdot \frac{\pi}{4}\left(\frac{U-F}{U}\right)^2 \tau\, CV \cos^4\theta$$

wherein E = image illumination in lux.
L = scene luminance in nits.
U = distance from lens to object.
F = focal length of lens.
τ = lens transmittance.
C = camera flare correction factor.
V = vignetting factor.
θ = angle of image point from axis of lens.
A = f-number of lens-aperture system.

Comparison of this equation with equation 2 shows that the quantity q is

$$q = \frac{\pi}{4}\left(\frac{U-F}{U}\right)^2 \tau\, CV \cos^4\theta \quad \dots \quad \dots \quad (4)$$

and it is evident that for different distances (U) of lens to object, and of position (θ) of the image point relative to the camera axis different values of q will exist. Nonetheless because the objective is to assess the exposure required for an average scene it has been found that in practice the variations of q due to the causes mentioned can be allowed for by allocating specific values to the given parameters which give a single value of q satisfactory for the exposure determination of a large majority of scenes. This value of q is that in equation 3 and in consequence provides the relationship between the quantities L_g and E_g.

USASI Standard PH2.12–1961 allocates the following values to the above parameters.

$U = 80F$
$\tau = 0{\cdot}95$
$C = 1{\cdot}03$
$V = 1{\cdot}0$
$\theta = 12°$

so that $q = 0{\cdot}69$ although a later assessment of this quantity gives it the value $q = 0{\cdot}65$, by assuming $\tau = 0{\cdot}90$.

If now the exposure required for acceptable photography of an average scene be denoted by H_g equations (1) and (3) may be combined to give

$$H_g = E_g t = q\frac{L_g}{A^2}\, t \quad \dots \quad \dots \quad \dots \quad \dots \quad (5)$$

2.2 Scene Luminance

The essential characteristic of a photograph is that it portrays a differing pattern of luminance comprising the object being photographed, but equation (3) which it is intended to use in assessing the exposure required for this range of luminance uses a single value of luminance L_g. The validity of the exposure determination method must, therefore, depend upon the acceptability of the resulting photographs which are produced by substituting a single value of luminance in the determination of exposure to represent the multiplicity of values of luminance of the scene itself.

In practice exposure determined by this substitution is satisfactory only for what may be termed average scenes. Unusual distributions of luminance require special exposure assessment.

From the point of view of the film, satisfactory photography depends upon the proper location on its exposure/density characteristic of the densities produced by the image illumination within the camera. The greatest and least significant luminances in the scene are required to cause exposure of the film within the usable part of its exposure/density characteristic. This implies that the important characteristics of the luminance are[1]:—

(i) the *ratio* of its maximum to its minimum value

(ii) its absolute value (of maximum or minimum)

for the former determines whether or not the film can reproduce the contrast range of the scene and the latter determines the exposure time necessary to provide an exposure which will locate the brightness scale of the scene correctly relative to the film characteristic.

The question of what single measure of scene luminance can be made which will allow adjustment of a camera to give satisfactory reproduction of a given scene is settled by the devices available for exposure determination. Until the advent of the cadmium sulphide cell the small electrical output obtainable from selenium cells resulted in exposure meters which received light from an extended area in order to provide the required electrical power to operate the device. These exposure meters make a measurement proportional to the total light received, but because the directional light sensitivity of any one exposure device is built into the device and therefore, does not vary, its indication can be taken as proportional to the arithmetic average luminance of the scene. The large majority of exposure determining devices make a measurement proportional to this arithmetical average and in consequence it is this quantity which is used in exposure determination. It may be noted here that it has been stated that the geometric average of the scene luminance is the better measure for the purpose of exposure determination, but because this quantity is no more closely related to the ratio of the extremes of luminance than is the arithmetic average, and moreover is not easily measured, it is not used in exposure determination for ordinary photography.

Equally it should be noted that the geometric mean is a convenient measure for the sensitometric determination of film speed of reversal colour films as will be shown later, and as such is of considerable importance. The use of the cadmium sulphide photoresistive cell has made available much more electrical power than formerly and this, of course, appears as an immediate advantage; but some caution is necessary. If the greater power availability is used to reduce to a small value the area of the scene from which light is received, the measurement made is no longer of the average scene luminance which it has been stated above is that on which the photographic constant P, as defined later, is based. In this case it would be necessary to know which part of the scene to select to obtain a measurement equal to the average, or alternatively a measurement of either the maximum or the minimum luminance could be made, but then a different value of the constant P would have to be determined and used.

2.3 Film Speed

Film speed is a number which indicates the characteristic of light sensitive material by comparing the exposure required to produce certain effects on the film, with an arbitrarily chosen constant exposure. For monochrome material this can be expressed by the equation

$$H_M S_a = n_1 \quad \dots \quad \dots \quad \dots \quad \dots \quad (6)$$

and for reversal colour material by the equation

$$H_R S_a = n_2 \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (7)$$

where S_a is the arithmetic film speed as described later, and n_1 and n_2 are the appropriate constant reference exposures.

These equations define the condition that a sensitometric measurement of exposure H_M or H_R is used to establish the relative photographic speed of films, and it is evident that the relationship between the sensitometric measure of exposure, $H_M(H_R)$ and the photographic exposure requirement H_g must be determined.

The relationship between H_g and $H_M(H_R)$ can be expressed by the equations

$$H_g/H_M = k_1 \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (8)$$

$$H_g/H_R = k_2 \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (9)$$

in which k_1 and k_2 are numbers (not necessarily equal).

2.4 The Basic Photographic Requirement

The relationships previously given can now be combined to show the basic relationship between the parameters involved in the determination of the exposure required for an average scene, and also to provide the basis upon which calibration techniques of exposure devices are decided. Combining equations 5, 6 and 8 or 5, 7 and 9 gives

$$H_M S_a = \frac{H_g}{k_1} S_a = \frac{E_g t S_a}{k_1} = \frac{q L_g t S_a}{A^2 k_1} = n_1$$

$$\text{and } H_R S_a = \frac{q L_g t S_a}{A^2 k_2} = n_2$$

But as from the photographic point of view the exposure H_g is to be determined, we obtain

$$H_g S_a = \frac{q L_g t S_a}{A^2} = n_1 k_1 \text{ (or } n_2 k_2) \quad \dots \quad \dots \quad (10)$$

Since however an exposure device should give satisfactory results for both monochrome and reversal colour films without change of calibration level $n_1 k_1$ and $n_2 k_2$ must be equal, and equation 10 can be written

$$H_g S_a = \frac{q L_g t S_a}{A^2} = P \quad \dots \quad \dots \quad \dots \quad \dots \quad (11)$$

The constant P is the basic photographic constant and can be considered to be either (i) the average image illumination required for light sensitive material having unity film speed when exposed for a time of one second or (ii) a constant reference exposure.

In equation (11), exposure H_g which results from luminance L_g and time t is that required to produce a film density located at some specified point on the exposure density curve of the film.

Different average luminances will be located at this same point of the curve. This specified point will be such that for an average scene the extremes of luminance will produce film densities giving in the finalized photograph, reproduction of the luminances of the scene, as reasonably acceptable as can be expected. This statement implies that acceptance of a photograph is not dependent upon the exact reproduction of the luminances of the scene over their full range, but that it is known that this ideal is impossible and the normal observer will accept imperfections of reproduction as an inherent condition of photography.

2.5 Film Speed Systems

Two systems of describing the sensitivity of film are in common use. They will be dealt with separately under the headings arithmetic and logarithmic film speeds.

2.5.1 *Arithmetic Film Speed* S_a

The quantity S_a characterizing light sensitive material is defined in two ways. In the first, as stated previously, S_a is determined by means of a sensitometric test in which the exposure/density curve of the material is plotted and a particular value of exposure defined as H_M for monochrome material and H_R for reversal colour material (as described later) are referred to arbitrarily chosen constant exposures

$$H_M S_a = n_1$$
$$H_R S_a = n_2$$

In the second way, S_a is determined by a photographic test, and is equated to the reciprocal of the effective exposure time when a satisfactory photograph is taken with a camera set at *f*/16, on a clear sunny day with a solar altitude of about 40 degrees. In this case equation (11) is applicable, i.e.,

$$H_g S_a = q \frac{L_g S_a t}{A^2} = P$$

It is evident that the two methods of film speed assessment determine in effect the ratio $k_1 = H_g/H_M$ of equation (8).

The conditions of the sensitometric tests for both monochrome and reversal colour film are given in national standards[4,5].

For monochrome material the speed criterion is obtained from a curve relating film density to the logarithm to the base 10 of the exposure required to produce this density. In Fig. 1 two points M and N are shown on the curve. M is located 0·1 above fog-plus-base density. N lies 1·3 log exposure units from M in the direction of greater exposure. The development time of the negative material is so chosen that point N lies at a density interval $D = 0{\cdot}8 \pm 0{\cdot}05$ above the density at point M. The exposure H_M corresponding to point M represents the sensitometric parameter at which speed is calculated.

Arithmetic speed is then defined by the formula

$$S_a H_M = 0{\cdot}8 \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (12)$$

where H_M is the exposure (in lux-seconds) corresponding to the point M on the density-$\log_{10}$ exposure curve. Exposure $n_1 = 0{\cdot}8$ is indicated on Fig. 1.

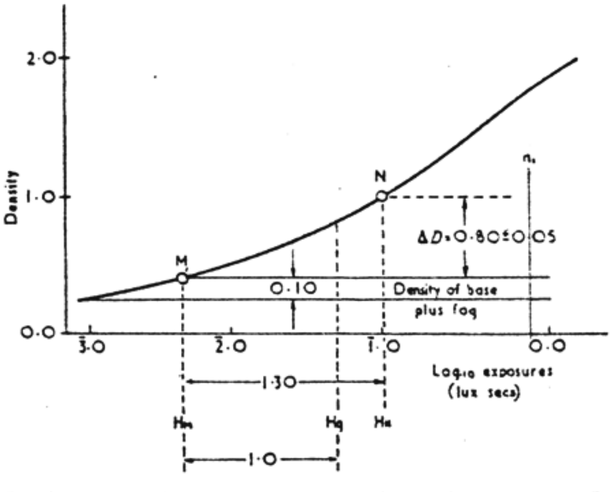

Fig. 1. Method of Speed Determination (Monochrome material).

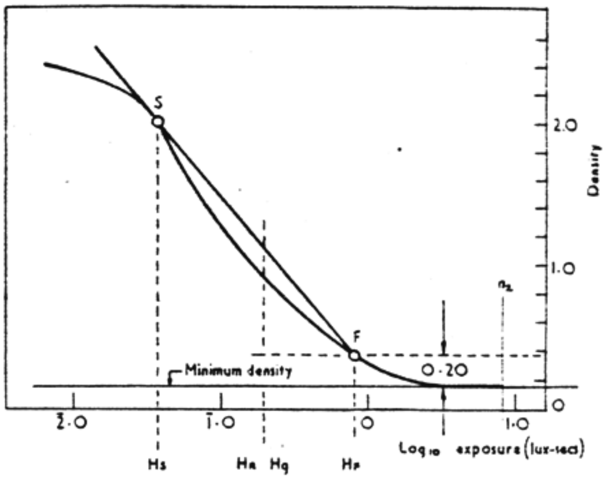

Fig. 2. Method of Speed Determination (Reversal Colour Material).

For reversal colour film the speed criterion and method of calculation of speed are again obtained from a curve relating film density to the logarithm to base 10 of the exposure. In Fig. 2, point F is located on the curve 0·2 above the minimum density. A straight line is drawn from point F tangential to the curve at point S. If the tangent is at density greater than 2·0 above the minimum density, then S is located on the curve where the density is 2·0 above the minimum density.

The speed is calculated from the equation

$$H_R S_a = 8 \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (13)$$

where H_R is the geometric mean between H_F and H_S i.e., $H_R = \sqrt{H_F H_S}$ and thus lies midway on the log exposure scale between S and F. The relationship between the photographic exposure H_g and the sensitometric exposure H_M for monochrome material has been shown to be[3]

$$\frac{H_g}{H_M} = 10 \text{ so that } k_1 = 10$$

and equation (11) becomes

$$H_g S_a = 8 \text{ and hence } P = 8 \quad \ldots \quad \ldots \quad \ldots \quad (14)$$

Monochrome photography has been carried out successfully over a long period and in consequence the conditions for its satisfactory exposure determination for an average scene are presumed to be known with reasonable accuracy. Further, because an exposure device should give satisfactory results for both monochrome and reversal colour films without change of calibration levels it can be taken that

(11) expressed in terms of S_D becomes

$$H_g\,0\cdot8\,.\,10^{\frac{S_D}{10}}=P=8$$

$$\text{or}\quad H_g\,10^{\frac{S_D}{10}}=10 \qquad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \qquad (20)$$

A cursory glance at equation (18) would suggest that a more reasonable alignment between the arithmetic film speed and logarithmic film speed systems would result in the relationship

$$S_D=10\log S_a$$

The reason why this alignment has not been obtained is because both systems have delevoped from initially different concepts of the manner in which film speed should be expressed. The attempt to obtain mutually consistent systems, conditioned as it must be by the previous history of this subject has been only partially successful.

If it is decided to alter the constant n_2 in equation (7) from 8 to 10, i.e., to make the sensitometric criterion $H_R S_a=10$ without modification of the photographic criterion $H_g\,S_a=8$ as at present, it will obviously be necessary to alter the constant $k_2=H_g/H_R$ from $1\cdot0$ to $0\cdot8$ but there will then unfortunately be some inconsistency in the misalignment of the arithmetic film speed and logarithmic film speed systems.

If $S_a=\frac{10}{H_R}$ and also $S_D=10\log\frac{10}{H_R}$ then $S_D=10\log S_a$ which is not the relationship established between the two systems by consideration of monochrome photography.

This inconsistency could be eliminated by an alteration of definition of S_D to $S_D=10\log\frac{12\cdot5}{H_R}$ (and $H_g/H_M=0\cdot8$). This, if done, would preserve for colour photography the relationship established for monochrome photography, i.e., $S_D-1=10\log S_a$, but this does not appear to be a satisfactory procedure.

2.6 Exposure Time and Aperture

In a well-made camera it is usually considered that the aperture, which depends upon the physical size and shape of the components, is made with considerable accuracy and in consequence the aperture markings on the camera (the *f*-numbers [A]) are also accurate. Similarly, techniques exist[7] for the accurate measurement of exposure time (t) (shutter speed), and it is, therefore also considered that t can be known with accuracy. In view of these conditions it is not necessary to deal further with these parameters.

2.7 The Values of the Constants

The value allocated to the constant P depends upon the acceptability to a number of observers, of a number of photographs, and further these photographs are presumed to be of average scenes. It is well known[3,9,10,11] that different observers assess differently the acceptability of a photograph, and that one particular photograph may be considered by one observer to be over-exposed and by another to be under-exposed. In consequence the level of exposure which is to be taken as acceptable must be determined by statistical analysis of a large number of photographs of different scenes. This process not only eliminates the uncertainties caused by differences in individual tastes, it also provides in effect an answer to the question. What is an average scene? No precise definition can be given which will specify exactly whether or not any one scene is "average".

To what extent can it be expected that the photographic constants will be the same if determined by independent tests at different parts of the world? This will depend upon two factors (a), the consistency of human vision, or the validity of the average visibility curve and (b) the consistency of the spectral distribution of sunlight throughout the world.

For the first factor, it is presumed that the visual characteristics of the human race, with what may be called normal vision, do not vary widely from place to place or race to race. There are normally no infra-red or ultra-violet detecting eyes! For the second factor the radiation of the sun is known to be nearly constant and the distance from sun to earth varies from the mean by only one part in 60. As a result of the nature of the atmosphere and the preponderance of vertical subjects, correct exposure for subjects under a clear sun varies remarkably little over the earth and at various times of the year[12].

Thus the value of the constant P should not vary appreciably if determined in different places by different observers. Monochrome photography over many years has resulted in a figure of $P=8$, and with a factor $q=0\cdot65$ suggested as suitable for modern cameras a value for $\boxed{K \text{ of } \frac{8}{0\cdot65}=12\cdot3}$ may be considered as reasonable. It is of interest to note that the German Standard DIN 19010, January 1961 gives a value equivalent to $12\cdot7$, and the Russian figure is $12\cdot8$[10], whilst a recent American paper[13] gives it as $12\cdot4$.

In view of the fact that the latitude in exposure which is permissible in order to obtain an acceptable photograph is generally considered to be $\pm\frac{1}{3}$ step ($\pm\frac{1}{3}\,E_v$ or $0\cdot1$ log unit), the agreement between these figures is remarkable, for they have been independently obtained, or at least independently verified.

It is of interest that a figure of K for the separate exposure meter, proposed for international acceptance (but not yet agreed upon) ranges from $10\cdot6$ to $13\cdot4$ with an average of $12\cdot0$.

The values quoted for the constants k, K and P are not to be considered as having the precise and invariant quality which a physical constant, such for instance as the resistance temperature coefficient of a metal at a certain temperature, is known to have. They result from a large number of photographic and sensitometric tests, and are the most acceptable averages of the statistically determined quantities concerned. As such they will be subject in the future to whatever adjustment further experiment may call for.

3. CALIBRATION CONDITIONS

Whereas equation (11) can represent the photographic requirement only for average conditions it can be used to represent exactly the conditions for calibration of exposure devices, for under calibration conditions all of the parameters are under control, they can be measured and adjusted to specific values, and known uniform luminances at specific effective colour temperatures can be used.

It remains only to verify that the calibrating conditions provide an exposure device which is satisfactory in photographic use. This is effected by photographic tests using the exposure device concerned. The photographic tests consist of the statistical analysis of the result of assessment by a number of observers of a number of photographs taken under a wide range of subject matter and light conditions [8,9,10,11]. Since the photographic determination of S in the first place is made by a test of this nature, the testing of the exposure device in this way takes account of those other factors not so far considered, which can affect the accuracy of the measurement of exposure.

These factors are as follows:—

(i) the effective colour temperature of the light source used in the sensitometric determination of film speed may differ from that used in the photographic determination.

(ii) the effective colour temperature of the light source used in calibration of the exposure device similarly may differ from that which it encounters in normal use.

(iii) the scene viewed by the light receptor of the exposure device may differ from that viewed by the camera lens.

3.1 The Effective Colour Temperature of the Light Source used in Film Calibration

The sensitometric determination of film speed is carried out using a light source having an effective colour temperature closely resembling the type of light by which it is intended to take photographs[4]. For instance, light sources are available which allow simulation of daylight, flash and photo-floodlight by the use of a suitable optical filter together with a tungsten lamp. The simulation of daylight is, of course, not perfect, for the tungsten lamp is deficient in blue radiation, but the result of this method of film calibration is that no serious error is introduced by the difference in colour temperature of the scene relative to that of the calibration source. Further, because the quantity $k_1 = \frac{H_g}{H_M}$ $\left(\text{and } k_2 = \frac{H_S}{H_R}\right)$ is determined by a statistical check on films and photographs any error introduced by the effect under consideration is taken into account by the choice of k.

3.2 The Effective Colour Temperature of the Light Source used in Exposure Device Calibration

Exposure devices are usually calibrated by reference to lamps of known candle power and effective colour temperature. At some time in their development they must also have been subjected to a test to verify that they do in fact provide the correct exposure information for acceptable photography. That is, that the value of the constant K used in their calibration is also correct photographically. When the calibrated device performs satisfactorily a specific relationship is thus established between calibration, effective colour temperature and the constant K. If it is then decided to alter the colour temperature of the calibrating source a new value of the constant K can be found. This is done by taking an exposure device known to be satisfactory photographically and determining its constant in the laboratory over a range of colour temperatures. A curve can be plotted showing K against colour temperatures, and any colour temperature convenient to the manufacturer can then be used for calibration by suitable adjustment of K. In practice this means that the uniform luminance to which the device is subjected during calibration is calculated from $K_1 = \frac{L_g\, t\, S_a}{A^2}$ in which K_1 has the value appropriate to the colour temperature of the calibrating source.

Although from the above it might appear that the effective colour temperature of the calibrating source is not of great importance, experience in the manufacture of exposure meters shows that a value of 4700°K is advantageous. This colour temperature lies intermediately between those of tungsten lighting and sunlight, and represents a reasonable compromise between these two, for, in order to minimize the effects of scatter of performance of individual photosensitive elements about their mean performance, it is better to choose a reference colour temperature (4700°K) as near as possible to that of ultimate usage of the meter, i.e., about 2700–3200°K for tungsten lighting and about 5500–6000°K for sunlight.

3.3 The Effect of a Difference in the Scene viewed by Exposure Device and Camera Lens

Choice of exposure by the reflected light method requires to some extent selection of the area of which the luminance is to be measured. For a subject which stands against a light background such as the sky, the inclusion in the exposure device receptor of light from this background will cause an exposure indication less than is desirable. To reduce errors of this kind the light receptor of an automatically controlled camera may receive light from a different area from that which is "seen" by the camera lens. This effect is taken into account by the introduction of a further factor in equation (11). If when the camera is subjected to uniform luminance L_g the exposure device receptor is subjected to luminance L_c and $L_c = pL_g$, then for the exposure device the calibration equation becomes

$$H_g\,S_a = qp\,\frac{L_g\,t\,S_a}{A^2} = 8$$

$$\text{or}\quad H_g\,S_a = qpK = 8 \qquad \ldots \qquad \ldots \qquad \ldots \qquad \ldots \qquad (21)$$

4. EXPOSURE DEVICES

Three variants of the exposure determining device can be considered.

(i) The controlled camera with its exposure device receiving light through the camera optical system (TTL metering).

(ii) The controlled camera with its exposure device light receptor separate from the camera optical system, but an integral part of the total mechanism.

(iii) An exposure device separate from the camera—an exposure meter.

4.1 Camera with Common Optical System

A camera in which the optical system is common for both the photographic and exposure requirements (through the lens metering) is such that the exposure device receives light from the same area as the camera lens. In consequence, the factor p of equation (21) is unity. Since the camera has its own particular optical transmission the factor q will vary according to the camera used, and its own particular value can be used.

4.2 Camera with Separate Optical Systems

A camera in which the exposure device receptor is separate from the camera lens system can have the receptor directed towards a different area from that to which the camera lens is directed, in which case the factor p of equation (21) may not be unity, and its value must be taken into account. Since in this type of condition the camera again has its own particular optical transmission and hence value of q, this must also be taken into account.

The necessity to take the value of q into account results in a value of K different from that given in section 2.7. Because the actual value of q can vary widely[14], $K_1 = \frac{P}{q}$ for automatically controlled cameras will have a wider range than for separate exposure meters. A range of 10·6 to 17 is at present under consideration.

4.3 Exposure Meter

An exposure meter separate from a camera is designed to measure only scene luminance, it cannot directly control any of the camera parameters. In consequence it cannot allow for the particular value of q of any one camera but must assume that a value of q can be found which will be satisfactory for all cameras. Previously, the value $q = 0{\cdot}69$ has been used for exposure meter calibration as shown in equation (16) but it is to be noted that this value is, and has been under continuous investigation by the photographic tests which are carried out, and there may be in future the need to change it to $q = 0{\cdot}65$. With regard to the factor p, this is taken into account for the separate exposure meter by instructions on its method of use, in which the meter is directed downwards to exclude excessive skylight. Its value is, of course, unity in this case.

5. THE SPECIAL CASE OF THE 8mm FILM

In order to obtain adequate screen illumination in the projection of 8mm film a less dense film is required than for films of larger format. Since this is in effect a statement that an 8mm film requires more exposure than other film, this could be taken into account by a change of the constant in equation (2) and in consequence a change in the marked film speed. In fact it is apparently taken into account by change of the constant K applicable to automatic cameras using this film, but of course, for the separate exposure meter which must be usable with any type of camera, it is taken into account by a change of film speed. This amounts to a $\frac{1}{3}$ step change. That is, where for large format film a film speed of say, 25, might be called for and used in the exposure meter setting, for 8mm film of the same marked speed, the exposure meter setting would be 20. A range of 13·4 to 21 for the value of K_1 is being considered for automatically controlled 8mm film cameras.

6. CONCLUSION

It has been suggested in the foregoing that the determination of correct exposure is dependent upon certain parameters the relationship between which can be expressed by the equation

$$H_g S_a = \frac{qL_g\,t\,S_a}{A^2} = P$$

and that this equation is to be considered as the basic photographic equation.

Initially, before the advent of the automatically controlled camera, exposure was determined by an exposure meter separate from a camera and in consequence it was necessary to assume a specific value for the constant q, and that this could reasonably be considered as applicable to all cameras. This resulted in the derivation of the equation

$$\frac{L_g\, t\, S_a}{A^2}=\frac{P}{q}=K_1$$

and the constant K_1 has come to be regarded as of primary importance in exposure determination.

For automatically controlled cameras the quantity q need not be assumed to have one specific value, it can be measured, and its actual value applied individually to each camera, in which case the constant K_1 is derived from the basic constant P and the actual value of q.

Thus two problems exist for the exposure device designer, one is to verify that the established value of the basic constant P is the best average obtainable from the statistical information of photographic tests available, and the other, either to measure q for the device concerned, or if this is not convenient or possible, to show that the derived constant K provides as satisfactory results photographically as the constant P.

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NEW BOOKS

Photographic Recording of High-Speed Processes. By A. S. Dubovik. Pergamon Press Ltd., Headington Hill Hall, Oxford. Price £7.

Designed for physicists, experimentalists and optical engineers this monograph is devoted to a description of methods of recording photographically high-speed processes and a description of high-speed photographic equipment. The book may be of use to graduates and students of advanced courses in Universities.

History of Color Photography. By J. S. Friedman. Focal Press, 31, Fitzroy Square, London, W.1. Price £7 7s. 0d.

First published in 1944 and reprinted as soon as 1946 this classic of photographic literature has been unobtainable for many years. It is now being re-issued with a biographical introduction and an appendix by L. E. Varden of Columbia University, N.Y. This appendix covers a variety of developments that have taken place since the original book was written

Applied Optics. By L. Levi. John Wiley & Sons, Ltd., Chichester, Sussex. Price £8 18s. 0d.

A volume in the Wiley Series in Pure and Applied Optics this book is intended to serve as a reference work, as well as a text suitable for self-study, for engineers and scientists who require an up-to-date understanding of the analysis and design of optical components and systems.

Physical and Photographic Principles of Medical Radiography. By H. E. Seemann. John Wiley & Sons Ltd., Chichester, Sussex.

This book for physicists and radiologic technologists gives an elementary, practical and thorough treatment of the physical principles of medical radiography. Considerable emphasis is given to the sensitometric characteristics of X-ray film while the stress is on descriptive, rather than quantitative X-ray physics. Many of the experiments discussed in the text could be modified to form the basis of a laboratory course.