



THE FOCAL LIBRARY

MOTION PICTURE & TELEVISION FILM

IMAGE CONTROL & PROCESSING TECHNIQUES

D. J. CORBETT

A BBC ENGINEERING TRAINING MANUAL

FOCAL PRESS • LONDON • NEW YORK

MOTION PICTURE & TELEVISION FILM IMAGE CONTROL & PROCESSING TECHNIQUES

D. J. Corbett

The work of the motion picture laboratory is but sparsely served by literature. At long last this book covers the subject comprehensively and in depth.

The author has brought together and co-ordinated all the information and data that matters and is needed in film processing laboratories. He has done so in a uniquely concise text, illustrating every point with lucid diagrams.

The material was originally assembled for a series of lectures to members of the B.B.C. Engineering Department responsible for the processing of black and white films. The lectures were designed to cover not only the elements of film processing, but also the more theoretical aspects of photometry which are required to advise film cameramen and other staff concerned with the making of films.

Thus the book provides the basic technical background for those engaged in motion picture or television film-processing or related activities. Much of its contents is of vital interest to many film or television engineers and technicians working in adjacent fields as well.

Twelve chapters deal with light, chemistry, the physical characteristics of film stock, light-sensitive materials, the principles of sensitometry, the chemistry and technology of film processing, as well as the characteristics and assessment of the photographic image.

D. J. CORBETT is Film Technical and Training Manager in Film Operations and Services Department at the British Broadcasting Corporation. He is an Associate Member of the Institute of Electronic Engineers, a Member of the British Kinematograph Sound and Television Society and an Associate of the Royal Photographic Society.

£4 10s.

OTHER TITLES IN THE FOCAL LIBRARY

CHEMISTRY OF PHOTOGRAPHIC MECHANISMS
by K. S. Lyalikov

RADIOGRAPHIC PROCESSING
by D. H. O. John

PROBLEMS IN PHOTOGRAPHIC RESEARCH
by N. I. Kirillov

GENERATION OF OPTICAL SURFACES
Edited by K. G. Kumanin

MANUAL OF OSCILLOGRAPHY
by Howard W. Hoadley

THIN FILMS IN OPTICS
by H. Anders

PHOTOGRAPHIC EMULSION CHEMISTRY
by G. F. Duffin

PHOTOGRAPHIC PROCESSING CHEMISTRY
by L. F. A. Mason

PHOTOGRAPHIC FILM DOSIMETRY
by K. Becker

MICROCOPYING METHODS
by H. R. Verry

D. A. SPENCER'S COLOUR PHOTOGRAPHY IN PRACTICE
by Lt.-Col. The Viscount Hanworth, L. A. Mannheim

A SYSTEM OF OPTICAL DESIGN
by Arthur Cox

HIGH SPEED PHOTOGRAPHY
by R. F. Saxe

PHOTOGRAPHIC SCIENCE: Torino 1963
Edited by G. Semerano and U. Mazzucato

XEROGRAPHY AND RELATED PROCESSES
Edited by J. H. Dessauer and H. E. Clark

PHOTOGRAPHIC GELATIN
by R. J. Croome and F. G. Clegg

ELECTROPHOTOGRAPHY
by R. M. Schaffert

FILM COATING THEORY
by B. V. Deryagin and S. M. Levi

MEASUREMENT OF OPTICAL RADIATIONS
by Georg Bauer

STEREOSCOPY
by N. A. Valyus

CHEMICAL ANALYSIS IN PHOTOGRAPHY
by G. Russell

PRACTICAL PHOTOMICROGRAPHY
by J. Bergner, E. Gelbke and W. Mehliß

PHOTOGRAPHY ON EXPEDITIONS
by D. H. O. John

MAKING AND COATING PHOTOGRAPHIC EMULSIONS
by V. L. Zelikman and S. M. Levi

PHYSICAL OPTICS IN PHOTOGRAPHY
by G. Franke

FOURIER METHODS IN OPTICAL IMAGE EVALUATION
by E. H. Linfoot

GENERAL SENSITOMETRY
by Yu. N. Gorokhovskii and T. M. Levenberg

BASIC PHOTOGRAPHY
by M. J. Langford

SPECTRAL STUDIES OF THE PHOTOGRAPHIC PROCESS
by Yu. N. Gorokhovskii

MOTION PICTURE AND TELEVISION FILM



THE FOCAL LIBRARY

Editorial Board

Prof. Dr. W. F. BERG,
General Editor and Chairman of the Editorial Board, Director, Photographisches Institut der E.T.H.,
Zürich, Switzerland.

Dr. SUZANNE BERTUCAT,
Editor, "Science et Industries Photographiques",
Paris, France.

Prof. Dr. K. W. CHIBISOV,
Committee of Scientific Photography and Cinematography, Department of Chemistry,
Moscow, U.S.S.R.

Prof. Dr. Dr.-ing h.c. J. EGGERT,
Professor Emeritus, Eidgenössische Technische Hochschule,
Zürich, Switzerland.

Prof. Dr. H. FRIESER,
Director, Institute for Scientific Photography, Technische Hochschule,
Munich, Germany.

Prof. Dr. A. HAUTOT,
Director, Physical Laboratories, University of Liège,
Liège, Belgium.

Dr. T. H. JAMES,
Editor, "Photographic Science and Engineering", Research Laboratory, Eastman Kodak Company,
Rochester, N. Y., U.S.A.

Dr. F. W. H. MUELLER,
Associate Director of Research and Development, General Aniline and Film Corporation,
New York, U.S.A.

E. W. H. SELWYN, B.Sc.,
Chief Physicist and Head of Library and Information Department, Kodak Ltd.,
Harrow, England.

Prof. Dr. G. SEMERANO,
Professor of Physical Chemistry, University of Bologna,
Bologna, Italy.

Prof. Dr. M. TAMURA,
Department of Industrial Chemistry, Faculty of Engineering, University of Kyoto,
Kyoto, Japan.

Dr. C. WALLER,
Research Manager, Ilford Ltd.,
Ilford, Essex, England.

Prof. Dr. W. D. WRIGHT,
Professor of Applied Optics, Imperial College of Science and Technology,
London, England.

Assistant Editors

R. B. COLLINS,
Technical Director, Photographic Film Division, 3M Company,
St. Paul, Minnesota, U.S.A.

JOHN H. JACOBS,
Principal Research Physicist, Bell & Howell Research Center,
Pasadena, California, U.S.A.

Executive Editor

R. J. COX, B.Sc., F.R.P.S.
Editor, "Journal of Photographic Science"
London, England.

Publishers

THE FOCAL PRESS,
31 Fitzroy Square, London, W.1, England
and *20 East 46 Street, New York, N. Y. 10017, U.S.A.*

MOTION PICTURE AND TELEVISION FILM

IMAGE CONTROL AND PROCESSING TECHNIQUES

D. J. Corbett, C.ENG., M.B.K.S., A.R.P.S., A.M.I.E.R.E.

Film Technical and Training Manager
Film Operations and Services
British Broadcasting Corporation

A BBC ENGINEERING TRAINING MANUAL



THE FOCAL PRESS

LONDON and NEW YORK

© BRITISH BROADCASTING CORPORATION 1968

First published 1968 by arrangement with the BBC

Printed and bound in Great Britain
at the Pitman Press, Bath

CONTENTS

PREFACE	9
ACKNOWLEDGEMENTS	11
I. LIGHT	13
Light radiation	13
Light sources	15
Light units and measurements	20
Transmission, opacity and density	28
Integrating sphere	31
Filters	33
Appendix 1.A: Full radiator	36
Appendix 1.B: Relationship between flux and luminous intensity	37
Appendix 1.C: Photometric units and conversion factors	39
II. CHEMISTRY	41
Introduction	41
Atomic structure	41
Chemical compounds	42
Ions and ionization	42
Chemical change	43
Acids, alkalis and salts	45
pH values	46
Colloids	47
Oxidation and reduction	47
Silver halides	48
Organic chemistry	48
III. PHYSICAL CHARACTERISTICS OF FILM STOCKS	50
General	50
Base material	50
Construction of the film	51
Film dimensions	52
Dimensional changes	53
Cores and winding	55
Storage of film	55
Identifying markings on film stock	57
Static marks	57
Sound on film	58
Machine leader film	58
BBC film leader	60
IV. THE LIGHT-SENSITIVE MATERIAL	66
Constituents	66
Gelatin binder	66

Silver halide crystals	68
Preparation of emulsion	69
Emulsion structure	70
Sensitivity centres	71
Latent image	72
Development of latent image	72
Dye-sensitizers	73
Emulsion classification according to colour sensitivity	73
Latent image theories	74
V. SENSITOMETRY: PRINCIPLES	82
Characteristic curve of a photographic emulsion	82
Gradient of characteristic curve	85
Failure of reciprocity law	89
Sensitometers and densitometers	91
Sensitometers	91
Densitometers	98
VI. CHEMISTRY OF FILM PROCESSING	104
Introduction	104
Composition of a developing solution	105
The developing agent	105
The alkali	106
The preservative	108
The restrainer	110
Superadditivity	111
Types of developer in use	112
Fine grain development	113
Effects of agitation	114
Effects of developer exhaustion	117
Effects of variation in developer constituents	118
Fixing and washing	119
Reversal processing	123
VII. SENSITOMETRY: APPLICATIONS	124
Control of development	124
Film speed measurement	128
Speed point determination and speed measurement systems	132
Comparison between speed measurement systems	139
Specialized methods of speed rating	142
Measurements on a telerecording film	142
Working tolerances	144
VIII. MEASUREMENT OF LIGHT	147
Light meters	147
Photoemissive cells	147
Photovoltaic cells	151
Photoconductive cells	154
Comparison between photocell types	155
Exposure meters	157
Appendix 8.A: Calibration of integrating exposure meters	162

IX. ASSESSMENT OF THE PHOTOGRAPHIC IMAGE	164
Grain structure of image	164
Sharpness and acutance	166
Resolving power of emulsion	168
Modulation transfer function of a film	173
Modulation transfer function of a lens	175
Multiplicative property of modulation transfer functions	175
Spread functions	178
Signal-to-noise ratio	181
Bandwidth-restricted systems	184
X. PRINTERS	188
Types of printer	188
Intermittent contact printers	188
Intermittent optical printers	188
Non-intermittent or continuous printers	191
Reduction printing	192
Light control	193
'Contact', 'S.M.P.T.E.' and other prints	194
Sprocket holes in 16-mm film leaders	196
XI. FLARE—THE QUADRANT DIAGRAM—REVERSAL PROCESSING	197
Flare	197
The quadrant diagram	198
Reversal processing	205
XII. PROCESSING EQUIPMENT	206
Introduction	206
Basic requirements	206
Early apparatus	206
Continuous processing machines	207
Design considerations	207
Machine leader	207
Machine output speed	208
Film transport	210
Film reservoir or storage unit	213
Reservoir design	214
Magazines	215
Film joining	215
Operation of reservoir	215
Speed control	216
Solution distribution and control	216
Temperature control	217
Recirculation and agitation	218
Solution replenishment	220
Air knives and squeegees	220
The drying process	222
Silver recovery	223
SUBJECT INDEX	227
AUTHOR INDEX	231

PREFACE

This manual is intended to provide an elementary technical background for those engaged in motion-picture or television film-processing work or related activities. Much of the contents should also be of interest to other film or television engineers and technicians.

The book is based on material prepared by the author for various series of lectures delivered at the BBC Engineering Training Centre, Woodnorton Hall, Evesham. Much of the material used was originally obtained from internal BBC sources, but considerable help was naturally found in the literature; great kindness was also received from manufacturers and others.

The publishers of many of the reference sources listed in the Chapter bibliographies have kindly given permission for the use of valuable diagrams and tables. With regard to the text, as the manuscript was prepared largely from teaching notes made over some time, and of such varied origin that it is impossible now to particularize, it is hoped that the lack of individual acknowledgements will be excused, and that the author will be forgiven if he has leaned rather heavily on any sources, whether listed or otherwise.

ACKNOWLEDGEMENTS

The BBC and the author wish jointly to express their gratitude for permission to use illustrations and tables taken or adapted from the sources shown. They also offer sincere apologies for any case in which, by accident, permission has not been sought and obtained.

Figs. 1.3 and 1.4, from *Textbook of illumination engineering*, by J. W. T. Walsh. Pitman, 1947.

Table 1.3, from *Photometry*, by J. W. T. Walsh. Third edition. Constable, 1952.

Figs. 1.6, 1.9, 5.13 and 5.14 and Tables 1.2 and 1.4, from *Artificial light and photography*, by G. D. Rieck and L. K. Verbeek. Philips Technical Library. Centrex, Eindhoven, 1952.

Table 1.6, from "Inside filters", by Richard D. Zakia and Hollis Todd. *Modern Photography*. July 1961, pages 80-85.

Figs. 1.7, 4.1, 6.9, 8.6, 8.7 and 9.24 and Tables 3.1 and 3.2, from *Photography, its materials and processes*, by C. B. Neblette. Sixth edition. Van Nostrand, 1962.

Fig. 1.8, from *Principles of lighting*, by W. R. Stevens. Constable, 1951.

Fig. 1.15, from *Photo electric cells*, by A. Sommer. First edition. Methuen, London, 1946.

Figs. 1.17, 4.3, 6.2, 6.4, 6.8, 6.10, 9.11 and 9.14 and Table 4.1, from *Fundamentals of photographic theory*, by T. H. James and G. C. Higgins. Second edition. Morgan and Morgan, New York, 1960.

Figs. 1.21 and 1.22, from *Wratten light filters*. Kodak, 1961. Ten further illustrations, as well as two tables, are also used by permission of Kodak Limited. Four of them were provided specially for use in this manual.

Figs. 3.1 and 3.2 and Tables 6.1 to 6.3 and 9.1, from *The Ilford manual of photography*, edited by A. Horder. Fifth edition, fourth reprint, 1963.

Figs. 3.3 and 3.4, extracted from British Standard 677, *Motion picture film* (Part 1: 1958, 35-mm film, and Part 2: 1958, 16-mm film), are reproduced by permission of the British Standards Institution, 2 Park Street, London W.1, from whom copies of the complete standard may be obtained.

Figs. 4.7, 4.9, 6.3, 6.6, 7.6 to 7.9, 9.1, 9.12, 9.13 and 11.1, redrawn with permission of the Macmillan Company from *The theory of the photographic process*, by C. E. K. Mees and T. H. James. Copyright © The Macmillan Company, New York, 1966.

Figs. 5.15 and 5.19 and Table 6.4, from *Control techniques in film processing*, produced by the Society of Motion Picture and Television Engineers, 1960.

Figs. 5.23 and 5.24, kindly provided by Evans Electro Selenium Ltd. Fig. 5.25, kindly provided by Westrex Ltd. Fig. 5.26, kindly provided by Baldwin Ltd.

Figs. 7.1 and 7.2, from *An easy approach to photographic sensitometry for the craftsman*, by J. W. W. Smith and J. C. Sheppard. Ilford. Fig. 7.3, from *Ilford technical information sheet No. A50.1*. Figs. 8.15 and 8.16, from *Instruction manual or the S.E.I. photometer*. Ilford.

Fig. 7.20, from "Safety factors in camera exposures", by C. N. Nelson. *Journal S.M.P.T.E.* Volume 69, pages 479-483.

Figs. 8.2 to 8.4, from *Photoemissive cells*. Mullard.

Fig. 9.9, from "Methods of appraising photographic systems", by F. H. Perrin. *Journal S.M.P.T.E.* Volume 69, pages 151-156.

Fig. 9.17, from "The application of sine wave techniques to image forming systems", by R. W. Lamberts. *Journal S.M.P.T.E.* Volume 71, pages 635-640.

Figs. 9.19, 9.21 to 9.23 and 9.26 to 9.28, from "Modern methods of evaluating the quality of photographic systems", by R. Shaw. *Visual* (Ilford Journal). Volume 1 (1963), No. 2, pages 19-24.

Figs. 10.1, 10.2 and 10.3, from *Principles of cinematography*, by L. J. Wheeler. Third edition. Fountain Press, 1963.

Further thanks are due to The Fountain Press for permission to use the quotation on page 67 from *The science of photography*, by the late Dr D. C. Baines. A new edition of this book, revised by E. F. Bomback, was published in 1967.

Thanks are also due to the following members of BBC staff for their kindness in reading parts of the manuscript or for general help with advice and suggestions: Mr H. Henderson, Head of Engineering Training Department, Mr A. B. Palmer, and Mr A. Branson, to the last of whom the author is particularly indebted.

Similar thanks are due to Mr L. J. Wheeler, of Ilford Limited, to Mr G. J. Craig and Mr B. J. Davies of Kodak Motion Picture Division, and to Drs Alan and Joyce Wagland for advice on chemistry.

And, last but by no means least, the author wishes to thank Mr A. Kraszna-Krausz, Managing Director of Focal Press, at whose suggestion Chapter 12 was written.

I. LIGHT

Light Radiation

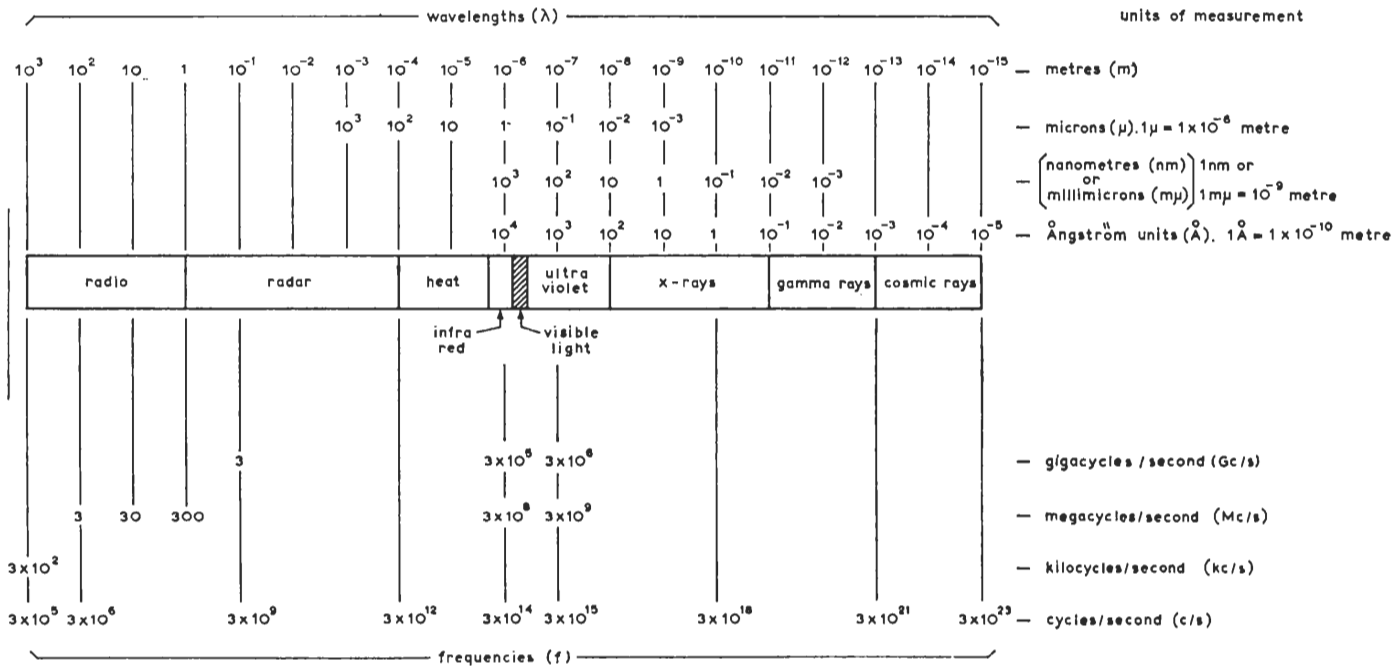
Fig. 1.1 shows the spectrum of electromagnetic radiation. Between a wavelength of about 400 nm* and a wavelength of about 700 nm the radiation is visible to the eye as light. Within this band, the response of the eye is not

TABLE 1.1
CHARACTERISTICS OF VISIBLE SPECTRUM

Physical Characteristics		Subjective Characteristics	
Wavelength (nm)	Frequency (c/s $\times 10^{12}$)	Colour	Relative Luminosity
760	394.8		0.00006
740	405.3		0.00025
720	416.7		0.00105
700	428.7	Red	0.0041
680	441.1		0.017
660	454.5		0.061
640	468.8		0.175
620	483.7		0.381
600	500.0	Orange	0.631
580	517.3		0.870
560	535.6	Yellow	0.995
558	537.6		1.0
540	555.6	Green	0.954
520	577.0		0.710
500	599.8	Blue-green	0.323
480	625.0		0.139
460	652.3	Blue	0.060
440	681.6		0.023
420	714.3	Violet	0.004
400	750.3		0.0004
380	789.2		

uniform, but falls off on either side of a point of maximum sensitivity which for most people is at a wavelength of about 558 nm. Fig. 1.2(a) shows the response curve for a "standard eye" at normal levels of illumination (the photopic curve) and Fig. 1.2(b) shows the eye response curve at low levels of

* The nanometre (nm) or millimicron (m μ) is equal to 10^{-9} metre.



velocity (v) = frequency (f) x wavelength (λ) = 3×10 metres/second or 186,000 miles/second

Fig. 1.1. The Electromagnetic Spectrum

illumination (the scotopic curve). The two curves are very similar in shape, but the scotopic curve is displaced so that the point of maximum sensitivity occurs at 520 nm. The difference between the two indicates the change in the eye from rod vision to cone vision with reducing levels of illumination and the shift in the point of maximum sensitivity is called the *Purkinje shift*.

The physical and subjective characteristics of the visible spectrum are shown

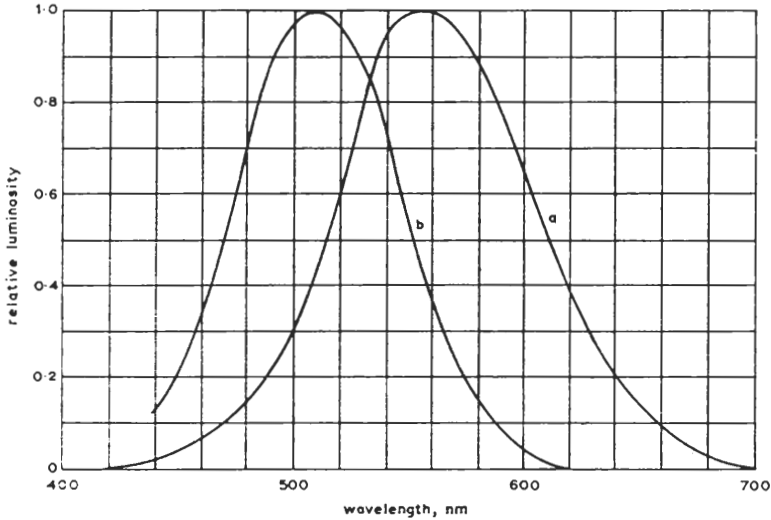


Fig. 1.2. Spectral Response of the Average Eye
 (a) Response to Normal Illumination (Photopic Curve: Cone Vision)
 (b) Response to Low Illumination (Scotopic Curve: Rod Vision)

in Table 1.1. No exact point in the wavelength scale separates one colour from another, so the points selected in the table must be used for guidance only.

Light Sources

Photography depends on the action of light falling on a light-sensitive surface, and the quality of the light varies from source to source. This can be seen in Fig. 1.3, which shows how the light energy from various sources is distributed through the spectrum. The quality of any source can be indicated in this way, but a second method is normally used when the light comes from an incandescent source, such as a tungsten lamp. This second method consists in comparing the colour of the light from the lamp with the colour of the light radiated from a perfect *full radiator* (sometimes known as a *black body*). It is found that the two colours are the same when the full radiator is at one particular temperature, called the *colour temperature* of the lamp.

This method depends on two things. The first is the fact that the quality of the light from a full radiator depends only on the temperature of the radiator.

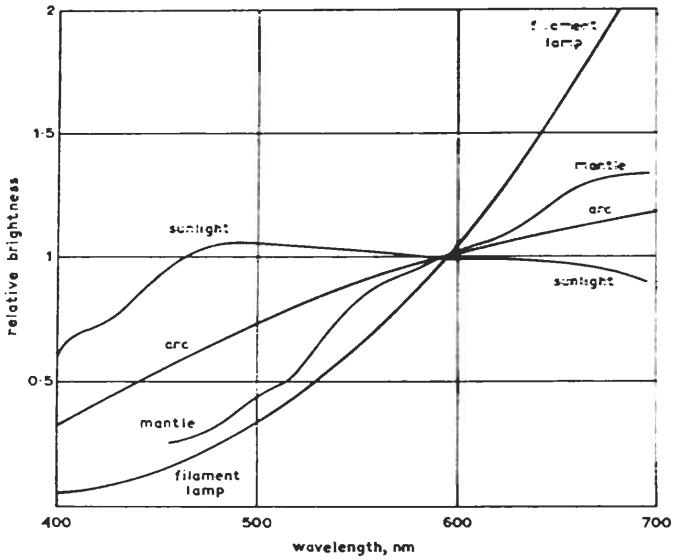


Fig. 1.3. Spectral Distribution from Various Types of Light Source

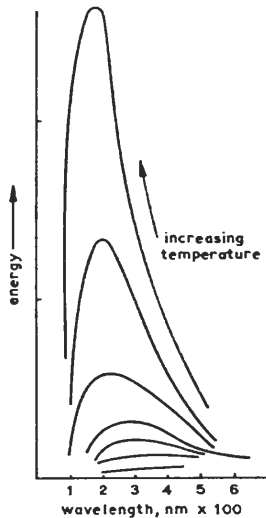


Fig. 1.4. Energy Distribution of Full Radiator at Different Temperatures

The second is the supposition that the quality of the light from the full radiator and the quality of the light radiated by the lamp under test are sufficiently alike for a comparison to be meaningful. Figs. 1.4 to 1.6 show how the radiation

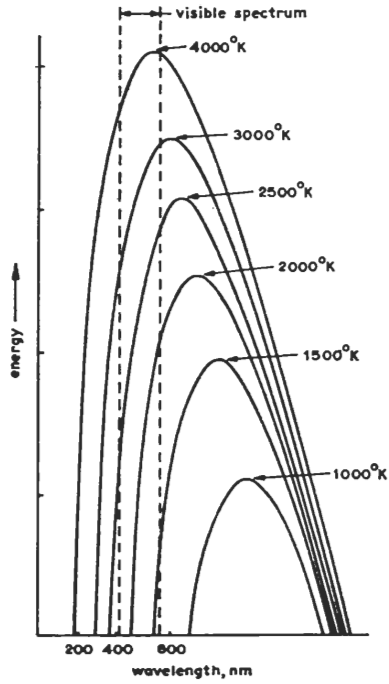


Fig. 1.5. Energy Distribution of Full Radiator, showing Region of Visibility

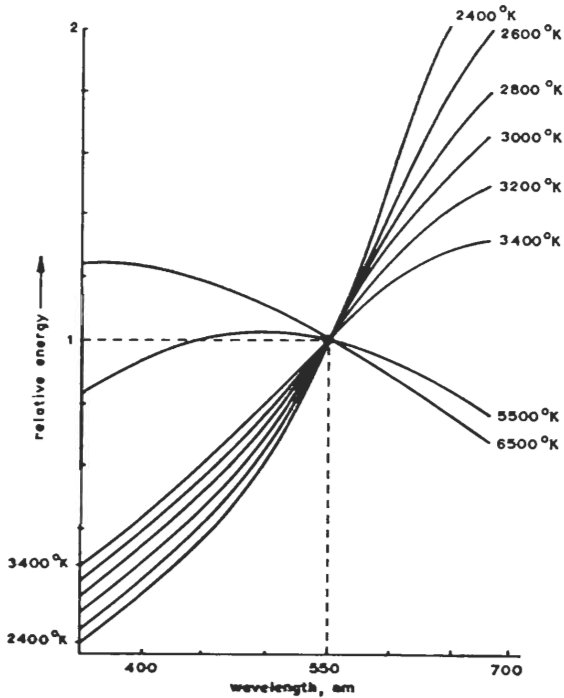


Fig. 1.6. Relative Spectral Energy Curve for Full Radiator: Energies Normalized at 550 nm.

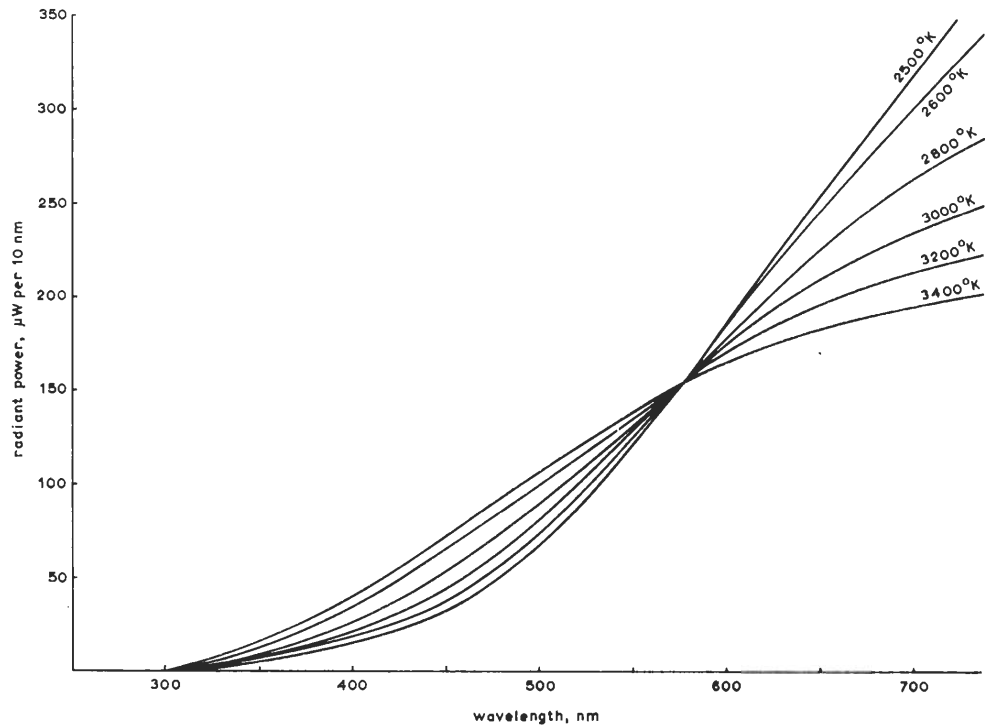


Fig. 1.7. Spectral Energy Curves for Typical Tungsten Lamps
(Courtesy of D. Van Nostrand Company, Inc.)

from a full radiator varies with temperature; in Fig. 1.6 the curves are so arranged that the relative energies are made equal (or "normalized") at 550 nm. Fig. 1.7 is a similar diagram showing the radiation from a tungsten lamp; it can be seen that any curve in Fig. 1.7 can be matched fairly closely by a curve in Fig. 1.6. The properties of a full radiator are described more fully at the end of the Chapter, in Appendix 1.A.

Table 1.2 shows the radiating properties of tungsten. The *Full Radiator*

TABLE 1.2
QUALITY OF LIGHT PRODUCED BY INCANDESCENT TUNGSTEN.

<i>True Temp.</i> (deg. K)	<i>Full Radiator Temp.</i> (deg. K)	<i>Colour Temp.</i> (deg. K)	<i>Total Emission</i> (watts/cm ²)	<i>Percentage Energy in 400/700-nm Band</i>	<i>Percentage Energy in 300/400-nm Band (ultra-violet)</i>
2200	2028	2242	38	4	0.01
2300	2111	2347	47	5	0.02
2400	2193	2452	57	6	0.04
2500	2275	2557	69	8	0.06
2600	2357	2663	83	9	0.1
2700	2437	2770	100	10	0.1
2800	2517	2878	119	12	0.2
2900	2596	2986	139	14	0.2
3000	2675	3094	162	15	0.13
3100	2753	3202	189	17	0.45
3200	2829	3311	221	18	0.55
3300	2903	3422	254	19	0.7
3400	2978	3533	291	22	0.8

Temperature of column 2 is the temperature of the radiator which radiates the same power (at a wavelength of 650 nm) as the tungsten.

Fig. 1.8 shows the spectral distribution curves for various conditions of daylight; it is seen that they can be fairly described by giving them colour temperatures. The colour temperature method is also often applied to non-incandescent sources. Fig. 1.9 shows the outputs of three different types of discharge tube. The discontinuous spectrum of the mercury vapour lamp means that no colour temperature can be given to it, but the two types of fluorescent lamp have outputs which are continuous over the visible spectrum and can be roughly described by colour temperatures.

Whether such a description is fitting or not depends very largely upon the circumstances under which the light is being used. Table 1.3 gives the colour temperatures of some common light sources. The possible limitations on validity should be borne in mind.

To determine the colour temperature of a light source, a colour-temperature meter is normally used. The light is first passed through a red filter and then through a blue filter and for each filter the meter reading is noted. The two readings so obtained are compared and, from their ratio, the colour temperature can be determined by means of a rotary calculator on the meter or from tables. If the light source is not incandescent, an error can result, since the figure

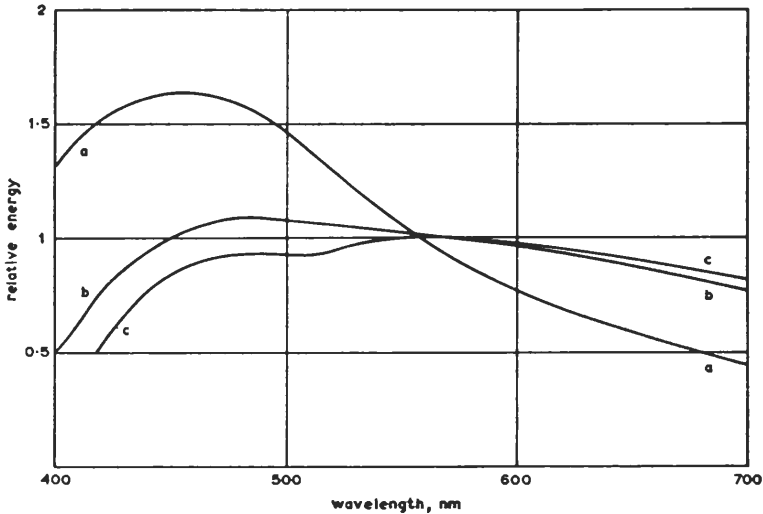


Fig. 1.8. Spectral Energy Distribution Curves for Daylight
 (a) North Skylight, (b) Noon Sun, (c) Average Sun

obtained for such a source depends on the exact wavelengths measured by the meter.

Light Units and Measurements

INTRODUCTION. A lamp radiates power in the form of light, and its output can therefore be measured in watts. Such a measurement gives no indication of the relative luminosity of the radiation, and for this reason most light measurements are made in units which take into account the visual effect produced.

The symbols for the properties of light used in this book are those standard in photography. These are not the same as those used in photometry and the two sets are compared in Table 1.5.

TABLE 1.3
COLOUR TEMPERATURES
OF COMMON LIGHT SOURCES

<i>Light Source</i>	<i>Colour Temperature (degrees K)</i>
Standard Candle	1930
Dawn Sunlight	2000
Vacuum Tungsten Lamp	2400
Gas Filled Tungsten Lamp	2760-2960
Warm-white Fluorescent Lamp	3000
Photographic Lamp	3200
Paste Filled Flashbulb	3300
Photo Flood Lamp	3400
Flashbulb Filled with Wire or Shredded Foil	3800
Plain Carbon Arc	3800
Daylight Fluorescent Lamp	4500
Mean Noon Sunlight	5400
Blue Coated Flashbulb	6000
Electronic Flash	6000
Average Daylight	6500
Blue Sky	12,000-18,000

LUMINOUS INTENSITY (L). The luminous intensity of a light source is measured by making a visual comparison between it and a standard light source. This is done with an instrument called a *photometer*. The unit of luminous intensity is the *candela* (abbreviation, *cd*). The candela is based on the brightness of a full radiator at the melting point of platinum (2046.6°K), which is taken to be 60 candelas/cm^2 . There is little difference between the candela as so defined and the old standard candle, and the luminous intensity of a lamp is often quoted in "candle-power".

LUMINOUS FLUX (F). A light source radiates flux, and an ideal point source radiates flux evenly in all directions. The unit of flux is the *lumen* (abbreviation, *lm*). This is the amount of flux which falls onto a surface of unit area (at right-angles to the flux) which is illuminated from unit distance by a point source of one candela as illustrated in Fig. 1.10.

ILLUMINATION (I). If a point source of light has a luminous intensity of one *candela*, an object one foot away from it receives an illumination of 1 lumen/sq ft.

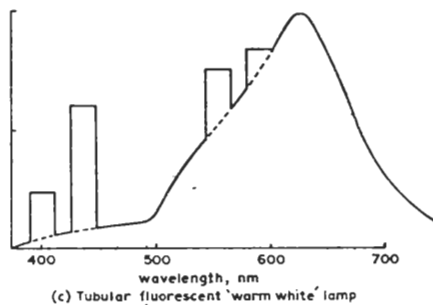
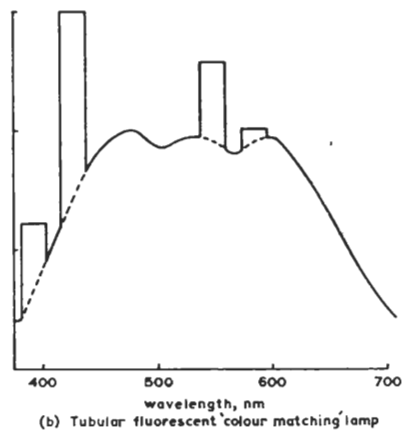
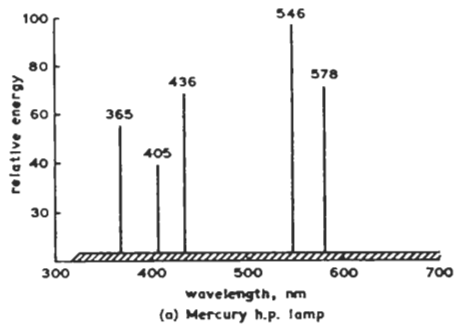


Fig. 1.9. Spectra for Various Types of Discharge Lamp

There is a close relation between flux, F , illumination, I , and area illuminated, A . The illumination of a surface is the flux falling on unit area of the surface. That is,

$$I = \frac{F}{A} \text{ lumens/unit area.}$$

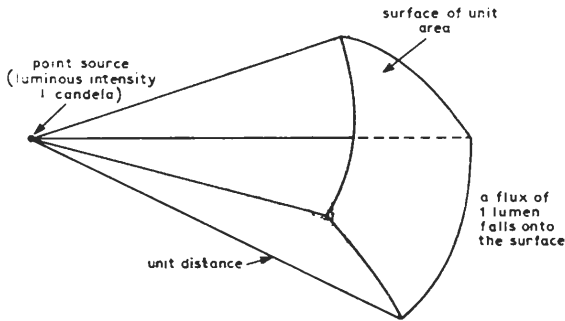


Fig. 1.10. Surface of Unit Area Illuminated from Unit Distance by Point Source whose Luminous Intensity is One Candela
Note that all points on the surface are at unit distance from the point source

The relationship between flux, illumination and luminous intensity is considered further at the end of the Chapter, in Appendix 1.B.

EXPOSURE (E). The definition of photographic “exposure” follows from that of illumination. A film is “exposed” when it is illuminated for a period of time. The exposure E which the film receives is the product of the illumination I and the time t . Thus,

$$E = It.$$

INVERSE SQUARE LAW. Fig. 1.11 shows a point light source illuminating a surface of area A_1 at a distance d_1 . Let F be the total flux falling onto the surface and let I_1 be the illumination of the surface. Then

$$I_1 = \frac{F}{A_1} \text{ lumens/unit area.}$$

Suppose that the surface of area A_1 is removed, and another parallel surface of area A_2 is substituted at a distance d_2 from the source, so that the total flux F falling on A_1 and A_2 is the same. The illumination of the surface of area A_2 is

$$I_2 = \frac{F}{A_2}.$$

From the geometry of Fig. 1.11,

$$\frac{A_2}{A_1} = \frac{d_2^2}{d_1^2}$$

Thus,

$$A_2 = A_1 \frac{d_2^2}{d_1^2}$$

and

$$I_2 = \frac{F}{A_1} \cdot \frac{d_1^2}{d_2^2}$$

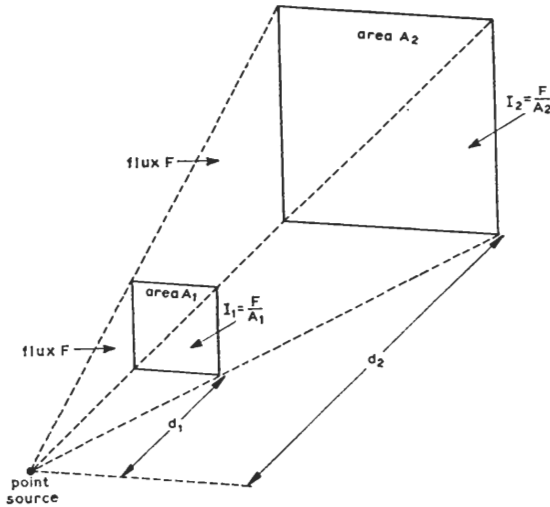


Fig. 1.11. Inverse Square Law for Light

If A_1 is made to represent unit area and d_1 unit distance, then if A_1 and A_2 are at right-angles to the flux, and if the point source has a luminous intensity of L cd, the value of F is L lumens, and

$$I_2 = \frac{L}{d_2^2} \text{ lumens/unit area.}$$

This is the inverse square law for light. It means that the illumination of a surface is proportional to the luminous intensity of the light source and inversely proportional to the square of the distance between the source and the surface.

When the surface is at an angle θ to the flux, the effective flux falling on the surface is reduced by a factor of $\cos \theta$, as can be seen in Fig. 1.12. This reduces the illumination to

$$I = \frac{L}{d^2} \cos \theta$$

BRIGHTNESS OR LUMINANCE (B). Illumination is a measure of the light which falls onto a surface; the light emitted by a surface determines its brightness (or luminance). This light can be emitted either because the surface is an extended light source (such as a fluorescent lamp) or because the surface is reflecting some of the light which is falling on it. For a reflecting surface, the

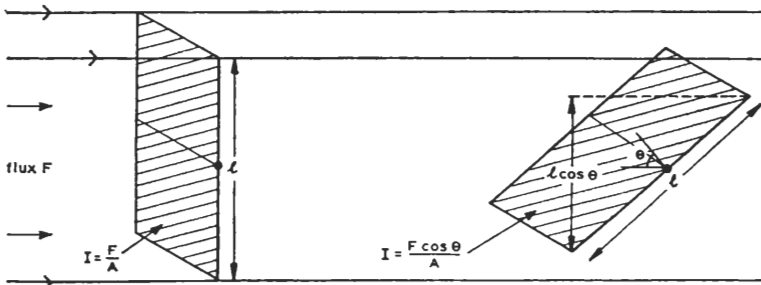


Fig. 1.12. Reduction in Illumination due to Inclination

brightness depends on three factors: the first is the amount of the incident illumination; the second is the reflection coefficient, ρ , of the surface, where

$$\rho = \frac{\text{Total flux reflected from surface}}{\text{Total flux incident on surface}};$$

the third is the manner in which the reflection occurs. In a mirror, for example, a thin pencil of light is reflected as a thin pencil of light, and the angle of incidence is equal to the angle of reflection. This is known as specular reflection, and the mirror is called a specular surface. It is clear from Fig. 1.13 that the

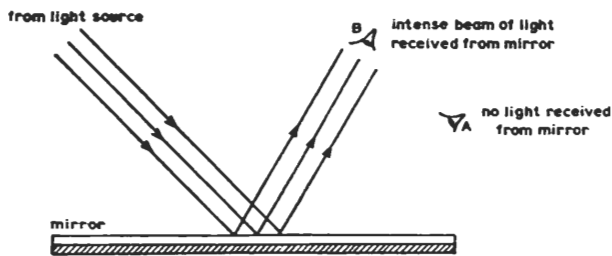


Fig. 1.13. Variation of Brightness of a Mirror with Angle of View

brightness of such a surface will vary enormously with the angle from which it is viewed.

A different type of reflector is the uniformly diffusing surface, represented in Fig. 1.14, whose brightness is independent of the angle of view. This is because the reflected light falls off according to the same (cosine) law as that by which

the effective size of the area seen is reduced, so that the light emitted per visible unit area remains constant.

Although no real surface acts in quite this way, many common ones, such as blotting paper or a matt painted surface, come quite close to it. Most surfaces in practice have reflection characteristics which are intermediate between those of a mirror and those of a uniform diffuser. A list of such surfaces is given in Table 1.4, which indicates the reflection coefficient and type of reflection of each. When a uniformly diffusing surface has a reflection coefficient of unity, it is called a "Lambert surface" or a "perfectly diffusing surface".

The unit of brightness in the British system is the foot-lambert. If a Lambert surface emits a total radiation of one lumen/sq ft, the brightness of the surface

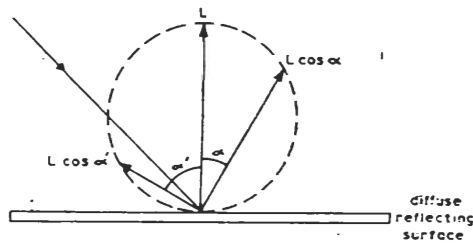


Fig. 1.14. Diffuse reflecting surface obeying Lambert's cosine law, the polar distribution characteristic for reflected light being thus a circle

is one foot-lambert. If ρ is equal to one, the brightness of a Lambert surface which has an illumination of I lumens/sq ft is I foot-lamberts; this is because the total incident light is equal to the total reflected light.

If the surface is uniformly diffusing, with a reflection coefficient of ρ , then the brightness of the surface when it is illuminated with I lumens/sq ft is ρI foot-lamberts.

OTHER UNITS. The units of luminous intensity (the candela) and flux (the lumen) are internationally agreed, but the units of illumination (the lumen/unit area) and brightness depend on the measurement of area and are therefore different in the British and Continental systems. The unit of illumination I in the M.K.S. (metre-kilogramme-second) system is important, because it is the standard light unit used in photography. It is called the lux, or the metre-candle, and one lux is the illumination received by a surface which is one metre away from a light source whose luminous intensity L is one candle power.

Light units employed in the M.K.S. and C.G.S. systems are tabulated at the end of the Chapter in Appendix 1.C. See also Table 1.5.

SYMBOLS. The photometric symbols used in photography are different from those internationally agreed by the C.I.E. Table 1.5 is a summary of light units and shows the photometric and photographic symbols for the more

TABLE 1.4
REFLECTION COEFFICIENTS OF VARIOUS
SUBSTANCES IN WHITE LIGHT

<i>Material</i>	<i>Type of Reflection</i>	<i>Reflection Coefficient</i>
Polished Silver	Specular	0.87-0.92
Aluminium or Silver on Glass		0.80-0.90
Aluminium Foil		0.85-0.87
Highly Polished Chromium		0.62-0.67
Polished Stainless Steel	Specular	0.55-0.65
Nickel		0.60-0.63
Commercial Aluminium		0.53-0.55
Anodized Aluminium	Mixed	0.72-0.80
White Enamelled Sheet Iron		0.60-0.70
Smooth White Porcelain		0.60-0.80
Dull Chromium		0.50-0.60
Magnesium Carbonate	Diffuse	0.93-0.97
Snow		0.93
White Plaster		0.90-0.92
White Cartridge Paper		0.80
White Paint		0.75-0.88
Matt White Porcelain	Diffuse	0.60-0.80
Television White		0.66
Marble		0.40-0.60
White Cloth		0.30-0.60
Light Oak	Diffuse	0.25-0.35
Face		0.33 appr.
Concrete		0.20-0.30
Brickwork		0.10-0.15
Dark Oak	Diffuse	0.10-0.15
Black Paper		0.05
Black Cloth		0.01-0.015
Black Velvet		0.004-0.01

TABLE 1.5
LIGHT QUANTITIES: SYMBOLS AND UNITS

Quantity	Symbol		Units	Name		
	Photo-graphic	Photo-metric		British System	M.K.S. System	C.G.S. System
Luminous Intensity	L	I	candela (cd) or lumen/ steradian	candela	candela	candela
Luminous Flux	F	F	lumen (lm)	lumen	lumen	lumen
Intensity of Illumination or Illumination	I	E	lumen/unit area	lumen/ft ²	lux, or lumen/m ²	phot, or lumen/cm ²
Brightness or Luminance	B*	L	candela/ unit area lumen/ft ²	candela/ ft ² ft-lambert	cd/m ² or nit lm/m ² or <i>apostilb</i>	cd/cm ² or <i>stilb</i> lm/cm ² or <i>lambert</i>

* Sometimes L.

Unit names in italics are deprecated.

important quantities. The photographic symbols are used throughout this book.

Transmission, Opacity and Density

DEFINITIONS. When light falls on a partially transparent surface, such as a developed film, some of it is reflected from the surface, some is absorbed and some is transmitted. This is illustrated in Fig. 1.15(a).

Transmission factor T , is defined by

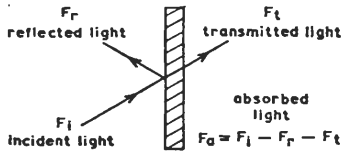
$$T = \frac{\text{Flux transmitted } (F_t)}{\text{Flux incident } (F_i)}$$

$$T = \frac{F_t}{F_i}$$

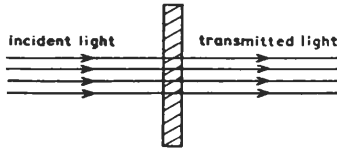
Opacity, O , is the reciprocal of transmission, and so is given by

$$O = \frac{\text{Flux incident } (F_i)}{\text{Flux transmitted } (F_t)}$$

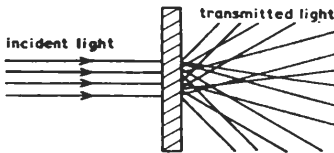
$$O = \frac{F_i}{F_t} = \frac{1}{T}$$



(a) Reflection, absorption & transmission



(b) Specular transmission



(c) Diffuse transmission

Fig. 1.15. Reflection, Absorption, and Specular and Diffuse Transmission

Density, D , is the logarithm of opacity. Thus

$$D = \log_{10} O.$$

CALLIER COEFFICIENT. A discussion of transmission, opacity and density is complicated by the fact that the values obtained for these depend both on the optical system of the measuring device used and on the way the material under test scatters the light transmitted through it.

Fig. 1.16 shows three ways of measuring density. In method (a) the test specimen is illuminated by parallel rays of light and only the substantially

parallel or “specular” component of the transmitted light is collected and measured. This enables the *specular density* of the material to be determined.

In method (b) the illumination of the specimen is again by parallel light but here all the emerging light is collected and measured. This enables the *diffuse density* of the material to be determined.

In method (c) the illumination of the specimen is by diffuse incident light and

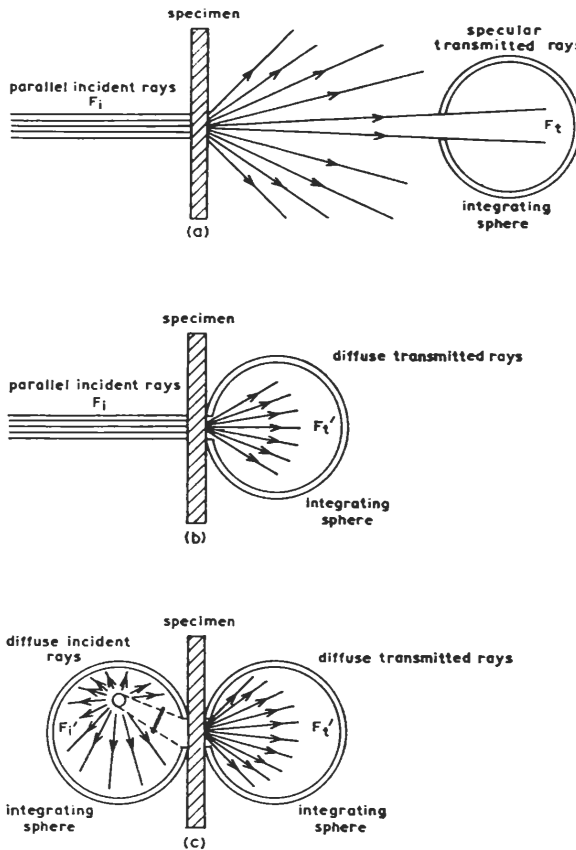


Fig. 1.16. Methods of Measuring (a) Specular Density, (b) Diffuse Density and (c) Double-diffuse Density

again all the emerging light is collected and measured. This enables the *double-diffuse density* of the material to be determined.

For any material the specular density is higher than the double-diffuse density; which in turn is higher than the diffuse density. The ratio between specular density and diffuse density, for any given values of the two, is known.

as the Callier coefficient or Q factor. The value of Q depends on density and on the nature of the material. Fig. 1.17 shows how the Q factor for a given photographic material varies with density.

Integrating Sphere

The integrating sphere has various other photometric applications in addition to its use in densitometry. It is a large hollow sphere, matt white inside, and

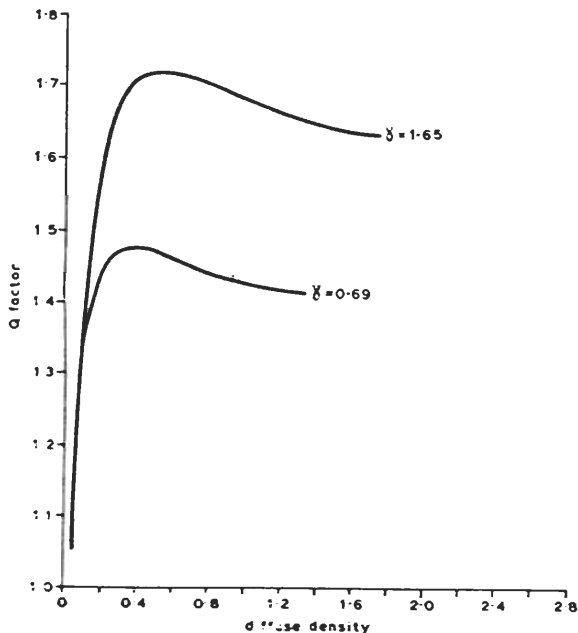


Fig. 1.17. Variation of Callier Coefficient Q with Density

has openings in its wall for light to enter and for the insertion of instruments to measure the brightness of the inner surface. Any light which falls onto the inner surface is diffused around the whole of the interior wall, so that the brightness of any part of the wall is proportional to the total luminous flux falling onto all parts of the wall. Any brightness measurement made is thus independent of the pattern of light distribution from the source, provided that the measuring instrument used is shielded from direct illumination.

Figs. 1.18 to 1.20 show details of the use of an integrating sphere to measure reflection and transmission factors.

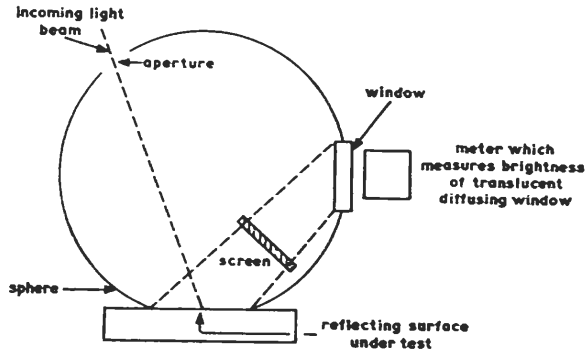


Fig. 1.18. Use of Integrating Sphere to Measure Specular/Diffuse Reflection Factor

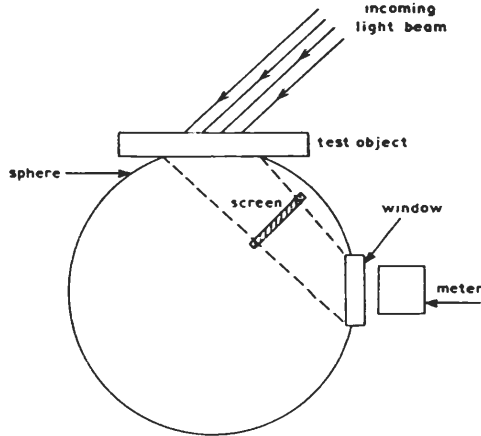


Fig. 1.19. Use of Integrating Sphere to Measure Specular/Diffuse Transmission Factor

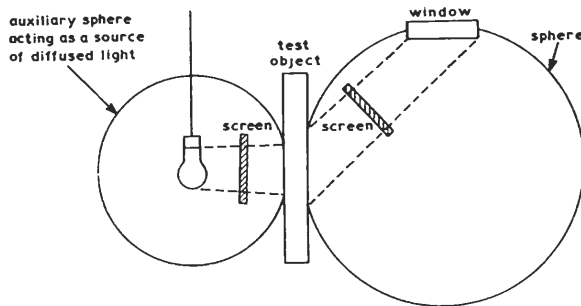
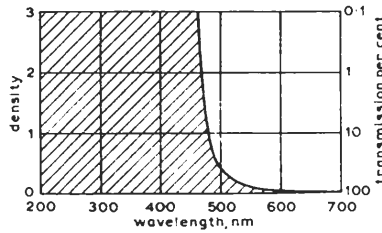


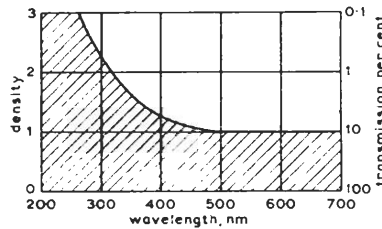
Fig. 1.20. Use of Integrating Sphere to Measure Diffuse/Diffuse Transmission Factor

Filters

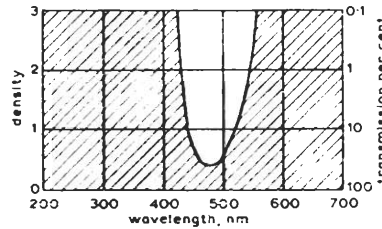
TYPES OF FILTER. Filters are used to modify the spectral characteristics of light from a light source or the light falling on a film. There are two types of



(a) K_2 filter



(b) Neutral density filter



(c) No 45 filter

Fig. 1.21. Behaviour of Various Wratten Filters

(a) K_2 filter absorbing ultra-violet and some blue; it appears yellow

(b) Neutral density filter with neutral density of 1.0

(c) No. 45 filter absorbing red, some blue and green, and much ultra-violet; it appears blue-green

filter in common use, the dye filter, which works by absorbing some of the light passing through it, and the interference filter, which reflects unwanted light and transmits the rest.

Dye filters are the more usual type. Fig. 1.21 shows the spectral characteristics for three of them, a K_2 filter, a No. 45 filter and a neutral-density filter.

The neutral-density filter, as its name suggests, absorbs all wave-lengths equally. The K_2 filter absorbs the blue end of the spectrum. The No. 45 filter is a band-pass type which absorbs the blue and red ends; as it appears blue-green when seen by transmitted light, it is called a "blue-green filter".

There are various methods of supporting the dye and Table 1.6 gives the advantages and disadvantages of each method.

TABLE 1.6
TYPES OF DYE FILTER

<i>Filter Support</i>	<i>Advantages</i>	<i>Disadvantages</i>
Gelatin	Very thin. No significant effect on focusing regardless of where it is placed. Excellent optical properties.	Requires careful handling. Difficult to clean. Has limited re-use.
Cemented gelatin in optical glass	Easier to handle. Can be cleaned	Increases the thickness. Has more effect on focusing. Tends to separate on handling
Solid glass	Easy to handle. Can be cleaned. Good stability. Does not separate	Difficult to control spectral absorption during manufacture. Thickness can present focusing problems
Plastic	Inexpensive. Quite adequate for use in non-image forming areas	Poor optical qualities
Liquid	Can provide very precise spectral absorption qualities	Thick, bulky and messy

Interference filters are used where a very accurately determined response is needed or one which for some other reason cannot be achieved by the use of dye. These filters depend upon the cancellations and reinforcements which occur between the incident and reflected light beams at a boundary surface between two mediums of different refractive index. Filters constructed on this principle have several characteristics which distinguish them from ordinary dye filters.

1. They can possess very narrow pass or stop bands, which can be as small as 0.1 nm.
2. The loss due to absorption is very low.
3. The reflection in the stop band and the transmission in the pass band are both very high.
4. The transmitted and reflected rays vary in colour with the angle of incidence.

A large variety of interference filters can be obtained for particular purposes. One application is to “conversion filters”, used for converting the spectral response of a tungsten filament lamp to the equivalent of daylight.

COLOUR TEMPERATURE CORRECTION. A specialized use for colour filters is colour temperature correction. If a filter which absorbs the red end of the spectrum to a greater extent than the blue end is placed in front of a light source, then the light which is transmitted through the filter appears to have

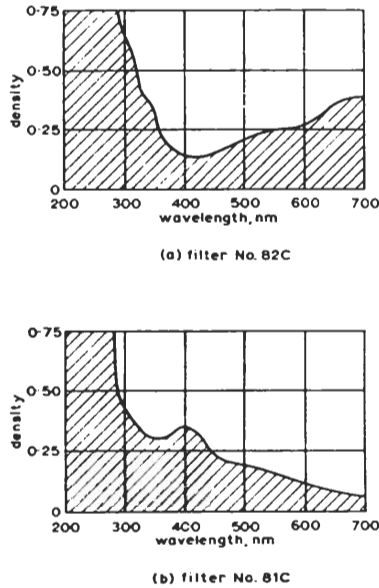


Fig. 1.22. Behaviour of Colour Temperature Correcting Filters

- (a) No. 82C is a bluish filter used to raise the colour temperature of a source and has a mired shift value of $-44\frac{1}{2}$
- (b) No. 81C is a yellowish filter used to lower the colour temperature of a source and has a mired shift value of $+35$

come from a light source of higher colour temperature. In a similar manner, the apparent colour temperature of a light source can be reduced by using a filter which absorbs the blue to a greater extent than the red. Fig. 1.22 shows the behaviour of two filters intended for the purpose just mentioned.

The effect of a colour temperature correcting filter (C.T.C. filter) is easily calculated. If such a filter is placed in front of a light source of colour temperature $T_1^\circ\text{K}$ and the resultant light has a colour temperature $T_2^\circ\text{K}$, then:

$$\left(\frac{1}{T_1} - \frac{1}{T_2}\right) \text{ is a constant for the filter.}$$

This means that if the same filter is used to “convert” a light source from colour temperature $T_3^\circ\text{K}$, to $T_4^\circ\text{K}$, then

$$\left(\frac{1}{T_1} - \frac{1}{T_2}\right) = \left(\frac{1}{T_3} - \frac{1}{T_4}\right)$$

MIRED VALUES. Often the colour response of a lamp is specified by its *mired* value, where the mired value of a lamp whose colour temperature is $T^\circ\text{K}$ is given by $10^6/T$. (*Mired* stands for “micro-reciprocal degrees”.)

If M_1 is the mired value of a light whose colour temperature is $T_1^\circ\text{K}$ and M_2 is the mired value of a light whose colour temperature is $T_2^\circ\text{K}$ then $(M_1 - M_2)$ is the mired shift of a filter which converts light of a colour temperature $T_1^\circ\text{K}$ to a colour temperature $T_2^\circ\text{K}$.

The performance of a colour temperature correcting filter is normally given by the mired shift that the filter produces. If the filter has a positive mired value the colour temperature of the source is reduced, while if it has a negative value the colour temperature is increased.

The following examples illustrate the use of mired values.

1. It is required to change the colour temperature of a light source from 2850°K to 5400°K . What is the mired shift required of the C.T.C. filter?

The mired value of the light source is $10^6/2850$, or 351 mired. The required light source has a mired value of $10^6/5400$, or 185.2. The shift required is therefore -165.8 mired.

2. A light source of 2400°K is masked by a colour temperature correction filter whose mired shift is $+50$. What is the colour temperature of the resulting light?

The mired value of the light source is $10^6/2400$, or 416.7 mired. After filtering, the mired value of the light source is $(416.7 + 50)$ mired. This corresponds to a colour temperature of 2142°K .

APPENDIX 1.A

Full Radiator

The name *full radiator* is given to a theoretically existing body which possesses the following properties:

1. It absorbs all radiation falling on it.
2. When heated it radiates more energy than any other body at the same temperature.
3. The spectral distribution or “colour” of the energy radiated depends only on the temperature to which the body is raised.

The radiation from a full radiator, sometimes known as a *black body* or *Planckian radiator*, is given by:

$$E_{\lambda} = v_{1}\lambda^{-5} (e^{\frac{v_2}{\lambda T}} - 1)^{-1}$$

- Where E_{λ} = energy at wavelength λ cm.
 T = absolute temperature in degrees K.
 $v_1 = 8\pi h v = 3.738 \times 10^{-5}$ erg cm² sec⁻¹.
 $v_2 = h v / R = 1.4385$ cm deg⁻¹.
 h = Planck's constant = 6.62×10^{-27} erg sec.
 v = velocity of light = 2.99774×10^{10} cm sec⁻¹.
 R = atomic gas constant = 8.3145×10^7 erg deg⁻¹ mole⁻¹.

APPENDIX 1.B

Relationship between Flux and Luminous Intensity

The luminous intensity of a lamp in any given direction is determined by the flux radiated by the lamp per unit solid angle in the given direction.

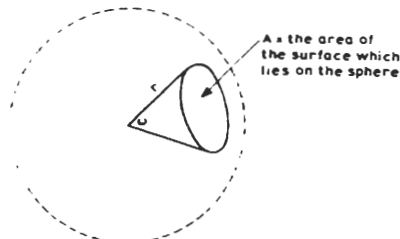


Fig. 1.23. Solid Angle

For a uniform point source:

Luminous intensity,

$$L = \frac{\text{Flux } F \text{ radiated into solid angle } \omega}{\text{Solid angle } \omega}$$

i.e.
$$L = \frac{F}{\omega} \text{ lumens/steradian, or candelas.}$$

The meaning of the term "solid angle" can be seen from Fig. 1.23. Just as the radian is the angle subtended at the centre of a circle by an arc of length equal to the radius, so the unit of solid angle, the steradian, is the solid angle subtended at the centre of a sphere by an area on the surface equal to the radius squared. If the radius is r and the area on the surface of the sphere is A , then $\omega = A/r^2$. When $A = r^2$, $\omega = 1$ steradian, or unit solid angle. This is shown

in Fig. 1.24. Since the total area of the sphere is $4\pi r^2$, the total solid angle about a point is 4π steradians.

Since $F = L\omega$, the total flux radiated by a uniform point source is $4\pi L$ lumens, or $12.566L$ lumens.

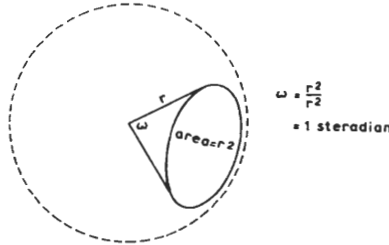


Fig. 1.24. Solid Angle of One Steradian

When the radiation from the lamp is not uniform, the luminous intensity is the limit of the ratio F/ω as ω tends to zero.

$$L = \lim_{\omega \rightarrow 0} \left(\frac{F}{\omega} \right)$$

or

$$L = \frac{dF}{d\omega}$$

The relationship between luminous intensity L and illumination I can be quickly established. Referring to Fig. 1.25, the flux falling on the area A is $L\omega$

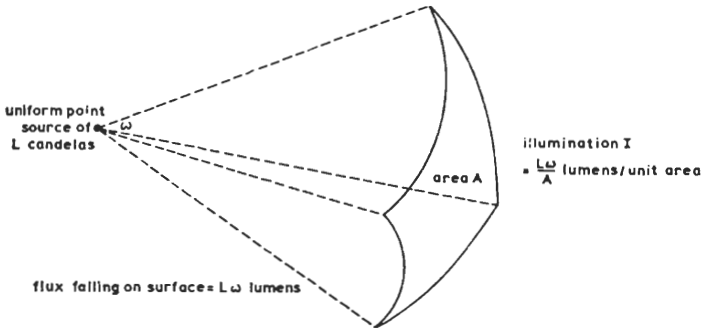


Fig. 1.25. Relationship between Luminous Intensity and Illumination

lumens. Since $\omega = A/d^2$, the illumination is therefore $L\omega/A$.

Thus

$$I = \frac{L \frac{A}{d^2}}{A} = \frac{L}{d^2}$$

as has been previously established.

APPENDIX 1.C

Photometric Units and Conversion Factors

1. Photometric Units

International Standards

The units of luminous intensity (candela) and luminous flux (lumen) are international standards. There is no international standardization of the units of illumination or of luminance. A summary of the various systems is given below. Terms marked with an asterisk are not accepted in British Standard 233 (Glossary of Terms Used in Illumination and Photometry).

British System

Illumination	lumen/sq ft
Luminance (or brightness*)	candela/sq ft ft-lambert

M.K.S. System

Illumination	lux (lumen/sq metre)
Luminance (or brightness)	nit (candela/sq metre) apostilb* (lumen/sq metre)

C.G.S. System

Illumination	phot* (lumen/sq cm)
Luminance (or brightness)	stilb* (candela/sq cm) lambert* (lumen/sq cm)

2. Conversion Factors

Illumination Units

	<i>Lux</i>	<i>Phot</i>	<i>Lumen/sq ft</i>
<i>Lux</i>	1	10^{-4}	9.29×10^{-2}
<i>Phot</i>	10^4	1	929
<i>Lumen/sq ft</i>	10.764	1.07×10^{-3}	1

Luminance or Brightness Units

	<i>Nit</i>	<i>Stilb</i>	<i>Candela/sq ft</i>
<i>Nit</i>	1	10^{-4}	9.29×10^{-2}
<i>Stilb</i>	10^4	1	929
<i>Candela/sq ft</i>	10.764	1.076×10^{-3}	1

	<i>Apostilb</i>	<i>Lambert</i>	<i>Foot-lambert</i>
Apostilb	1	10^{-4}	9.29×10^{-3}
Lambert	10^4	1	929
Foot-lambert	10.764	1.076×10^{-3}	1

The following relationships apply when the units of luminance are being used to describe a uniformly diffusing surface:

$$\begin{aligned}
 1 \text{ nit} &= \pi \text{ apostilbs} \\
 1 \text{ stilb} &= \pi \text{ lamberts} \\
 1 \text{ candela/sq ft} &= \pi \text{ foot-lamberts}
 \end{aligned}$$

Bibliography

- [1] WALSH, J. W. T., *Photometry*. Third revision. Constable, 1952.
- [2] WALSH, J. W. T., *Text book of illumination engineering*. Pitman, 1947.
- [3] STEVENS, W. R., *Principles of lighting*. Constable, 1951.
- [4] KODAK, *Wratten light filters*. 1961.
- [5] RIECK, G. D. and VERBEEK, L. H., *Artificial light and photography*. First English edition. Philips Technical Library. Centrex, Eindhoven, 1952.
- [6] AMOS, S. W. and BIRKINSHAW, D. C., *Television engineering*. Volume 1, second edition. Iliffe, 1963.
- [7] NEBLETTE, C. B., *Photography*. Sixth edition. Van Nostrand, 1962.
- [8] JAMES, T. H. and HIGGINS, G. C., *Fundamentals of photographic theory*. Second edition. Morgan and Morgan, New York, 1960.
- [9] HORDER, A., (Editor), *The Ilford manual of photography*. Fifth edition, fourth reprint, 1963.
- [10] RICHARD D. ZAKIA and HOLLIS TODD, Inside filters, *Modern Photography*. July 1961, pages 80-85.

II. CHEMISTRY

Introduction

A familiarity with the meaning of certain chemical terms and ideas is essential to the understanding of the action of developing agents and developers, and this Chapter is intended to provide such a familiarity. No attempt will be made to give a formal background of chemistry, but after reading this Chapter, those with no previous knowledge of the subject should be able to understand the arguments which will be advanced later.

Atomic Structure

The fundamental unit of chemistry is the *atom*. This is the smallest division of matter which can take part in a chemical reaction, and consists of a central nucleus round which rotate electrons. The major components of the nucleus are a number of particles of two different types. The first is a heavy particle which is called the *proton* and has a unit positive electrical charge; the second is a particle called the *neutron* which has the same mass as the proton but possesses no electrical charge. The mass of these two types of particle is so great that the mass of the atom is largely determined by the number of protons and neutrons in its nucleus. The electrons which rotate around the nucleus each have a unit negative charge, and as the complete atom has a net charge of zero, the number of protons in the nucleus must equal the number of orbital electrons. The number of protons in the atomic nucleus of any chemical element is known as the *atomic number*, and the weight of the nucleus is known as the *atomic weight* of the element concerned. Atomic number and atomic weight are measured by comparison with the oxygen atom, which is taken to have an atomic weight of 16. The elements can be arranged in a table in order of increasing atomic number, each successive element in this table having a further proton added to its nucleus.

The additional electrons required to neutralize the increasingly positive nuclei of successive elements are added in a definite order. They are arranged around the nucleus in a series of orbits, and electrons are added to the outer orbit as the atomic number of the atom increases. Each orbit can hold up to a certain number of electrons, after which the orbit is filled and further electrons are added to the next orbit out. This process continues until the third orbit, or "shell", is filled. For the remaining shells, the procedure, while similar, is more complicated.

An atom thus consists of a nucleus having a certain positive charge with a corresponding number of electrons in orbit around it. These electrons are arranged in a number of filled, or inner, orbits and an outer orbit (or orbits) which is incomplete except in neon and other "inert gases". The electrons in unfilled orbits are very important, as they determine the chemical nature of the atom in a way which will be shown later. The "inert gases", with their completed outer orbit, undergo no chemical reaction whatsoever, except in very exceptional circumstances. Fig. 2.1 gives some examples of the construction of

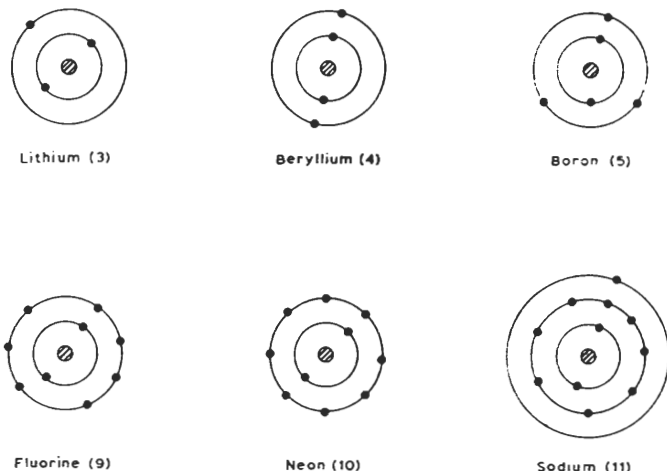


Fig. 2.1. Atomic Structure of Various Elements (Atomic numbers are given in brackets)

the atom, showing the filled inner orbits and the usually incomplete outer orbits.

Chemical Compounds

When a substance is made up of two or more elements chemically united, it is called a *compound*. An example is water, which is a compound of the elements hydrogen and oxygen. The smallest portion of a compound or element which is capable of independent existence is called a *molecule* and the symbolic representation of a molecule of a compound, in terms of the elements from which it is constructed, is called a *formula*. The formula for water is H_2O . This formula shows that two atoms of hydrogen (symbol H_2) and one atom of oxygen (symbol O) are present in one molecule of water.

Ions and Ionization

Although a complete atom is always electrically neutral, there are some

atoms which have electrons in their outer orbits which can be removed with relative ease; there are also types of atom to the outer orbits of which electrons can be added with similar ease. When such electrons are added to (or removed from) an atom, no change occurs to the nucleus and so no change occurs in the atom's total positive charge. This means that the addition (or removal) of these electrons must leave the atom with a net negative (or positive) charge, and an atom or group in this state is known as an *ion*.

An ion which has a deficit of electrons has a net positive charge and is called a *cation*. Typical cations and the symbols representing them are:

<i>Symbol</i>	<i>Name</i>	<i>State</i>
H ⁺	Hydrogen ion (or proton)	Lacking one electron
Na ⁺	Sodium ion	Lacking one electron
Al ⁺⁺⁺	Aluminium ion	Lacking three electrons

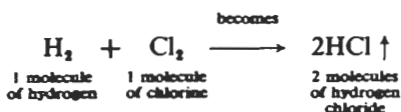
An ion with a surplus of electrons has a net negative charge and is called an *anion*. Some typical examples are:

<i>Symbol</i>	<i>Name</i>	<i>State</i>
OH ⁻	Hydroxyl ion	Surplus one electron
Cl ⁻	Chloride ion	Surplus one electron

The process by which an atom is converted into an ion is called *ionization*, and the atom is said to be *ionized*.

Chemical Change

A chemical change in a substance is one which involves an alteration of its chemical composition due to an increase, a decrease, or a re-arrangement of the atoms within its molecule. In all chemical reactions, the central nuclei of the atoms remain unchanged, but the orbital electrons are disturbed. Sometimes a whole group of ions retains its identity through chemical changes which affect the rest of the molecule to which it belongs, and such a group is known as a *radical*. Examples of radicals are ammonium, NH₄⁺, and the sulphate radical, SO₄⁻. What occurs in a chemical reaction can be shown by a chemical equation, as in the following examples.





In the latter example, SO_4 is seen behaving as a radical.

The combining power of an atom is called its *valency*. This is defined as the ability of an atom to combine with or replace hydrogen atoms, and depends on the difference between the number of electrons in its outer orbit and the number

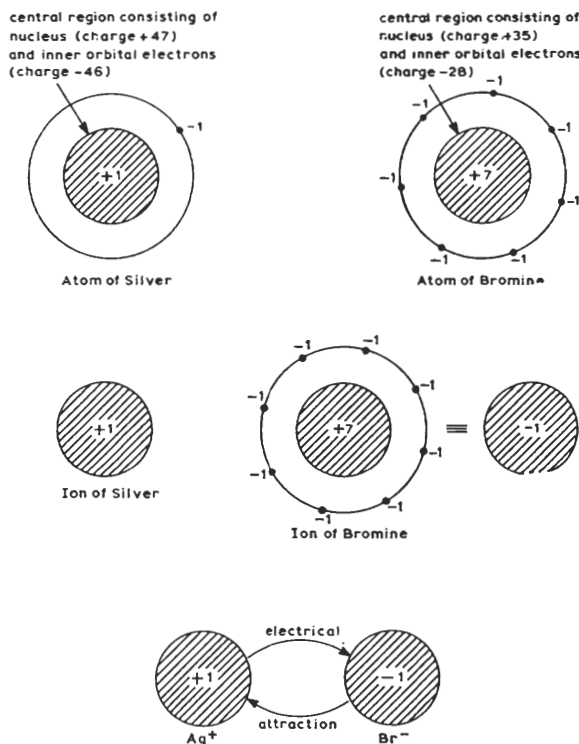


Fig. 2.2. Formation of Silver Bromide

required to fill this orbit. The significance of valency can be seen from the following example.

Silver bromide (AgBr) is formed from the reaction between silver (Ag) and bromine (Br). Now, silver has an atomic number of 47, and of its 47 electrons, only one is in its outer orbit. The atom can therefore be represented as in Fig. 2.2. Bromine however, has an atomic number of 35, and of its 35 electrons, 7 are in its outer orbit, which requires just one more electron for completion. The bromine atom is also represented in Fig. 2.2. When the bromine and silver atoms are brought together, the silver atom donates its solitary outer orbital electron to the bromine atom, thus filling the outer orbit of the bromine

and emptying that of the silver. The resulting silver anion and bromine cation are attracted to each other by their opposite electrical charges which cause them to form the neutral salt silver bromide.

Acids, Alkalis and Salts

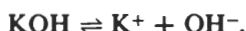
Certain compounds become ionized on being dissolved in water, when they form ionic solutions. Not all compounds do this; those which do are called acids, alkalis (or bases), and salts. Acids are substances which form hydrogen ions in solution, alkalis (or bases) are substances which form hydroxyl ions in solution, and salts are substances prepared from acids and alkalis in certain specified manners.

Hydrogen chloride, HCl, is an acid in solution, when it is known as hydrochloric acid. It partly dissociates into ions and an equilibrium exists between the ionized and non-ionized parts. The facts that HCl is ionized and that an equilibrium exists are indicated as shown:



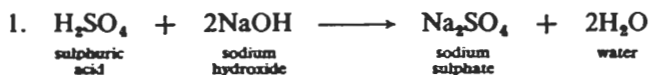
The acid has dissociated into hydrogen ions and chlorine ions and its acidity is provided by the hydrogen ions, H^+ .

Potassium hydroxide, KOH, is a typical alkali and in solution it dissociates as indicated:

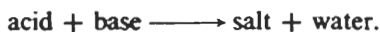


The alkali has dissociated into potassium ions and hydroxyl ions with a state of equilibrium existing between the ionized and non-ionized parts.

Sodium chloride or common salt, NaCl, is a salt and dissociates almost completely in water into sodium ions, Na^+ and chlorine ions, Cl^- . Some ways of forming a salt are shown in the succeeding reactions.



This is a type of reaction which can be generalized to:



This reaction can be generalized to:



The metal replaces the hydrogen of the acid to form the salt.

pH Values

It is convenient to have a method of measuring the acidity or alkalinity of a solution. The *pH* scale is used for this. A *pH* of 7 indicates a neutral solution, a *pH* of greater than 7 indicates an alkaline solution and a *pH* of less than 7 indicates an acid solution. The basis of this scale depends on two facts:

1. Pure water is ionized to a very slight extent, as shown:



2. If the concentration of hydrogen ions in gramme ions/litre is represented by (H^+) , and the concentration of hydroxyl ions in gramme ions/litre is represented by (OH^-) , then, for any aqueous solution, the product $(\text{H}^+) \times (\text{OH}^-)$ is a constant.

Now, the addition of an acid to a solution increases (H^+) and therefore reduces (OH^-) to keep the product of the two constant; similarly the addition of an alkali to a solution increases (OH^-) and therefore decreases (H^+) . As the product of $(\text{H}^+) \times (\text{OH}^-)$ is a constant, the specification of either (H^+) or (OH^-) is sufficient to establish the acidity or alkalinity of a solution. This is the method used in the *pH* system.

The *pH* of a solution is given by

$$\text{pH} = \log_{10} \left(\frac{1}{\text{H}^+} \right)$$

For pure water, $(\text{H}^+) \times (\text{OH}^-) = 10^{-13.8}$

$$\simeq 10^{-14}$$

$$\therefore (\text{H}^+) \simeq 10^{-7}$$

as $(\text{H}^+) = (\text{OH}^-)$ for a neutral solution.

$$\therefore \text{the pH of a neutral solution} = \log_{10} \left(\frac{1}{10^{-7}} \right)$$

$$= 7.$$

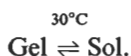
As (H^+) is increased, $1/(\text{H}^+)$ is reduced and the *pH* of an acidic solution is therefore less than 7. As (OH^-) is increased, (H^+) is reduced and $1/(\text{H}^+)$ is increased. The *pH* of an alkaline solution is therefore greater than 7.

When acids and alkalis are used for photographic purposes, the ability of these solutions to resist changes in *pH* due to the addition of further acids or alkalis, or due to dilution, is often of great importance. This ability is known as the *buffering ability* of a solution and a solution with high buffering ability is said to be "well buffered". The question of buffering is considered further in Chapter 6.

Colloids

Another type of solution which is important to photography is the colloidal solution. A *colloid* consists of a fine suspension of micro particles in a medium. The difference between a colloid and a solution is rather indeterminate but it depends on the size of the suspended particles. In a colloid these are perhaps of the order of $1\ \mu$ while those of a solution are around $0.1\ \text{nm}$. There are several types of colloid, and the photographic emulsion is one of them. Strictly speaking, the word "emulsion" is incorrect here, as it refers to a colloid which consists of a liquid suspended in another liquid. The photographic emulsion has solid suspended particles and should therefore be called a "suspensoid", but usage is too strong to be challenged.

If a colloid is in a fluid state it is called a *sol* while if it is in a solid state it is called a *gel*. Gelatin is an example of a colloid which is a sol above a certain temperature and a gel below it. This reversibility, and the conditions for it, can be indicated by the expression shown:

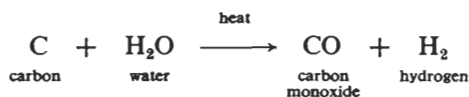


This means that above 30°C the colloid is a sol, and below 30°C it is a gel.

Oxidation and Reduction

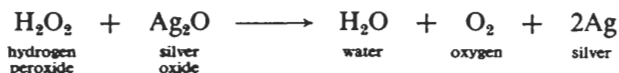
Among the chemical processes which occur during development, those of oxidation and reduction are among the most important.

When a substance X is acted upon to become XO, it is *oxidized*. For instance, in the reaction:



the carbon is oxidized to carbon monoxide.

If the substance XO is acted upon to become X, it is *reduced*, as, for instance, in the reaction:

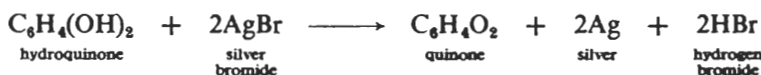


in which the silver oxide becomes reduced to metallic silver.

Although the essence of oxidation and reduction is conveyed by the two reactions described above, a wider meaning is normally given to these terms. Thus, a substance is said to be *oxidized* not only when it gains oxygen, but also in general when it gains any electronegative atoms or groups, these being

atoms or groups which behave as negative ions, including oxygen, the halogens (mentioned later) and sulphur. A substance is also oxidized when it loses any electropositive atoms or groups, these being atoms or groups which behave as positive ions, such as hydrogen, the metals and ammonium. In general, a substance is *reduced* when it *loses* either oxygen or any other electronegative atoms or groups or *gains* any electropositive atoms or groups.

A reaction which illustrates most of these features, and which is also a basic reaction of photographic development, is the following:



The silver bromide is reduced to metallic silver by the loss of its electronegative atom, bromine. The hydroquinone is oxidized by the loss of its hydrogen, which is electropositive. The hydroquinone acts as a reducing agent on the silver bromide.

Silver Halides

The light-sensitive salts used in photography are almost exclusively the silver halides, which are compounds formed between metallic silver, Ag, and the stable* *halogens*, i.e., fluorine, F, chlorine, Cl, bromine, Br, and iodine, I. The sensitive salts are:

AgF	.	.	silver fluoride
AgCl	.	.	silver chloride
AgBr	.	.	silver bromide
AgI	.	.	silver iodide

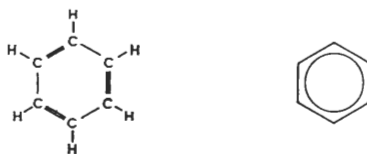
Organic Chemistry

Most photographic developing agents, including hydroquinone, are *organic* compounds, that is to say, they are compounds of carbon with hydrogen. The study of such compounds, excluding the metal carbonates and the oxides of carbon (such as carbon dioxide, CO₂), is called *organic chemistry*.

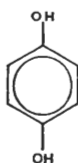
Often these compounds become very complex, and their formulae are frequently given in structural form. For instance, benzene, C₆H₆, can be represented by the structure on the left in Fig. 2 3(a), which shows not only the composition of the substance, but also the manner in which its molecule is put together. The links represent valency bonds and show how the tetravalent

* A further halogen, astatine, At, is also known, but is unstable.

carbon forms the basic benzene ring. Often the simplified ring shown on the right of Fig. 2.3(a) is used, and when compounds are formed by replacing some of the hydrogen atoms by certain monovalent radicals the new compound can



(a) Benzene ring C_6H_6 and simplified version



(b) Hydroquinone $C_6H_4(OH)_2$

Fig. 2.3. Some Structural Formulae used in Organic Chemistry

be represented by the simple benzene ring which is modified to show merely where the new radical has been placed.

For instance the structure shown in Fig. 2.3(b) represents hydroquinone, $C_6H_4(OH)_2$, and shows that two hydrogen atoms have each been replaced by an hydroxyl group. Structural formulae will only be used for reference purposes for the remainder of this book.

III. PHYSICAL CHARACTERISTICS OF FILM STOCKS

General

Motion-picture film stock consists of a light sensitive emulsion which is coated onto a flexible support. The present Chapter is concerned with the physical characteristics of this stock.

Base Material

There are many requirements which a material must satisfy before it can be used for a film base. Before the war the base was usually made of cellulose nitrate, but the disadvantage of this was its unstable chemical composition; it was liable to decompose in storage, and when this occurred the fire risk which resulted was similar to that for stored explosive. A much more suitable material is cellulose triacetate, which has excellent all-round properties and was the first safety base to have the necessary toughness for motion picture use. It had to wait for the economical production of its only practicable solvent, methylene chloride, before it could be used, but this came with the war and since 1951 all Kodak and Ilford film has been supplied on safety base of this type (except for

TABLE 3.1
PROPERTIES OF CELLULOSE TRIACETATE
(For sheet 0.005 in. thick.
Relative humidity, 50% at 70°F)

<i>Property</i>	<i>Value</i>
Specific gravity	1.28
Refractive index	1.48
Water absorption	5.5%
Linear swell in water	0.8%
Tensile strength	14,000 lb/in ²
Ultimate elongation	35%
Modulus of elasticity	5.5×10^5 lb/in ²
Folding endurance (MIT)	45
Tear resistance	50 gm
Heat distortion	150°C
Resistivity	10^{16} ohm/cm ³

reversal film, which uses bases of the acetate propionate type). The fire risk presented by safety base film is classified in the same group as news print and the material has excellent storage properties.

A base material must be satisfactory optically: it must be transparent, transmission through it must be specular and, except for special purposes, it must be colourless. It must be satisfactory chemically: it must be stable, inert to the emulsion, unaffected by the chemicals used in development, and moisture resistant, and it must allow the emulsion a satisfactory key. It must resist wear and have a long life, it must be free from curl and buckle, it must be

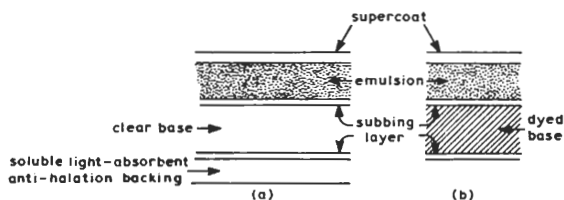


Fig. 3.1. Cross-sections through Typical Films, (a) with Anti-halation Backing and (b) with Dyed Base

dimensionally stable, and it must have a high softening temperature and be slow burning.

It can be seen that these requirements are severe, and in many cases, conflicting. Cellulose triacetate is one of the few materials in which the requirements are satisfactorily met, and its physical characteristics are shown in Table 3.1.

Construction of the Film

As gelatin cannot key itself into cellulose triacetate, a sub-coat, or subbing layer, has to be provided to prevent the gelatin layer from frilling when wet or stripping when dry. To provide this layer, the film may be coated with a solvent which on drying leaves a thin deposit of gelatin and cellulose nitrate (or cellulose acetate). The cellulose nitrate or acetate in the deposit adheres to the base and the gelatin provides a key for the emulsion. It is usual to sub both sides of the base, as this helps to counteract the uneven shrinkage which otherwise occurs when the coated emulsion dries, and which causes the dried film to curl up towards the emulsion, which shrinks much more than the cellulose triacetate. Not only does the subbing layer help to prevent curl, but it can also help to reduce the liability to static discharge when a roll of film is rapidly unwound.

Cross-sections through typical motion-picture films are shown in Fig. 3.1. The supercoat applied to both specimens is a thin layer of gelatin which helps

to protect the emulsion from surface friction and abrasion. The soluble light-absorbent backing layer applied to film (a) and the dyed base of film (b) are both used to prevent *halation*, which is unwanted exposure of the sensitive emulsion to light reflected from the back surface of the base. (Fig. 3.2). The soluble backing works by reducing reflection; the dye works by attenuating the light as it passes in each direction through the base.

Also illustrated in Fig. 3.2 is the effect known as *irradiation*, which is caused

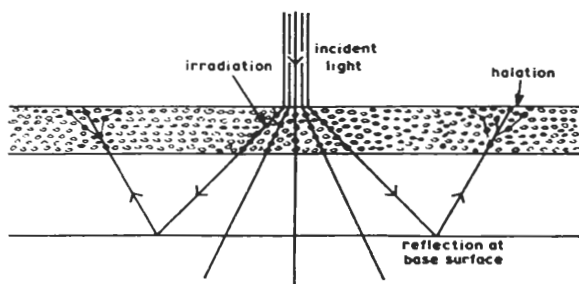


Fig. 3.2. Halation and Irradiation

by light scattered by crystals in the emulsion striking further crystals and exposing them. The effect of irradiation can be reduced by making the emulsion layer as thin as possible.

Film Dimensions

The emulsion is coated onto the film base, which may be in rolls 50 inches wide and 3,000 feet long. After coating, the film is cut to size and perforated. Elaborate testing and inspection takes place to ensure that dimensions are within specified tolerances, normally those of British Standard 677: 1958, shown in Fig. 3.3 (for 35-mm film) and Fig. 3.4 (for 16-mm film). These tolerances apply immediately after cutting, and a film need not comply with them when measured at a later time. Since most films are perforated according to the dimensions given in the British Standard, any departure from this is indicated in the manufacturer's specification for the film.

The shape and pitch of the perforations for 35-mm negative film are different from those for 35-mm positive film. This is because a negative film suffers relatively little wear and so the shape of its perforations can be designed for accurate location. A positive film, however, may have to pass through an intermittent projector or printer mechanism many times and so the shape of its perforations must be designed for maximum wear resistance. With modern film-base materials, this point is perhaps of less importance than formerly. The two perforation shapes are shown in Fig. 3.5. The difference in pitch (dimension *B*, Fig. 3.3) is introduced because experiments indicate that a reduction in

pitch for negative stock of about 0.2% gives optimum printing characteristics, allowing for the fact that at the time of printing the negative film has already been processed whereas the positive has not.

Dimensional Changes

Dimensional changes to which film is liable fall into two main groups, temporary and permanent. Temporary changes comprise:

1. *Changes due to moisture content.* These are dependent almost entirely on the relative humidity of the air, and a typical value is 0.007% per 1% change in relative humidity.
2. *Changes due to temperature.* A typical figure is 0.003% per degree F at constant relative humidity.
3. *Processing swell and shrinkage.* Film swells during processing and contracts during drying.

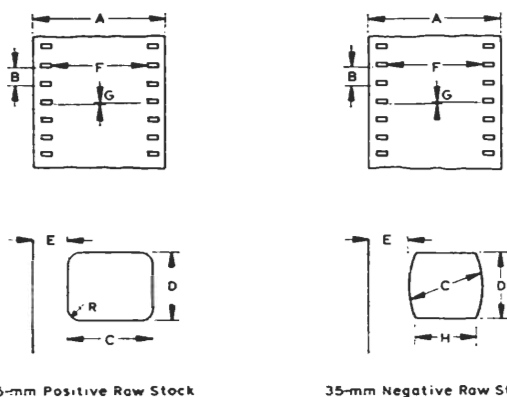


Fig. 3.3. 35-mm Raw Stock: Cutting and Perforating Dimensions (From British Standard 677: Part 1: 1958)

Dimensions and Tolerances (Inches)		
Reference	Positive Stock	Negative Stock
A	1.378 +0 -0.002	1.378 +0 -0.002
B	0.187 ±0.0005	0.1866 ±0.0005
C	0.110 ±0.0004	0.110 ±0.0004
D	0.078 ±0.0004	0.073 ±0.0004
E	0.079 ±0.002	0.079 ±0.002
F	0.999 ±0.003	0.999 ±0.002
G	0.001 maximum	0.001 maximum
H	—	0.082
L*	18.70 ±0.015	18.66 ±0.015
R	0.02 nominal	—

* L is the length of any 100 consecutive perforation intervals

The net change varies a little either side of zero, the amount depending on such factors as processing machine tension, relative humidity and the physical properties of the film. Dimensional changes are also greatly affected by drying temperature. Excessive drying can cause permanent deformation. Other permanent changes are due to aging. The potential aging shrinkage due to all causes is about 0.2%, and the rate at which it occurs depends on the conditions

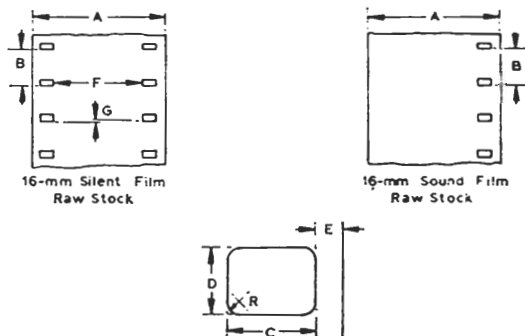


Fig. 3.4. 16-mm Raw Stock: Cutting and Perforating Dimensions (From British Standard 677: Part 2: 1958)

Dimensions and Tolerances (Inches)		
Reference	Silent Film	Sound Film
A	0.629 +0 -0.002	0.629 +0 -0.002
B	0.300 ± 0.0005	0.300 ± 0.0005
C	0.072 ± 0.0004	0.072 ± 0.0004
D	0.050 ± 0.0004	0.050 ± 0.0004
E	0.0355 ± 0.002	0.0355 ± 0.002
F	0.413 ± 0.001	—
G	0.001 maximum	—
L*	30.00 ± 0.03	30.00 ± 0.03
R	0.010	0.010

* L is the length of any 100 consecutive perforation intervals

of storage. It is accelerated in conditions of high humidity and temperature. In a typical instance nearly all the eventual changes may be expected to occur within two years.

Film manufacturers publish detailed information on the dimensional variations which are to be expected with different types of base. The coefficients of change are not usually the same for changes in length as for changes in width. The differences are due to the methods used to make the base material.

In practical conditions, dimensional changes across the width are aggravated, because

- (a) in the rolled film, the ambient humidity has most effect near each edge, and
- (b) shrinkage across the width is increased relatively by the perforations.

Table 3.2, which gives examples of dimensional characteristics, relates to cellulose triacetate.

Cores and Winding

Films can be provided on a variety of cores. A number of these are for

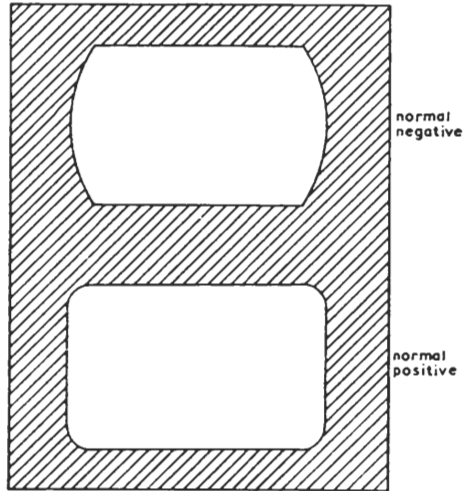


Fig. 3.5. Shapes of Perforation Holes used for 35-mm Film (A third perforation shape, the Dubray-Howell, is not shown, but its use is restricted to some colour release prints)

particular cameras and details may be found in the appropriate manufacturers' catalogues.

The three most common cores are the U, T and Z types. The U (or Universal) core is a 2-inch 35-mm type, with a keyway extending all the way through the centre. The Type T is a 2-inch diameter 16-mm core similar in construction to the Type U; the Type Z is a similar 3-inch diameter 16-mm core. Further details of the Type U core are given in Table 3.3.

There are two different types of winding, Type A and Type B, which are used for 16-mm film which is perforated along one edge. If the core is held so that the film leader comes from the top of the core towards the observer, Type A has its perforations to the left and Type B has its perforations to the right.

Storage of Film

The nominal *photographic shelf life* of a film in suitable storage is generally taken as two years. The shelf life is defined as the period during which the maker's photographic specification including speed rating is maintained.

The rate of deterioration of film stock is increased both by heat and by moisture. The effects of moisture can be largely eliminated by storing the film

TABLE 3.2
DIMENSIONAL CHANGE CHARACTERISTICS
OF TWO TYPES OF FILM (BOTH 0.005 INCH THICK)

<i>Characteristic</i>	<i>Motion Picture Negative</i>	<i>Motion Picture Positive</i>
Humidity coefficient of linear expansion (10^{-5} in/in/1% rel. hum.)	8.0	6.0
Thermal coefficient of linear expansion. (10^{-5} in/in per deg. F)	3.0	3.0
Processing dimensional change, per cent	-0.07	-0.05
Aging dimensional change, per cent (1 year after processing at 78°F. 60% rel. hum.)	-0.15	-0.30

TABLE 3.3
DIMENSIONS OF KODAK TYPE-U 35-mm
PLASTIC FILM CORES

<i>Measurement</i>	<i>Dimension (Inches)</i>
Width of core	1.375 ± 0.000 -0.031
Outside diameter	1.968 ± 0.010
Inside diameter	1.020 ± 0.008
Width of keyway	0.157 ± 0.008
Depth of keyway	0.147 ± 0.008

in a sealed container. Unexposed negative material should be stored at a temperature below 55°F so that its speed is maintained; this is not so important for a positive stock and a temperature of up to 65°F may be permitted, so long as the storage conditions are uniform. Higher temperatures than these are permissible for brief periods; the ones given are suitable for storage periods of six months or more.

Humidity causes no damage as long as the can remains sealed, but after removal from storage the film must be allowed time to reach ambient temperature before the seals are broken; otherwise, spotting or mottling of the final

image may occur. Relative humidities in excess of 60% to 70% should be avoided if rusting of the cans, damage to labels and mould are to be prevented.

Identifying Markings on Film Stock

Most films carry a series of markings printed on the base which identify the type of film, the type of base, the footage, and the various machines used in

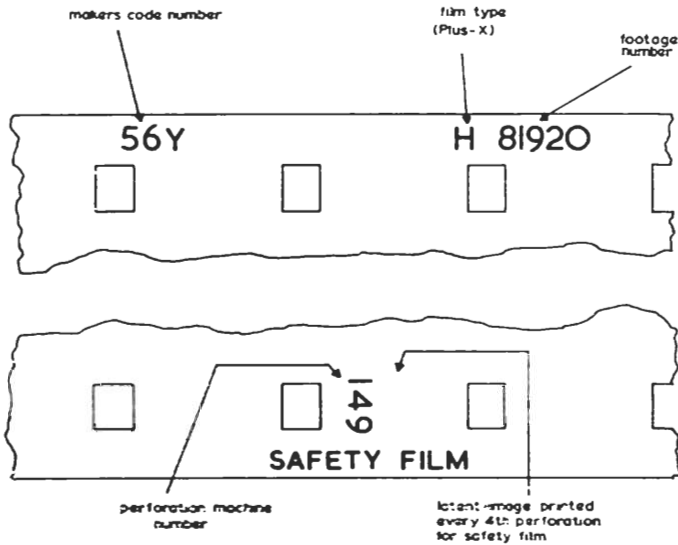


Fig. 3.6. Example of Typical Markings on Film Stock: Kodak Type 4231 (Plus-X)

manufacture. Fig. 3.6 shows the details marked on one type of film (Kodak Type 4231) and Table 3.4 gives a list of commonly used types of film and their codings.

The old Kodak Type-7374 film, a 16-mm blue-sensitive *clear-base* television film recording stock, has been discontinued. The old Kodak Type-8374 film, a 16-mm blue sensitive *dye-d-base* television film recording stock, has been renumbered 7374 in place of the clear-base stock mentioned.

Static Marks

“Static” marks are a form of fogging which can be produced on raw stock by an electrical discharge between turns of the film. The marks may be caused by rapid unwinding or excessive tension and become severe if the humidity is low.

TABLE 3.4
COMMONLY USED TYPES OF FILM STOCK

Maker	Name	Type No.		Code	Description
		35 mm	16 mm		
Kodak	Plus-X	4231	7231	H	Pan. neg.
	Double-X	5222	7222	C	Pan. neg.
	4-X	5224	7224	G	Pan. neg.
		5633	7633		Fine grain release pos. (dyed base)
		5302	7302		Fine grain rel. pos.
		—	7374		Television rec. (dyed base).
		5374	—		Television rec.
Ilford	FP3			L or M	Pan. neg.
	Mark V			S or T	Pan. neg.
	HPS			F or G	Pan. neg.
	Pan F			J or K	Pan. neg. (very fine grain)

Sound on Film

There are a number of ways by which sound can be recorded. A list of these methods together with the appropriate code system is given in Table 3.5.

Further details may be found in BBC Engineering Monograph No. 27, "The Equipment of the BBC Television Film Studios at Ealing", and in the film manufacturers' handbooks.

Machine Leader Film

When a film is processed, it is stapled to a length of leader film which draws it through the processing machine. Subsequent films can, of course, be stapled directly to the previous film, provided that no change of speed is required between the two films. If a change of speed is necessary, a length of leader is inserted between consecutive films so that the first film is clear of the developer baths before the second film has entered them. The change of speed can then be made so that each film receives its correct development; the change of fixing time experienced by the first film is of no account, unless different types of emulsion needing widely different fixing times are being used.

After operations have ceased for the day the machine is left threaded with leader film so that it is all ready to start working again when required.

Since the leader film is left threaded overnight, it must have a special base which is tough and designed to withstand prolonged immersion. If normal-base film were left in the machine, it could also stick to the rollers.

Table 3.6 gives details of types of Kodak leader film available.

TABLE 3.5
SOUND FILM CODING SYSTEM

<i>Picture Film Gauge (mm)</i>	<i>Method of Providing Sound</i>	<i>Code Name</i>
35	Combined optical track	35 comopt
35	Combined magnetic track	35 commag
16	Combined optical track	16 comopt
16	Combined magnetic track	16 commag
35	One optical track on separate 35-mm film	35 seopt
35	One magnetic track on separate 35-mm film	35 sepmag
16	One optical track on separate 16-mm film	16 seopt
16	One magnetic track on separate 16-mm film	16 sepmag
35	Two magnetic tracks on separate 35-mm film	35 sepumag
16	Two magnetic tracks on separate 16-mm film (For three tracks replace <i>du</i> by <i>tri</i>) (For four tracks replace <i>du</i> by <i>quad</i>)	16 sepumag
16	One magnetic track on separate 35-mm film	16/35 sepmag
16	Two magnetic tracks on separate 35-mm film (For three tracks replace <i>du</i> by <i>tri</i>) (For four tracks replace <i>du</i> by <i>quad</i>)	16/35 sepumag
35	Magnetic tape	35/T sepmag
16	Magnetic tape	16/T sepmag
35	Picture only	35 mute
16	Picture only	16 mute

TABLE 3.6
KODAK LEADER FILM

<i>Name</i>	<i>Description</i>	<i>Thickness</i>	<i>Max. Length</i>	<i>Core</i>	<i>Perforation</i>
Eastman coated leader film	Standard motion-picture film, not suitable for photographic use	0-0055 in (approx.)	1000 ft (35 mm)	U	35-mm British standard negative or positive
			1200 ft (16 mm)	Z	
Eastman No. 6 black and white opaque safety leader	Opaque, black on one side, and white on the other. Suitable for use in most types of processing machines	0-0083 in	800 ft (35 mm)	U	Oversize positive. 16-mm British standard sound (winding B)
			800 ft (16 mm)	Z	

BBC Film Leader

A standard BBC leader is spliced to all telecine films. It consists of a length of film (about 25 ft) which is marked with a number of signals and which is designed to ensure that the film is laced up correctly and that correct operating conditions are reached before picture and sound are transmitted.

If a length of 35-mm leader film is examined, it will be found that not only is it marked with signals which ensure that the sound and picture in a 35-mm comopt system are properly synchronized, but it is also marked with signals which are appropriate (after reduction printing) for use in both 16-mm comopt and 16-mm commag systems. This means that one type of leader of each gauge is sufficient for the common sound systems and that the 16-mm leader can be printed directly from the 35-mm one.

In the description which follows of the various marking of the leader, the 35-mm version will be the one explicitly described. The patterns and frame relationships will apply also to the 16-mm version, but the interval between footage markings will no longer be a foot. As the frame repetition rate is the same for both gauges, the timings will be the same in both cases.

The leader consists of:

1. A "protective head" of 2 to 3 feet of blank film. This provides a wrapping around the outside of a roll of film and also allows for shortening due to losses caused by repeated attachments to take-up spools, etc.

2. The Title: "A BBC Television Film".

3. A black area for scratching on the title and reel number.

4. A clear area, the result of providing a similar facility on the negative version of the leader.

5. A series of symbols which are designed to ensure correct sound/picture frame separation. Different methods of recording sound require different separation between the sound head and the picture. The three requirements are:

16-mm *Commag*. Sound leads picture by 28 frames.

16-mm *Comopt*. Sound leads picture by 26 frames.

35-mm *Comopt*. Sound leads picture by 20 frames.

The synchronization is done on the leader by having a reference frame, known as the *sync cross* or *envelope*. It is preceded by three separate reference marks. The first one, leading the sync cross by twenty frames, is labelled "35 comopt" and bears a triangular code-mark; the second one, leading the sync cross by twenty-six frames, is labelled "16 comopt" and bears a circular code-mark; the third one, leading the sync cross by twenty-eight frames, is labelled "16 commag" and bears a square code-mark. Whatever the sound system used, when the sync cross is in the picture gate the appropriately marked

frame should be in the sound head. These markings are shown in Fig. 3.7(a) and their order, from the head end, will be:

- The clear area described in (4) above—
- followed after 3 frames by the “16 commag” reference
- followed after 2 frames by the “16 comopt” reference
- followed after 6 frames by the “35 comopt” reference
- followed after 20 frames by the sync cross.

(The sync cross is both preceded and followed by 6 triangular warning symbols, as shown in Fig. 3.7(b).)

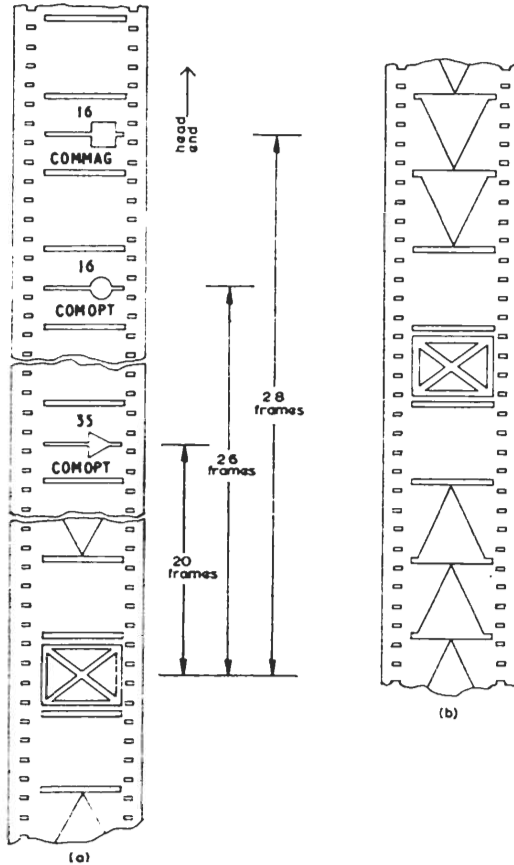


Fig. 3.7. Standard BBC Film Leader, showing(a) Sync Cross and Sound Sync Markings, and (b) Warning Symbols flanking Sync Cross

6. The leader continues with a series of footage numbers which show the amount of leader that remains before the start; these run from 12, through 11, 10, 9, etc. to 3. The remaining length of three feet is black, so that the output

8. Additional checks of sound synchronization can be made using the basic sound type identification symbols (the square, the circle and the triangle) which are printed 28, 26 and 20 frames respectively in advance of each footage number, as shown in Fig. 3.9(a). Since there are only 16 frames to the foot on 35-mm film, the identification symbols are in fact in advance of the adjacent footage number, as indicated in a general way in Fig. 3.8.

There is a further check on combined optical sound film. A pip of 400-c/s tone is recorded for one frame, 20 frames before the 4-foot frame, and a pip of

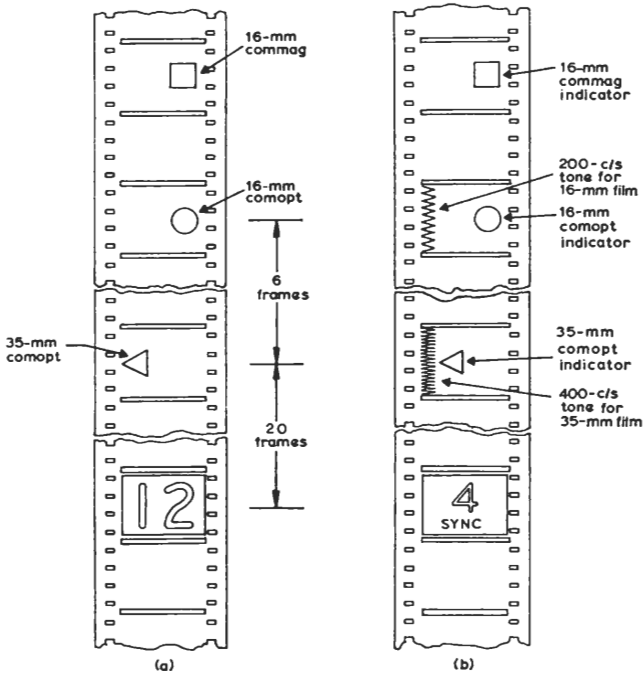


Fig. 3.9. (a) Basic Sound-type Identification Symbols, and (b) Comopt Sync Indicators

200-c/s tone is recorded for one frame 26 frames before the 4-foot frame. (The 4-foot frame in both instances is with reference to 35-mm film.) These two frames are shown in Fig. 3.9(b). The pip of 400-c/s tone is used to check the synchronization of 35-mm film, and if this is correct, the 4-foot mark will appear on the screen at the same time as a pip of tone at 400 c/s is heard. The pip of 200-c/s tone is used to check the synchronization of 16-mm film, and if this is correct the appropriate mark will appear on the screen at the same time as the pip of tone at 200 c/s is heard.

Both pips and both marks appear on all leader film because 16-mm leader is merely a reduction print of 35-mm leader as stated earlier on.

9. Provision is made for sep sound sync. At the appropriate distances (28, 26 and 20 frames) ahead of the *JOIN PICTURE HERE* line there are rows of squares, circles and triangles which indicate the correct splicing points for 16-mm sepmag, 16-mm sepopt and 35-mm sepopt respectively. This is shown in Fig. 3.10.

10. Alternative 35-mm leaders are available with the 400-c/s pip at the 4-foot mark. Such a leader can be joined to a separate optical sound track

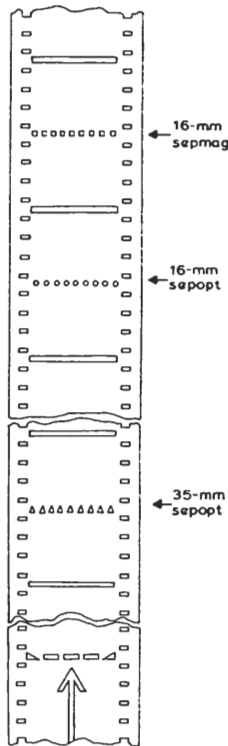


Fig. 3.10. Separate-sound Splicing Points

film and may then be used to check that the synchronization between the picture and separately laced sound reels is correct.

16-MM LEADER. As a result of the printing of 16-mm leader from 35-mm leader, the “footage” numbers no longer indicate footage, but the time lapse which they represent is not altered. Double-perforated 16-mm leaders are obtainable, but their use is deprecated. Prints are available of contact or S.M.P.T.E. type. (See Chapter 10.)

Bibliography

[1] NEBLETTE, C. B., *Photography*. Sixth edition. Van Nostrand, 1962.

[2] JAMES, T. H. and HIGGINS, G. C., *Fundamentals of photographic theory*. Second edition. Morgan and Morgan, New York, 1960.

[3] HORDER, A., (Editor), *The Ilford manual of photography*. Fifth edition, fourth reprint, 1963.

IV. THE LIGHT-SENSITIVE MATERIAL

Constituents

The photographic emulsion has two principal ingredients, silver halide crystals and gelatin. The silver halide crystals, which form the light-sensitive medium, are held apart from each other by the gelatin, which acts as a colloidal binder. The emulsion is used in the form of a thin layer coated onto an appropriate base material, which for motion picture film is of a modern safety type such as cellulose triacetate.

There are other forms of light-sensitive material, but they will not be considered in this book.

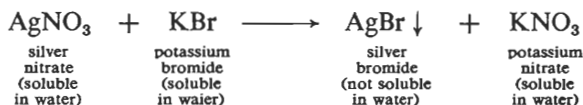
Gelatin Binder

Gelatin is the binder material nearly always used. It has the following desirable properties:

(a) When dry it is strong and tough, securing the silver halide grains firmly to the support, and protecting them from physical damage by abrasion.

(b) It holds the halide grains apart, and dispersed throughout the emulsion.

(c) When dissolved in water, it provides a convenient medium in which solutions of silver nitrate and alkali halides can be brought together to form crystals of water-insoluble halide. The reaction occurring when a solution of silver nitrate is added to a solution of potassium bromide is shown below.



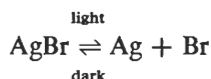
The water-insoluble silver bromide produced is immediately precipitated out of solution and in the absence of gelatin the resultant mixture clouds over; the crystals so formed coagulate at once and settle to the bottom of the container as a pale yellow curd. In the presence of gelatin, however, the silver bromide is held in a clear yellow colloidal suspension which remains transparent for some time.

(d) During the coating operation, the emulsion must be applied in the form of a sol, becoming a gel afterwards. In gelatin, the change from a sol to a gel takes place at a convenient temperature and is reversible.

(e) When dry gelatin is placed in water, it swells, and this allows penetration of processing agents in solution. The amount of swelling depends on the pH value and the salt concentration of the solution. The swollen gelatin is extremely soft and is easily penetrated by small-sized molecules, such as those of developers.

(f) Gelatin is stable with time.

(g) It acts as a sensitizer and as a bromine acceptor. The necessity for a bromine acceptor can be seen from the following reaction, which shows how the action of light forms a latent image of silver from the silver halide crystal.



The reaction also shows that the silver and bromine recombine to form silver bromide when the light is removed. This, of course, ruins the photographic effect, but the latent image can be made permanent if bromine acceptors in the gelatin remove the bromine as it is formed, thus preventing it from completing the second part of the reaction.

(h) It prevents the reduction of unexposed silver bromide crystals. This it does by becoming *adsorbed* to the crystal, producing a barrier which results in a difference in the rate at which exposed and unexposed crystals are attacked by the developer. *Adsorption* is the condensation, in the form of a film, of molecules of a suspended substance upon the surface of a solid.

(j) It is fairly easy to manufacture in bulk in a reproducible manner.

(k) It serves to regulate the sizes of the crystals formed when the silver halide is precipitated and provides a suitable environment for modifying the crystal size.

A tribute to the value of gelatin to photography has been paid by the late Dr. D. C. Baines in his book, *The Science of Photography*, where he says, "Such a remarkable combination of useful characteristics seems almost more than coincidence, and one feels that the Almighty must have created the cow with photography in mind. Perhaps the only improvement which one could suggest would be the inclusion of silver halide in the cow."

Gelatin is a mixture of related chemical compounds of the protein group, with molecules made up of amino acid residues in chains from 250 to 500 units long. It is also related to glue and is made by boiling down hide clippings or the bones of cattle and pigs.

The composition of gelatin is complex and variable. Its preparation for photographic use involves the removal of unwanted impurities in a succession of chemical baths followed by a series of closely controlled boilings. Much of the difficulty of the process lies in the necessity to reproduce the photographic properties of the material from batch to batch within a reasonable tolerance. This is complicated by the fact that the precise mechanism by which gelatin influences the final photographic process is not fully understood.

Silver Halide Crystals

The silver halides are a group of salts which are outstandingly sensitive to light and are formed by the combination of silver with the halogens. In a negative emulsion the salts used are silver bromide with a small percentage of silver iodide and in a positive emulsion they are either silver chloride or a combination of silver chloride and silver bromide. The crystals in negative emulsions range from the sub-microscopic size to a maximum of 3 to 5 microns, and constitute from 30% to 40% of the total emulsion weight. They are not pure

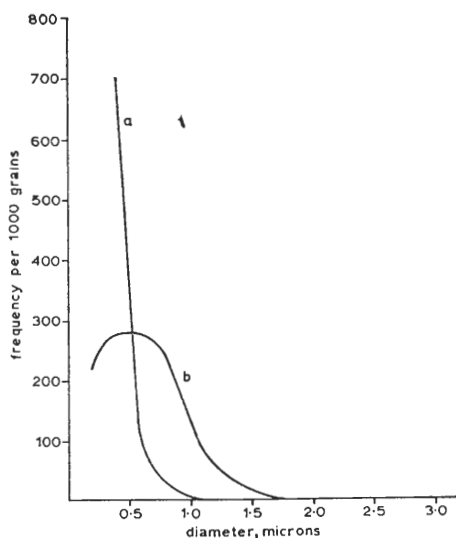


Fig. 4.1. Size/Frequency Distribution of Silver Halide Crystals in (a) Slow Positive Emulsion and (b) Fast Negative Emulsion

(Courtesy of D. Van Nostrand Company, Inc.)

silver halides, but mixtures of silver halide with small quantities of silver sulphide, colloidal silver and gelatin.

The range in crystal size is considerably greater in bromo-iodide negative emulsions than in silver chloride or silver bromo-chloride emulsions of the type used in printing. The average crystal size is also much larger for negative emulsions than for the slower positive ones. Fig. 4.1 shows the size/frequency distribution in two typical emulsions. Except where crystals are actually in contact, each acts as an individual unit in exposure and development. The sensitivity increases with crystal size, but there are differences in sensitivity among crystals of the same size.

The properties of an emulsion are largely given by the sum of the properties of the crystals of which it is composed. Numerous other compounds are added to the emulsion in the later manufacturing stages. These are often called

the "finals", and include sensitizing dyes, stabilizing agents, hardeners, spreaders, and so on.

Preparation of Emulsion

The constituents of the emulsion are selected, blended and tested and are then subjected to a number of processes which consist broadly of the following:

PRECIPITATION AND EMULSIFICATION. These stages establish the *potential* characteristics of the emulsion. Their realization is accomplished by the later stages which are largely concerned with the surface and external conditions of the grains.

A non-soluble silver halide (or combination of silver halides) is precipitated in a solution of water and gelatin by a reaction which is essentially that given near the beginning of the Chapter. Due to the protective action of the colloidal gelatin, the precipitate does not coagulate and settle, but forms an emulsion.

In negative emulsions, this precipitation takes place in a solution of gelatin varying in concentration from 1% to 5% at a temperature normally between 45°C and 75°C. The precipitation usually occurs with no free silver nitrate and usually with an excess of silver halide. The gelatin is inert, that is, free from sensitizing materials.

There may be up to 5% of potassium iodide present when the mixture is made and this does not crystallize directly but enters into the crystals of silver bromide, the amount absorbed into any crystal increasing with crystal size. This silver iodide absorption has a marked effect on sensitivity and is necessary in the preparation of high speed emulsions. The sensitivity increases as the iodide content rises to about 5% and then sharply decreases. Some emulsions contain ammonia, which increases the solubility of the silver halide and tends to increase sensitivity.

The relative proportions of the emulsion constituents have a great effect on the potential crystal size and size-range. Both of these are increased by (a) reducing the gelatin concentration, (b) increasing the soluble halide concentration and (c) reducing the concentration and rate of application of the silver solution.

RIPENING. The amount of silver solution added in the emulsification is considerably less than the amount required to convert all the soluble halide to silver halide. The next stage therefore takes place with an excess of alkali halide (KBr).

The emulsion is subjected to heat treatment, being kept at a temperature of from 50°C to 80°C for a time of between 30 minutes and two hours. Ripening time is short when a high contrast negative is required. At this stage the silver

halide crystals are slightly soluble in the emulsion, due to the presence of the excess alkali halide (KBr) and this allows the larger crystals to increase in size at the expense of the smaller ones by a process known as *Ostwald ripening*. It is found that the solubility of crystals varies with the crystal size, the smaller ones being the more soluble. They therefore pass into solution and crystallize out on the larger crystals. A consequence of this is that not only do the large crystals grow bigger but the grain size distribution gets wider. This action is favoured by heat, by the presence of ammonia or iodide and by the excess of alkali halide, and is influenced by the type of gelatin. During treatment, the crystals of silver halide attain the size-distribution which determines the characteristics (in particular, speed, contrast and graininess) of the final material. The emulsion is kept under carefully controlled conditions and continually stirred. The minute grains of silver halide grow and take up a flat crystalline shape.

COOLING AND WASHING. After ripening has been completed, the sol is permitted to gel, and then cut into strips and washed to eliminate the excess soluble salts. At this stage Ostwald growth no longer occurs.

AFTER-RIPENING. A second stage of heat treatment is now undergone, known as after-ripening, second ripening or digestion. The emulsion is melted again and held at 50°C for an hour or so. A final addition is made of "active" gelatin which contains sensitizing complexes. There is no change in the size of the silver halide crystals at this stage, but there is a great increase in the sensitivity of the emulsion due to the formation on the crystals of sensitivity centres which consist of either silver or silver sulphide. Gold sensitizing is sometimes used, but this can increase fog and reduce stability. Substances such as alum and a soluble bromide may be added at this stage in order to produce hardening, prevent unnecessary swelling, reduce fog and stabilize the emulsion.

Emulsion Structure

The structure of the grains in the emulsion varies widely and depends on the emulsion constituents, the manner of mixing, the temperature, and so on. Normally, the more sensitive the emulsion the greater the variation in grain size. In any emulsion, the larger grains are always more sensitive than the smaller ones and contain a larger proportion of iodide. Fig. 4.2* is an electron micrograph of grains of a negative-type silver-iodobromide emulsion and shows the shape of the grains very clearly. Table 4.1 shows how the average grain size and the grain density vary with different types of emulsion, and Fig. 4.3

* Fig. 4.2 faces page 96.

shows for a typical emulsion the grain-size frequency distribution and total projection area relative to grain size.

As a general rule, the greater the average size of the grains in an emulsion, the greater the size-range. As large grains usually have greater sensitivity than

TABLE 4.1
AVERAGE GRAIN STRUCTURE
OF REPRESENTATIVE EMULSIONS

<i>Emulsion Type</i>	<i>Average Grain Size</i> (square microns)	<i>Grains/cm²</i>
Motion-picture positive	0.31	117.85×10^9
Fine grain roll film	0.49	52.35×10^9
Portrait film	0.61	25.66×10^9
High speed roll film	0.93	22.61×10^9
X-ray film	2.30	6.32×10^9

small grains, an emulsion with a wide range of grain sizes has a much greater latitude and a much lower contrast than an emulsion with a limited grain-size range. This is because in the latter type of emulsion the sensitivity of one

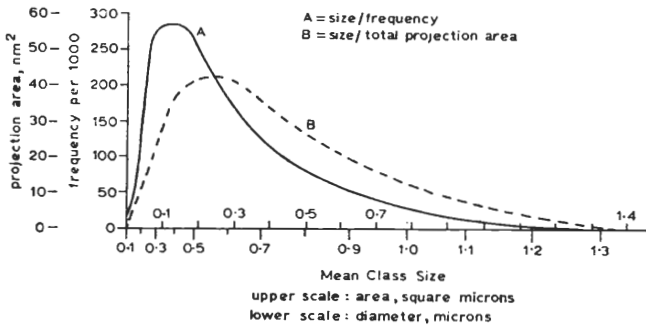


Fig. 4.3. Size/Frequency Distribution of Grains in Typical Emulsion and Total Projection Area relative to Grain Size

particular grain is much the same as that of any other grain, and so all become developable with about the same exposure.

Sensitivity Centres

When an exposed grain starts to develop, it does so at a limited number of isolated points on its surface. These points are called development centres and

it is thought that they are due to small deposits of either metallic silver or silver sulphide adsorbed to the surface of the silver halide crystal prior to exposure. It has been shown that these can be caused by unstable reactive sulphur compounds, present in certain types of gelatin, which decompose on warming during the after-ripening stage. These deposits form only about 1/1,000,000 of the surface of the grains and are distributed over the surface according to the laws of chance. They play the roll of sensitivity centres or "specks" and form the site of the development centres after the crystal has been exposed to light. An excess of sensitizers, too high a temperature during ripening or digestion prolonged beyond a given point gives too high a proportion of grains which can be reduced spontaneously by the developer without prior exposure to light and results in chemical fog.

Latent Image

No visible change occurs when an emulsion is exposed to light, but a latent image is produced which does not become apparent until the emulsion is developed. The effect of the latent image is to cause an increase of between 10 and 100 times in the rate at which a grain bearing it is reduced to metallic silver by a developer. The critical exposure necessary to initiate development of the grain depends on the nature of the developer and on the time and temperature of development, so that statements about the existence of the latent image have little meaning without reference to some arbitrarily standardized development condition.

On development the emulsion blackens to a degree which depends on the extent of the development and on the exposure. The blackening of the negative is caused by the presence of developed silver grains derived from the silver halide crystals originally present in the emulsion. The degree of blackening of the film is called the *density*, and consequently the more silver in a particular place the higher the density.

It is probable that the action of light on the silver halide crystal causes a minute speck of silver to form on the surface of the crystal, the latent image being thus formed of metallic silver.

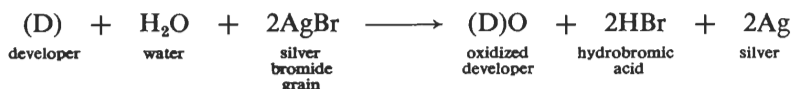
Development of Latent Image

There are two main types of development, chemical and physical. Most practical developers depend on chemical development but some rely on both types.

CHEMICAL DEVELOPMENT. This consists in the reduction to metallic silver of those sensitive grains which have been rendered developable by the action of

light. The developer, as has been said, reduces all the silver halide grains to silver in time, but the presence of the silver forming the latent image accelerates the reduction of exposed grains by a considerable factor (10–100 times). Consequently the application of the developer for a limited time differentiates between the exposed and unexposed grains, reducing the former to metallic silver while leaving the latter substantially unaltered. The developer can be thought of as amplifying the action of light.

The basic reaction of development is



The reaction favours those places where the metallic silver has been deposited, the silver appearing to act as a catalyst.

PHYSICAL DEVELOPMENT. This is the deposition of metallic silver directly on the development centres without interfering with the actual grain material, the silver deposited being obtained from the developer itself. Physical development requires an initial exposure of many times that of chemical development if the same shadow details are to be obtained.

Dye-sensitizers

The light sensitivity of untreated silver halide grains is restricted to a limited range of wavelengths. The range varies slightly with the type of silver halide, but for a normal bromo-iodide emulsion it may extend from 350 to 520 nm, covering the blue, violet and ultra-violet regions. This range may be considerably increased if the silver halide grains are dye-sensitized. The mechanism by which dye-sensitizing operates is not understood nor can the action of any new dye be predicted; it is known however, that for any effect to be obtained, the dye must be adsorbed to the crystal grain.

Emulsion Classification According to Colour Sensitivity

There are four main classes of emulsion from the point of view of colour sensitivity.

1. **NON-COLOUR-SENSITIZED EMULSIONS.** Untreated emulsions with limited colour response are perfectly satisfactory in some applications; an example is negative material used with black and white subjects such as printer stock.

2. ORTHOCHROMATIC EMULSIONS. These cover the range roughly from 350 to 580 nm, and are thus satisfactory up as far as the green portion of the spectrum but are not sensitive to red.

3. PANCHROMATIC EMULSIONS. These cover the range from 350 to 660 nm, which includes red. They include the class of hypersensitive panchromatic emulsions in which the response at red wavelengths is exaggerated and which are used for photography in artificial light.

All panchromatic emulsions depend on a class of dyes known as the cyanines.

4. INFRA-RED EMULSIONS. Infra-red emulsions are sensitive over a range from 750 to 1,200 nm. Fig. 4.4 shows spectrograms for emulsion of varying types.

Latent Image Theories

GENERAL. There is no explanation of the photographic effect which is universally recognized. However, much of the behaviour of the silver halide gelatin emulsion can be satisfactorily accounted for by considering the crystal structure of the silver halide grain, its electrical properties when prepared with an excess of alkali halide and the modifying effect on the crystal of the gelatin binder.

SILVER HALIDE PRECIPITATE. Silver bromide on precipitation possesses a lattice structure; an individual silver ion does not belong to an individual bromine ion but each silver ion is surrounded by six bromine ions and vice versa. The overall combination ratio is still unity and the structure is shown diagrammatically in Fig. 4.5.

Consider the simplest type of cube faced crystal; if this is formed in a solution in which the concentrations of Ag^+ and Br^- ions are equal, then in a neutral solution the resultant crystal will be electrically neutral. Silver bromide is slightly soluble and ionizes in solution, and an equilibrium condition is reached between a crystal and its constituent ions. The free ions in the neutral solution are in equal numbers, and a crystal such as is represented in Fig. 4.6 is formed. The resultant crystal is therefore six faced (a cube), is electrically neutral and has sides which are formed of mixed silver ions and bromine ions.

Now if the crystal is formed from a reaction which has an excess of, say, potassium bromide then a crystal forms which is as illustrated in Fig. 4.7. The excess Br^- ions in the solution are attracted to the crystal as if they were normal Br^- ions. They are in intimate contact with the surface of the crystal and are thus held strongly in position. As there are no spare Ag^+ ions to confer electrical neutrality upon the resultant crystal, potassium ions, K^+ are attracted to the crystal. The attraction is only weak, because the shape of the K^+ ion does

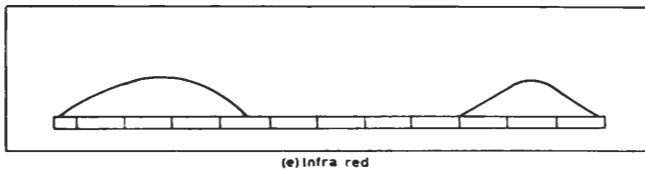
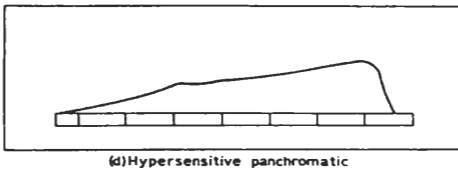
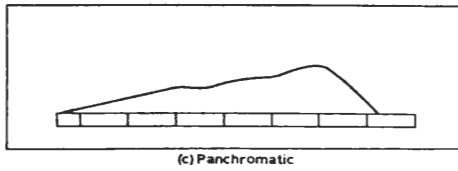
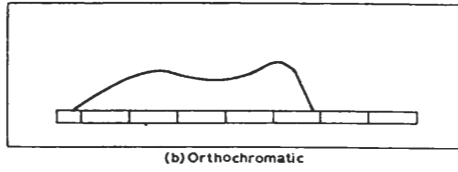
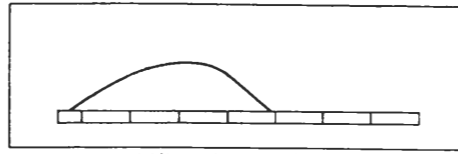


Fig. 4.4. Typical Wedge Spectrograms showing Colour Sensitivities of Principal Emulsion Classes

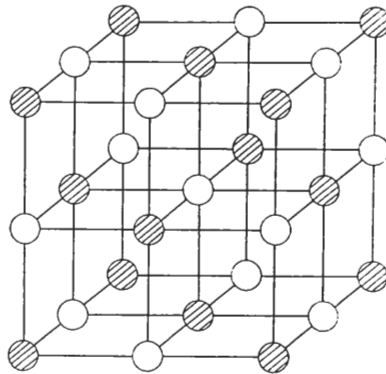


Fig. 4.5. Cubic Crystal Lattice of Silver Chloride or Silver Bromide
 (The dark circles represent chlorine or bromine atoms and the white circles represent silver atoms)

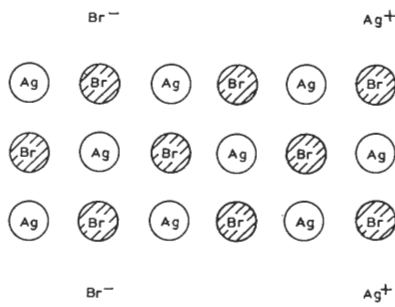


Fig. 4.6. Crystal Lattice of Silver Bromide prepared in Neutral Solution

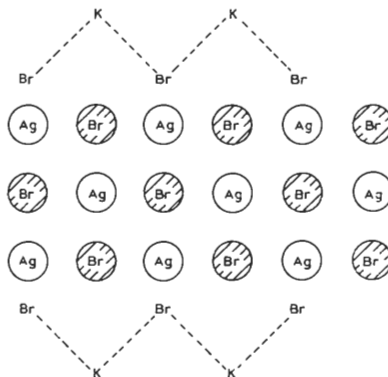


Fig. 4.7. Crystal Lattice of Silver Bromide prepared in excess of Alkali Halide (KBr)

not suit the structure of the silver bromide crystal, and the ions are thus free to move away and be replaced by others. The crystals can therefore be regarded as electrically charged towards other crystals should these approach.

The shape into which a crystal grows depends on its environment. The crystals formed in a photographic emulsion are not usually simple cubes, but have an octahedral surface in which all of one kind of ion or all the other are on the surface. Fig. 4.8 shows how such a face is produced by a cleavage plane in the crystal lattice. It can be seen that two types of crystals are possible,

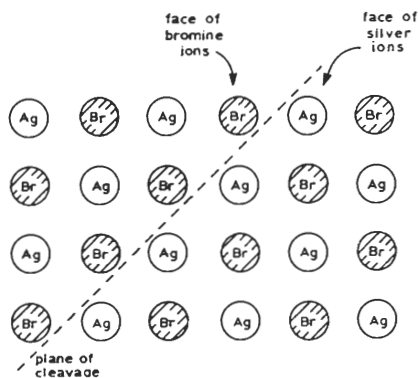


Fig. 4.8. Cleavage Plane in Silver Bromide Lattice resulting in Octahedral Crystal

those with all faces of silver ions and those with all faces of bromine ions; both these are illustrated in Fig. 4.9.

Fig. 4.9(a) shows the crystal that is formed in an excess of alkali halide; because of its adsorbed bromine ion, it is negatively charged. Fig. 4.9(b) shows the crystal formed in an excess of silver nitrate, and because of its adsorbed silver ion, this crystal is positively charged. The negatively charged crystal is the one used in photographic emulsions. The positively charged crystal is immediately reduced by normal developing solutions whether it has been exposed to light or not.

There are two important crystal characteristics which result from a negative charge:

1. Individual crystals of silver halide, prepared with the same kind of excess, possess an electrical charge of the same type and thus repel one another.
2. The charge repels negatively charged developer ions.

EFFECTS OF THE GELATIN. The gelatin is strongly adsorbed to the silver bromide grain. Every particle is surrounded by a gelatin layer attached to the grain at various points by the active groups of the gelatin. This coating produces an inactivation of the surface of the grain depending upon the hydrogen ion concentration (pH) and the silver ion concentration (pAg).

The coating restrains flocculation (i.e., the coalescence of a finely divided precipitate into larger particles), but does not prevent the growth of the silver bromide grains when a solvent for the silver halide is present. Such a solvent, for example, ammonia or an excess of soluble halide, permits the grain to grow despite the presence of the gelatin.

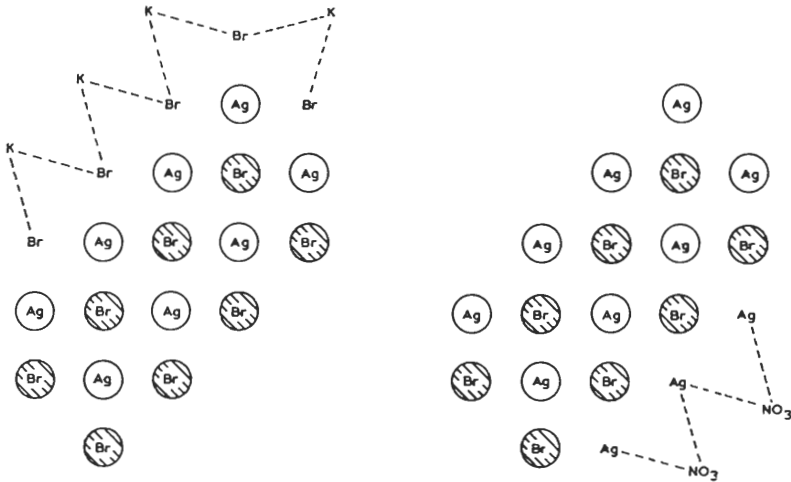


Fig. 4.9. Octahedral Faces of Silver Bromide Crystal: (a) Negatively charged crystal prepared in excess of alkali halide; (b) Positively charged crystal prepared in excess of silver nitrate

The gelatin also has other (largely unexplained) effects due to various additives or impurities. These compounds include:

- (a) Sulphur sensitizers,
- (b) Ripening sensitizers,
- (c) Ripening accelerators,
- (d) Activators,
- (e) Anti-fogging agents,
- (f) Fats,
- (g) Optical sensitizers.

The gelatin used for photographic purposes seems to contain very small quantities (1 part in 50,000) of a sulphur compound, allyl isothiocyanate. In the presence of silver halide grains a complex compound is formed with the crystal and, when the overall solution is alkaline, silver sulphide is formed and is adsorbed to the crystal surface. As previously stated, the points on the crystals where these specks of silver sulphide are formed are known as sensitivity centres and they appear to be distributed in the emulsion according to the laws of chance.

Gelatin also contains impurities which act as bromine acceptors, which prevent the breakdown of the latent image with time. These may be substances such as sodium sulphite, sodium nitrate or several possible organic compounds.

DEFECTS IN SILVER HALIDE CRYSTAL. It appears experimentally that a perfect crystal of silver halide does not exhibit photosensitivity. The Gurney-Mott latent image theory, discussed under a later heading, depends on the existence of *Frenkel defects* in the crystal.

A Frenkel defect consists of an ion which is out of its normal lattice position and which has moved into an interstitial position as illustrated in Fig. 4.10.

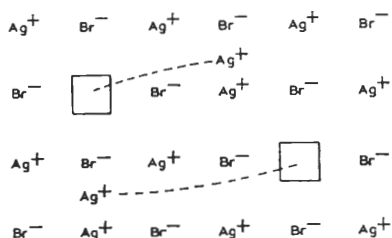


Fig. 4.10. A Frenkel Defect

In the silver halide crystal, only cationic (silver ion) defects are possible as there is not sufficient energy available to move the much larger halide ion so that an anionic defect is caused.

The cationic defect ions can move about the crystal and account for its very small electrical conductivity in the dark. The frequency of Frenkel defects seems to depend on crystal size; initial experiments on large crystals did not confirm the frequency required by the Gurney-Mott hypothesis, but later experiments on small crystals gave frequencies a hundredfold greater than the earlier results.

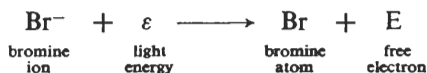
ELECTRICAL CONDUCTIVITY OF SILVER HALIDE

(a) *Ionic Conductivity.* There is a small current, known as the dark current, which flows in a crystal of silver halide when a potential is applied across it in the absence of light. This current is due to the presence of the interstitial silver ions discussed above.

(b) *Photoconductivity.* There is a large increase in the conductivity of a crystal of silver halide when light falls on it, the energy contained in the light being sufficient to liberate electrons from the bromine ions (which have spare electrons, being Br^-) in the crystal. These electrons are able to move freely through the crystal and are therefore available for conduction, while the bromine ions revert to bromine. In the language of semiconductor physics, the energy contained in the light has been sufficient to create a hole-electron pair in the crystal,

as it is found that the bromine atom which is formed can wander through the silver-halide crystal in exactly the same way as can a hole through a crystal of germanium.

GURNEY-MOTT HYPOTHESIS. According to this hypothesis, the formation of the latent image is the result of the production of photo-electrons in the interior of the small crystals of silver halide dispersed throughout the emulsion. These photo-electrons are liberated by the reaction



The usual way in which the action continues is for the bromine atom to diffuse through the crystal to the surface of the grain, where it is captured by the bromine acceptors present in the gelatin. The free electron is captured by one of the sensitivity centres of metallic silver or silver sulphide. This gives the sensitivity centre a negative charge, and one of the positively charged silver ions, present in the crystal due to Frenkel defects, is attracted towards the centre and is neutralized by it. The silver ion is thus converted to a silver atom and deposited on the sensitivity centre.

The process thus consists of two stages:

1. A primary, electronic process associated with photo-conductance.
2. A secondary, ionic process involving the migration of interstitial silver ions.

These two stages can be represented symbolically by the formulae

1. $\text{Br}^- + \varepsilon \longrightarrow \text{Br} + \text{E}$
2. $\text{Ag}^+ + \text{E} \longrightarrow \text{Ag}$

ε represents the energy absorbed by the crystal from the incident light, and is equal to hf joules, where h is Planck's constant (6.625×10^{-20} joule/sec), f is the frequency of the radiation in c/s and E represents an electron liberated by the energy ε .

When the exposure is made at usual temperatures and with moderate light intensities, the above is the most usual sequence of events. There are however, two other possible sequences.

The first is for the bromine atom to be captured as before by a bromine acceptor but for the electron to be neutralized directly by an interstitial silver ion; this gives rise to an internal latent image which is very much weaker than the surface one.

The second possible sequence is for the electron to recombine directly with the bromine atom; this occurs when the rate of bromine liberation is high (due to a high absorbed light intensity) and the bromine acceptor is unable to capture the bromine atoms before they are neutralized. It can be seen that in

extreme cases this results in a noticeable loss of photographic effect, as a doubling of the intensity does not result in a doubling of the number of silver halide grains being reduced to metallic silver. The name *reciprocity failure* is given to this effect because the photographic effect of an exposure can no longer be calculated from the simple relationship $E = It$ when the intensity of illumination exceeds a certain value.

Reciprocity failure also occurs when the intensity of illumination is below a certain level, and the reason for this is thought to be as follows: When the formation of a development centre is at an early stage (probably when it exists as a single atom only of silver) it is unstable and is liable to emit an electron and revert to a silver ion. When the exposure is to light of very low intensity, any given development centre will be unstable for a relatively long time, due to the slow build-up of the latent image. It is thus more likely to be destroyed than when the exposure occurs at a greater rate.

For most modern emulsions the reciprocity law holds to a sufficient degree of accuracy over a range of illumination between 0.1 and 10 lux.

SUB-LATENT IMAGE. The latent image must reach a certain size before it functions as a development centre, but the limiting size depends on the condition of development. A latent image speck which is too small to act as a development centre under a given set of development conditions is called a *sub-latent image*, and such a sub-latent image could well become a full latent image with more vigorous development.

Bibliography

[1] MEES, C. E. K. and JAMES, T. H., *The theory of the photographic process*. Third edition. Macmillan, New York, 1966.

[2] JAMES, T. H. and HIGGINS, G. C., *The fundamentals of photographic theory*. Second edition. Morgan and Morgan, New York, 1960.

[3] NEBLETTE, C. B., *Photography*. Sixth edition. Van Nostrand, 1962.

[4] HORDER, A., (Editor), *The Ilford manual of photography*. Fifth edition, Fourth reprint, 1963.

[5] BAINES, D. C., *The science of photography*. (Revised by BOMBACK, E. E.) Second edition. Fountain Press, 1967.

V. SENSITOMETRY: PRINCIPLES

Characteristic Curve of a Photographic Emulsion

If a specimen of film stock is first exposed to light and then developed, the degree of blackening produced is found to vary with the exposure, provided that the development conditions are kept constant. Table 5.1 shows the

TABLE 5.1
RESULTS OF MEASUREMENTS ON TYPICAL NEGATIVE FILM

No.	Exposure (E) (metre- candle seconds)	Increase in Exposure (ΔE)	Log Exposure (log E)	Increase in Log Exposure ($\Delta \log E$)	Opacity (O)	Increase in Opacity (ΔO)	Density (D)	Increase in Density (ΔD)
1	0	—	—	—	1.072	—	0.03	—
2	0.01	0.01	2.0	0.3	1.096	0.024	0.04	0.01
3	0.02	0.01	2.3	0.3	1.175	0.079	0.07	0.03
4	0.04	0.02	2.6	0.3	1.318	0.143	0.12	0.05
5	0.08	0.04	2.9	0.3	1.660	0.242	0.22	0.10
6	0.16	0.08	1.2	0.3	2.291	0.631	0.36	0.14
7	0.32	0.16	1.5	0.3	3.388	1.097	0.53	0.17
8	0.64	0.32	1.8	0.3	5.754	2.366	0.76	0.23
9	1.28	0.64	0.1	0.3	10	4.246	1.0	0.24
10	2.56	1.28	0.4	0.3	17.78	7.78	1.25	0.25
11	5.12	2.56	0.7	0.3	31.62	13.84	1.50	0.25
12	10.24	5.12	1.0	0.3	56.23	24.61	1.75	0.25
13	20.48	10.24	1.3	0.3	100	43.77	2.0	0.25
14	40.96	20.48	1.6	0.3	162.2	62.2	2.21	0.21
15	81.92	40.96	1.9	0.3	229.1	66.9	2.36	0.15
16	163.84	81.92	2.2	0.3	295.1	66.0	2.47	0.11
17	327.68	163.84	2.5	0.3	346.7	51.6	2.54	0.07
18	655.36	327.68	2.8	0.3	380.2	33.5	2.58	0.04
19	1310.7	655.36	3.1	0.3	389.0	8.8	2.59	0.01
20	Long	Long	—	—	398.1	9.1	2.60	0.01

Note 1: Line No. 1 in the table gives the density for zero exposure; this density is that of fog plus base.

Note 2: Line No. 20 gives the maximum density, D_{\max} , as indicated for example on Fig. 5.5.

results obtained from a series of exposure on a typical negative film. The exposures form a geometrical progression and are tabulated both as exposures and as log exposures. The amount of blackening which results from each

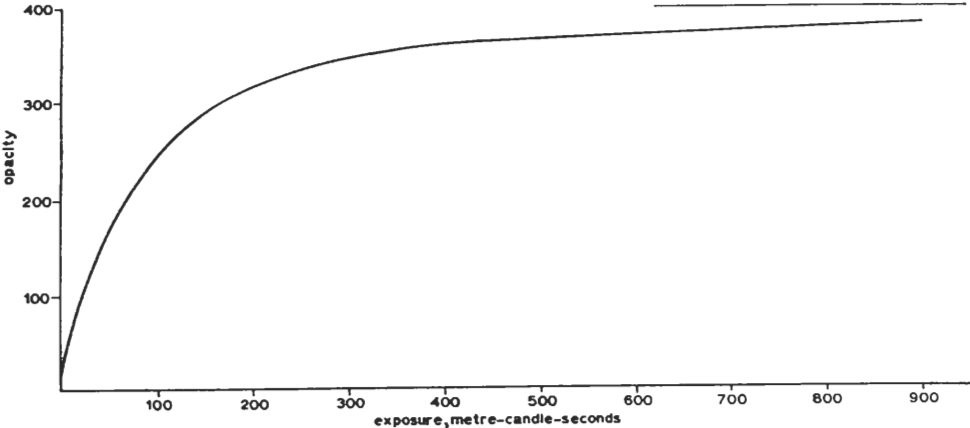


Fig. 5.1. Relationship between Opacity and Exposure

exposure is found by measuring the opacity of the film and the results are tabulated both as opacities and as densities (log opacities).

Figs. 5.1 to 5.4 indicate graphically the relationships between the quantities

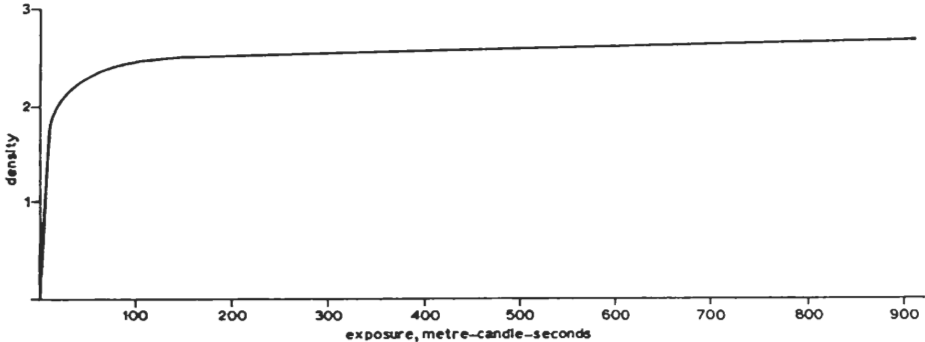


Fig. 5.2. Relationship between Density and Exposure

given in Table 5.1. Fig. 5.1 shows the relationship between opacity and exposure, Fig. 5.2 shows the relationship between density and exposure, Fig. 5.3 shows the relationship between opacity and log exposure, and Fig. 5.4 shows the relationship between density and log exposure. It can be seen that the relationship is expressed most clearly in Fig. 5.4. The logarithmic scale of

exposures avoids the inconvenient cramping of the scale which occurs at low values on the linear scale of exposures and the logarithmic scale of density avoids a similar cramping at low opacity values. A further advantage of a

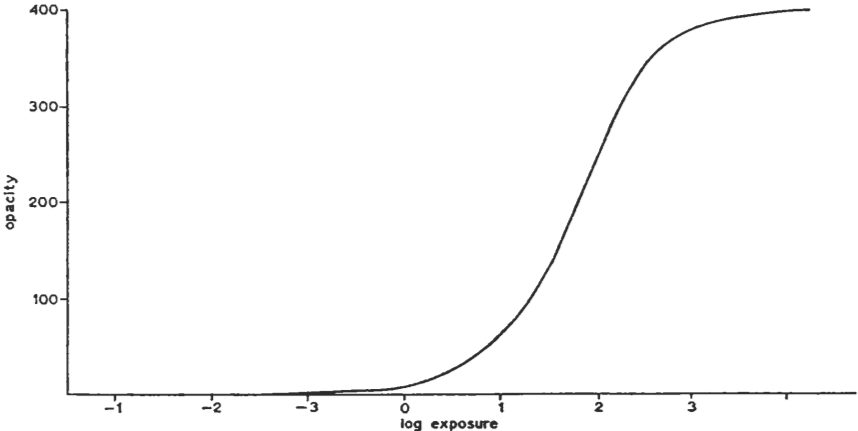


Fig. 5.3. Relationship between Opacity and Log Exposure

density scale is that the visual effect of an image is more accurately represented by density than by opacity.

The density/log exposure diagram, shown in greater detail in Fig. 5.5, is called the *characteristic curve* of the emulsion, and the subject of sensitometry

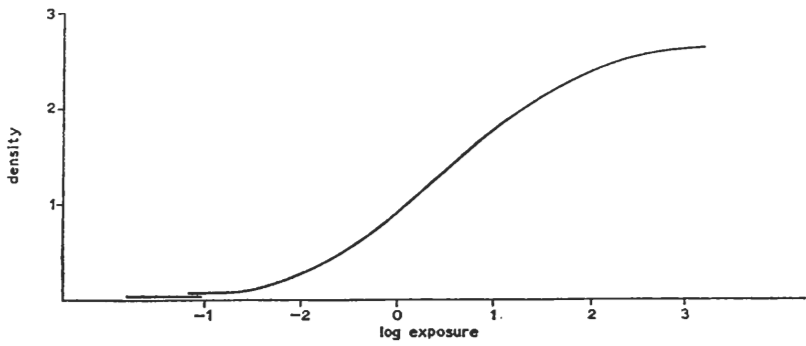


Fig. 5.4. Relationship between Density and Log Exposure

is essentially the study of this curve and the factors which affect its shape. The characteristic curve is sometimes referred to as the “*D log E* curve”, because of its axes, or as the “H. and D. curve”, after Hurter and Driffield who pioneered its use.

The following notes explain the significant features of the curve, which are marked in Fig. 5.5.

1. *Density of Base plus Fog.* This is the density reading obtained when a developed but unexposed part of the film is measured.

2. *Threshold.* For very low values of log exposure, no photographic result is observed. The threshold is the first point at which an exposure gives a measurable increase in density above the level of base plus fog.

3. *Toe.* The toe is the region of the curve where equal increments in log E produce increasing increments in density. The gradient of the curve in this region is therefore increasing with log E .

4. *Straight-line Portion.* This is the portion of the curve where equal increments in log E produce equal increments in density. For the film tested, it

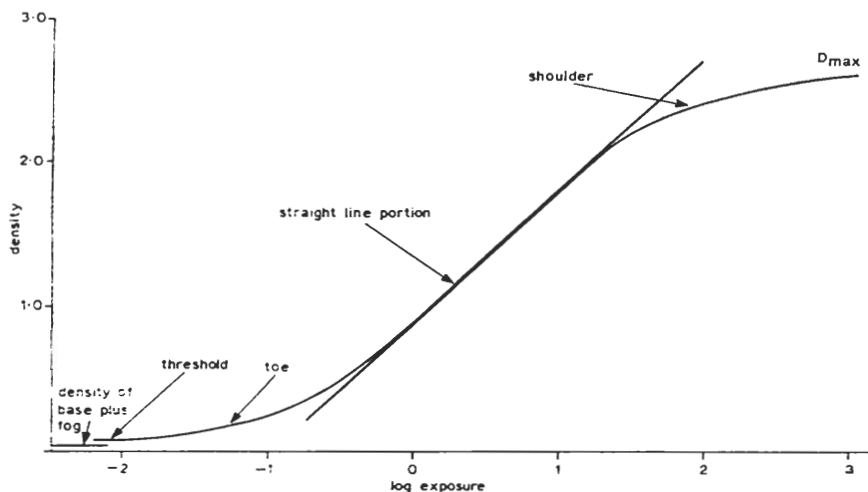


Fig. 5.5. Features of the Characteristic Curve

extends from exposure No. 8 to exposure No. 13. Many modern emulsions have no straight-line portion, or at the best have only a very short one.

5. *Shoulder.* This is the region of the curve where equal increments in log E produce decreasing increments in density. The gradient of the curve in this region is therefore decreasing with increasing values of log E .

6. D_{\max} . This is the maximum film density which can be obtained under the given conditions of development.

Gradient of Characteristic Curve

Fig. 5.6 shows a characteristic curve which has a short toe and a long straight-line portion. The gradient of the straight-line portion with respect to the log E axis is called the γ (gamma) of the curve. The gamma value gives a good

indication of the degree of development and contrast of a film so long as the straight-line portion covers most of the working range.

In Fig. 5.6, $\gamma = \Delta D / \Delta \log E$, or $\tan C$.

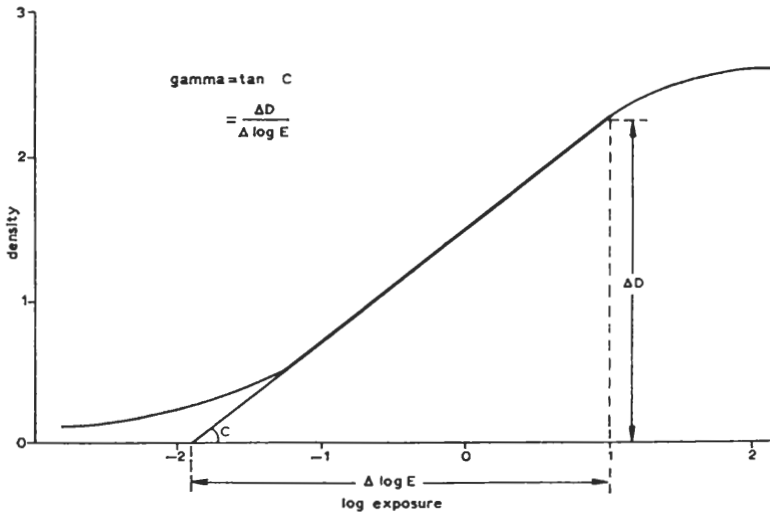


Fig. 5.6. Determination of Gamma for an Emulsion having a Characteristic Curve with a Long Straight-line Portion

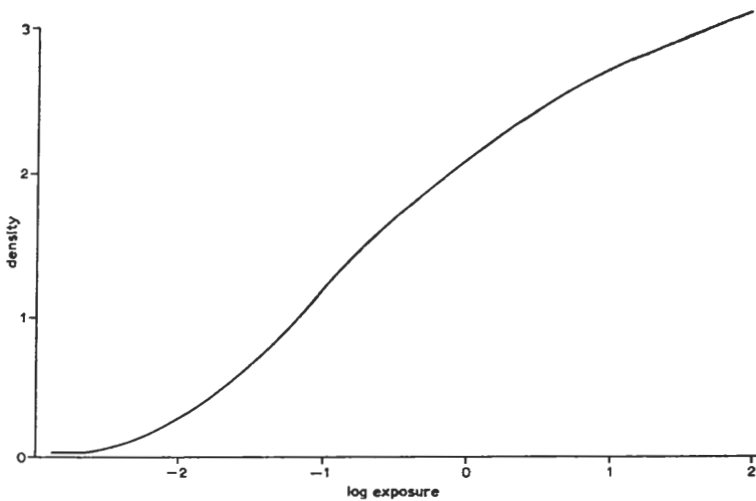


Fig. 5.7. Characteristic Curve of a Typical Modern Emulsion

Fig. 5.7 shows a characteristic curve which is more typical of modern emulsions. There is virtually no straight-line portion but there is instead a point of inflection which separates an extended toe region from an extended shoulder

region. Usually the working range of such a film includes a large part of the curved toe; a simple gamma measurement is therefore inappropriate as it measures the degree of contrast of a small and unimportant part of the curve.

For such emulsions, an *average gradient* measurement is much to be preferred. This is a measurement of the gradient between the line joining two points on the characteristic curve and the log E axis. The points are specified so that the

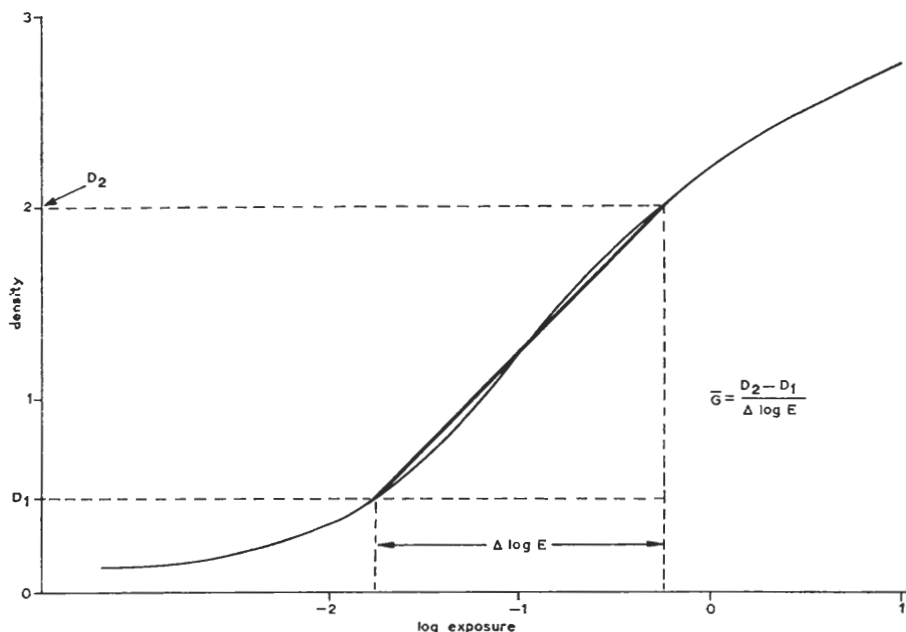


Fig. 5.8. Determination of Average Gradient (\bar{G}) between Fixed Densities

working range of the film is covered, and methods for doing this are shown in Figs. 5.8 to 5.10.

Fig. 5.8 shows the average gradient \bar{G} (pronounced *gee bar*) between two given densities, D_1 and D_2 . From the diagram, $\bar{G} = (D_2 - D_1)/(\Delta \log E)$.

Fig. 5.9 shows the average gradient between two given values of log exposure, $\log E_1$ and $\log E_2$. Here, $\bar{G} = D/(\log E_2 - \log E_1)$.

Fig. 5.10 shows a combination of the previous two methods of determining \bar{G} . The lower point is a point whose density is given, often a point whose density has a fixed value above fog level. The upper point is a point whose log exposure is a certain increment above the log exposure of the lower point. In the example, the log exposure increment is 1.5, and it results in a change of density from D_1 to D_2 . Therefore, $\bar{G} = (D_2 - D_1)/1.5$.

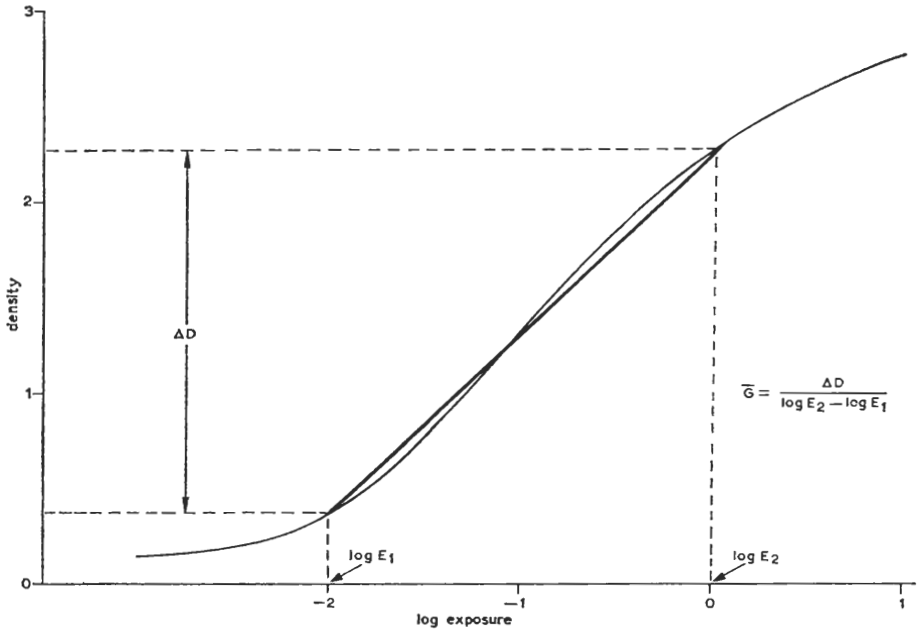


Fig. 5.9. Determination of Average Gradient (\bar{G}) between Fixed Exposures

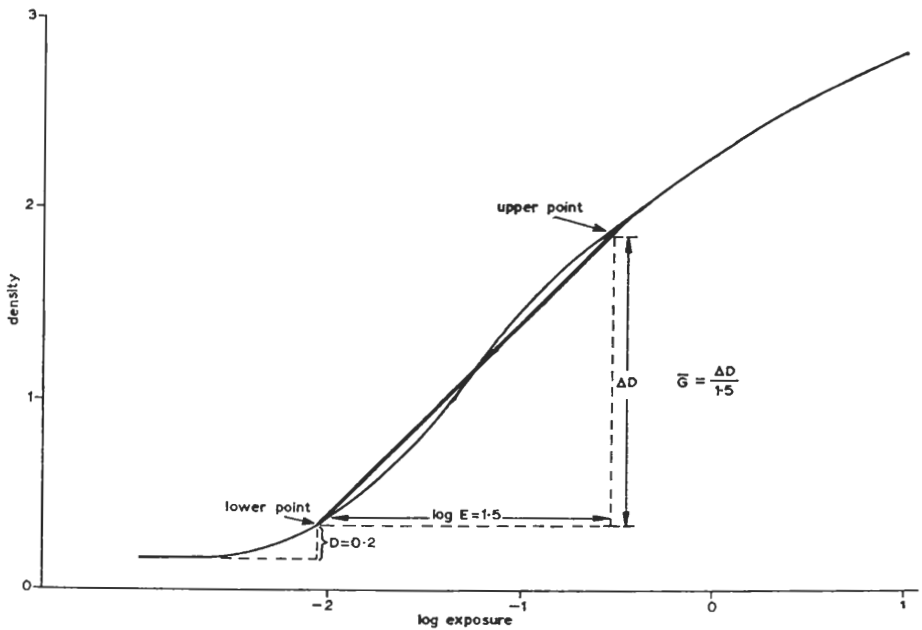


Fig. 5.10. Determination of Average Gradient (\bar{G}) between a Fixed Density and a Fixed log E Increment

Fig. 5.11 shows two examples of the measurement of *point gamma*, which is the gradient of the tangent to the characteristic curve at a stated point. The first example shows the point gamma at a point whose density is 0.2 above fog

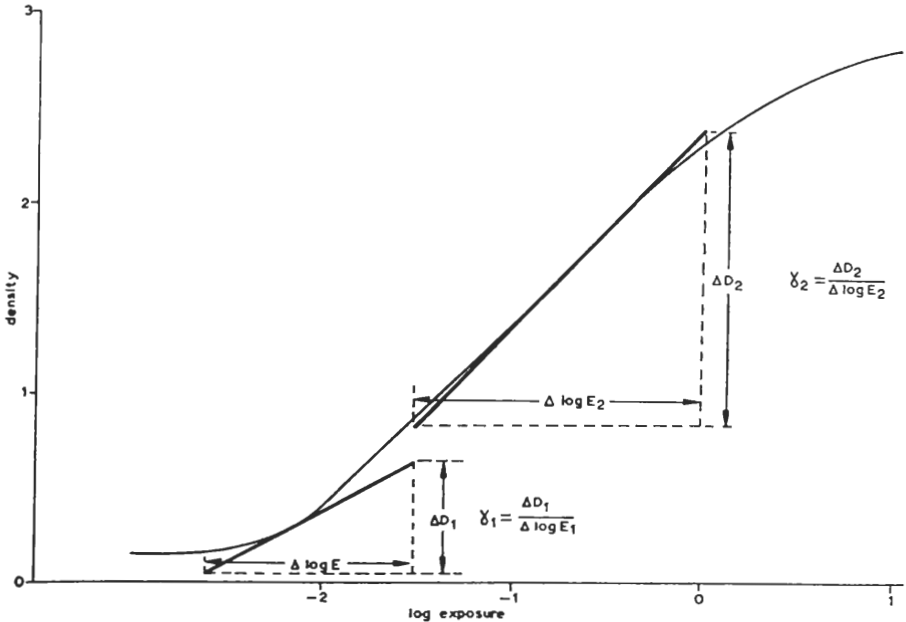


Fig. 5.11. Determination of Point Gamma (1) at Point of Density 0.2 above Fog Density and (2) at Point of Inflection of D/log E Curve

level. The second example shows the gradient at the point of inflection; this gives the maximum value for the point gamma on any normal curve.

Failure of Reciprocity Law

Exposure, *E*, is the product of illumination, *I*, and time, *t*, that is, $E = It$, and exposure can therefore be varied in either of two ways. In the first, called *time-scale modulation*, the time of the exposure is varied while the intensity of illumination stays constant; in the second, called *intensity-scale modulation*, the intensity of illumination is varied while the time of the exposure stays constant. It is found experimentally that the photographic effect of a range of exposures produced by one method is not the same as the photographic effect of an identical range of exposures produced by the other method. The effect of an exposure, *E*, is thus dependent not only on the product *It*, as it would be if a law of reciprocity applied, but also on the individual values of *I* and *t*.

Fig. 5.12 illustrates this effect and shows curves of log *E* (that is, log *It*)

plotted against $\log I$ for fixed values of density. If varying I and t reciprocally had no effect on density, the result would be a series of straight lines parallel to the dotted line shown; the extent of the failure of the reciprocity law is shown by the degree of curvature of the continuous lines. Point A is the position of maximum sensitivity and for small variations in $\log I$ around this point the effect of reciprocity failure is small. For many negative films the reciprocity law holds approximately for values of illumination between about 1 and 10 lux.

An approximate expression for the effective value of exposure is given by $E = It^\rho$, where ρ is the Schwarzschild coefficient. This relationship holds at

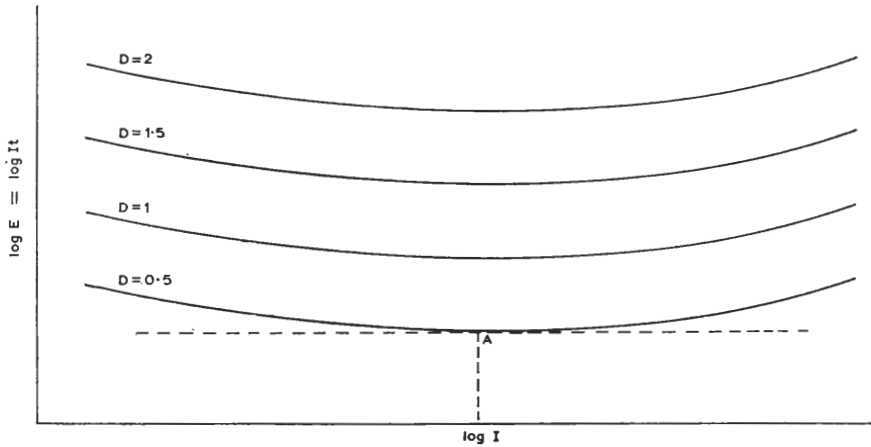


Fig. 5.12. Constant-density Curves, Illustrating Reciprocity Law Failure Caused by Dependence of Effect of $\log E (= \log It)$ on Value of $\log I$

low intensities, for which ρ is about 0.8, but requires a variable value for ρ at high intensities.

A probable reason for the reciprocity failure at high intensities is that electrons are released in the silver halide crystals at such a rate that they arrive at the sensitivity centres faster than the mobile silver ions can neutralize them. This means that the sensitivity centres become negatively charged, and repel further electrons which either form shallow development centres or are neutralized by the bromine ions formed during the exposure and are lost for latent image formation.

At low intensities, a possible explanation for the failure of the law is that a silver centre in the early stages of its formation is unstable, and becomes stable only on reaching a certain size. Before that the centre can be disintegrated by the thermal ejection of an electron from the silver atom. This electron may subsequently take part in the formation of another silver atom, but may instead recombine with a bromine ion with no resultant photographic effect.

The probability that the electron will be ejected increases with time, and therefore the probability that disintegration will occur before a second silver atom reinforces the silver centre increases with decreasing light intensity.

Sensitometers and Densitometers

The practical determination of characteristic curves for a photographic material requires the use of two instruments, a *sensitometer* for making calibrated test exposures and a *densitometer* for measuring the resulting photographic densities.

Sensitometers

GENERAL. Sensitometers have three essential features:

1. A source of light, to permit exposure of the photographic material under test.
2. An arrangement for varying or "modulating" the light in order to provide different exposures on different portions of the test material.
3. A holder for the test material.

LIGHT SOURCE. In modern sensitometers, the light source is always a tungsten-filament lamp. This is usually supplied by the maker of the sensitometer together with a calibration chart which enables the candle power and luminous intensity to be determined for given values of voltages.

For accuracy in measurement, the lamp should be fed from a constant-voltage supply. Fig. 5.13 shows the effect of voltage variation on the light output from a lamp, while Fig. 5.14 shows the effect of voltage variation on colour temperature.

The variation in light output from a lamp due to aging is shown in Fig. 5.15, in which curve (a) represents the change in performance when the lamp is supplied from a constant-voltage source and curve (b) represents the change when the lamp is supplied from a constant-current source; the latter gives the more desirable result. Constant-current regulation is, however, rarely used, because although the light output from a lamp varies as the 3.5th power of voltage, it varies as the 6th power of current. This means that a constant-current generator would need to have a much better performance than a constant-voltage generator for similar results, and voltage regulation is therefore normally used.

The light output from the lamp should be checked regularly against a standard lamp retained for this purpose, and changed when the output begins to fall.

If the colour of the exposing light is to correspond to the internationally agreed sunlight values, the lamp must be operated at a colour temperature of

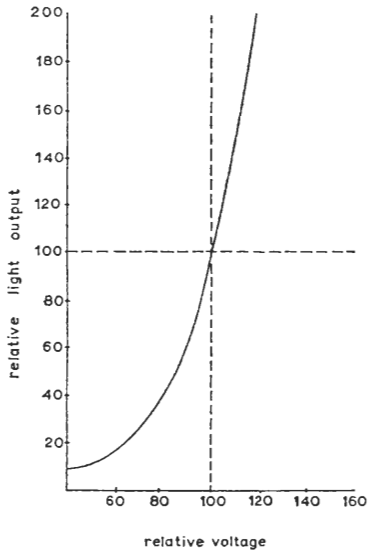


Fig. 5.13. Change in Light Output from a Tungsten-filament Lamp with Working Voltage

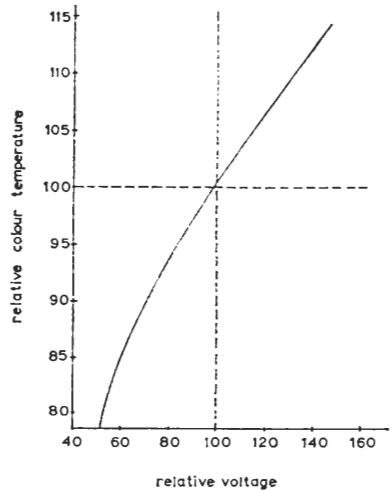


Fig. 5.14. Change in Colour Temperature of a Tungsten-filament Lamp with Working Voltage

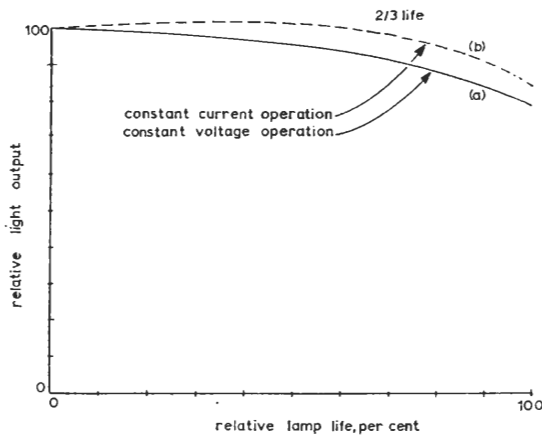


Fig. 5.15. Aging of a Tungsten-filament Lamp when operated under (a) Constant-voltage and (b) Constant-current conditions

2360°K and the light output converted to 5400°K by means of a Davis-Gibson liquid filter.

METHODS OF MODULATION. Sensitometers can be either time-scale or intensity-scale modulated. In motion-picture photography the range of exposure times available is small and the exposure of the film is effectively intensity-modulated

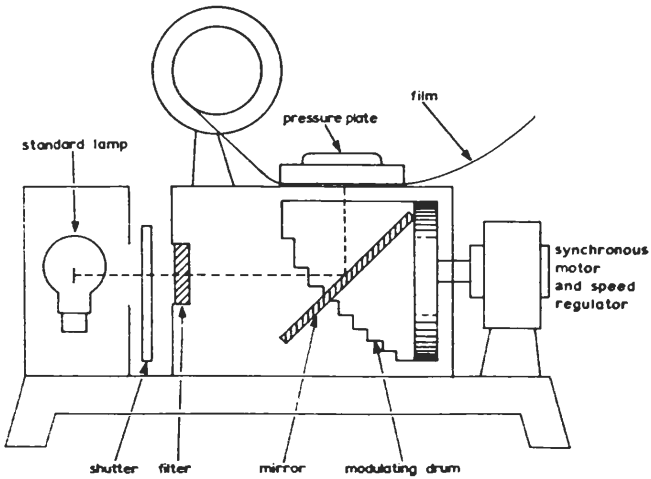


Fig. 5.16. Eastman Type-IIB Time-scale Sensitometer: Simplified Diagram

by the aperture. Because of reciprocity failure the effects of time- and intensity-modulated exposure are different, and since ideally the test conditions should correspond to those encountered in practice, intensity-scale modulation is the method to be preferred. Most laboratories have now introduced intensity-scale sensitometers or have modified their old time-scale instruments to intensity-scale operation, but since a number of Kodak time-scale sensitometers are still in use, both methods of modulation will be described.

TIME-SCALE MODULATION. Fig. 5.16 shows the layout of a typical time-scale sensitometer, the Eastman Type IIB. In this instrument, light from a standard

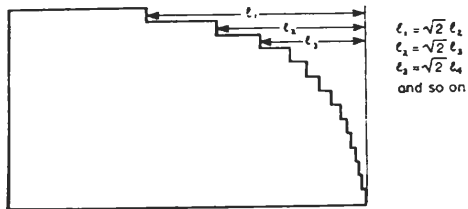


Fig. 5.17. Eastman Type-IIB Sensitometer: Developed View of Sector Drum

lamp passes through a shutter and filter and is reflected towards the film under test by a plane mirror. Between the mirror and the film is a drum on the curved wall (Fig. 5.17) of which is cut a series of 21 slots whose lengths increase in a geometric progression of ratio $\sqrt{2}$. The drum rotates at 10 r.p.m., and the

shutter is arranged to open for the duration of one revolution precisely, allowing light to pass through the slots in the drum wall and onto the film. The film thus receives an exposure which varies with the lengths of the slots and therefore increases by a factor of $\sqrt{2}$ from one slot to the next. This corresponds to an increase in $\log E$ of $\log \sqrt{2}$ or 0.15.

The advantage of a time-scale instrument is in the ease and accuracy with which an exposure ratio can be obtained.

In the equipment described, a rheostat enables the supply to the lamp to be adjusted for the desired light intensity or colour temperature. For checking

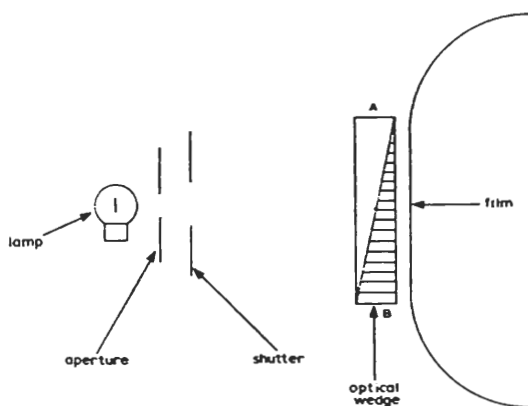


Fig. 5.18. Basic Layout of an Intensity-modulated Sensitometer. (Even illumination of the optical wedge is an essential requirement)

purposes a voltmeter and ammeter are provided, visible through a safelight screen.

INTENSITY-SCALE MODULATION. The basic layout of an intensity-scale sensitometer is shown in Fig. 5.18. A shutter allows light from a lamp to fall for a time t onto an optical wedge. The wedge has a density which varies from a minimum at A to a maximum at B. Thus, if the illumination of the film is I_1 at A and I_2 at B, the exposure will vary from $I_1 t$ to $I_2 t$. In most sensitometers the illumination of the wedge is uniform from A to B and the value of $\log E$ therefore varies directly with the density of the wedge.

The best wedges are made of a colloidal dispersion in gelatin, such as cast carbon. They are more uniform than photographic wedges and have better spectral density characteristics than dyed gelatin or coloured glass. The spectral density characteristics for cast carbon and photographic silver wedges are shown in Fig. 5.19.

A disadvantage of intensity-scale over time-scale modulation is that it is virtually impossible to manufacture a wedge which gives equal increments in density between successive steps. After a wedge is made it is individually

calibrated and a number of awkward increments usually result. This means that plotting is slow and tedious unless a template is made giving to scale the

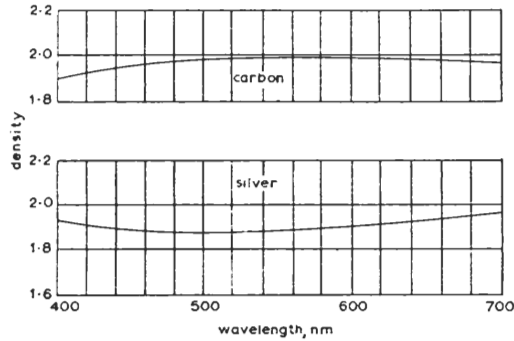


Fig. 5.19. Spectrograms of Cast Carbon and Photographic Silver Step Wedges measured on a Density Step in the Region of $D = 2.0$

log E increments which result from using a given wedge. The calibration of an intensity-scale sensitometer and the making of a template are explained later.

Classification of Sensitometers

Sensitometers are classified according to whether they:

1. are intensity-scale or time-scale modulated,
2. give an intermittent or non-intermittent (i.e., continuous) exposure,
3. produce a wedged (continuous) or stepped (non-continuous) scale of exposures.

This leads to the following type classification:

TYPE I: INTENSITY-SCALE MODULATED

A. Exposure Intermittent

1. Wedged exposure
2. Stepped exposure

B. Exposure Non-intermittent (i.e., Continuous)

1. Wedged exposure
2. Stepped exposure

TYPE II: TIME-SCALE MODULATED

A. Exposure Intermittent

1. Wedged exposure
2. Stepped exposure

B. Exposure Non-intermittent (i.e., Continuous)

1. Wedged exposure
2. Stepped exposure.

Thus, for example, it can be seen that the Kodak *IIB* sensitometer is a time-scale modulated continuous-exposure instrument.

In place of the above system, makers' own type numbers are also sometimes used.

STEPPED AND WEDGED EXPOSURES. Fig. 5.20 indicates the appearance of a series of stepped exposures made onto a film. Most sensitometers used for testing film produce stepped exposures; non-stepped (i.e., continuously variable or "wedged") exposures are sometimes used for testing photographic papers.

KODAK X-6 SENSITOMETER. The Kodak X-6 is a modern intensity-scale sensitometer. A general view of this instrument is given in Fig. 5.21, while its basic layout is shown in Fig. 5.22.

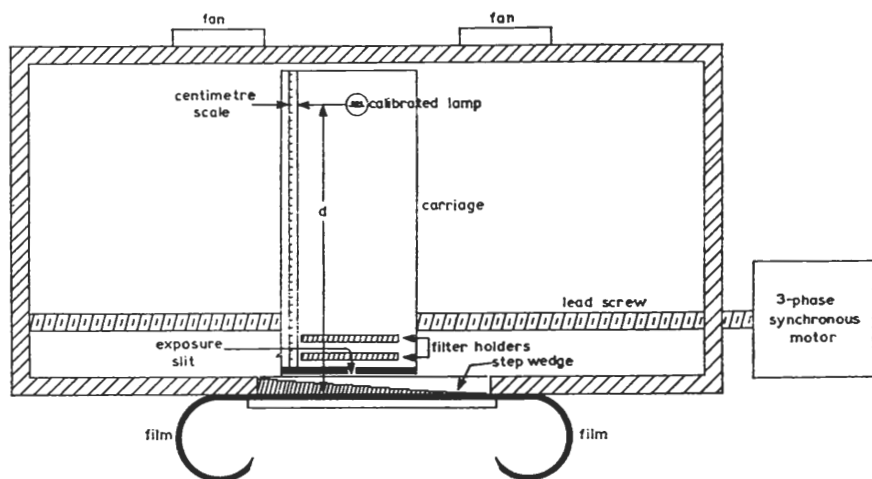


Fig. 5.22. Kodak X-6 Sensitometer: Layout

The principal of operation is that a lamp on a carriage is moved at a constant speed past a step wedge, the lamp being housed in a box which is light-tight except for a small slit which lets a narrow band of light fall on the wedge. The thickness of the slit and the speed of the carriage determine the effective time of exposure; the intensity of the lamp and its distance from the step wedge determine the illumination.

The movement of the carriage results in an even exposure along the length of the wedge, and if the film under test is held against the wedge, it will be given

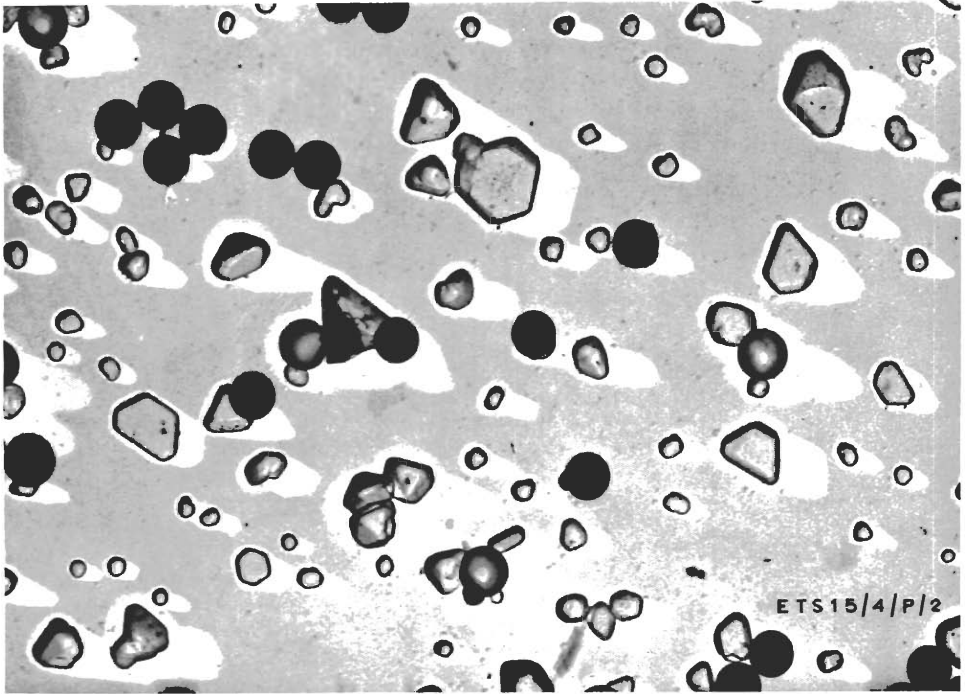


Fig. 4.2. Electron Micrograph showing Grains of Negative-type Silver-iodobromide Emulsion.
(The black disks are latex spheres introduced for measurement purposes)
(See Page 70)

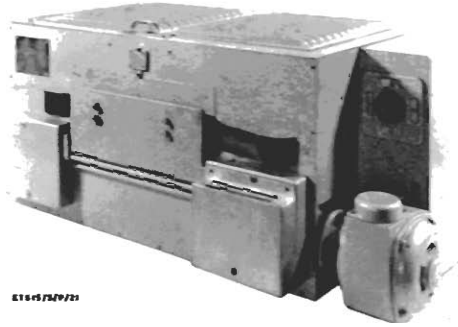


Fig. 5.21. Kodak X-6 Sensitometer: General View

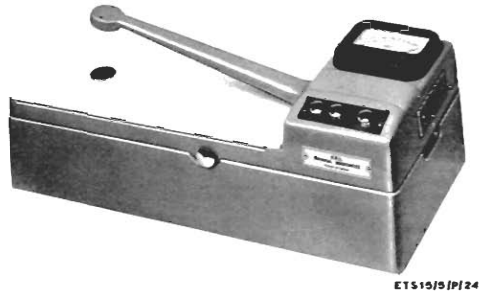


Fig. 5.24. E.E.L. Densitometer: General View

Fig. 5.20. Appearance of a Series of Stepped Exposures

a series of exposures which are controlled by the density increments on the wedge.

The test wedge usually consists of 21 steps each of 10·16 mm in length. The total width of the exposed area is 25 mm and its length is 222 mm.

The carriage moves on an accurately made leadscrew with an 8-mm pitch, driven at 1500 r.p.m. by a 220-volt 3-phase synchronous motor. The carriage thus travels at 20 cm/sec, moving from right to left and from left to right for successive exposures. The motor works from a relay circuit which is started by pressing a pushbutton. As the carriage moves it closes a pressure pad which holds the film in contact with the step wedge.

The lamp is a 500-watt 115-volt Class-A1 projector type, supplied from a voltage-regulated supply and considerably underrun. The performance of a typical lamp is shown in Table 5.2.

TABLE 5.2
OPERATING DATA FOR 500-WATT
CLASS-A1 PROJECTION LAMP AS USED
IN KODAK X-6 SENSITOMETER

<i>Voltage</i>	<i>Candle Power</i>	<i>Colour Temperature</i> (degrees K)
105·9	993	3000
93·2	664	2850
78·0	360	2560
56·0	106	2360

Between the lamp and the step wedge is an assembly which is made to carry two 76 mm by 76 mm filter holders and two rotating disks as follows:

1. A disk to carry filters. This has four (29 mm by 29 mm) windows for colour-temperature-correction filters and for separation filters for colour.

2. A disk which determines the exposure time. This has slits which give exposures of $\frac{1}{16}$, $\frac{1}{32}$ or $\frac{1}{64}$ second. There is also a position providing for a fourth, optional, exposure time. The exposure slits pass very close to the step wedge so that diffusion is reduced to a minimum.

The lamp is mounted on a holder which permits the distance between the lamp and the working plane to be varied between 10 and 26 cm. This distance can be read off on a brass ruler fixed to the carriage.

The calculations which are necessary to work out the exposures on the film are straightforward. Referring to Fig. 5.22, if the distance between the step and the lamp is d metres and if the luminous intensity of the lamp is L candelas, then the illumination I of the step wedge is given by:

$$I = L/d^2 \text{ metre-candles (or lux).}$$

The width of the slit and the speed of the carriage can both be taken into

account by describing the slit in terms of the exposure-time it produces. If this time is t seconds, the exposure on the step wedge is

$$E = It = Lt/d^2 \text{ metre-candle-seconds (or lux-seconds).}$$

Before the light can expose the film, it has to pass through the step wedge. Consider just one step, and let its density be D_n and its opacity O_n . If the illumination on the step is I , the illumination transmitted will be I/O_n . The exposure of the film behind this step will therefore be

$$E = It/O_n.$$

The logarithm of the exposure is usually required and this is

$$\begin{aligned} \log E &= \log It/O_n. \\ &= \log I + \log t - \log O_n. \\ &= \log I + \log t - D_n. \end{aligned}$$

Since $\log I$ and $\log t$ are constants for any one exposure, the exposures on the film will vary only with the densities of the step wedge.

The X-6 step wedge has 21 steps, and each wedge is calibrated individually. The difference in density between steps is made as close as possible to 0.15 and the total density range is about 3.0. The calibration of the step wedge used at the BBC Television Film Studios, Ealing is shown in Table 5.3.

When the test strip has been developed and the densities measured, the characteristic curve should be plotted and it can be seen from Table 5.3 that this involves an awkward series of $\log E$ increments. To overcome this difficulty a celluloid scale can be marked with the position of each $\log E$ step resulting from the use of a particular wedge. This is best done by taking as reference point the density of the densest step of the wedge as this will produce the smallest value of exposure on the film. The density decrements between successive steps are then measured off on the scale as corresponding $\log E$ increments. The column in Table 5.3 marked *Distance on Scale* shows the distance of the step marks measured from the origin when $1 \text{ cm} = 0.2 \log E$. Once this scale has been made it is sufficient to calculate the $\log E$ exposures on the film for the densest step, mark this value on the graph paper as a reference, and lay off all the other points by using the scale. This establishes the $\log E$ values absolutely. Often it is sufficient to know only the relative $\log E$ values and the ruler markings can then be used from any convenient reference point.

Densitometers

GENERAL. The necessary parts of a modern densitometer are:

1. *A lamp and optical system which provide a fixed illumination on the film*

TABLE 5.3
 CALIBRATION CHART FOR A CAST CARBON TEST WEDGE
 (ALSO SHOWING DIMENSIONS FOR A LOG E MEASURING SCALE)

<i>Step No. on Wedge (counting from lowest densities)</i>	<i>Density of Step</i>	<i>Change in Density or Change in Resulting log E (increasing log E)</i>	<i>Cumulative Density Change</i>	<i>Distance on Scale (1 cm = 0.2 log E measured from min. log E)</i>	<i>Step No. on Test Strip and Ruler (counting from lowest log E values)</i>
21	3.24	—	—	—	1
20	3.07	0.17	0.17	0.85	2
19	2.93	0.14	0.31	1.55	3
18	2.78	0.15	0.46	2.3	4
17	2.63	0.15	0.61	3.05	5
16	2.48	0.15	0.76	3.8	6
15	2.32	0.16	0.92	4.6	7
14	2.17	0.15	1.07	5.35	8
13	2.01	0.16	1.23	6.15	9
12	1.87	0.14	1.37	6.85	10
11	1.72	0.15	1.52	7.6	11
10	1.58	0.14	1.66	8.3	12
9	1.43	0.15	1.81	9.05	13
8	1.28	0.15	1.96	9.8	14
7	1.12	0.16	2.12	10.6	15
6	0.97	0.15	2.27	11.35	16
5	0.83	0.14	2.41	12.05	17
4	0.69	0.14	2.55	12.75	18
3	0.55	0.14	2.69	13.45	19
2	0.40	0.15	2.84	14.2	20
1	0.25	0.15	2.99	14.45	21
<i>Total Change</i>	2.99	2.99	2.99	14.45	

under test. For photographic work, the densitometer usually subjects the sample to parallel incident light.

2. *A measuring device, usually a photocell, which measures the proportion of the incident light transmitted through the sample.* Some types of densitometer measure the diffuse component and some the specular component of the transmitted light; the choice depends on the future use of the film being measured. If a negative film, for example is to be contact printed, it is usual to measure the diffuse density, as all the light transmitted is effective in printing; if the film is to be optically printed, it is usual to measure the specular density, because the light which is scattered plays no part in making the print.

3. An indicating circuit, which accepts a signal from the measuring device, and allows the density of the sample to be read directly on a meter. Although the property of the sample which is measured is opacity, for convenience the densitometer must be calibrated in density. If an even scale is required, the indicating circuit must therefore incorporate a stage which converts a linear input corresponding to opacity into a logarithmic output which corresponds to density. This is done using either a logarithmic amplifier or a meter with a logarithmic response.

These points are best illustrated by considering three practical densitometers.

E.E.L. DENSITOMETER. The basic layout of the E.E.L. densitometer is shown in Fig. 5.23. There is no amplifier, and the output from the photocell is read

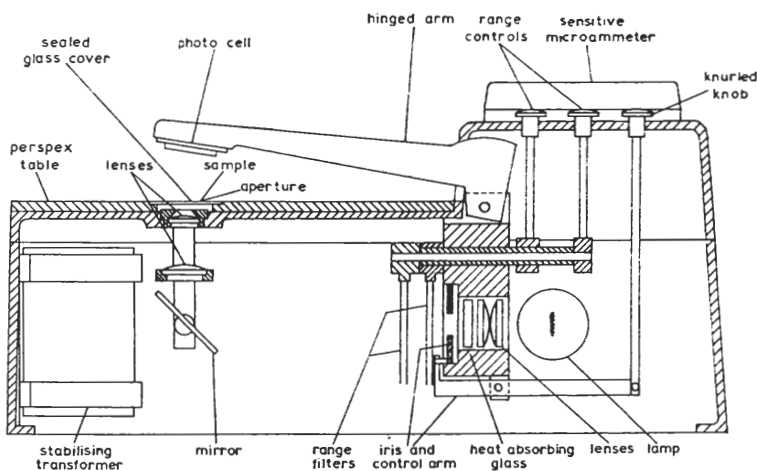


Fig. 5.23. E.E.L. Densitometer: Cross-section

directly on a logarithmic microammeter with a full-scale deflection of $7 \mu\text{A}$.

The photocell is mounted in an arm which can be lowered to a position above a small hole in the base of the instrument through which light passes. Fig. 5.24 shows the meter with the arm up.

The densitometer is lined up for operation by adjusting the light which falls onto the photocell so that the meter indicates zero density when no sample is in position. This is done by adjusting an iris control which is between the lamp and the sample position. The sample is then placed in position and the density read on the meter.

The meter reads directly over the range $D = 0$ to $D = 2$, and the range can be changed by removing neutral density gauze filters from the light path. There are two such filters; the removal of one filter shifts the range by one density unit, so that the meter reads from $D = 1$ to $D = 3$; the removal of the second

filter shifts the range by a further one unit, so that the meter reads from $D = 2$ to $D = 4$.

The lamp is a 12-volt 6-watt tungsten-filament type, and variations in light output resulting from mains-voltage variations are prevented by the use of a 250/12-volt constant-voltage transformer.

WESTREX DENSITOMETER. The optical arrangements of the Westrex densitometer are shown in Fig. 5.25. Light from an exciter-lamp is interrupted by a

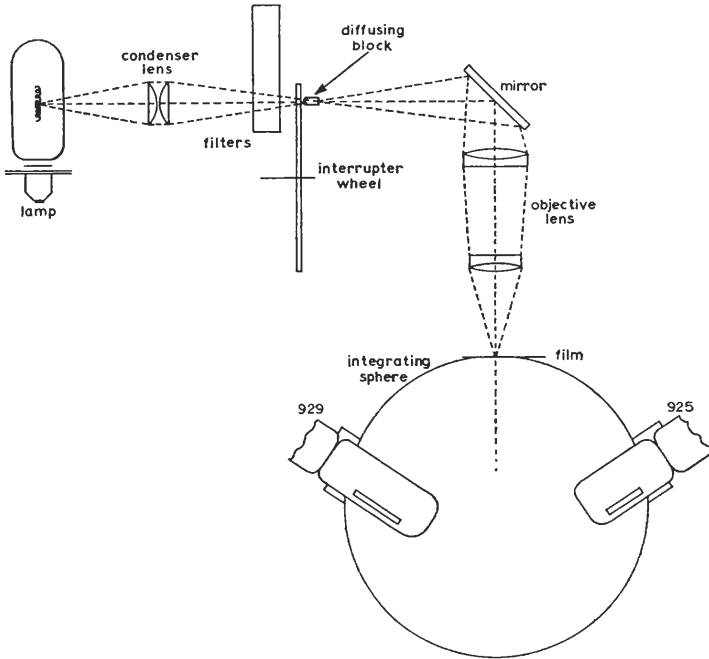


Fig. 5.25. Westrex Densitometer: Optical Arrangement

light chopper and directed through the film and a limiting aperture by suitable lenses. After passing through the film the light enters an integrating sphere and produces a signal in two photocells. The amplified and rectified output from the photocells is indicated on a logarithmic meter calibrated in terms of density.

The lamp is a 5-amp 10-volt tungsten-filament type, fed from a regulating transformer and run at 4.8 amps so that it operates at a low temperature. The light flux from the lamp is interrupted at 375 c/s (on a 50-c/s supply) by an interrupter wheel driven by a synchronous motor. An a.c. output is therefore obtained from the photocells, thus allowing an a.c. amplifier to be used, and so overcoming the long-term stability problems associated with d.c. amplifiers.

The diffusing block shown in Fig. 5.25 is used to avoid producing an image

of the lamp filament on the film. The diffusing block re-radiates the flux which falls on it and ensures even illumination.

The two photocells used in the integrating sphere are of different types, a Type-929 blue-sensitive cell and a Type-925 red-sensitive cell. Their outputs are connected in parallel so that a full range of wavelengths can be detected.

The meter is scaled to read densities between 0 and 1.1, and range changing is carried out electrically by means of pushbuttons which give ranges of 0-1,

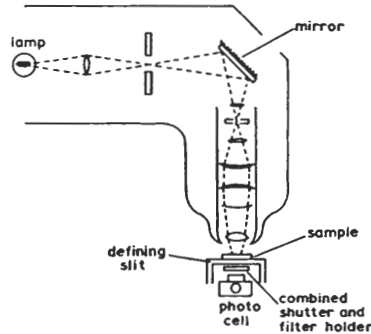


Fig. 5.26. Baldwin Type-MND/LD Line Densitometer: Optical Arrangement

1-2, 2-3, and 3-4. The extra 0.1 division on the meter scale permits a small overlap between ranges.

BALDWIN DENSITOMETER, This consists of two parts, a line densitometer Type MND/LD which constitutes the optical part of the instrument and a photometer Type MND which constitutes the electronic part.

The optical arrangement of the line densitometer is shown in Fig. 5.26. The light from a lamp is projected through the sample and onto a photocell, having

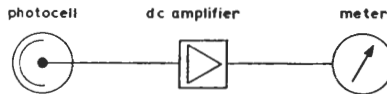


Fig. 5.27. Baldwin Type-MND Photometer: Block Diagram

first passed through a defining slit the longer dimension of which is parallel to the perforation holes in the film. The slit dimensions are 0.10 by 0.02 in. for black-and-white measurements and 0.10 by 0.045 in. for colour film.

In the photometer part of the instrument, the output from the photocell is amplified by a d.c. amplifier and measured by a meter as shown in Fig. 5.27. Full-scale deflection of the meter is obtained when 0.1, 1 or 10 millilumens are incident on the photocell, the required sensitivity being selected by a range-changing switch.

The apparatus will read densities over the range 0-3 to an accuracy of 0.02, and up to 4.0 with a slight falling off in accuracy. The range can be extended by increasing the light intensity of the lamp, and then adjusting the gain of the amplifier so that a zero reading is obtained with a neutral density filter of a known value in the light path. When the filter is removed and the sample substituted, its density is found by adding the filter density to the meter reading.

Bibliography

[1] S.M.P.T.E., *Control techniques in film processing*. 1960.

[2] LOBELL, L. and DUBOIS, M., *Sensitometry*. First edition. Focal Press, 1955.

[3] RIECK, G. D. and VERBEEK, L. H., *Artificial light and photography*. First English edition.

Philips Technical Library. Centrex, Eindhoven, 1952.

[4] WHEELER, L. J., *Sensitometric control in film making*. BBC Engineering Division Monograph No. 33.

VI. CHEMISTRY OF FILM PROCESSING

Introduction

In development, the emulsion is treated with a solution which converts the unexposed silver halide to black silver. The final state reached depends on the time allowed for the reaction to take place. The distinction which the developer makes between the exposed and unexposed halide grains is primarily in the rate of reduction, it being generally supposed that the latent image speck on the exposed grain acts as a catalyst to accelerate the reduction of silver ions. As a result, more silver is formed on the latent image centre and further catalyses the reaction; this process is cumulative and the reaction is said to be *auto-accelerated*.

There are two types of development, chemical and physical. A *chemical developer* is essentially a solution of reducing agents which differentiates chemically between unexposed and exposed silver halide, and converts the exposed halide to metallic silver.

A *physical developer* contains chemical reducing agents and silver compounds in solution which deposit silver on the latent image centre, the silver deposited coming from the solution and not from the halide. In practice many developers, particularly slow-acting ones, behave in both ways although most of them are primarily chemical developers.

When a silver halide crystal in an emulsion starts to "develop", it does so at a limited number of points, from which development spreads outwards until the whole crystal is converted to silver.

It used to be thought that a grain either developed completely or not at all, but modern research has shown this to be untrue; indeed, the whole basis of "fine grain development" is the smaller grain size which results from incomplete development. The development starts at the latent image centres where silver was deposited during exposure, and reduction of the silver halide takes place about these centres. A possible explanation for this catalytic action is found in the Gurney-Mott latent image theory, according to which the latent image speck causes a break in the negatively charged sheath around the silver halide grain and so permits negatively charged developer ions to approach the grain against smaller repulsive forces than exist for non-sensitized grains.

There have been several attempts to establish an empirical relationship between developer ability and chemical structure, but so far no attempt has included all developing agents, although the great majority of these are aromatic compounds, principally simple benzene derivatives.

Composition of a Developing Solution

A developing solution normally contains the following:

(a) *A Developing Agent (or Agents)*, to convert the silver halide grains in the emulsion to metallic silver.

(b) *An Alkali*, which is needed to activate most developing solutions, and is sometimes called the *accelerator*.

(c) *A Preservative*, to prevent oxidation of the developer and the staining which can be caused by the products of oxidation.

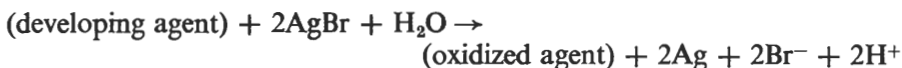
(d) *A Restrainer*, to prevent too rapid development of the unexposed grains.

In addition, there must be a solvent for these ingredients, and this is nearly always water.

Each main constituent will be considered in detail.

The Developing Agent

A “developing agent” is, in fact, a reducing agent, and the development process is thus one of reduction. The general reaction is



This reaction is strongly catalysed by the latent image material formed by the action of light. With the types of developing agent to be considered the basic action is chemical, and the extent to which physical development occurs is dependent on the presence or otherwise of silver halide solvents.

Many compounds act as developers. A few are inorganic, such as some ferrous salts, but most are organic. There is no satisfactory way of forecasting the behaviour of a compound as a developer and new types are found largely by trial and error.

The developers to be considered in this book are *Metol*, *Phenidone* and *Hydroquinone* and the mixtures of these three, and *Phenylenediamine*.

METOL: FIG. 6.1(a). Metol, or monomethylpaminophenol sulphate, has the chemical formula $\text{OH} \cdot \text{C}_6\text{H}_4(\text{NH} \cdot \text{CH}_3)\frac{1}{2}\text{H}_2\text{SO}_4$. It is also known as *Elon* (by Kodak), and as *Armol*, *Genol*, *Graphol*, *Photol*, *Pictol*, *Rhodol* and *Veritol*. The structural formula is shown in Fig. 6.1(a).

Metol developers give high emulsion speed, low contrast and fine grain, and are particularly valuable when maximum shadow detail is required. Metol may be used as the sole developing agent, but it is normally employed in conjunction with a second developing agent, hydroquinone.

PHENIDONE: FIG. 6.1(b). Phenidone, or 1-phenyl-3-parazolidone, has the formula $C_6H_5N \cdot NH \cdot CO \cdot CH_2 \cdot CH_2$. If used alone, phenidone gives a high emulsion speed with low contrast, but is not satisfactory as it has a tendency to fog. It is not therefore recommended for use by itself, but it shares with metol the ability to activate hydroquinone.

Phenidone developers are usually stable and have a long life.

HYDROQUINONE: FIG. 6.1(c). Hydroquinone, or parahydroxybenzene, is a relatively simple compound, with the formula $C_6H_4(OH)_2$. It is a low energy developer, whose activity is increased in the presence of metol and phenidone. Used by itself, a hydroquinone developer is characterized by high contrast, but sometimes fogs fast materials, and is also particularly liable to produce *aerial*

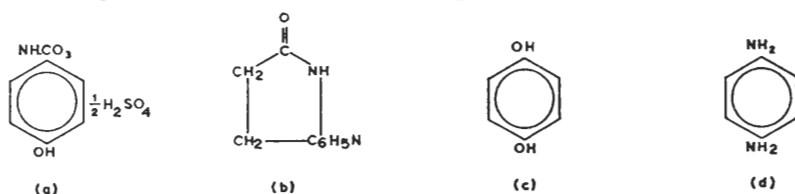


Fig. 6.1. Structural Formulae of Developers: (a) Metol, (b) Phenidone, (c) Hydroquinone, and (d) Paraphenylenediamine

fog if a piece of unexposed film is placed in it and not completely immersed, the surface layer of the developer fogging the emulsion strongly. Hydroquinone is only active in a solution of high pH value, and is ineffective below a pH of 9.2 when in the absence of metol or phenidone. The speed of reaction of hydroquinone developers is greatly increased by their own oxidation products. At a pH value of about 11.5, hydroquinone becomes fully ionized, and no further increase in activity occurs if the pH is increased still further.

A metol-hydroquinone developer is known as an *M.Q. Developer* and a phenidone-hydroquinone developer is known as a *P.Q. Developer*. Their characteristics will be discussed later.

PARAPHENYLENEDIAMINE: FIG. 6.1(d). Paraphenylenediamine, formula $C_6H_4(NH_2)_2$, behaves as a slow-acting fine-grain developer of low reducing energy. This behaviour and its solvent action on silver halide result in a loss of emulsion speed. Paraphenylenediamine is sometimes used with metol, which restores the emulsion speed at the expense of an increase in graininess.

The Alkali

An increase in the pH value (or alkalinity) of a developer generally causes an increase in the rate of development, at least over some range of values of

pH, and hence can cause a decrease in the time required to obtain a particular density or gamma.

Developers which contain one or two hydroxyl groups are more active in their ionized form than when non-ionized, and the degree of ionization increases with pH. Thus metol, with one hydroxyl group, and hydroquinone, with two, are both strongly affected by pH. Developers which do not contain hydroxyl groups are also affected by changes of pH, although the reasons for this are not clear. It has been suggested that the oxidation products interfere with the development process and that the stability of these oxidation products in solution depends on pH. Fig. 6.2 shows the effect of pH on the density

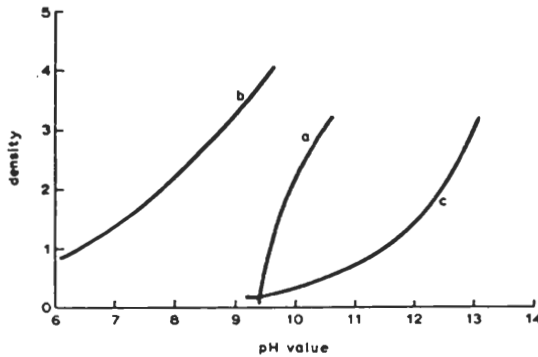


Fig. 6.2. Effect of pH on Density when Exposure and Time of Development are Fixed, using (a) Hydroquinone, (b) Metol, and (c) Paraphenylenediamine as the Developer

produced for a given exposure and a fixed development time using hydroquinone, metol and paraphenylenediamine which have respectively two, one and no hydroxyl groups.

At high pH values, the variation in development rate with pH becomes small for all three developers, partly because the degree of ionization is high and a further increase in pH produces little increase in the concentration of the active ions, and partly because diffusion of the developer through the gelatin becomes more important as the rate of development increases. At high pH values the diffusion rate largely controls the rate of development.

The pH value at which the developer works depends on the type of developing agent and the activity desired from the developer. Usually the activity of the developer does not depend very much on the nature of the alkali used to obtain a particular pH figure. Table 6.1 lists the more commonly used alkalis with their principal properties.

The buffering capacity of the alkali is important, as it is the pH of the solution within the layer of swollen gelatin which determines the actual rate of development of the layer; the pH of a poorly buffered solution may change much

TABLE 6.1
ALKALIS COMMONLY USED IN DEVELOPERS

<i>pH Value</i>	<i>Alkali</i>	<i>Remarks</i>
7.8-9.0	Sodium sulphite, $\text{Na}_2\text{SO}_3 \cdot 7\text{H}_2\text{O}$	Good buffer. Used in some low-energy fine-grain developers. Solvent action on silver halides introduces a significant amount of physical development
8-9	Borax (sodium tetraborate), $\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$	Very widely used. Strong buffer action
10-11	Sodium metaborate (Kodalk). Ammonium hydroxide, NH_4OH . Sodium carbonate, Na_2CO_3	Widely used for the more active developers
11-12	Sodium hydroxide, NaOH . Potassium hydroxide (caustic potash), KOH	The alkalis in this range are usually stored separately from the remaining constituents of the developer

more in this layer than in the bulk solution, particularly in areas of high exposure level. The nature of the buffer has only a slight effect on development rate.

The Preservative

Sodium sulphite, Na_2SO_3 , is commonly used as the preservative in developing solutions. In this role it has two functions, in addition to a third effect which is also of some interest.

1. PREVENTION OF OXIDATION. Sodium sulphite retards the reaction of oxygen with developing agents of the metol or hydroquinone type and thus acts as a preservative against aerial oxidation. A small quantity of sulphite will reduce the autoxidation considerably, as indicated in Fig. 6.3. However, as the sulphite is itself oxidized, a very large excess is usually included in any developer which has to be kept. Too much sulphite results in a reduced gamma and an increased fog level.

A possible explanation of the action of sulphite in preventing oxidation is that sulphite removes or prevents the formation of a catalyst for the oxidation process. In hydroquinone, the catalyst is probably quinone, $\text{C}_6\text{H}_4\text{O}_2$; it is formed by the oxidation process and itself catalyses the process which is therefore auto-accelerated. The reaction of sodium sulphite with the quinone is indicated in what follows.

2. REMOVAL OF STAINERS AND RESTRAINERS. Sodium sulphite also reacts with the development products to remove compounds which not only stain the gelatin and tan it but also restrain development. To see how this occurs, first

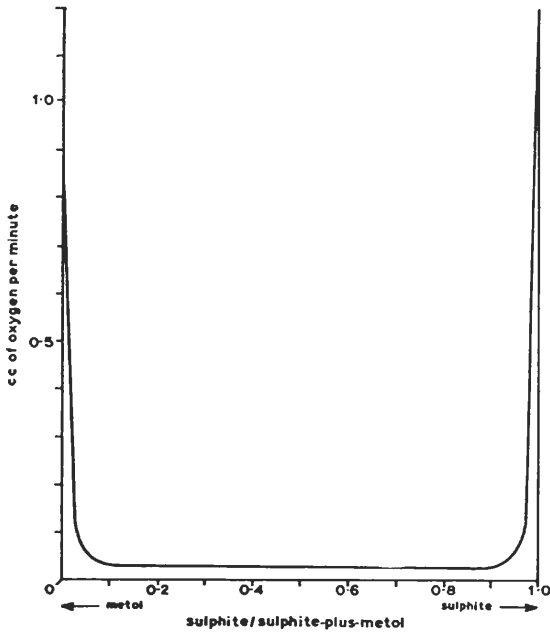
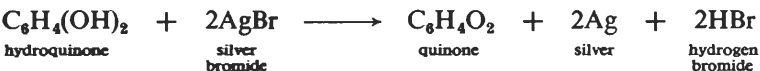
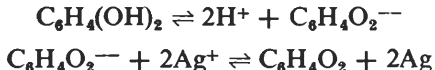


Fig. 6.3. Rate of Oxidation as Function of Sulphite to Sulphite-plus-Metal Ratio for pH of 6.6

consider the action of hydroquinone on silver bromide grains when there is no sulphite present.



It is thought that the oxidization of hydroquinone takes place in two stages, each involving the transfer of only one electron.



The quinone which is produced by the reaction combines with compounds in the emulsion to form stains which cannot be washed out. In addition to this, the hydrogen bromide which is produced is an acid and exists in solution as



which therefore reduces the pH of the developing solution.

When sulphite is present in solution, a further reaction takes place.



This additional reaction replaces the quinone with a stable nonreactive compound, and the sodium hydroxide produced tends to oppose the reduction in pH of the solution caused by the liberation of hydrogen bromide in the initial reaction.

In a P.Q. developer, a further reaction takes place with the phenidone which tends to make the sulphite less effective. This reaction will be examined later.

3. EMULSION SPEED INCREASE. Where sodium sulphite is employed as the preservative it can have a third effect on development. When sulphite is present in quantity in a developer solution, physical development takes place to a certain extent due to the solvent action of the sulphite on silver halide. As the rate of physical development is nearly constant, the lower the energy of the chemical development, the greater relatively is the effect of physical development. As the chemical energy of the developer is increased—as by increasing pH—so the importance of physical development is reduced. Care must be taken to ensure that the developer can reduce the silver produced by the sulphite, because, if it cannot, a layer of silver is laid down on the negative and dichroic fog produced.

With many emulsions, there may be an increase of emulsion speed for development to a fixed gamma, for moderate gamma values, when sulphite is used. This is the result of an increase in the rate of development in the low exposure region relative to that in the high exposure region. The effect occurs with a developer having doubly-charged ions, such as hydroquinone, but not to any extent with singly-charged or uncharged developers.

The Restrainer

Potassium bromide (KBr) or sodium bromide (NaBr) is often added to the developer solution in amounts of up to a few grains per litre. In this concentration range, the bromide decreases the rate of fog development to a greater extent than it decreases the rate of image development in an active developer, and so acts as a fog restrainer. The decrease in the rate of image development is generally greater in the low than in the high exposure region and therefore, for development to equal gammas, the characteristic curve is displaced towards the highest exposures values, thus showing a loss of speed. The inclusion of bromide in a developer also helps to reduce the effects caused by soluble bromine being liberated by development. This is why bromide is used as a restrainer

in most formulae, particularly in the more active developer group whose pH lies between 10 and 11. A certain amount of fog is tolerated in negative material—say a fog density of 0.2—so that the speed of the emulsion may be maintained.

Fog here can have two specific causes. These are (1) inability of the developing agent to differentiate between exposed and unexposed silver halide grains, and (2) the acquisition of sensitivity specks by unexposed silver halide grains which thus become indistinguishable from exposed grains. The resultant fog is therefore due to the fog-producing properties of both the particular developer and the particular emulsion.

Superadditivity

A developer made up of metol and hydroquinone has photographic properties superior to the sum of the properties of the two components separately. This developer property is known as superadditivity and its mechanism is not fully understood. The two components need not be metol and hydroquinone, but in general consist of (1) an agent which is active as a doubly-charged negative ion (e.g., hydroquinone) and (2) an agent which is active as an uncharged molecule (e.g., phenidone at low pH values) or as a singly-charged negative ion (e.g., metol, or phenidone at higher pH values).

Phenidone has the same superadditive properties with hydroquinone as metol has but to a greater degree. Phenidone can frequently take the place of metol in a developer and, when it does, it is only required in about one-tenth of the quantity of the metol it is replacing. As the P.Q. mixture is more active, the pH of the developer can be reduced by comparison with that of an M.Q. mixture, with consequently better storage properties.

It has been seen that hydroquinone, in the presence of a sulphite, forms on development the oxidation product hydroquinone monosulphonate. With metol this is very nearly inert, but with phenidone it forms a superadditive system of appreciable developing power. This means that a P.Q. developer lasts for longer than an M.Q. developer and also that the sulphite in it is less effective as a preservative.

Bromide has less of a restraining effect on P.Q. than on M.Q. developers, especially at low pH. This is specially noticeable in borax buffered developers and means that replenishment on a topping-up basis can be worked for longer periods than with an M.Q. developer.

P.Q. developers have a longer induction period than M.Q. developers, but tend to build the image more quickly once it starts. (The induction period is the period where the rate of formation of density increases with the time of development. Afterwards, density builds up at a more uniform rate.)

At high values of pH, phenidone has a fogging tendency with high-speed materials and it is necessary to include an *antifoggant* such as benzotriazole.

Types of Developer in Use

There are thousands of possible developer formulae, but in practice they can be reduced to three types which cover most normal requirements. These are:

Type A. M.Q.-borax or P.Q.-borax developers, which are a soft-working fine-grain type. They contain a high concentration of sulphite whose solvent action permits a degree of physical development to take place; in addition the sulphite confers some buffering action. A limit on the sulphite concentration is set by the fog level and low image densities.

Type B. M.Q.-carbonate or P.Q.-carbonate developers, which develop to a greater contrast than Type A. They work at a moderate pH of 10 to 10.5 and a moderate bromine concentration. Sodium bisulphite is used sometimes to improve the buffering qualities of the alkali.

Type C. Hydroquinone-caustic developers, which process to high density and contrast. They work at high pH and a lot of restrainer is used to give maximum contrast and minimum fog. The solution is usually stored in two parts, with the alkali kept separate. A lot of developer is used to obtain rapid development. The amount of sulphite used is not critical as it is employed merely as a preservative.

CONSTITUENTS. The constituents of these developer types are shown in Table 6.2 and a number of typical formulae are given in Table 6.3. All the formulae are shown with quantities of chemicals required for 1000 cub cm of

TABLE 6.2
CONSTITUENTS OF THE THREE MAIN DEVELOPER TYPES

<i>Constituents</i>	<i>Type A</i>	<i>Type B</i>	<i>Type C</i>
Developing Agent	M.Q. or P.Q.	M.Q. or P.Q.	hydroquinone
Preservative	sodium sulphite	sodium sulphite	potassium metabisulphite
Alkali	borax	sodium carbonate	potassium hydroxide
Restrainer	M.Q.: none	M.Q.: potassium bromide	potassium bromide
	P.Q.: potassium bromide	P.Q.: potassium bromide (organic)	
<i>pH Value</i>	8.5-9.0	10-10.5	11.0
<i>Examples</i>	Kodak: D76 (M.Q.) Ilford: ID11 (M.Q.) ID68 (P.Q.)	Kodak: D16 (M.Q.) Ilford: ID2 (M.Q.) ID67 (P.Q.)	Kodak: D153 Ilford: ID13

TABLE 6.3
DEVELOPER FORMULAE

<i>Type A</i>	<i>D76 (M.Q.)</i>	<i>ID11 (M.Q.)</i>	<i>ID68 (P.Q.)</i>
Water to:	1000 cc	1000 cc	1000 cc
Phenidone	—	—	0.13 gr
Metol	2 gr	2 gr	—
Sodium sulphite (anhydrous)	100 gr	100 gr	85 gr
Hydroquinone	5 gr	5 gr	5 gr
Borax	2 gr	2 gr	7 gr
Boric acid	—	—	2 gr
Potassium bromide	—	—	1 gr
<i>Type B</i>	<i>D16 (M.Q.)</i>	<i>ID2 (M.Q.)</i>	<i>ID67 (P.Q.)</i>
Water to:	1000 cc	1000 cc	1000 cc
Phenidone	—	—	0.05 gr
Metol	0.31 gr	0.4 gr	—
Sodium sulphite (anhydrous)	40.0 gr	15.0 gr	15.0 gr
Hydroquinone	6.0 gr	1.6 gr	1.6 gr
Sodium carbonate	18.7 gr	7.5 gr	7.5 gr
Potassium bromide	0.86 gr	0.4 gr	0.4 gr
Citric acid	6.7 gr	—	—
Sodium metabisulphate	1.4 gr	—	—
I.B.T. restrainer solution	—	—	3 cc
<i>Type C</i>	<i>DI53 and ID13</i>		
Hydroquinone	12.5 gr		
Potassium metabisulphite	12.5 gr		
Potassium bromide	12.5 gr		
Water to:	500 cc		
<i>plus</i>			
Potassium hydroxide	25 gr		
Water to:	500 cc		

working solution. The ID67 is normally made up to five times the concentration shown in the table and diluted for use. The ID13 is normally stored as two solutions as shown by the dividing line.

Fine Grain Development

Apart from phenylenediamine, developing agents show little difference in the graininess of the image they develop; the important factors seem to be the rate of development, the presence or absence of silver halide solvents and the ratio of physical to chemical development. For instance, a fine-grain developer such as D-76 loses its fine-grain action if the pH of the solution is increased to the point where it becomes a rapid developer.

The nature of the granular structure of the image is discussed fully in a later chapter; here it is sufficient to say that the eye is conscious of an effect—called graininess—produced by the uneven distribution of the silver particles forming the image. The size of a grain is too small for graininess to be caused by the visibility of individual grains, but for a given distribution, the larger the mean grain size, the greater the impression of graininess. It follows that if development is stopped before some of the grains are fully developed the mean size of the grains will be smaller and the image will appear less grainy. The price to be paid for this reduced graininess is a loss in film speed, because a greater number of grains must be exposed to achieve a given density, and a longer exposure time is needed to do this. Fine grain development invariably results in a loss of speed, and claims that a developer both reduces graininess and increases speed need not be taken too seriously. If particularly fine grained results are wanted it is better to rely on the emulsion chemist and use a slow fine grain film, giving it normal development, rather than use a faster film and sacrifice speed for grain with some special developer.

Normal development in these respects means the use of a developer of the D-76 type, where the rate of development is kept low, as it seems generally agreed that the combination of slow development with the solvent action of sodium sulphite produces a result with a satisfactory speed-grain relationship. If the energy of the developer is increased the image is coarsened but the speed of the emulsion is enhanced, and the formulation of a developer always involves a compromise between these two factors.

There is a third factor which is considered important nowadays, and that is the sharpness of the image. Modern emulsions are capable of very high “acutance” and a developer can help or hinder the emulsion in the impression of sharpness given. “Acutance” is the name given to the objective measure of the subjective impression of sharpness. Old super fine-grain (and super slow!) developers such as phenylenediamine, which depended for their effect on solvent-action, were very poor in this respect, and are seldom used nowadays, the emphasis being on more vigorous development which preserves, and even heightens, the visual effect of a transition. Such developers are called acutance developers and, being vigorous, are not fine-grained developers, so there are in effect three factors to be considered when choosing a developer—graininess, speed and acutance. Any gain in one respect must inevitably be paid for by a loss in one or both of the others. The way in which acutance developers actually enhance edge contrast is discussed in the following section.

Effects of Agitation

In the absence of agitation, a quiescent layer of solution forms at the emulsion surface. Diffusion of the developing agent and other components of the

solution into the gelatin decreases the concentration of these substances in the quiescent layer. Bromine liberated in development diffuses into this layer, which thus becomes richer in bromine than the bulk solution. Both the developing agent dilution and the bromide ion concentration slow down development, and the greater the local density the greater the slowing down. Agitation disrupts the quiescent layer and tends to keep the surface of the emulsion in direct contact with developer of normal composition. Fig. 6.4 shows (at the right) the effect of various rates of brush-agitation on the characteristic of an emulsion; it can be seen that the change from no agitation to moderate agitation has a great effect, but that rapidly diminishing benefits result from increasing

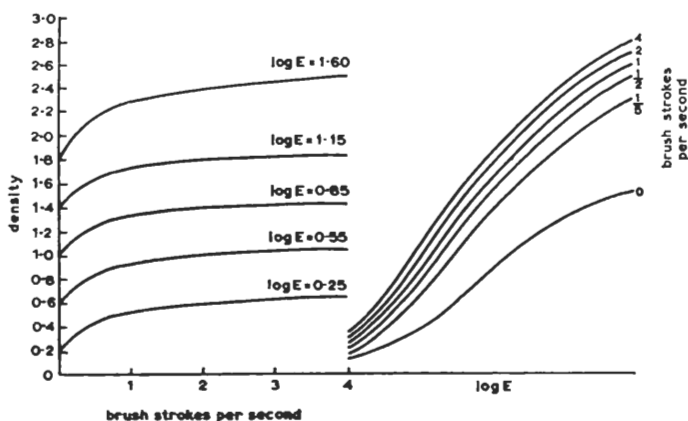


Fig. 6.4. Effect of Agitation on Rate of Development by a Rapidly-acting Developer

the rate of agitation beyond a certain value. Also shown (at the left) is the variation in density with agitation for given $\log E$ values.

The local exhaustion of the developer which results from the liberation of bromine causes a number of so-called *adjacency effects*. If the agitation is insufficient, the developer near an area of high density becomes more exhausted than the developer near a low density area. An adjacency effect occurs where there is an abrupt transition from the heavily exposed area to the lightly exposed one, as shown in Fig. 6.5(a), there being a migration of developer from one area to the other. While, on the one hand, the developer in the less dense area is degraded by exhausted developer migrating from the denser area, on the other hand the developer in the denser area is strengthened by developer migrating from the less dense area. The two effects are shown in Fig. 6.5(b).

The migration of fresh developer into the heavily exposed region results in a fine line of increased density on the dense side of the point of transition, which is called the *border effect*; the migration of exhausted developer into the lightly exposed area results in a fine line of reduced density on the less dense side of the

point of transition, which is called the *fringe effect*. These effects are illustrated in Fig. 6.5(c). The two lines show up on the developed image as a fine dark line on the darker side of the transition and a fine light line on the lighter side, and are called *Mackie Lines*. An impression of added sharpness can often result from the presence of these lines at an abrupt transition in density on the

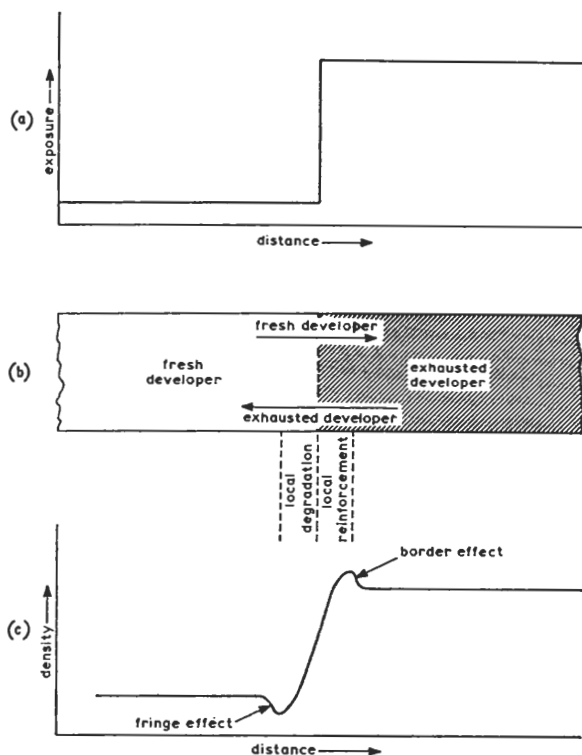


Fig. 6.5. Adjacency Effect Caused by Local Exhaustion of Developer and Insufficient Agitation

film; *acutance developers* depend on local exhaustion to produce such an impression.

Other manifestations of adjacency effect exist and have their individual names. The *Eberhard effect* is the name used to describe the variations of density which occurs when areas of equal exposure but unequal size are developed; the smallest areas have the greatest density, as can be seen in Fig. 6.6, while exhaustion produced by the large areas reduces the density which can be obtained in these. The *Kostinsky effect* is the change in the size and separation of two small closely-spaced image areas; the size of these areas is reduced and the spacing between them increased as shown in Fig. 6.7. *Streamers* are caused by insufficient agitation in a particular plane; exhausted developer from a

dense area and fresh developer from a light area migrate into adjacent areas and cause light and dark streamers respectively.

Effects of Developer Exhaustion

Many factors combine to cause the exhaustion and loss of developer. The most important of these are:

1. Carry-over of developing solution by wet film leaving the developing tank.

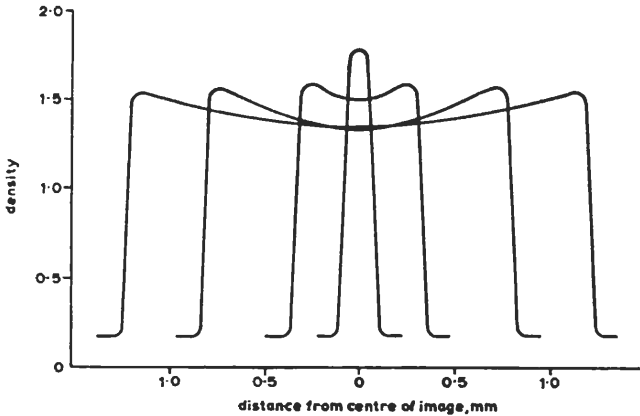


Fig. 6.6. Microdensitometer Traces showing Eberhard Effect

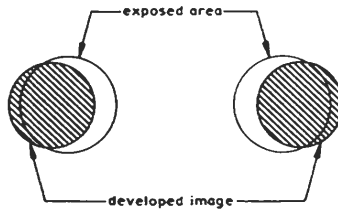


Fig. 6.7. Kostinsky Effect. (This makes images smaller than exposed areas and increases spacing between them)

2. Loss of developing agents due to development.
 3. Reduction in pH of the developing solution due to development.
 4. Loss of developing agents due to aerial oxidation.
 5. Increase in pH of the developing solution due to aerial oxidation.
 6. Loss of sulphite due to aerial oxidation and the action of development.
- Once this loss has passed a critical point, the rate of oxidation of the developer increases very rapidly, and staining of the film can then result.

7. Accumulation of the by-products of the development process, such as sodium bromide, sodium iodide and the oxidation products of development. These by-products have a greater restraining effect on development than the other factors so far enumerated, and tend to reduce both the extent of development and the emulsion speed, while the time of development to a given gamma increases.

In many processes a *replenisher* is added which keeps the volume of the developing solution constant. This replenisher is sometimes made to a special formula, designed to counteract at least to some extent the effect of exhaustion products of the bulk solution.

Effects of Variation in Developer Constituents

The effects of variation in the constituents of a developer are shown in Table 6.4, and the changes needed to produce a required result are shown in Table 6.5.

TABLE 6.4
EFFECTS OF CHANGES IN DEVELOPER CONSTITUENTS

<i>Constituent</i>	<i>Change</i>	<i>Effects</i>
Developing Agent	Increase Concentration	Gamma almost unchanged. Time for development to a given gamma reduced. Developer working life reduced
	Increase Hydroquinone Ratio	Development time reduced. Gamma almost unchanged
	Reduce Hydroquinone Ratio	Emulsion speed increased. Fog reduced
Sulphite	Reduce	Developer keeping properties reduced. The degree of solution-physical development may be reduced
Alkali	Increase pH	Developer activity increased. Gamma almost unchanged. Working life reduced
Restrainer	Increase	Fog reduced. Emulsion speed reduced. Time for development to a given gamma increased
Solution Concentration	Increase	Time for development to a given gamma reduced. The solution concentration is limited by solution chemistry and by the restriction which increasing salt content places on the swelling of the gelatin

TABLE 6.5
GAMMA AND DENSITY CHANGES
OBTAINABLE BY DEVELOPER MODIFICATION
(FIXED DEVELOPMENT TIME)

<i>Desired Change</i>		<i>Developer Modification to Obtain Desired Change</i>
<i>Gamma</i>	<i>Density</i>	
Increase	Increase	Increase pH Increase temperature
Increase	No change	Increase bromide Increase hydroquinone
Increase	Decrease	Increase bromide
Decrease	Decrease	Decrease pH Decrease hydroquinone Decrease temperature
Decrease	Increase	Decrease bromide Increase metol

Fixing and Washing

When the development process has been completed, the film passes through the following stages:

1. Rinsing bath,
2. Stop bath,
3. Fixing bath,
4. Hardening,
5. Washing,
6. Drying.

Sometimes some of these stages may be omitted or combined with others.

Rinsing is simply the washing of the film in water to remove the gross contamination of the film by the development products. It slows the process of development, but does not stop it. Often the rinsing bath is combined with a *stop bath* by making the rinsing water acidic; with most developers this is sufficient to stop development completely. Solutions of potassium metabisulphite (2½ per cent) or glacial acetic acid (1 per cent) are frequently used.

The primary purpose of a *fixing bath* is to remove the unexposed silver halide from the emulsion, and the main constituent of the bath is therefore a solvent for silver halide. This solvent must form complexes which may easily be removed without staining or otherwise affecting the silver image appreciably.

The two principal fixing agents are ammonium thiosulphate, $(\text{NH}_4)_2\text{S}_2\text{O}_3$, and sodium thiosulphate or "hypo", $\text{Na}_2\text{S}_2\text{O}_3 \cdot 5\text{H}_2\text{O}$. Both these agents have a solvent action on the silver image, and for this reason a developed film should not be left for more than about thirty minutes in a fixing bath. The silver halides are removed from the film by transformation into rather unstable ammonium (or sodium) argentothiosulphates, which must be removed by washing to prevent long-term staining. Great care must be taken to avoid using an exhausted fixing bath lest the film become stained by adsorbed complexes.

Precautions must be taken to avoid carry-over of developer into the fixing bath, because when this happens the preservative in the developer becomes

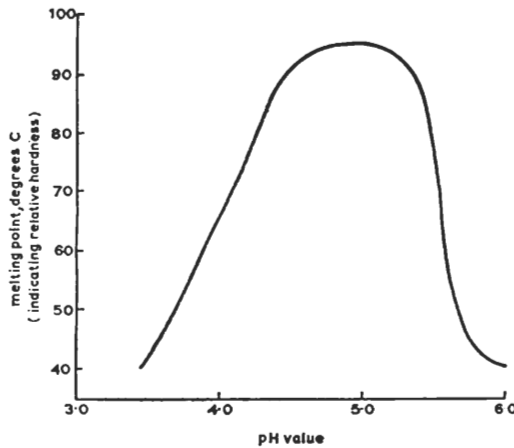


Fig. 6.8. Variation in Hardening with the pH of a Potassium Alum Fixing Bath

diluted, rapid oxidation of the developing agent takes place and the oxidation products stain the film. Also, the action of the developer in the presence of such a strong solvent of silver halide as the fixer causes a dichroic fog to form on the film. Both these dangers can be overcome by fixing at an acidic (i.e., low) value of pH, as this prevents further development from occurring. The bath is then known as an *acid fixing bath*. Film which is going to be handled a lot should be hardened and this can be done either in a special *hardening bath* or in the fixing bath. The period of greatest danger from abrasion is during the *washing* process when, because of the low salt content, swelling of the film is at its greatest; if the hardener is used with the fixer, protection is given in sufficient time. Suitable materials for hardening are white alum or chrome alum. The fixing bath should be held to an acidic pH and should have good buffering properties. Fig. 6.8 shows the effect on hardness of changing pH. A typical acid fixing and hardening bath contains potassium alum, ammonium thiosulphate, sodium sulphite and a weak acid such as glacial acetic.

RATE OF FIXING. This depends on:

1. *The nature and concentration of the fixing agent:* For emulsions with no iodide content, ammonium thiosulphate and sodium thiosulphate have similar rates of fixing. Most fast emulsions, however, contain some iodide, and with these the speed of reaction with sodium thiosulphate is greatly reduced. (Most high-speed fixers, such as Amfix, are based on ammonium thiosulphate.) Fig. 6.9 shows the effect of the concentration of a fixer on the rate of fixation. It can be seen that there is an obvious region where the concentration is an

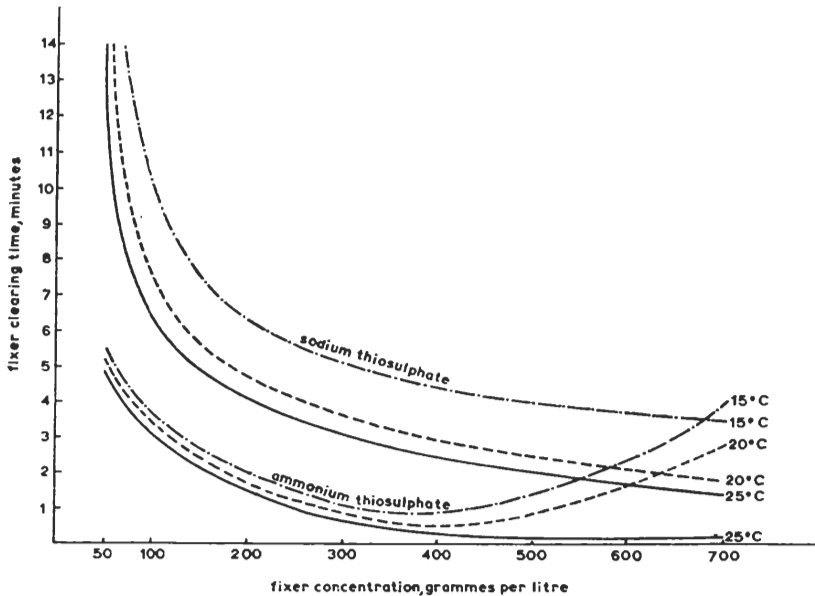


Fig. 6.9. Clearing Times in Sodium Thiosulphate and Ammonium Thiosulphate at Different Concentrations and Temperatures (Courtesy of D. Van Nostrand Company, Inc.)

optimum, with the rate of fixation hardly increasing beyond a certain value. (The impression given in Fig. 6.9 that the rate of fixation reduces with increasing concentration beyond a certain point is misleading. This is a result which occurs in the conditions used to obtain the results shown, but which does not occur when a large volume of fixer is present.)

2. *The temperature of the solution:* The increase in the speed of the reaction when the temperature is increased is shown in Fig. 6.9.

3. *The nature of the emulsion:* Fine-grain negatives fix faster than coarse-grain ones and thin emulsions faster than thick ones. Fig. 6.10 compares the rate of fixing for two emulsion types.

4. *Agitation:* This increases the speed of fixing up to a certain limit.

5. *The state of exhaustion of the fixer:* When the bath is used, it accumulates silver halides and silver thiosulphate complexes. These tend to slow down the reaction. Also, developer carry-over tends to raise the pH and dilute the fixer.

LIFE OF FIXING BATH. The rate of fixing is usually determined by measuring the *clearing time*. This is the time taken to reach the point at which the fixing seems to have finished as judged by the eye. At this point, fixing is not in fact complete and the *fixing time* is generally taken to be twice the clearing time.

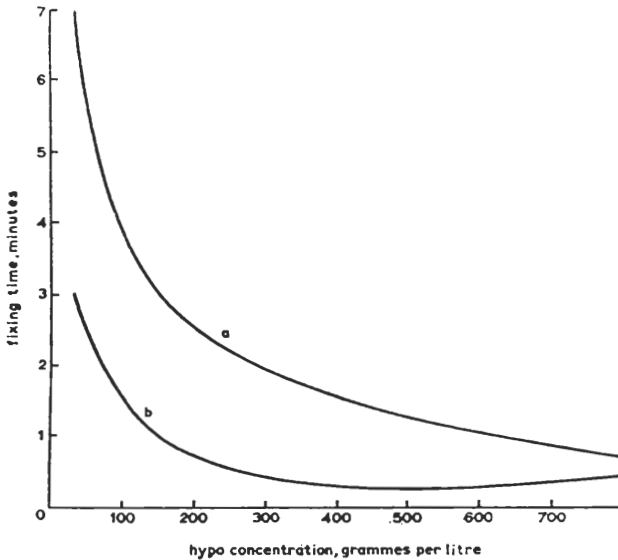


Fig. 6.10. Dependence of Fixing Time on Hypo Concentration for (a) Coarse-grain and (b) Fine-grain Emulsion

When the clearing time for a fixing bath has risen to twice the clearing time of a fresh bath, it should be replaced or replenished.

There is often some difficulty in determining the clearing time of a high speed fixing agent. The method to be described is due to May and Baker.

A two-inch square of the film to be examined is soaked for five minutes in distilled water at 68°F (20°C). About 50 cub cm of the fixing solution at its working concentration are poured into a shallow glass tray with a sheet of black paper underneath it. The square of film is removed from the water, blotted, and a drop of the fixing solution is placed on its emulsion side. After a quarter of the expected clearing time has elapsed, the film is plunged into the tray of fixer and a stop-watch started. The tray is kept agitated and the clearing time is taken as the number of seconds of immersion required for the spot on the film produced by the preliminary drop of solution to merge with the remainder of the emulsion. The mean of three tests should be taken.

WASHING. Washing removes all the soluble salts left in the emulsion layer after fixing; these are mainly the thiosulphates and complex silver salts. If thiosulphate is allowed to remain, it discolours the silver image, the sulphur in the residual thiosulphate combining with the image to form yellowish brown silver sulphide. If the complex silver salts are allowed to remain they may also decompose to form silver sulphide.

The effective speed of washing increases with temperature, but the increase in washing speed produced at temperatures above 75°F does not justify the increased risk of damage due to softening of the gelatin. Material fixed in an acid fixing and hardening bath requires more washing than film fixed in a plain solution.

DRYING. Drying should be done in a good circulation of *warm* air. When a film is dried for a short time in *hot* air, the surface skin becomes overdried while the inside of the emulsion is left moist; if the film is then projected immediately, there is excessive friction between the film and the gate runners, because the pitch of such an overdried film is shorter than normal.

Even when properly dried, a *green film* (straight from processing) is not in a suitable condition for immediate projection, because the emulsion layer is soft and easily scratched, and it also rubs off on the runners and channels of the film gate. If time is available, the film should be protected and lubricated by waxing.

Reversal Processing

Details of reversal processing are given at the end of Chapter 11.

Bibliography

[1] MEES, C. E. K. and JAMES, T. H., *The theory of the photographic process*. Third edition. Macmillan, New York, 1966.

[2] JAMES, T. H. and HIGGINS, G. C., *The fundamentals of photographic theory*. Second edition. Morgan and Morgan, New York, 1960.

[3] NEBLETTE, C. B., *Photography*. Sixth edition. Van Nostrand, 1962.

[4] HORDER, A., (Editor), *The Ilford manual of photography*. Fifth edition, fourth reprint, 1963.

[5] S.M.P.T.E., *Control techniques in film processing*. 1960.

VII. SENSITOMETRY: APPLICATIONS

Control of Development

The shape of the characteristic curve of an emulsion alters with the conditions of development, and film manufacturers publish curves similar to those shown in Figs. 7.1 to 7.5 so that processing conditions may be adjusted as required.

The effect of time on development can be seen from the family of curves shown in Fig. 7.1. As development time is increased, the characteristic moves

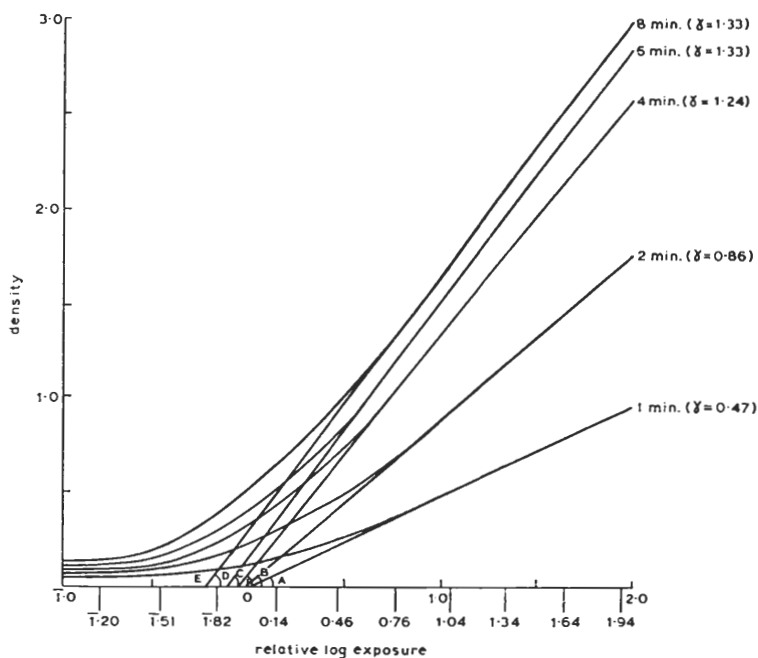


Fig. 7.1. Effect of Development Time on Emulsion Characteristic

to the left and the gamma, which is the slope of the straight-line portion, increases. The results shown in Fig. 7.1 can be used to produce the gamma/time curve shown in Fig. 7.2, which is of interest when development to a fixed gamma is required. Figs. 7.3 to 7.5 show families of characteristics and gamma/

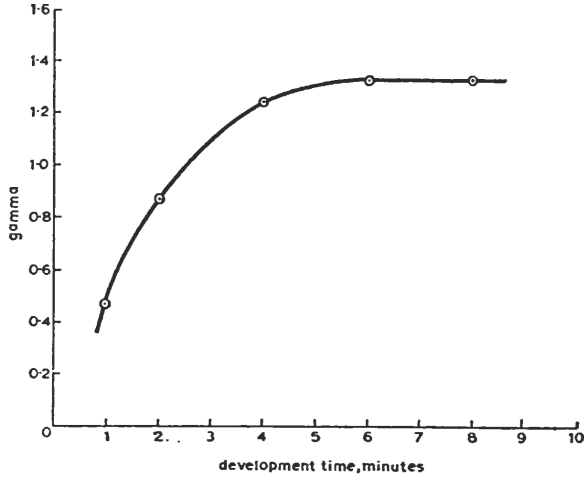


Fig. 7.2. Gamma/Time Curve Derived from Fig. 7.1

time curves for three typical modern emulsions as illustrated in the manufacturers' information leaflets; in two of the examples a fog/time curve is also shown. The exposure and development conditions applicable to the curves are

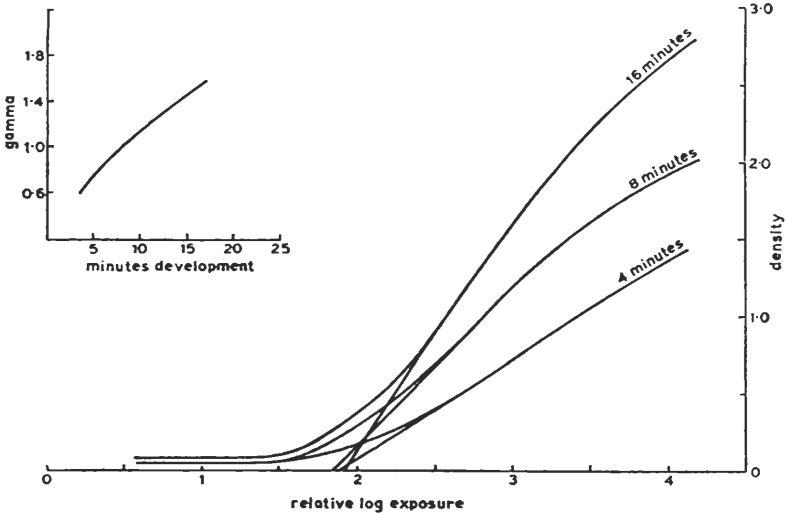


Fig. 7.3. Characteristic Curves for a Modern Fine Grain Negative Emulsion for Different Development Times

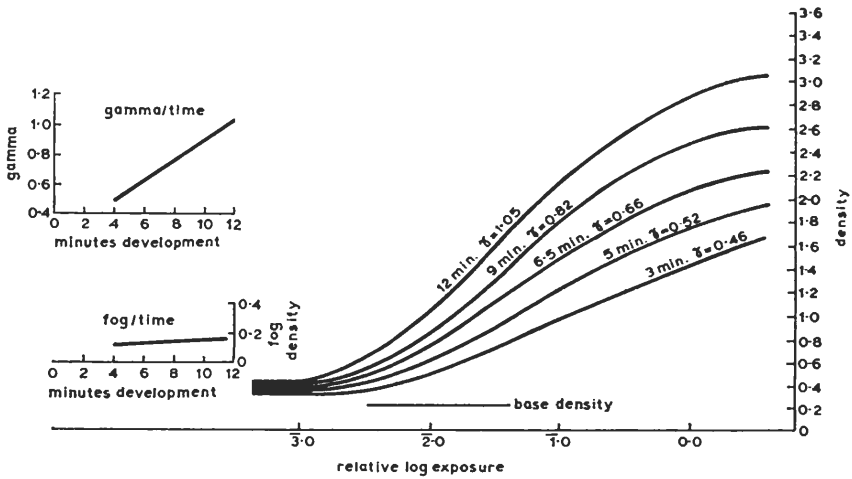


Fig. 7.4. Characteristic Curves for a Modern Fast Negative Emulsion for Different Development Times

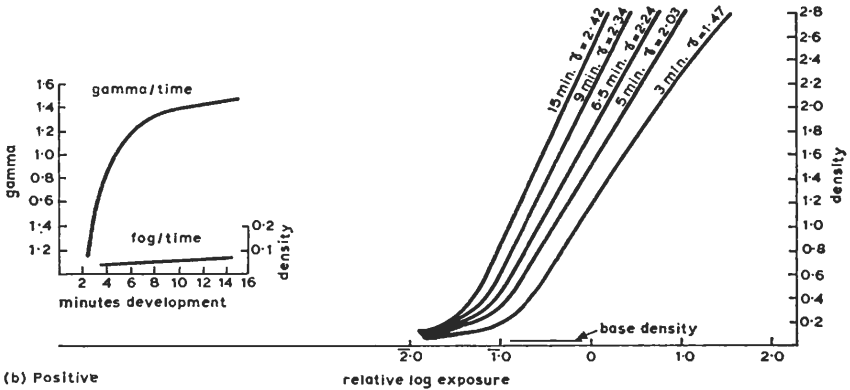
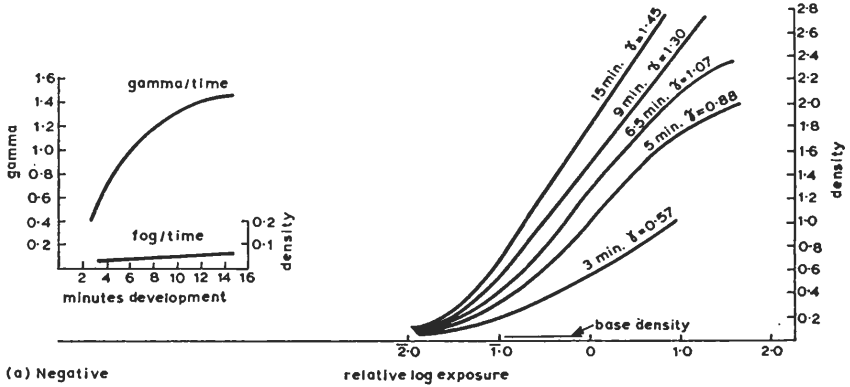


Fig. 7.5. Characteristic Curves for a Telerecording Film Developed (a) as a Negative and (b) as a Positive

always quoted, so that the user can allow for the difference between his own conditions and the manufacturers'. The importance of making this allowance is illustrated in Figs. 7.6 and 7.7; Fig. 7.6 compares the effect of non-intermittent

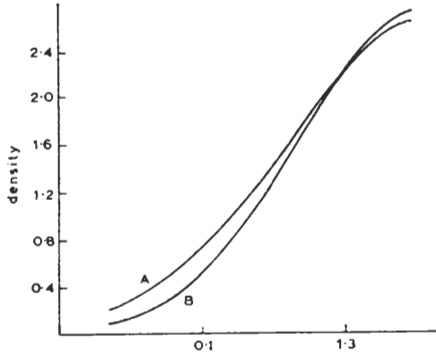


Fig. 7.6. Effects of (A) Non-intermittent and (B) Intermittent Exposures

and intermittent exposures and Fig. 7.7 compares the effect of intensity-scale and time-scale exposures. The difference is caused in each case by reciprocity failure and is too large to be ignored.

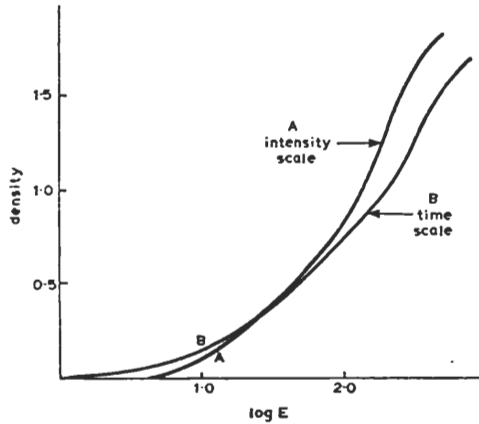


Fig. 7.7. Effects of (A) Intensity-scale and (B) Time-scale Exposures

Fig. 7.8 indicates the effect of temperature, using various developers, on the time taken to develop a film to a fixed gamma value. The curves shown were derived from families of characteristics resembling those shown in Fig. 7.1, but obtained by increasing the temperature instead of increasing the time.

The characteristic curve can be used to assess changes in the constituents of a developer, as illustrated, for example, in Fig. 7.9. The upper diagram,

Fig. 7.9(a), shows the curves for a range of development times using a developer containing no restraining bromide; the straight-line portions of these curves, when produced, meet at a point on the log E axis, called the *inertia point*. The lower diagram, Fig. 7.9(b), shows the curves obtained after a series of development times in a developer containing restraining bromide. The curves meet at a point below the log E axis and their inertia points, which are where the straight-line portions cut the log E axis, move to the left with increasing exposure.

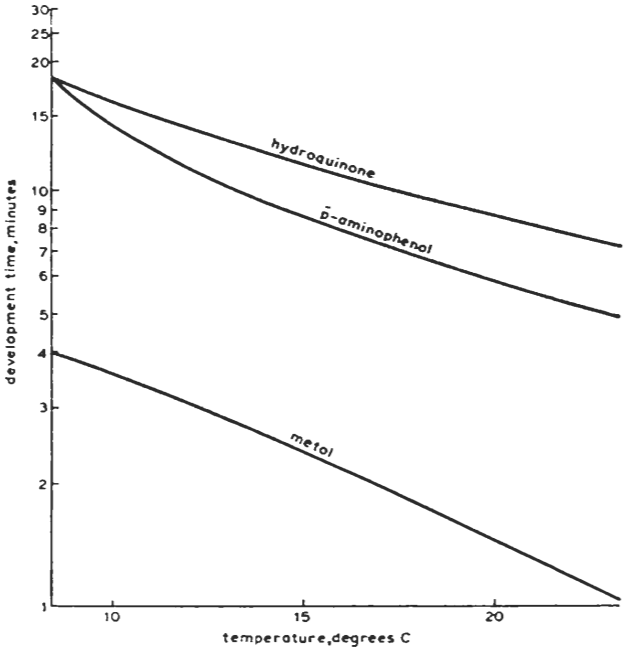


Fig. 7.8. Relationship between Time and Temperature for Development to a Fixed Gamma

This phenomenon is known as the *regression of inertia*. Many modern emulsions have no point where the straight line-portions meet, but the restraining effect of bromide at low values of exposure can still be observed, although not so clearly as when there is a common point as in the example chosen.

Film Speed Measurement

Fig. 7.10 shows how the range of exposures covered by the brightness range of a scene to be photographed can be represented on the characteristic curve; the effect of underexposure is illustrated in Fig. 7.10(a), satisfactory exposure in Fig. 7.10(b) and over exposure in Fig. 7.10(c). It can be seen that the correct

choice of exposure must depend on the brightness range of the subject and the shape and position on the $\log E$ axis of the characteristic curve.

The brightness range for an average sunlit scene has been established from a large number of observations, and the results expressed in terms of the average luminance of the scene as recorded by a calibrated integrating exposure

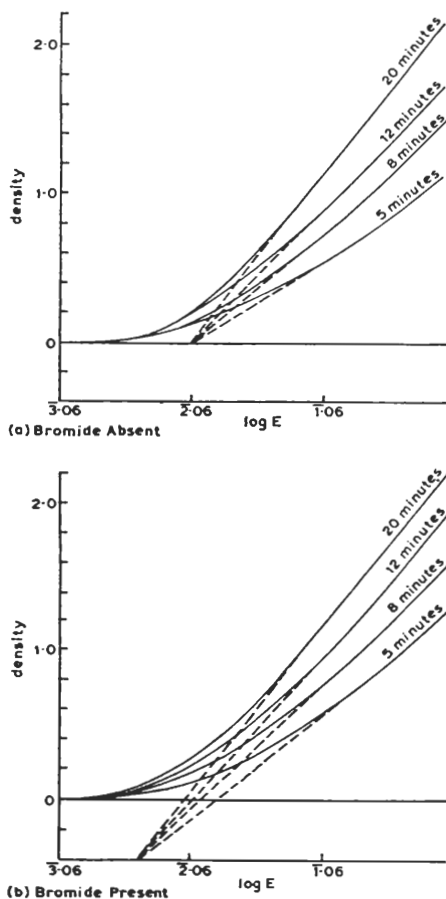


Fig. 7.9. Effects of Change in Developer Constituents on Shape of Characteristic

meter. The maximum luminance, in the highlights, is on average 0.55 $\log E$ units greater than the average luminance; the minimum luminance, in deepest shadow, is 1.8 $\log E$ units less than the highlight maximum. Fig. 7.11 shows how such a scene appears on the characteristic curve.

What a film speed measurement system has to do is fix a reference point on the characteristic curve so that a correct exposure can be made from a knowledge of the average scene luminance and the position of the reference point.

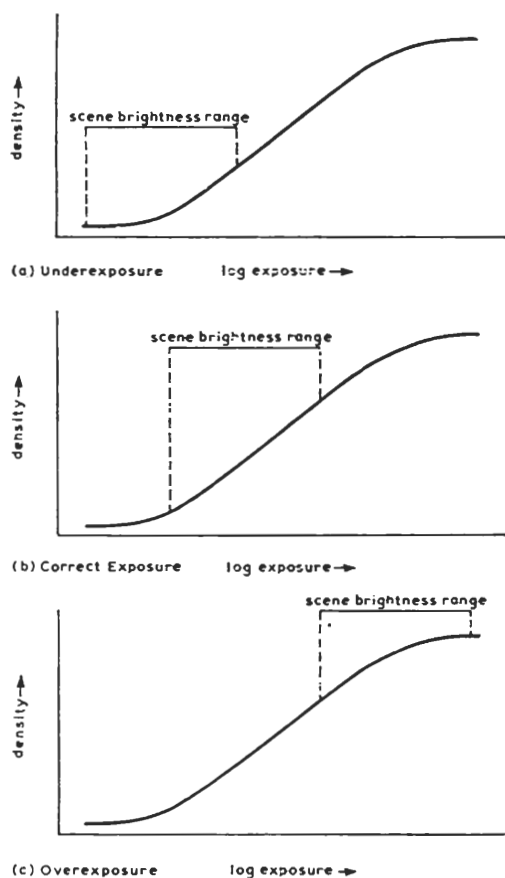


Fig. 7.10. Effects of (a) Underexposure, (b) Correct Exposure and (c) Overexposure

For most speed systems, the reference point, or *speed point*, is chosen to mark the position of minimum useful exposure on the curve. This enables the reading of average luminance shown by an exposure meter to be converted into a correct value of exposure for the film. To explain the method of conversion, it will be assumed that the film characteristic and the meter readings are as indicated in Fig. 7.11, and that the speed point has been determined (by a method to be discussed later). A further point of importance is the safety factor which is required. It is not usual to work at the minimum exposure values, because of the danger of underexposure, and the exposure is therefore usually increased by a safety factor, a reasonable value for which might be $\times 2$ or, in $\log E$ units, $+0.3$.

Fig. 7.12 shows how the correct exposure for a scene can be determined from these considerations. The speed point is shown marked at a $\log E$ value of $\log E_s$. If there were no safety factor, E_s would be the exposure given to the shadow detail of the scene, but allowance for the safety factor must be made,

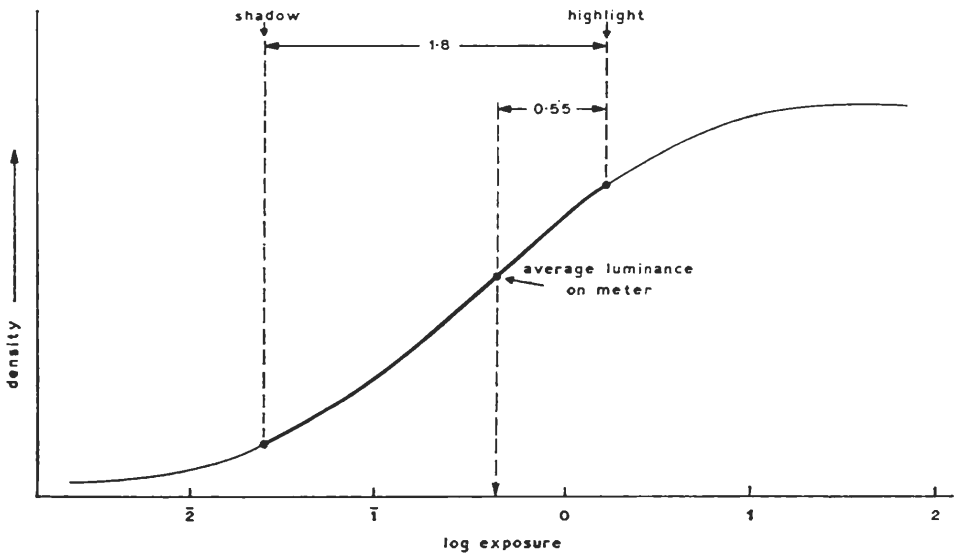


Fig. 7.11. Exposure Range of Average Sunlit Scene

and this is done by increasing the shadow exposure by $0.3 \log E$ units. The exposure of the highlight region is $1.80 \log E$ units greater than the shadow exposure. The exposure E_a for the average region is $0.55 \log E$ units below the highlights as stated earlier, which is $(1.80 - 0.55) \log E$ units above the shadows.

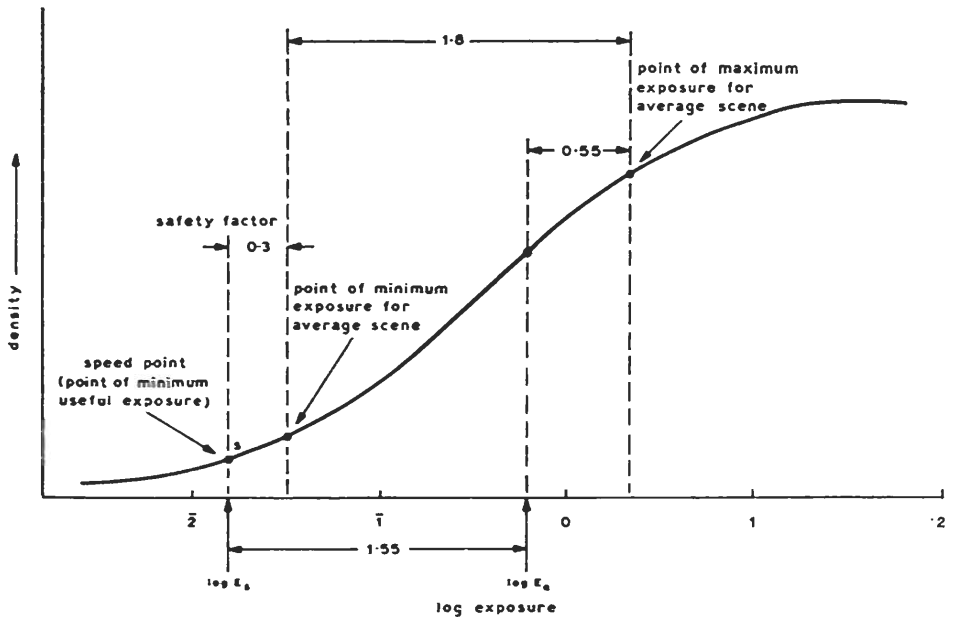


Fig. 7.12. Determination of Correct Exposure from Speed Point, allowing a Safety Factor of 2

The average exposure point E_a is connected to the speed point E_s by the relationship

$$\log E_a = \log E_s + 0.3 + 1.80 - 0.55,$$

or

$$\log (E_a/E_s) = 1.55,$$

therefore

$$E_a = 35.5 E_s.$$

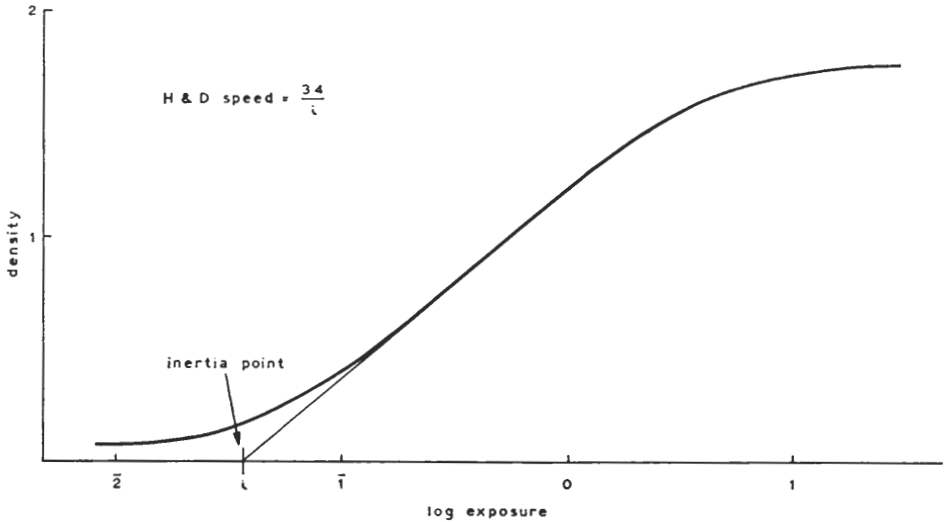


Fig. 7.13. Film Speed Determination by Inertia Method

The speed rating of the film depends on the system used to determine the speed point. For all arithmetic speed systems, the speed rating S is given by

$$S = K/E_s,$$

where K is a constant for the system.

For logarithmic speed systems,

$$S' = K' - \log E_s.$$

Speed Point Determination and Speed Measurement Systems

GENERAL. The speed point must locate the point of minimum useful exposure on the characteristic curve. The method used to determine this point must be simple and must produce reliable results when applied to any normal type of characteristic. Figs. 7.13 to 7.25 illustrate some of the methods which have been used.

INERTIA (OR HURTER AND DRIFFIELD) SYSTEM. Fig. 7.13 shows the inertia method of speed point determination used in the Hurter and Driffeld speed

measurement system. In this system the speed point is the point where the straight part of the characteristic cuts the $\log E$ axis. If the exposure at this point is i metre-candle-seconds, the H. and D. speed of the film is given by

$$S = 34/i.$$

The method has many disadvantages. If the developer contains bromide, the regression of inertia (see Fig. 7.9(b)) creates difficulties which prevent the method from being used; modern materials, moreover, often have no inertia point, no matter how they are developed. Other difficulties are that the method cannot distinguish between an emulsion with a short toe and one with a long sweeping toe, and that it is necessary for the characteristic curve to have a

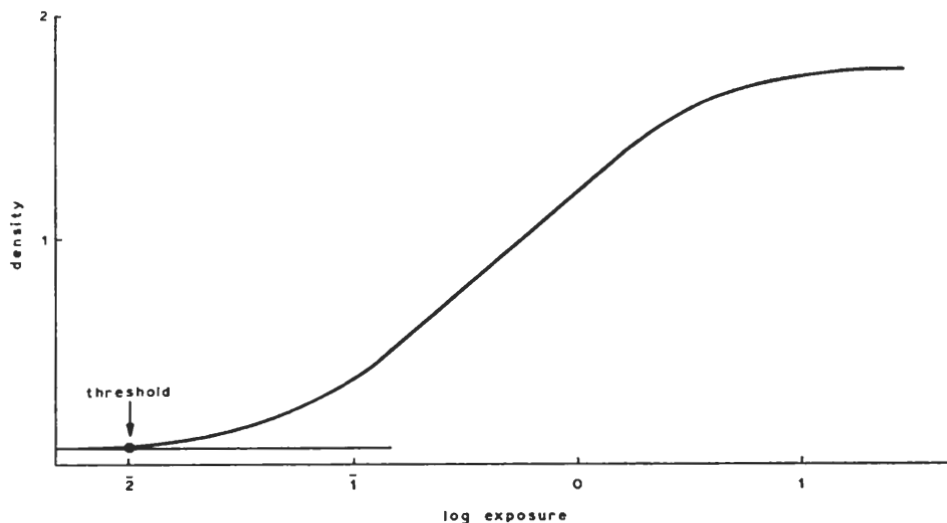


Fig. 7.14. Determination of Threshold Point

straight-line portion. Finally, the whole criterion is an arbitrary one, because the inertia point and the point of minimum useful exposure are not necessarily related.

THRESHOLD METHOD (SCHEINER SYSTEM). Fig. 7.14 shows the threshold method which is the basis of the now obsolete Scheiner system. The speed point is the value of exposure which gives the least density above fog that the eye can detect. With the Scheiner system, a series of exposures is made using a sensitometer which gives exposures with a ratio of 1.26 between steps. The speed is then the step number of the first step which produces a visible change in the density of the film; thus, if this step is numbered 10, the speed is 10 degrees Scheiner. A change of three degrees Scheiner indicates a doubling of the film speed, since the cube of 1.26 is 2.

The threshold method, like the inertia method, has considerable disadvantages. It fails to distinguish between the shapes of different characteristic curves, and it utilizes a point in the region of extreme underexposure; the selection of this point is in any event arbitrary, since it is difficult to decide exactly where the threshold really is.

FIXED DENSITY METHOD (D.I.N. SYSTEM). Fig. 7.15 shows the fixed density method which is the basis of the Deutsche Industrie Norm or D.I.N. system. The speed point is the exposure value producing a density of 0.1 above the density of the base and fog. The D.I.N. speed is obtained from the sensitometer step number which produces the required density; if this step number is

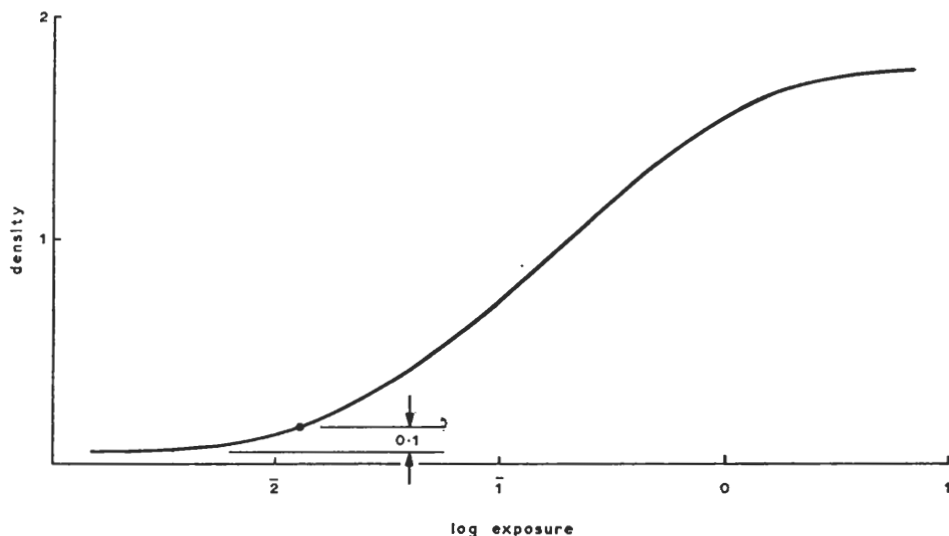


Fig. 7.15. Determination of Fixed Density Point

14, the D.I.N. speed is 14/10 degrees. The ratio between exposures is 1.26 as with the Scheiner system, and a doubling of film speed is therefore indicated by a difference of 3/10 degrees D.I.N.

The advantage of the system is that the speed point can be found both simply and accurately. The disadvantages are that the selection of a density of 0.1 is arbitrary and that, under the test conditions laid down, development is for maximum speed; this will seldom be the development required in practice.

SUBJECTIVE SPEED RATING. Each of the methods so far described can be criticized for its arbitrary choice of speed point. The subject of speed measurement was put on a rational basis by L. A. Jones, who made a statistical study of the effect of exposure variations on the quality of a finished print. For this investigation, a typical average scene was photographed on a wide range of

materials. Each type of material was given a series of increasing exposures, and a variety of developers was used.

The best print which could be made from each negative was selected, and the prints from a given negative exposure series were arranged in order of increasing exposure time. A panel of observers was asked to choose the first print considered "excellent" in each series. Each of the negatives producing a "first excellent" print was given a subjective speed rating by the method illustrated in Fig. 7.16. This diagram shows the characteristic curve for a typical negative, and the portion of it used to produce the "first excellent" print is shown marked between the points M and O. M corresponds to the point of

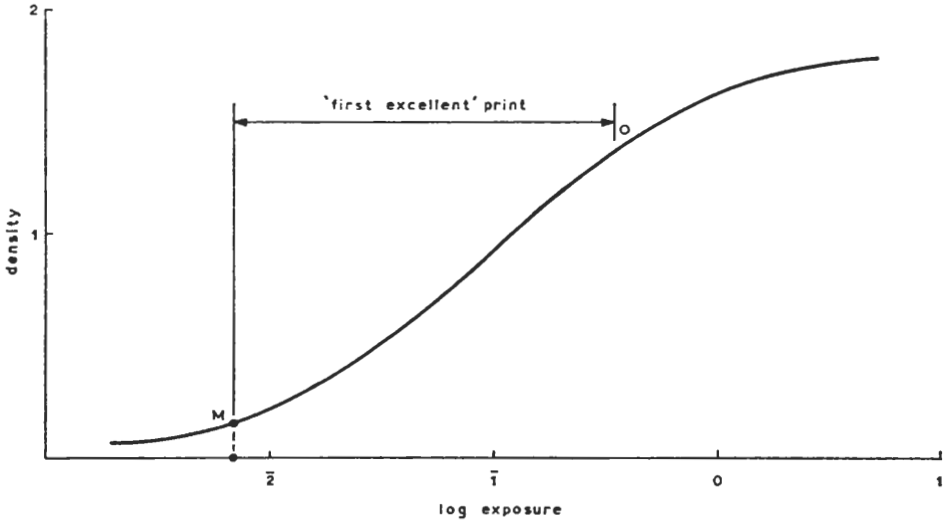


Fig. 7.16. Typical Range of Negative Exposures Producing a 'First Excellent' Print

minimum exposure, and the subjective speed rating of the film is defined as the reciprocal of the exposure at this point.

The speed ratings were evaluated for all negatives producing a "first excellent" print, and the results used to test the speed ratings obtained by objective measurements.

A.S.A. FRACTIONAL GRADIENT SYSTEM. A method of objective measurement which was introduced following the investigation described above is illustrated in Fig. 7.17. This is the American Standards Association's fractional gradient system. For a wide range of negative materials, it gives results in agreement with subjective measurements.

The speed point in this system is taken as the point where the gradient, γ , of the characteristic curve is equal to 0.3 times the average gradient, \bar{G} , of the used

portion of the curve. The average gradient is measured between the speed point and a point on the curve 1.5 log E units to the right of it. The speed point, E_s , is also called the *fractional gradient point*.

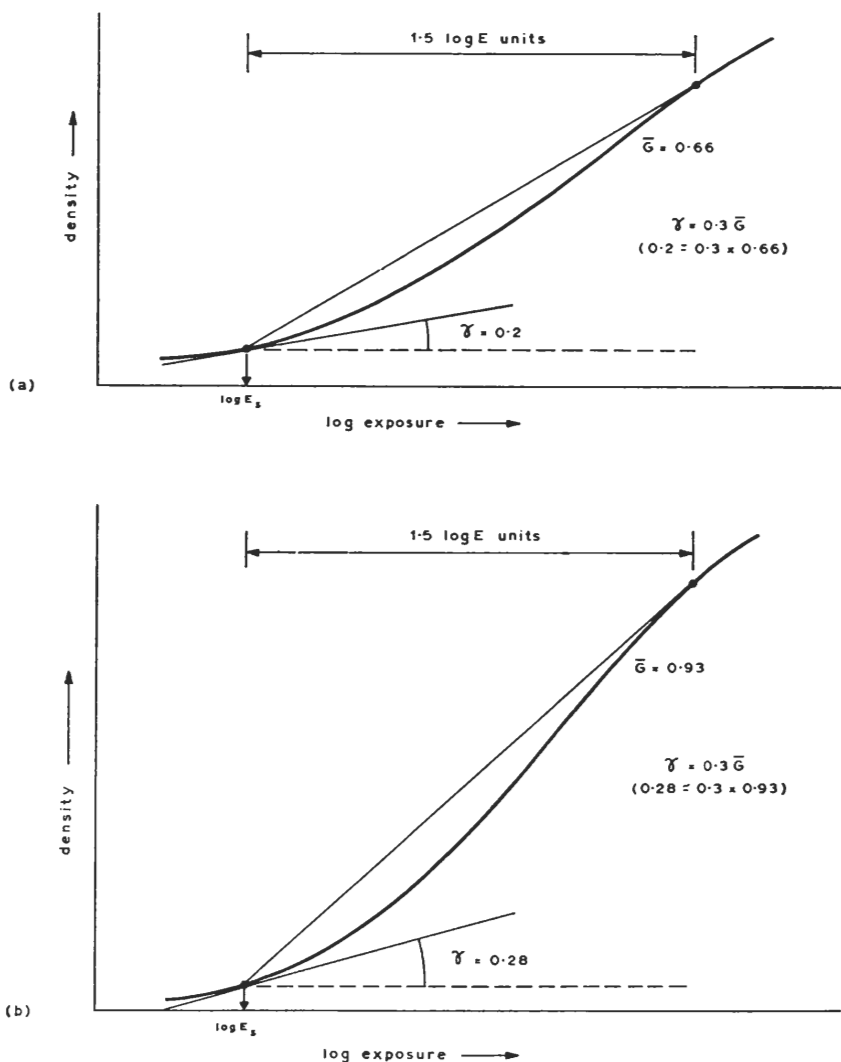


Fig. 7.17. Determination of Fractional Gradient Speed Point for Two Typical Characteristic Curves
The speed of the film is expressed as an *exposure index*, Z , given by

$$Z = 4/E_s.$$

The system was in standard use in America and the United Kingdom for many years. The exposure index figures obtained proved most satisfactory, but

a difficulty of the system was that the speed point could only be located by a lengthy trial and error process. The choice of the constant 4 in the formula for exposure index also excited criticism on the ground of allowing too great a factor of safety, since using an exposure meter with a standard calibration, the safety factor was 2.35. The predicted location of the exposure forms a scene as shown in Fig. 7.18 when the A.S.A. index is used. It can be seen that the safety factor is measured from just below the speed point; this procedure allows for

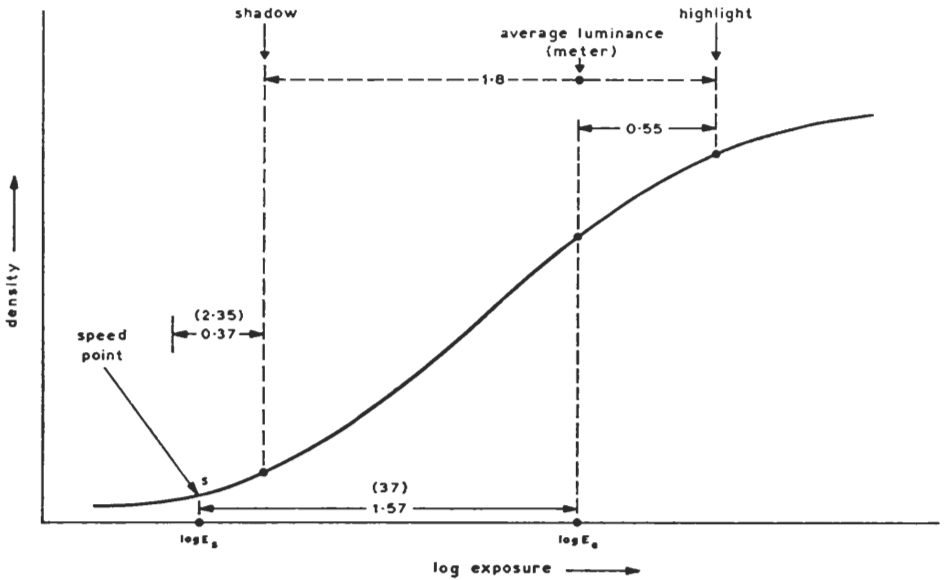


Fig. 7.18. The Predicted Location of an Average Scene on the D/log E Curve, when Exposure is Calculated using a Calibrated Exposure Meter and the A.S.A. 'Exposure Index' for the Film

the additional safety factor provided by the loss of contrast caused by the flare characteristics of a normal lens.

NEW A.S.A. SYSTEM. The new A.S.A. system for measuring speed is a simpler method based on the exposure giving a fixed density above fog under specified development conditions. The speed figures obtained by this method correlate well with those obtained by the fractional gradient system.

In the new system,

$$\text{speed} = 0.8/E_m,$$

where E_m is the exposure in metre-candle-seconds giving a density of 0.1 above fog with development to an average gradient, measured between exposure points E_m and $20 E_m$, of 0.62. This is equivalent to an average gradient of 0.62

measured between the speed point and a point $1.3 \log E$ units above it. Fig. 7.19 indicates these points.

In the expression, $\text{speed} = 0.8E_m$, the value of the constant is chosen so that the safety factor is reduced to 1.2, as compared to the safety factor of 2.35 given by the constant in the old A.S.A. system.

Very roughly, the new A.S.A. speed ratings are numerically twice the old

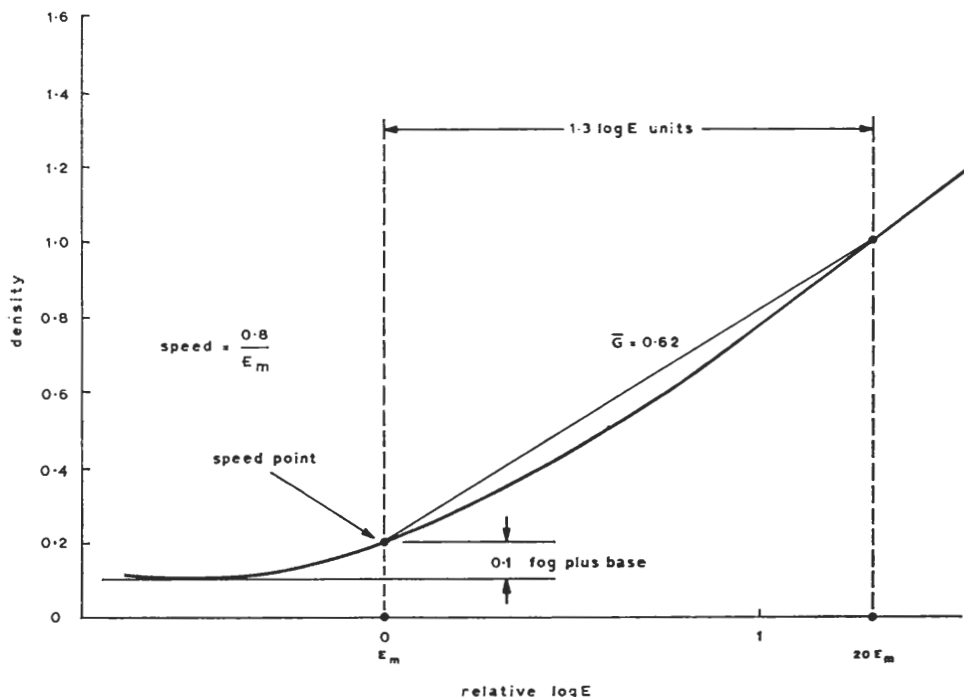


Fig. 7.19. Speed Point Determination using New A.S.A. System

“exposure indices”. Often manufacturers will quote four different speeds for their films to take this reduction into account. Table 7.1 gives an example.

TABLE 7.1
EXPOSURE METER SETTINGS
(A.S.A.) FOR FP3 EMULSION

Exposure	Setting	
	Daylight	Tungsten Lighting
Minimum	160	125
Average	80	64

The predicted location of the exposures on a negative exposed using the minimum-exposure A.S.A. speeds is shown in Fig. 7.20.

Comparison Between Speed Measurement Systems

Any comparison between speed measurement systems can only be approximate, for reasons illustrated in Fig. 7.21. Fig. 7.21(a) shows the characteristic curve for a material with a long sweeping toe and Fig. 7.21(b) shows the curve for a material with a sharp toe. On each of the curves the speed points have been found by the A.S.A. fractional gradient, the D.I.N. fixed density and the

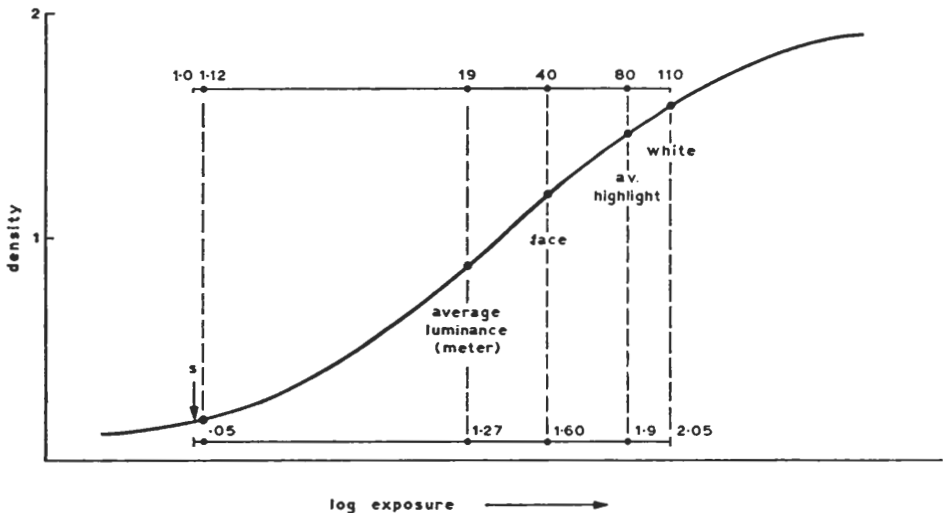


Fig. 7.20. The Predicted Location of an Average Scene on the D/log E Curve, when Exposure is Calculated using a Calibrated Exposure Meter and the 'New' A.S.A. Speed Rating for the Film

H. and D. inertia method. The relationship between the three speed points is not the same for the different materials and a simple table comparing the various systems is only satisfactory for a limited range of emulsions. An illustration of the difficulty is given by the fact that when the original tests were made for the old A.S.A. system, two emulsions were found having identical A.S.A. speeds but with D.I.N. speeds differing by a factor of eight. Table 7.2 shows approximate conversion factors between various speed systems.

EFFECTIVE FILM SPEED. Speed figures published by film manufacturers often differ from those obtained by individual processing laboratories, and the *effective* speed of any material using given processing equipment can only be established from tests made under normal (and specified) operating conditions.

TABLE 7.2
APPROXIMATE RELATIONSHIP BETWEEN SPEEDS IN DIFFERENT SYSTEMS

<i>New A.S.A. B.S.I. Arith- metic</i>	<i>New A.S.A. B.S.I. Logar- ithmic</i>	<i>New D.I.N.</i>	<i>Old A.S.A. B.S.I. Arith- metic</i>	<i>Old A.S.A. B.S.I. Logar- ithmic</i>	<i>Old D.I.N.</i>	<i>Weston</i>	<i>H. & D.</i>
6	19°	9°	3	16°	6°	3	80
8	20°	10°	4	17°	7°	4	100
10	21°	11°	5	18°	8°	5	125
12	22°	12°	6	19°	9°	6	160
16	23°	13°	8	20°	10°	8	200
20	24°	14°	10	21°	11°	10	250
24	25°	15°	12	22°	12°	12	320
32	26°	16°	16	23°	13°	16	400
40	27°	17°	20	24°	14°	20	500
50	28°	18°	25	25°	15°	25	640
64	29°	19°	32	26°	16°	32	800
80	30°	20°	40	27°	17°	40	1000
100	31°	21°	50	28°	18°	50	1250
128	32°	22°	64	29°	19°	64	1600
160	33°	23°	80	30°	20°	80	2000
200	34°	24°	100	31°	21°	100	2500
250	35°	25°	125	32°	22°	125	3200
320	36°	26°	160	33°	23°	160	4000
400	37°	27°	200	34°	24°	200	5000
500	38°	28°	250	35°	25°	250	6400
640	39°	29°	320	36°	26°	320	8000
800	40°	30°	400	37°	27°	400	10,000
1000	41°	31°	500	38°	28°	500	12,500
1300	42°	32°	650	39°	29°	650	16,000

Fig. 7.22 shows characteristic curves obtained for a number of films using the Lawley Junior continuous processing machines at Alexandra Palace. In each instance the developer temperature was 73°F and the gamma was 0.65. The gamma measurements were taken between the densities produced by specific steps of the X-6 stepwedge, because this procedure avoided errors introduced in estimating the position and measuring the slope of the straight-line portion of the curve. Table 7.3 shows the operating conditions for a range of films processed at Alexandra Palace. The machine speed required for each film in order to obtain the specified gamma value was calculated using gamma/time curves similar to Fig. 7.2, taking into account the known length of the film path in the developer.

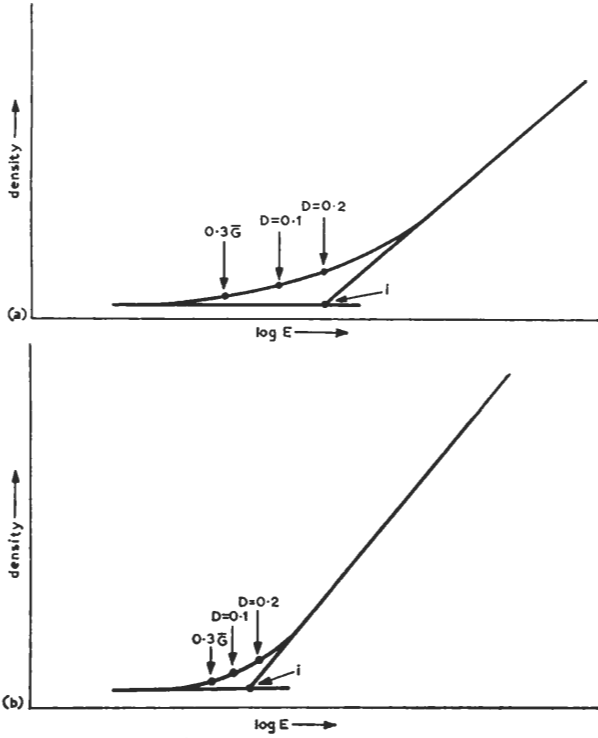


Fig. 7.21. Effect of Shape of Characteristic on Relationship Between the Different Speed Points: (a) Characteristic with Long Sweeping Toe and (b) Characteristic with Sharp Toe

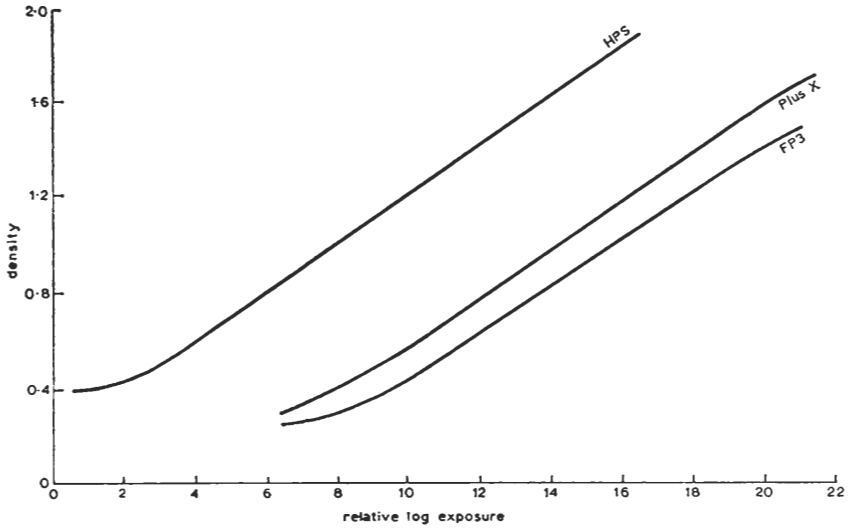


Fig. 7.22. Comparison of Three Negative Emulsions when Developed in Lawley 16-mm Film Processing Machine

TABLE 7.3
OPERATING CONDITIONS FOR LAWLEY JUNIOR FILM
PROCESSING MACHINE

<i>Machine No.:</i> 1635001		<i>Type:</i> 16-mm sprocket driven	
<i>Conditions:</i> all lower rollers 1 in. from bottom of tank		<i>Development Temp.:</i> 73° F	
<i>Film Type</i>	<i>Nominal Machine Speed (ft/min)</i>	<i>Required Gamma</i>	<i>X-6 Steps Measured</i>
FP3	53	0.65	9-19
HPS	20	0.65	6-16
Plus-X	65	0.65	8-18
7374 neg.	39	1.00	6-13
7374 pos.	34	1.10	4-11

Specialized Methods of Speed Rating

Manufacturers often use a simplified system for expressing the speed of a particular film so that they can check that its performance is within production tolerances. Since the speed figures concerned are not for general use, they can be obtained by a method designed expressly for an individual film stock, as illustrated by the following examples.

Measurements on a Telerecording Film

1. USED AS A NEGATIVE. The exposures are made using a microflash sensitometer which gives an exposure time of 1 μ s. The film is developed in a specially aged solution for 6½ minutes at 20° ± ½° C. Fig. 7.23 shows the characteristic curve obtained. The speed of the film is given by:

$$\begin{aligned} \log \text{ speed} &= \log (10/E_s), \\ &= 1 - \log E_s. \end{aligned}$$

where E_s is the exposure required to produce a density 0.3 above fog level.

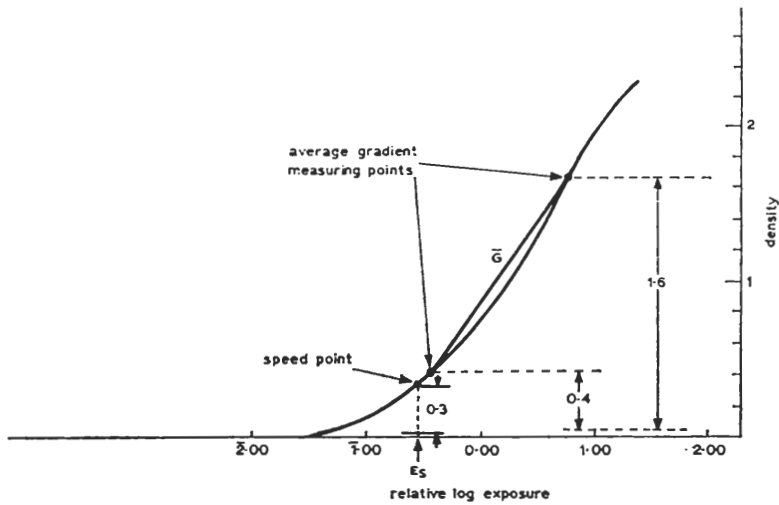


Fig. 7.23. Manufacturing Control Measurements on a Telerecording Film (used as a Negative)

Fig. 7.23 also shows the method used to check the average gradient, which is measured between two points on the characteristic curve with densities of 0.4 and 1.6 respectively above fog level.

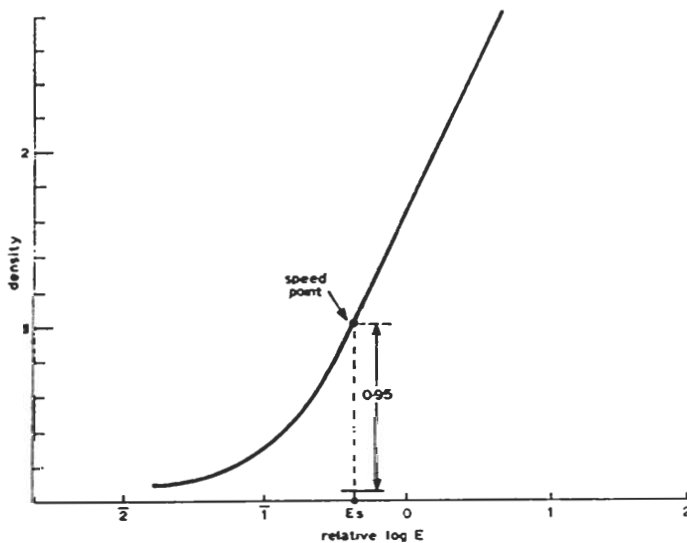


Fig. 7.24. Manufacturing Control Method of Obtaining Speed Point for a Telerecording Film (used as a Positive)

2. USED AS A POSITIVE. The exposures are made using an X-6 sensitometer which gives an exposure time of 10 ms at a colour temperature of 2850°K. The film is developed in a D16 solution for 6½ minutes at 20° ± ½° C. Fig. 7.24

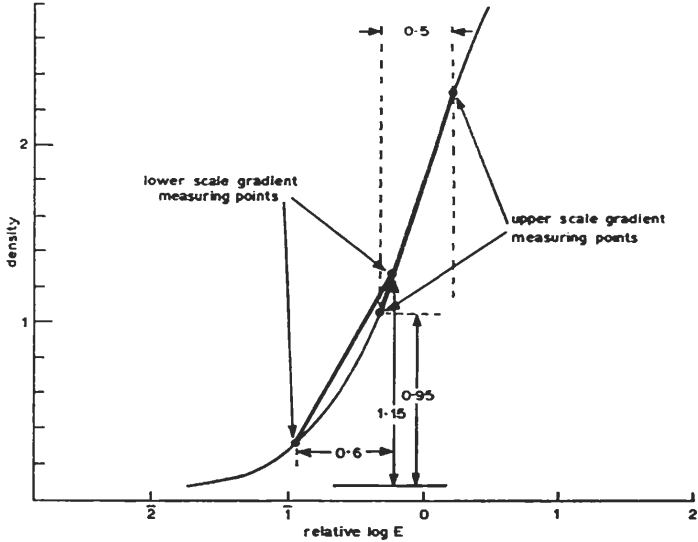


Fig. 7.25. Upper and Lower Scale Gradients Measured on a Telerecording Film

shows the characteristic curve obtained. The speed of positive film is expressed as a printer rating, and is given by:

$$\text{printer rating} = 100(1 - \log E_s),$$

where E_s is the exposure required to produce a density 0.95 above fog level.

Two values of average gradient are measured as shown in Fig. 7.25. The first is called the *toe gradient* or *lower scale gradient* and is measured between a point where the density is 1.15 above fog and a second point whose log exposure is 0.6 less than that of the first point. The second gradient is called the *upper scale gradient*, and is measured between a point where the density is 0.95 above fog and a second point whose log exposure is 0.5 greater than the first.

Working Tolerances

The accuracy of a sensitometric result depends both on the operator and on his equipment. Fig. 7.26 shows the results of some tests carried out at Alexandra

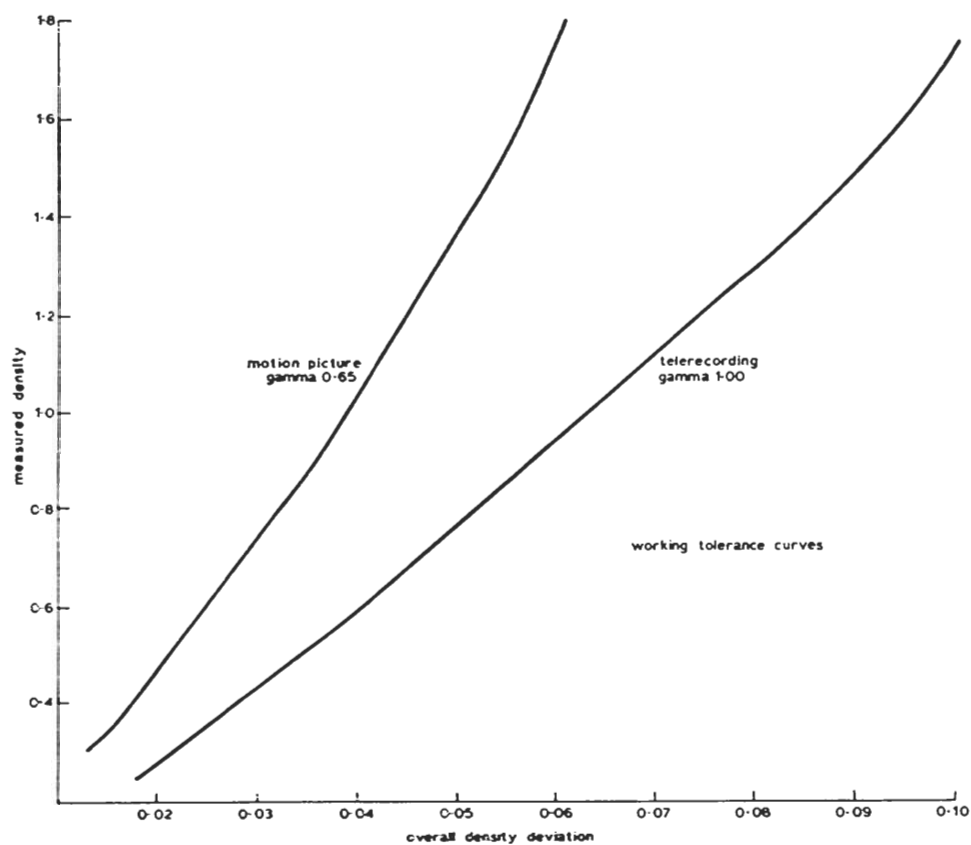


Fig. 7.26. Overall Variation in Measured Density Due to Sensitometer, Densitometer and Operator Combined

Palace to determine the probable overall error. The magnitude of error appears to depend both on the value of the density being measured, and on the rate of change of density, i.e. on gamma.

Bibliography

[1] MEES, C. E. K. and JAMES, T. H., *The theory of the photographic process*. Third edition. Macmillan, New York, 1966.

[2] JAMES, T. H. and HIGGINS, G. C., *The fundamentals of photographic theory*. Second edition. Morgan and Morgan, New York, 1960.

[3] NEBLETTE, C. B., *Photography*. Sixth edition. Van Nostrand, 1962.

[4] S.M.P.T.E., *Control techniques in film processing*. 1960.

[5] *Technical information sheet No. ASO.1*. Ilford.

[6] LOBEL, L. and DUBOIS, M., *Sensitometry*. First edition. Focal Press, 1955.

[7] WHEELER, L. J., *Sensitometry in film making*. BBC Engineering Division Monograph No. 33.

[8] NELSON, C. N., *Safety factors in camera exposures*. *Journal S.M.P.T.E.*, volume 69 (July 1960), pages 479-483.

[9] SMITH, J. W. W. and SHEPPHERD, J. C., *An easy approach to photographic sensitometry for the craftsman*. Ilford.

VIII. MEASUREMENT OF LIGHT

Light Meters

Most modern light meters embody a photocell of some kind, and photoelectric meters have several advantages over meters which rely on the eye to make a visual judgement of brightness. These advantages are:

1. Greater precision.
2. Greater speed in reading.
3. Freedom from Purkinje effect.
4. Freedom from difficulty in comparing the brightness of differently coloured surfaces.
5. The possibility of selection or adaptation to fit any desired spectral response curve.

There are three main types of photocell, and they each have their applications in the measurement of light.

Photoemissive Cells

PRINCIPLES. Photoemissive cells depend on the fact that the incidence of radiation on the surface of certain metals causes the emission of electrons. A metal contains a large number of ionized atoms and the corresponding electrons can move more or less freely through the metal, although there is a net force near the surface which prevents electrons escaping unless their energy can be raised by some means. The extra energy required can come from radiation, and an electron can escape when it receives energy greater than its *work function* Φ . This is a constant for the type of metal and its surface, and is usually measured in electron-volts, one electron-volt being equal to 1.602×10^{-5} joule.

The emission of electrons becomes a continuous process if an electric field is established, with the metal as the cathode, while suitable radiation persists.

There are two laws which govern photoelectric emission:

1. For a given spectral distribution, the rate of emission of electrons is proportional to the intensity of the radiation.
2. The frequency of the radiation must be greater than the *threshold frequency* of the metal surface. The maximum amount of energy which any released electron can have is proportional to the difference between the frequency of the radiation and this threshold frequency.

It can be shown that the energy ϵ received by an electron from radiation of frequency f falling on it is given by

$$\epsilon = hf \text{ joules,}$$

where h is Planck's constant, equal to 6.625×10^{-20} joules per second.

From this relationship, the threshold frequency can be expressed in terms of the work function of the metal.

For emission to occur,

$$\epsilon > \Phi$$

Therefore, $hf > \Phi \times 1.602 \times 10^{-5}$ joules.

Let f_0 be the threshold frequency corresponding to λ_0 , the threshold wavelength.

At this frequency,

$$hf_0 = \Phi \times 1.602 \times 10^{-5}.$$

But, for an electromagnetic wave,

$$\lambda_0 f_0 = v = 3 \times 10^{10} \text{ metres per second,}$$

therefore, $\lambda_0 = (1/\Phi) \times 12.398 \times 10^2 \text{ nm.}$

No emission occurs unless λ is less than λ_0 .

The work functions Φ and threshold wavelengths λ_0 for some common metals are shown in Table 8.1.

TABLE 8.1
WORK FUNCTIONS AND THRESHOLD WAVELENGTHS

<i>Metal</i>	<i>Work Function</i> Φ (<i>electron-volts</i>)	<i>Threshold Wavelength</i> λ_0 (<i>nm</i>)
Platinum	6.3	197
Tungsten	4.54	273
Sodium	2.46	504
Potassium	2.24	554
Rubidium	2.18	568
Caesium	1.9	650

CONSTRUCTION. The construction of a photoemissive cell is shown in Fig. 8.1. There are two common types of photoemissive surface which are used to form the photocathode:

1. A thin layer of an alkali metal, such as caesium, deposited onto oxidized silver. In practice, the cathode may consist of sensitive films of caesium, caesium oxide and silver in various arrangements designed to give maximum sensitivity at desired parts of the spectrum.
2. An alkali metal deposited on a layer of a metal such as antimony or bismuth, or on a composite layer of bismuth, oxygen and silver. Cells made

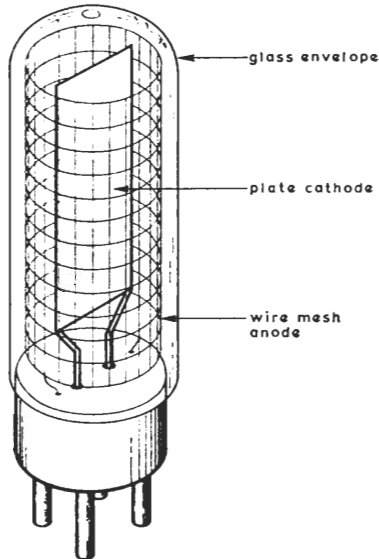


Fig. 8.1. Construction of Photoemissive Cell

with this form of cathode have high sensitivity over the greater part of the spectrum.

Photoemissive cells can be either vacuum-type or gas-filled. Vacuum cells are evacuated to a pressure of about 10^{-6} mm of mercury, while gas-filled cells contain an inert gas, such as argon, at a pressure of about 1 mm.

PROPERTIES. The characteristics of some typical photocells are shown in Figs. 8.2 to 8.4. Fig. 8.2 shows the spectral responses for both types of photocathode, and compares them with the response of the eye and of a typical panchromatic emulsion. Fig. 8.3 shows the sensitivity curves for a vacuum cell and Fig. 8.4 shows those for a gas-filled cell of similar construction. The breakdown voltage for the vacuum cell is 100 volts with a caesium antimony

cathode, or 250 volts with a caesium oxidized silver cathode; gas-filled cells are limited by gas ionization, and should not be operated above 90 volts, irrespective of their type of cathode. A *dark current* flows in a cell when there is no visible light; this current is very dependent on the sensitivity of the cell to the

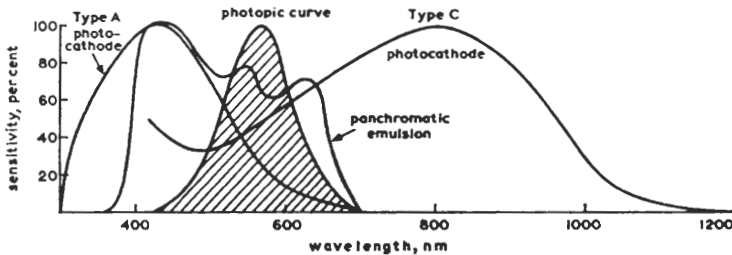


Fig. 8.2. Spectral Sensitivities of Different Photoemissive Cells, compared with a Panchromatic Emulsion and with the Photopic Curve. (Type A: Caesium Antimony, Type C: Caesium Oxidized Silver)

infrared region. For a caesium oxidized silver photocathode, a typical dark current value at 20°C is 0.005 μA per square inch of photocathode area; this figure could be doubled at 30°C.

Vacuum cells are to be preferred in photometry, because they are stable over long periods, and their photo-current for a given illumination is nearly

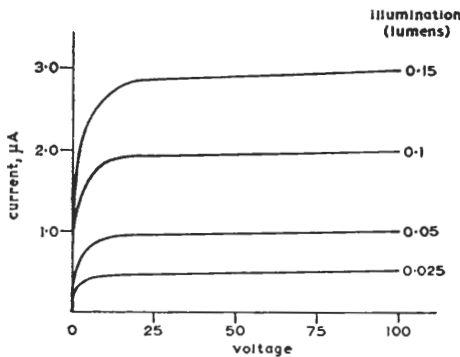


Fig. 8.3

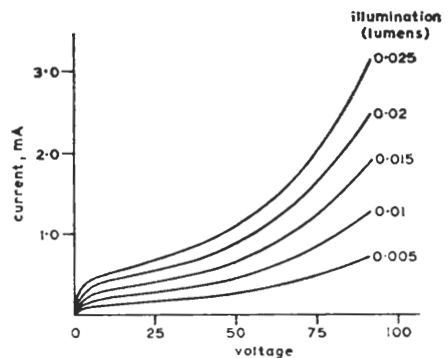


Fig. 8.4

Characteristics of Two Photoemissive Cells, both with Caesium Oxidized Silver Photocathode. Fig. 8.3 shows Mullard Vacuum Cell Type 58CV; Fig. 8.4 shows Mullard Gas-filled Cell Type 58CG. (The indicated total illumination in lumens is incident on a light-sensitive area of 0.17 square inch)

independent of anode voltage, provided they are operated above the knee of the characteristic. The sensitivity of a gas-filled cell, by contrast, is affected by fluctuations in both gas pressure and applied voltage.

The sensitivity of a photoemissive cell is seldom constant over the whole surface of the photocathode, and the ray of light being measured should fully illuminate the surface of the cell if consistent results are to be obtained.

Photovoltaic Cells

GENERAL DESCRIPTION. No battery is required for the operation of photovoltaic cells, because their current is generated by direct conversion of the energy of incident light.

The cell consists of a very thin transparent film of metal which is coated onto a layer of semiconductor. Light passes through the metallic film and falls on the surface of the semiconductor, producing a difference in potential between the two, the semiconductor being positive with respect to the metal.

The usual form of construction is shown in Fig. 8.5. The metal film is usually gold and the semiconductor is usually selenium. The selenium layer

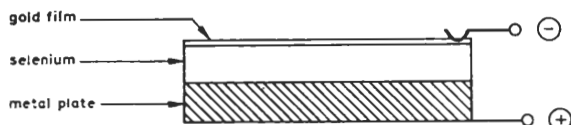


Fig. 8.5. Construction of Barrier Layer Cell

is supported by a metal plate which plays no part in the action of the photocell but merely acts as a physical support.

Cells made in this way are called *barrier layer cells*. They are robust and retain their properties for a long time, but may be damaged by high temperatures or high currents; the resistance of the associated electrical measuring circuit should therefore be made high enough to limit the current to a safe value when the cell is subjected to the maximum expected light intensity.

MEASURING CIRCUIT. The characteristics of one type of barrier layer cell are shown in Figs. 8.6 and 8.7; the current/illumination curves of Fig. 8.6 show that the measuring circuit should have a very low resistance if a linear response to light is required, while the spectral response curve of Fig. 8.7 shows that little or no colour correction is required when the cell is used for photographic purposes and that modification to the photographic curve is readily accomplished when required.

A measuring circuit which presents an effective short-circuit to the cell is the Campbell-Freeth circuit, shown in Fig. 8.8. A galvanometer is connected across the cell terminals, and its reading V_1 is adjusted to zero by varying the voltage V_2 by means of resistor R . The cell is then working into a short-circuit, and from the characteristics shown in Fig. 8.6, the current flowing through it gives a linear indication of its illumination.

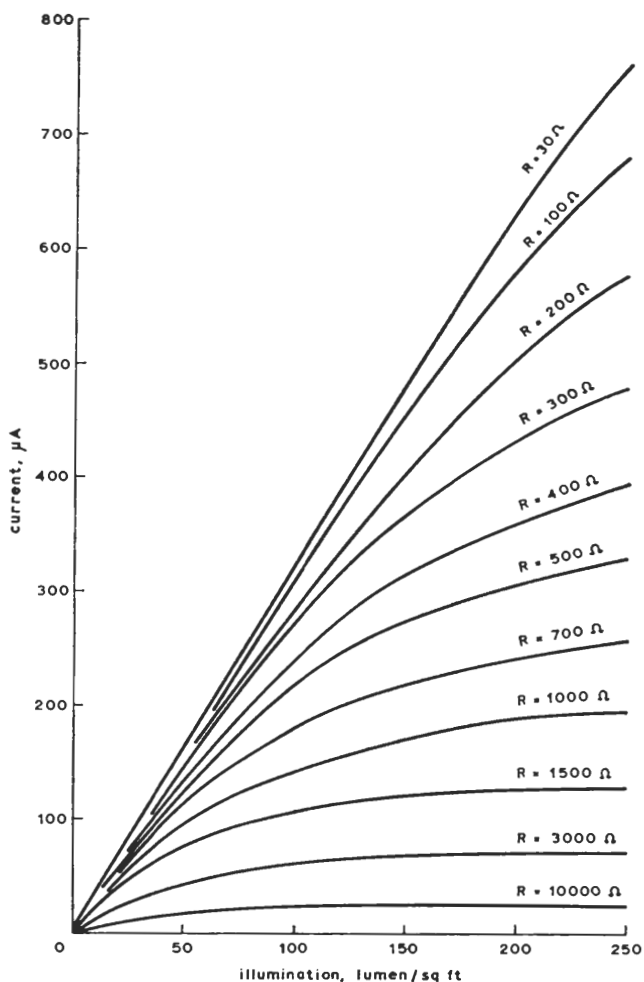


Fig. 8.6. Current/Illumination Characteristics of Barrier Layer Cell
(Courtesy of D. Van Nostrand Company, Inc.)

When V_1 is zero, the value of the current i is calculated from the relationship

$$Ri = V_2,$$

whence

$$i = V_2/R.$$

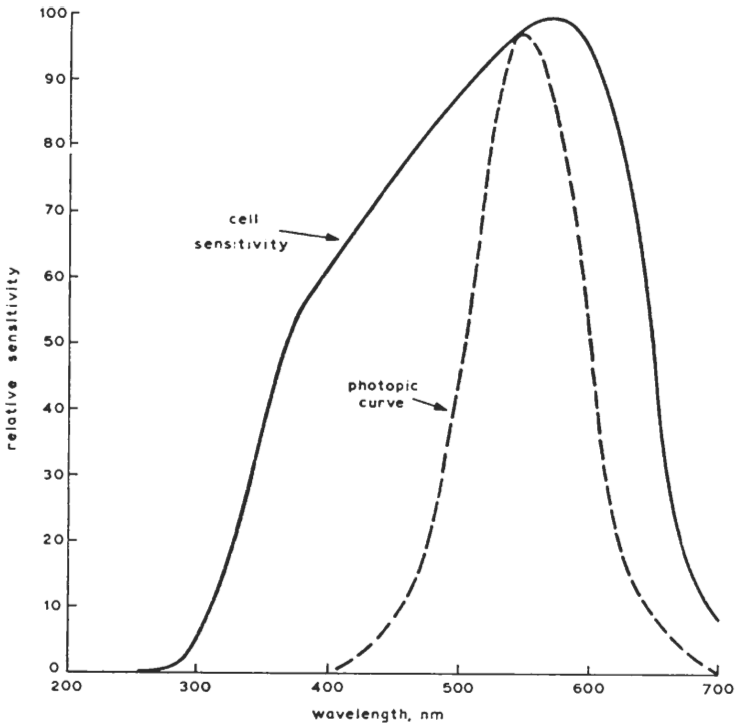


Fig. 8.7. Spectral Sensitivity of Typical Barrier Layer Cell, with Photopic Curve for Comparison (Courtesy of D. Van Nostrand Company, Inc.)

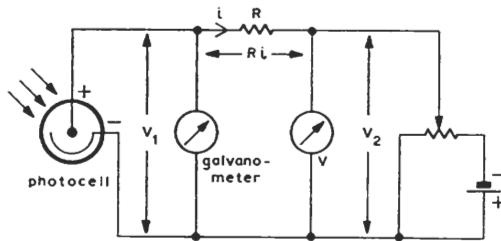


Fig. 8.8. Campbell-Freeth Circuit

The circuit can be calibrated to read illumination directly from the reading of the voltmeter measuring V_2 . The current/illumination characteristics for $R = 0$ can be described by the straight-line relationship

$$I = ki,$$

where I is the incident illumination, k is a constant for the photocell, and i is the current flowing.

Since, however, $i = V_2/R$,

it follows that $I = V_2/kR$.

This expression is valid over a very wide range of incident illumination.

An interesting feature of the circuit is the protection which it provides against excessive currents damaging the cell if the intensity of illumination is suddenly increased. The measuring circuit simulates a short-circuit only when

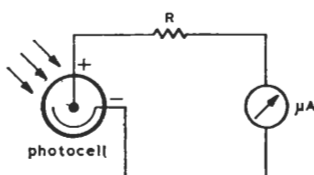


Fig. 8.9. Simple Light Meter

balanced; as soon as conditions change the e.m.f. produced by the cell changes and V_1 will therefore no longer be zero.

When less accuracy is required the simple circuit shown in Fig. 8.9 is used. The resistance value determines the degree of linearity of the scale, and deliberate use is often made of the nonlinearity of the current/illumination scales with high values of circuit resistance to obtain a quasi-logarithmic characteristic.

Photoconductive Cells

A substance such as cadmium sulphide, CdS, is an insulator in its pure state but a semiconductor when doped with certain impurities. The electrical resistance of certain semiconductors is found to vary when the light falling on them is varied and the effect is particularly strong with cadmium sulphide. Fig. 8.10 shows this effect for a typical cell. When the scales are logarithmic, the response is nearly linear.

The photoconductive cell can be used in a circuit similar to the one shown in Fig. 8.11. The source of e.m.f. is usually a small mercury cell, which provides

almost constant voltage during its working life. The external resistance in the circuit modifies the response, particularly at high readings, and Fig. 8.12 shows

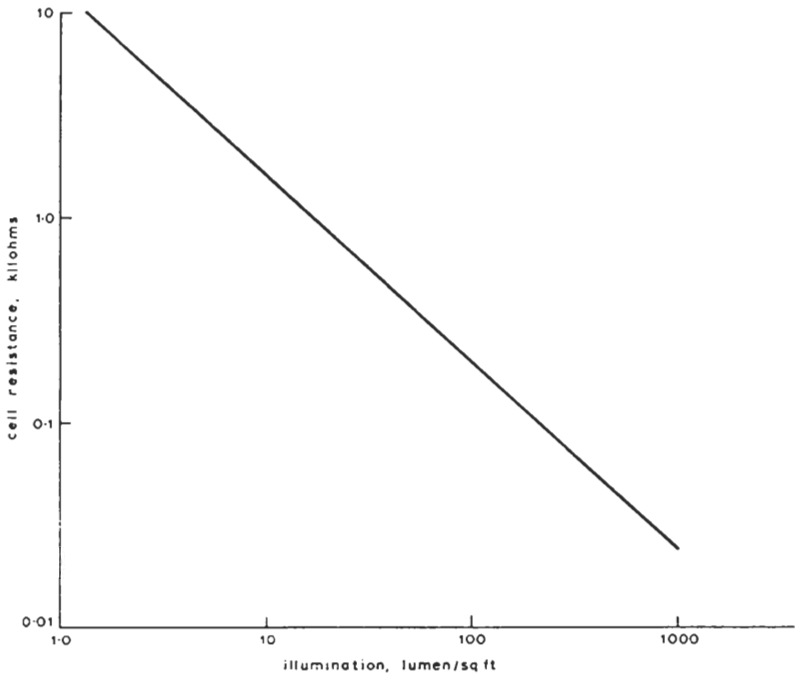


Fig. 8.10. Variation of Internal Resistance of Photoconductive Cell with Illumination

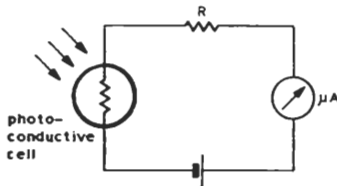


Fig. 8.11. Light Meter using Photoconductive Cell

the current/illumination characteristics of a typical cell for a number of different external resistances.

Comparison Between Photocell Types

PHOTOEMISSIVE TYPE. The advantages of photoemissive cells over photo-voltaic and photoconductive types are:

1. Greater accuracy.

2. Greater linearity.
3. Greater stability.

Their disadvantages are:

1. They need complicated power supplies.
2. They are not portable.
3. They are not robust.

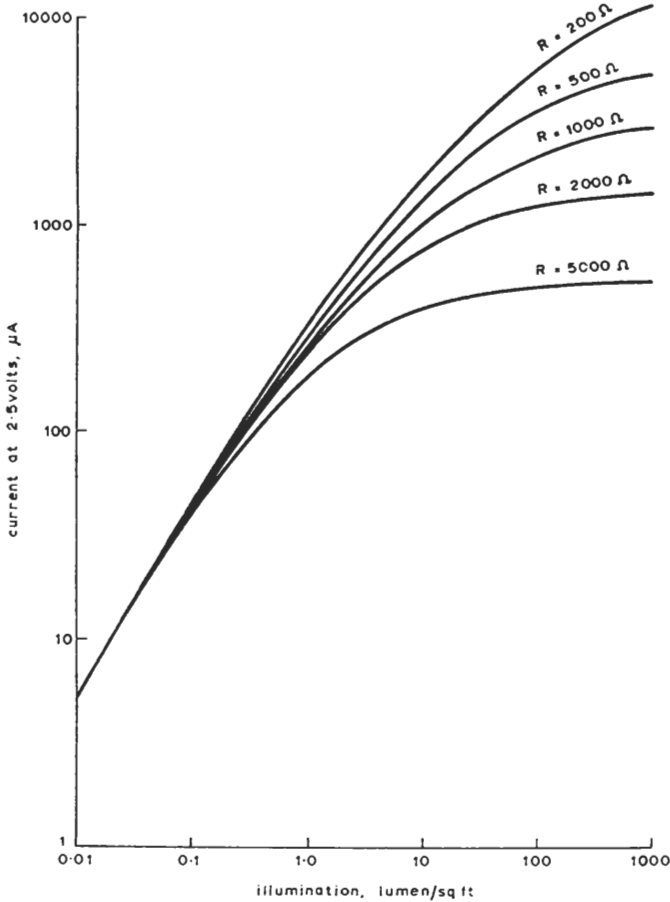


Fig. 8.12. Variation of Photoconductive Cell Current with Illumination and External Circuit Resistance

PHOTOVOLTAIC TYPE. The advantages of photovoltaic cells over photoconductive cells are:

1. Greater accuracy.
2. Greater stability, particularly at low illumination levels.
3. They require no source of power.

PHOTOCONDUCTIVE TYPE. The advantages of photoconductive cells over photovoltaic cells are:

1. A much higher output for a comparable size.
2. They can be made smaller and more robust for specific applications.
3. The necessity for a battery can sometimes be used to advantage, as the power available can be used to control the shutter and aperture settings of a camera.

Exposure Meters

TYPES OF METER. An exposure meter can be of one of two basic types: it can either be an integrating meter, which measures the average value of the light falling on it from a comparatively large part of a scene, or it can be a narrow-angle meter, which measures the brightness of a small part of a scene.

INTEGRATING EXPOSURE METERS. Integrating exposure meters usually rely on photovoltaic or photoconductive cells to measure the average value of the light falling on them, and their basic arrangements will be as illustrated in Figs. 8.9 and 8.11, together with two additional features:

1. A housing to give the required directional properties to the instrument.
2. A calculator of some sort to take into account such features as aperture-number and film-speed when converting the meter reading into an exposure-time.

There are two types of integrating meter, reflected-light meters and incident-light meters. Reflected-light meters are used at the camera position and are pointed towards the subject as shown in Fig. 8.13(a). Their angle of acceptance, about 50° to 70° , is usually controlled by making the body of the instrument act as a hood, although an optical system of lenses and louvres is sometimes used to get a more sharply defined field of view, as shown in Fig. 8.14(a).

Incident-light meters are used pointed towards the camera from the subject position as shown in Fig. 8.13(b). Their angle of acceptance is very wide, sometimes being as much as 300° . Reflected-light meters can be converted into incident-light meters by placing a diffusing cone over the photocell, as shown in Fig. 8.14(b); this modifies the angle of acceptance so that all the light is measured which would be reflected towards the camera by the subject.

Both types of meter give a reading which depends on the average value of illumination; they rely on the fact there is a reasonably constant relationship between the average value of the illumination of a scene and the maximum and minimum values, any variation in this relationship normally being masked by exposure latitude.

The spectral response of a suitable barrier layer cell can be sufficiently close to the response of a panchromatic emulsion to need no correction. Cadmium

sulphide cells can be made with a variety of spectral sensitivities and are modified or not as required.

It is shown in Appendix 8.A at the end of this Chapter that the relationship between light and exposure for a reflected-light exposure meter is:

$$A^2/t = BS/K,$$

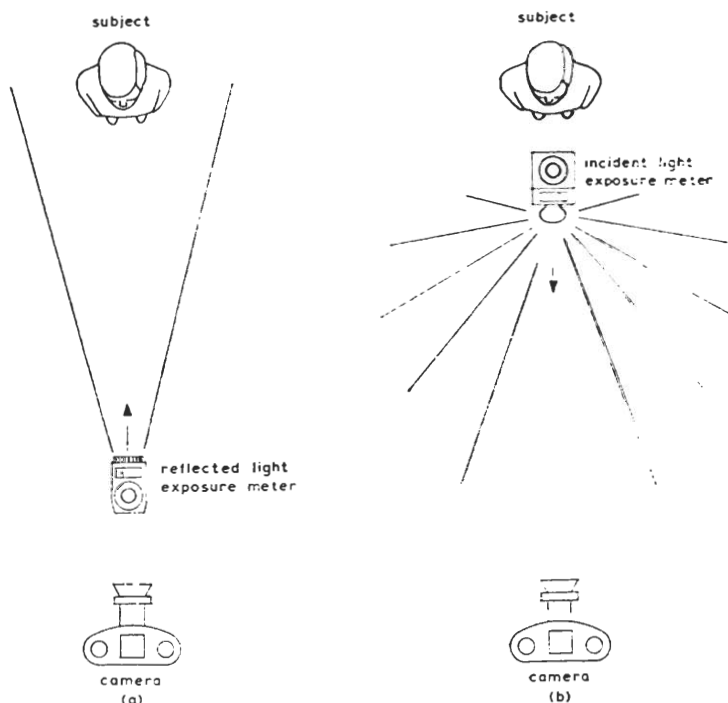


Fig. 8.13. Method of Use of Exposure Meters. (a) Reflected-light Meter, and (b) Incident-light Meter

where A = aperture number of lens (or f number).
 t = exposure time in seconds.
 S = A.S.A. speed rating of film.
 B = average scene brightness in foot-lamberts.
 K = a calibration constant for reflected-light meters.

The value of K in the A.S.A. system is 3.6 ± 0.53 for calibration at 2850°K , or 3.33 ± 0.50 for calibration at 4700°K .

When the meter is pointed towards the subject it reads a value which depends on B/K . The reading is then transferred to a form of rotary calculator which

can be set to take the A.S.A. speed of the film into account. This solves completely the right-hand side of the equation, BS/K , and the calculator presents a series of paired aperture numbers and shutter speeds which, assuming no reciprocity effects, give an equal value to A^2/t .

The situation is almost the same with incident-light meters. There is a slight change in the formula, to

$$A/t = IS/C,$$

where I = incident light in lumens/sq ft, and
 C = the exposure constant for incident-light meters.

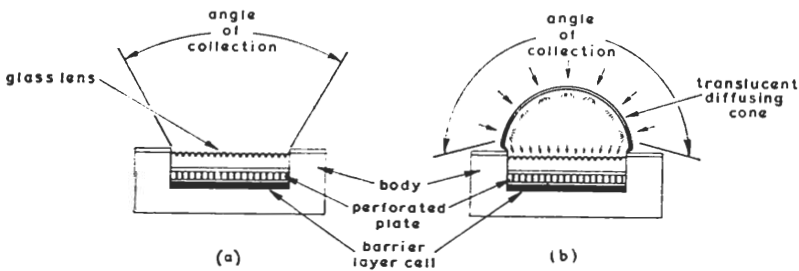


Fig. 8.14. Arrangements for Controlling the Field of View of Different Types of Exposure Meter. (a) Reflected-light Meter, and (b) Incident-light Meter

The value of C in the A.S.A. system is 22 ± 5 for calibration at 2850°K , or 20.8 ± 5 for calibration at 4700°K .

The above formula also is derived in Appendix 8.A. The value of the constant is chosen so that both types of meter indicate the same value of exposure when used on average scenes.

NARROW-ANGLE EXPOSURE METERS. Narrow-angle exposure meters are used when very accurate estimates of exposure are required or the relationship between the minimum and average luminances in a scene is unusual. With some meters the angle of view is as small as half a degree, and the exposure required by any part of the scene can be determined. An example of this type of meter is discussed under the next heading.

COMPARISON PHOTOMETERS. In comparison photometers, the brightness of the scene to be measured is compared visually with an area of standard brightness. A useful instrument in this class is the *spot photometer*, which is effectively a narrow-angle exposure meter designed to enable the *spot brightness* of any small area in the scene to be assessed. The S.E.I. photometer is a typical example, and is illustrated in Fig. 8.15. The subject is viewed through the

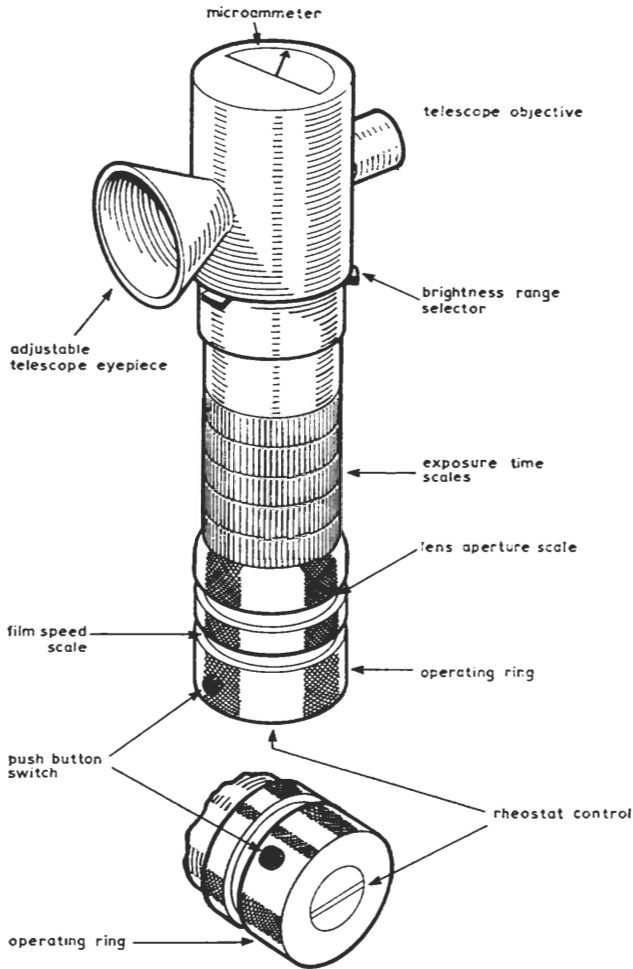


Fig. 8.15. Construction of S.E.I. Photometer

telescope of the instrument and a small spot in the middle of the field of view is made to coincide with the part of the scene to be measured. The brightness of the spot is varied until it matches the brightness of the selected area and, as the brightness of the spot is known, the exposure required can be calculated from a series of scales in the usual way.

The optical arrangements are shown in Fig. 8.16. The spot, which is formed by an adaptation of the Lummer-Brodhun cube, is illuminated by a small

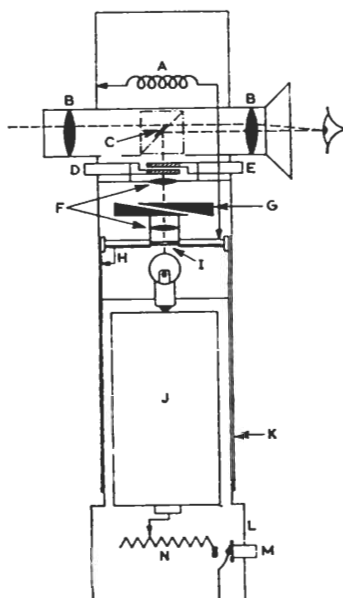


Fig. 8.16. Optical and Electrical Arrangements of S.E.I. Photometer

- | | |
|-------------------------|-------------------------------|
| A. Microammeter coil | H. Photocell |
| B. Telescope lenses | I. Diffusing screen |
| C. Mirror spot | J. Dry battery |
| D. Range-shift disk | K. Exposure scales |
| E. Colour-matching disk | L. Stop and film-speed scales |
| F. Collecting lenses | M. Lamp-switch |
| G. Optical wedges | N. Rheostat |

electric lamp via a diffusing screen. The output from the lamp is monitored by a photocell connected to a microammeter, and the supply to the lamp is adjusted by a rheostat so that the meter reads to a standard mark. The brightness of the spot is then made equal to the brightness of the scene by adjusting the density of a pair of photometric wedges which are between the lamp and the spot; this is done by rotating the base of the meter, and the position of the base gives the brightness of the scene. Neutral density filters and colour correcting filters enable the colour and brightness of the spot to be adjusted to suit the requirements of the scene being measured.

APPENDIX 8.A

Calibration of Integrating Exposure Meters

It can be shown that the average illumination I_a of an image at the focal plane of a camera is given by

$$I_a = \frac{BTH \cos^4\theta}{4A^2(1+M)^2} \text{ lumen/sq ft} \quad (1)$$

where B = average scene brightness in foot-lamberts,

T = transmission factor of lens,

θ = angle subtended at camera by object,

A = aperture number of lens,

M = magnification of image,

H = factor due to vignetting of lens.

For meter calibration, it is assumed that $T = 0.95$, that $\theta = 12^\circ$ and that the object distance is 40 times the focal length of the lens. Formula (1) then reduces to

$$I_a = \frac{qB}{A^2} \text{ lumen/sq ft} \quad (2)$$

the value of q being 0.22 for a lens having a flare factor of 1.03 and a vignetting factor of unity.

If the units of equation (2) are converted from lumen/sq ft to lux, the formula becomes

$$I_a = \frac{qB}{A^2} \times 10.76 \text{ lux} \quad (3)$$

If the camera shutter remains open for t seconds, the average exposure E_a is given by

$$E_a = I_a t \quad (4)$$

The relationship between the average exposure E_a and the speed point E_m in the A.S.A. "new" system is about 10:1. Consequently

$$E_m = \frac{I_a t}{10} \quad (5)$$

Now the A.S.A. speed S is given as explained in Chapter 7 by

$$S = \frac{0.8}{E_m}$$

Inverting, and substituting for I_a from (5):

$$\frac{0.8}{S} = \frac{I_a t}{10} \tag{6}$$

Substituting for I_a from (3):

$$\frac{0.8}{S} = \frac{qBt}{10A^2} \times 10.76$$

or
$$\frac{A^2}{t} = \frac{BS}{K}$$

where
$$K = \frac{10 \times 0.8}{10.76q}.$$

If q equals 0.22 as previously, the value of K is about 3.6. As the reflected light from the scene was the value measured in (3), the above value of K is appropriate for reflected-light meters.

Assuming the scene to be a diffusing surface, the incident light can be found from the formula

$$B = I\rho$$

where I is incident light in lumens per square foot of area, ρ is the reflection coefficient of the surface and B is the brightness of the surface in foot-lamberts.

If ρ is taken as 0.16 for an average scene, than the constant C for incident-light meters is given by

$$\frac{B}{I} = \frac{K}{C}$$

and
$$C = \frac{K}{\rho} = \frac{100K}{16} = \frac{100 \times 3.6}{16} = 22.2.$$

Bibliography

- | | |
|--|--|
| [1] NEBLETTE, C. B., <i>Photography</i> . Sixth edition. Van Nostrand, 1962. | exposures. <i>Journal S.M.P.T.E.</i> , volume 69 (July 1960), pages 479-483. |
| [2] WALSH, J. W. T., <i>Photometry</i> . Third edition. Constable. | [5] <i>Weston Master IV exposure meter handbook</i> . |
| [3] SOMMER, A., <i>Photo-electric cells</i> . First edition. Methuen, 1946. | [6] <i>S.E.I. photometer handbook</i> . |
| [4] NELSON, C. N., Safety factors in camera | [7] <i>Photoemissive cells</i> . Mullard. |

IX. ASSESSMENT OF THE PHOTOGRAPHIC IMAGE

Grain Structure of Image

A microscopic examination of a developed film shows that the image is formed by a very large number of extremely small opaque particles of silver. An observer, viewing a picture at a few magnifications, is however conscious only of a certain non-uniformity in the image of an area which has received a uniform exposure. This effect, described as *graininess*, is caused by random variations in grain concentration, and is not due as may be thought to the

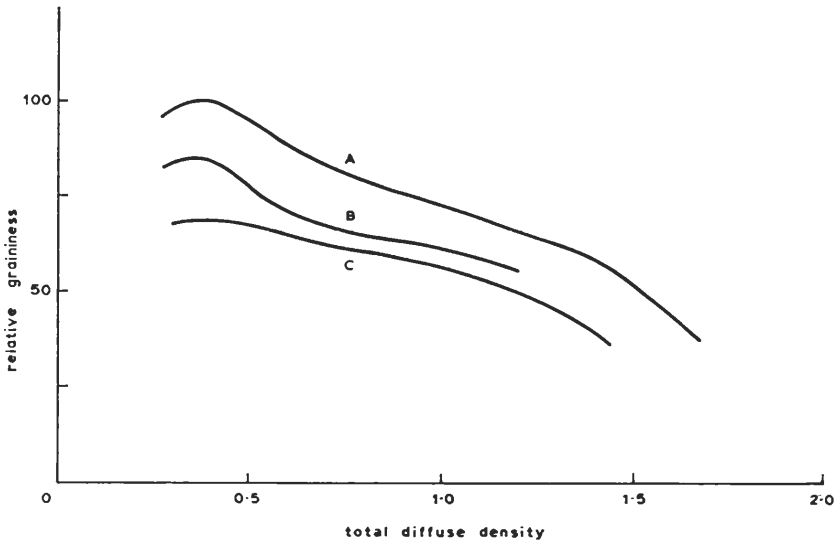
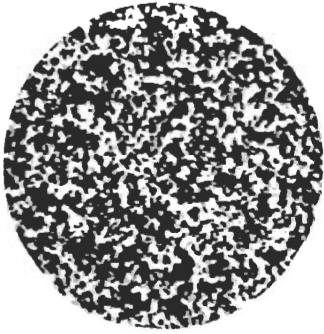


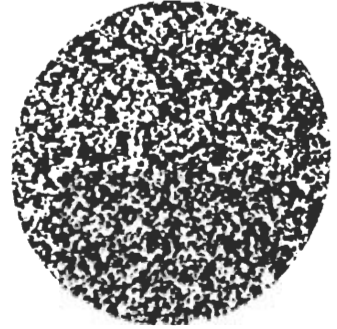
Fig. 9.1. Graininess/Density Function for (A) Relatively Coarse-grained, (B) Medium-grained and (C) Relatively Fine-grained Material

visibility of individual grains. These are much too small to be seen separately until the magnification approaches a hundred times, and tests made on grain patterning show that the effect is adequately explained by random distribution, there being no need to postulate special effects such as "clumping".

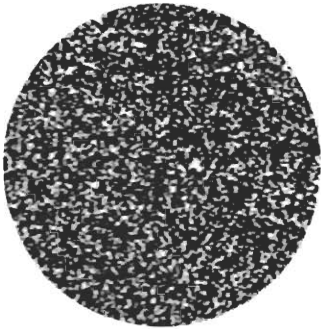
Many experiments have been made on the subjective assessment of graininess; the results are of great use to manufacturers, as a side-by-side comparison can be made between different emulsions for research purposes and for process control. However, the quantitative results obtained are so dependent upon the particular equipment used for experiments that there is no agreed system of units for subjective evaluation. Fig. 9.1 gives some results obtained from one



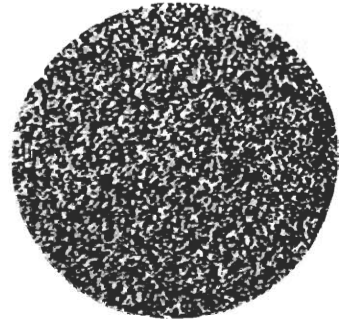
1. HPS: $\gamma = 0.63$



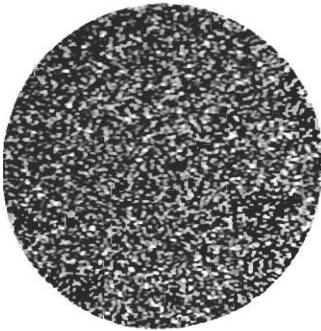
2. Tri X: $\gamma = 0.64$



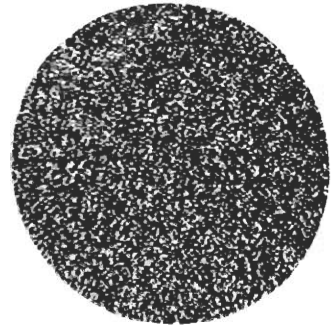
3. Plus X: $\gamma = 0.64$



4. Pan F: $\gamma = 1.0$

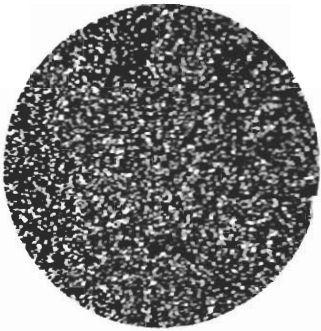


5. 7374: $\gamma = 1.0$

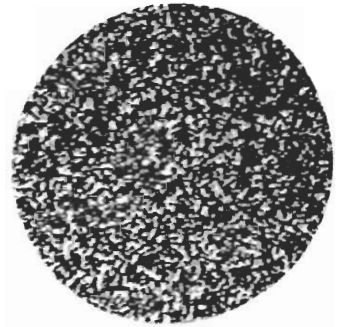


6. 5302: $\gamma = 2.4$

Fig. 9.2. Photomicrographs showing the Graininess of Different Kinds of Emulsion



density = 0.7
gamma = 0.63



density = 0.7
gamma = 1.1

Fig. 9.3. Effect of Gamma on Grain Size

of the experimental methods used. They show that graininess is most noticeable at low densities and how it depends on grain size; this is also illustrated in Fig. 9.2, which shows photomicrographs allowing the graininess of six emulsions ranging from fine-grain printing stock to extremely high-speed negative material to be compared.

Although *graininess* describes the subjective effect of grain structure, the name *granularity* is given to the objective measurement of its effect, and a lot of research has been made into this problem over the last forty years without any completely satisfying result. Modern methods are using techniques developed for the study of communication networks; the analogy between the effect of grain and the effect of noise is very close, and in television the effects

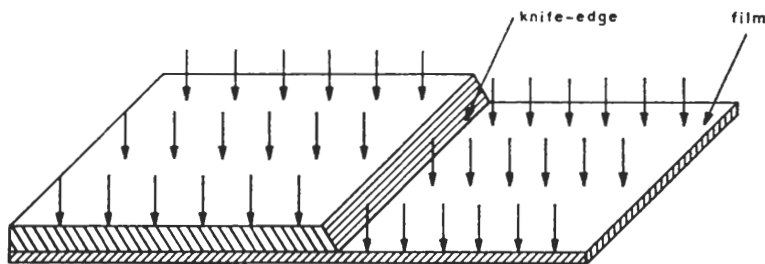


Fig. 9.4. Acutance-test Exposure using Knife-edge

of both coincide. These methods are considered later on in this Chapter. Some of the less controversial conclusions are listed below.

1. The effect of grain may be considered as consisting of two separate components:

- (a) The objective component, which is determined by the physical characteristics of the developed silver image, and specifically by the distribution of the silver grains within the image.
- (b) The subjective component, which is dependent upon the effect produced by the silver image on the eye.

Each of the two components is a function of density and the combination of the two functions gives the graininess/density function.

2. The grain size increases slowly with increasing density for a given emulsion.

3. Very approximately, for a given emulsion the mean signal-to-noise ratio is inversely proportional to the square root of density, provided that only lower frequencies are considered.

4. Granularity seems to be roughly proportional to the square root of the point gamma at a given density. Fig. 9.3 shows photomicrographs of the grain structure of a film developed to constant density but with two different gamma values.

Sharpness and Acutance

An observer viewing a projected picture receives a subjective impression of its quality of definition which is described as *sharpness*. The objective counterpart of this in terms of the measurable characteristics of the picture is called *acutance*.

The acutance of a film is measured from the curve of density plotted against

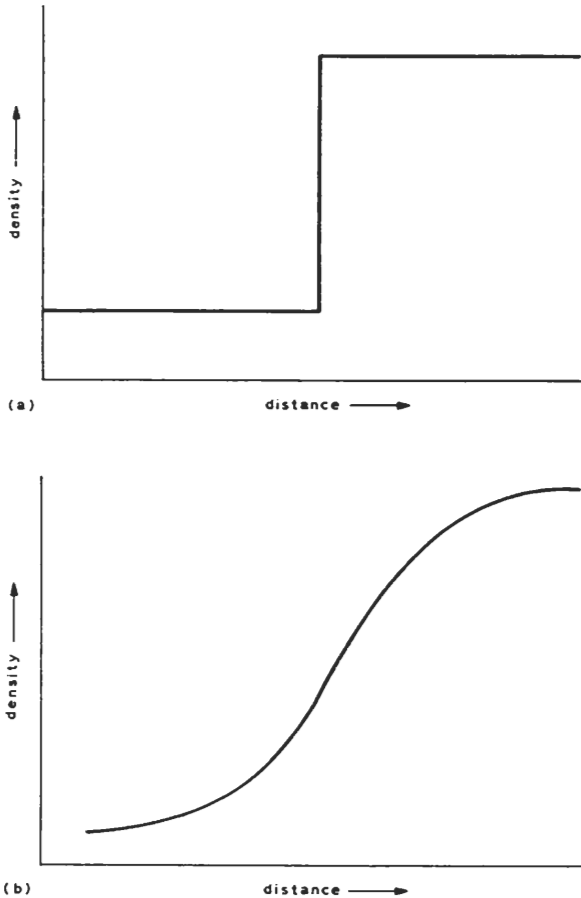


Fig. 9.5. Response of (a) Ideal Film and (b) Practical Film, to Knife-edge Exposure Illustrated in Fig. 9.4

distance which results from an abrupt change of exposure intensity, the film being exposed while partially shielded by a knife-edge in contact with the emulsion as shown in Fig. 9.4. The response of an ideal film, in terms of the resultant density/distance relationship, is shown in Fig. 9.5(a), while Fig. 9.5(b) shows a practical example.

The method used to measure acutance must take into account not only the total change of density and the average gradient but also the manner in which the changes take place. This is necessary because the eye, viewing for example the three pictures whose density/distance variations are shown in Fig. 9.6, sees

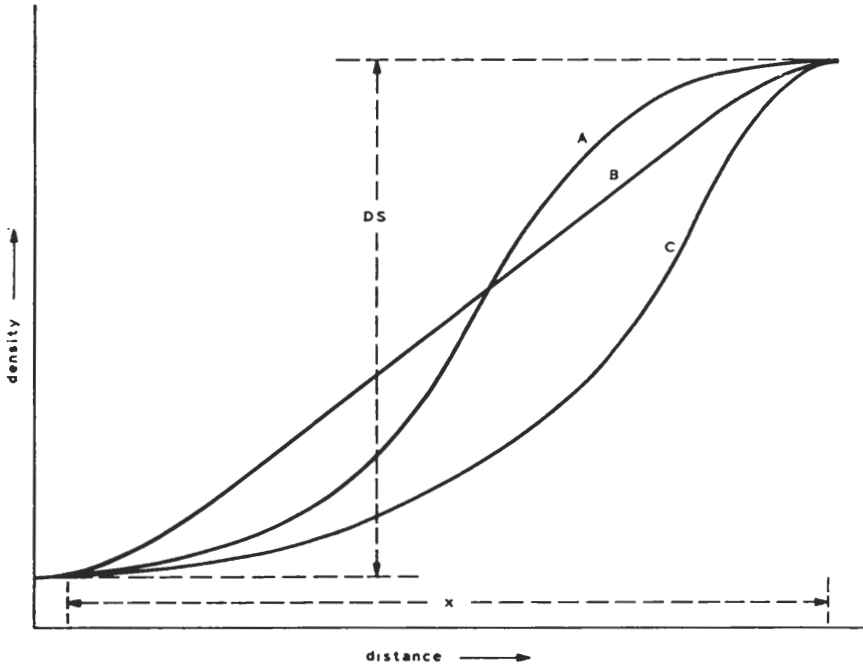


Fig. 9.6. Density/Distance Traces for Three Images

different values of sharpness despite the fact that (1) the initial and final values of density, (2) the change of density, (3) the distance over which the change takes place and (4) the average gradient, are the same in each instance. Fig. 9.7 illustrates the method adopted. A large number of point gradient measurements are made at equally-spaced intervals in microns along the density/distance curve between two threshold gradient points. If n measurements are made these can be expressed as $g_1, g_2, g_3 \dots g_n$. Each value of point gradient is squared, and the “mean value of the gradient squared”, G^2 , is obtained from the formula

$$G^2 = \frac{g_1^2 + g_2^2 + g_3^2 + \dots + g_n^2}{n}$$

or, more concisely,

$$G^2 = \frac{1}{n} \sum_{r=1}^{r=n} g_r^2$$

The acutance is then given by G^2/DS , where DS (standing for "density scale") is the density difference between the two threshold gradient points at which the gradient is 0.005 density units per micron.

This definition is found to correlate well with the impression of sharpness received by an observer for all but very unusual edge-shapes.

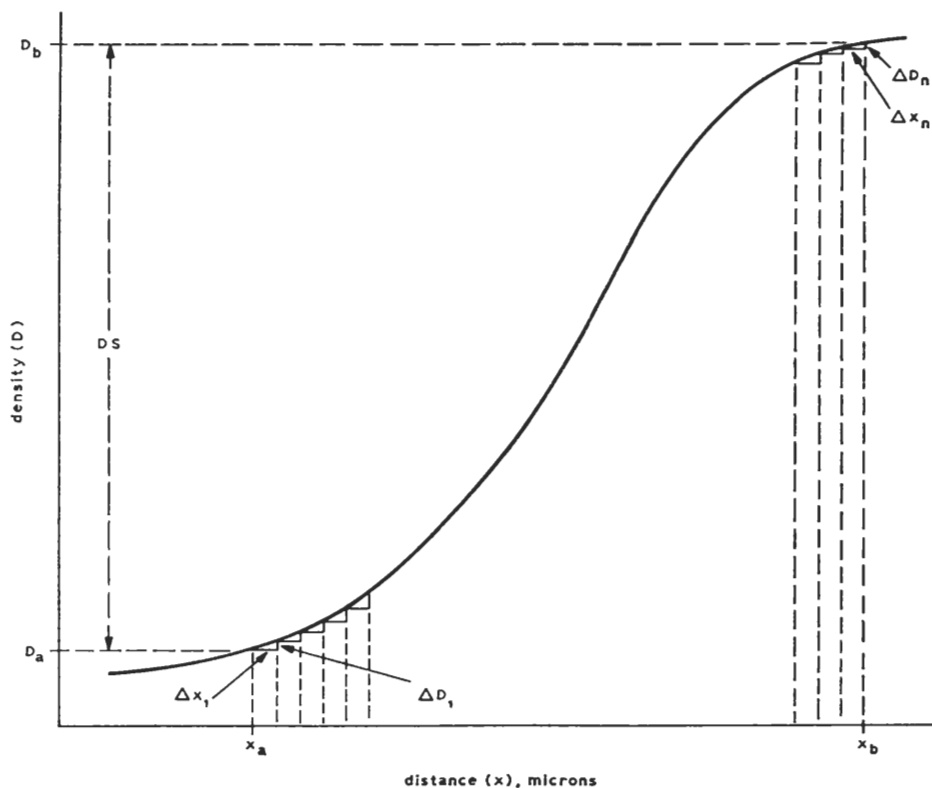


Fig. 9.7. Method of Calculating Acutance

Adjacency effects have a marked bearing on the acutance and sharpness of a picture; an example of this is shown in Fig. 9.8. The dotted curves show the change of density with distance when there are no adjacency effects, and the full lines show how this is modified by adjacency effects.

Fig. 9.9 shows how acutance depends on DS for different negative materials.

Resolving Power of Emulsion

MEASUREMENT. The ability of a photographic emulsion to record fine detail is called *resolving power*. It is usually measured by photographing groups of

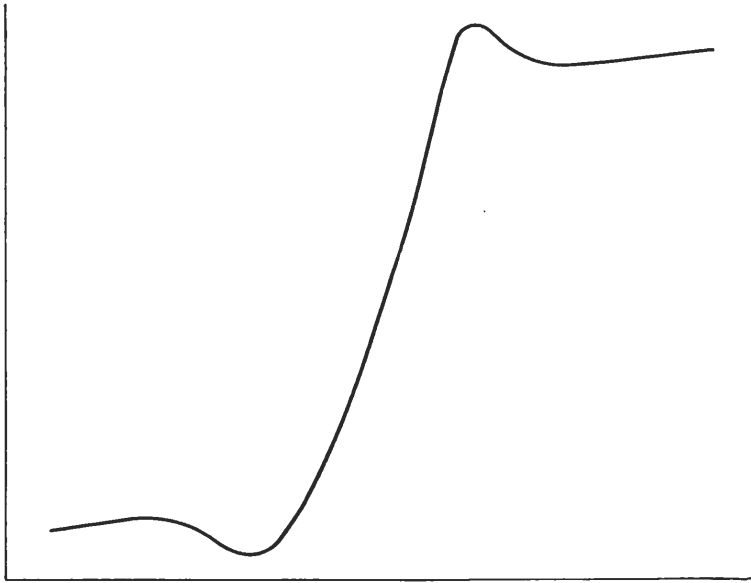


Fig. 9.8. Adjacency Effects, which Modify Acutance Values Considerably

lines of graded size; the finest group that can be distinguished in the developed image determines the resolving power of the film.

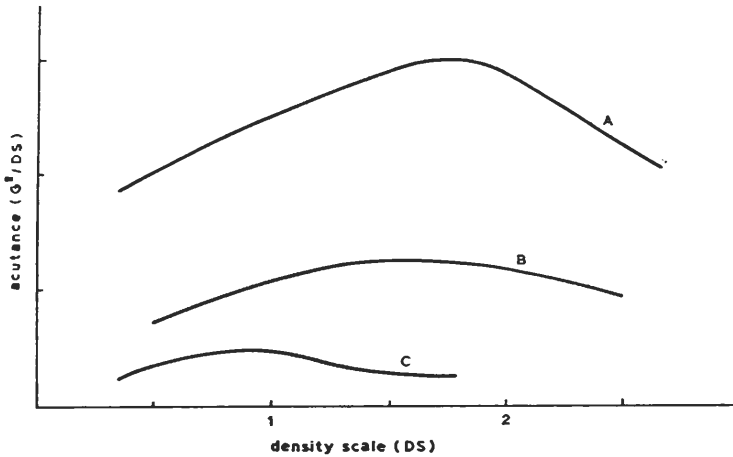


Fig. 9.9. Acutance/Density-Scale Curves for Three Typical Materials: (A) High-contrast Motion-picture Positive Film, (B) Fine-grain Landscape Film and (C) High-speed Landscape Film

A typical test object is shown in Fig. 9.10. It comprises a number of successively finer sets of parallel lines. Each set consists of three similar lines separated

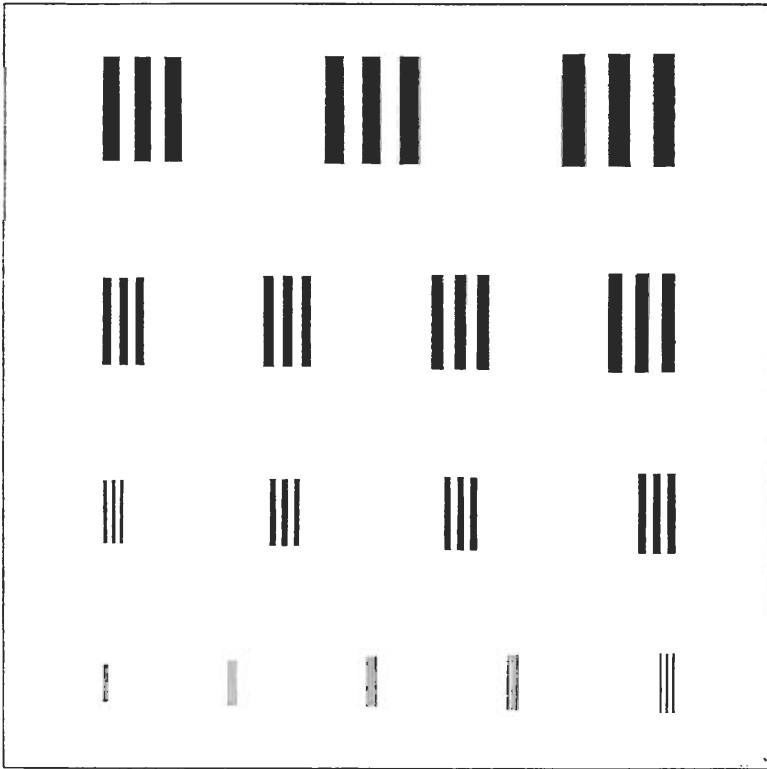


Fig. 9.10. Parallel-line Type of Resolving-power Test Object

by spaces of the same width as the lines. The test object is usually photographed with a reduction of 50 to 100 times, and the developed image is examined under a microscope to determine the finest set of lines which can be resolved. Some typical results are shown in Table 9.1.

TABLE 9.1
RESOLVING POWERS OF SOME TYPICAL MATERIALS

<i>Material</i>	<i>Limiting Resolution lines/mm</i>
Motion-picture negative	80-110
Motion-picture positive	120-180 with f/5 lens 200-300 with N/A 0.4 lens
Copying material	700
Special plates	1600

The size of the test pattern is specified in terms of the number of lines per millimetre, abbreviated to lines/mm. Often the term *spatial frequency* is used, with units of cycles per millimetre, abbreviated to cycles/mm or c/mm.

The behaviour of the camera lens degrades the contrast ratio of the test object, in the way shown in Fig. 9.11; this effect gets worse as the spatial frequency of the test pattern increases and a lens should be used which has a limiting resolution at least three times better than the emulsion being tested.

Even a perfect lens has a limiting resolution, which depends on its aperture. At the Kodak research laboratory an $f/5$ lens, giving a resolution of about

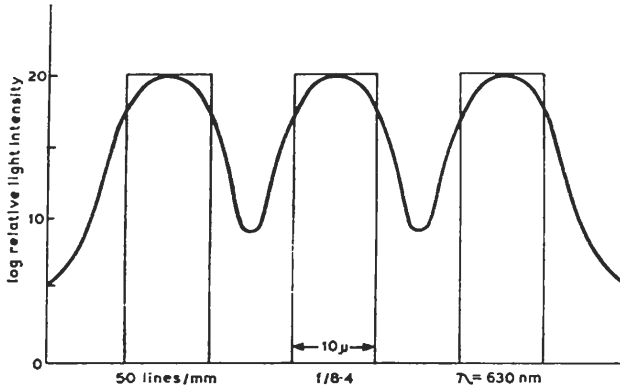


Fig. 9.11. Luminance Distribution in Lenticular Image of Test Object

320 lines/mm, is used to test film whose resolution is less than about 120 lines/mm. When this lens resolution is inadequate a microscope objective with a numerical aperture (N/A) of 0.4 is used.

The limiting resolution, R , of a perfect lens is determined by diffraction effects, and is given by the formula

$$R = \frac{1000}{1.22A\lambda} \text{ lines/mm,}$$

where A is the aperture number and λ is in microns.

Figs. 9.12 to 9.14 show how the measured resolving power of a film depends on a number of factors. Fig. 9.12 shows the relationship between gamma, density and resolving power for a high-speed material which is developed in a borax developer. Fig. 9.13 shows the relationship between resolving power, gamma and type of developer for a lantern-slide plate. When emulsions are measured, several different exposures are made, and a series of curves similar to those shown in Fig. 9.14 is obtained. The difference between the three curves shows the importance of the contrast ratio of the test object. In curve A, the ratio is 1000:1, in curve B it is 8:1, and in curve C it is 2:1.

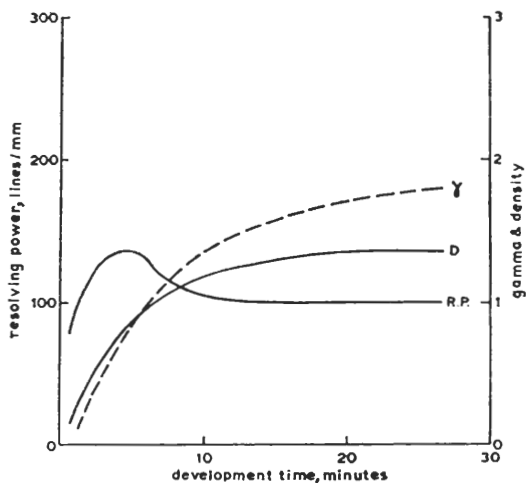


Fig. 9.12. Effect of Development Time on Density, Gamma and Resolving Power, for a High-speed Material Developed in a Borax Developer

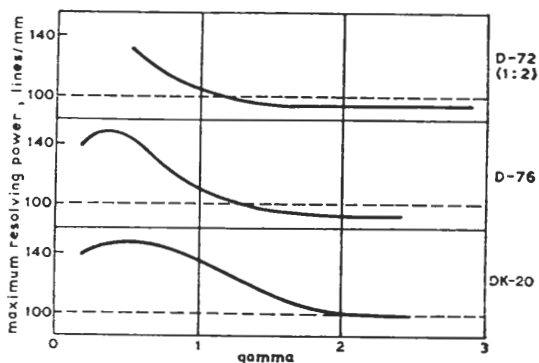


Fig. 9.13. Maximum Resolving Power as a Function of Gamma. (Gamma determined by time of development in three different Kodak developers)

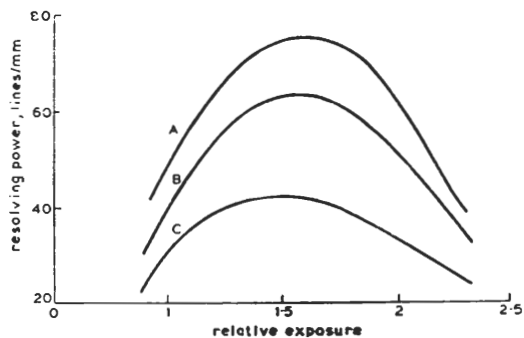


Fig. 9.14. Variation of Resolving Power with Exposure and with Contrast Ratio of Test Object. (Contrast ratios are (A) 1,000:1, (B) 8:1 and (C) 2:1)

SUBJECTIVE SIGNIFICANCE. The ability to resolve very fine detail was among the first qualities of an emulsion to be examined and measured. This is not surprising, since resolution would appear to be an important feature of image quality. It also seems to be an easy feature to measure and express in numerical terms, but in practice the subjective interpretation of numerical resolution measurements often presents difficulties. The dividing line between an image which is "resolved" and one which is not is a very fine one and at the limit of resolution the image is barely recognizable as a line structure at all; not only is it fuzzy in appearance, but the contrast between the lines and spaces becomes so reduced that the image is almost uniformly grey all over. Such an image is virtually useless so far as practical results are concerned, and if an assessment of the performance of a film is made on such data, the subsequent results are liable to be disappointing. A method which is much more satisfactory, particularly for film used in a bandwidth-limited system such as television broadcasting, is the evaluation of the modulation transfer function as explained below.

Modulation Transfer Function of a Film

The modulation transfer function, or sine-wave response, of a film is found by measuring its response to a number of sinusoidal test objects of varying spatial frequency. A typical test object is shown in Fig. 9.15; it has a mean transmission of b_0 which varies sinusoidally with distance from $(b_0 + b_1)$ to $(b_0 - b_1)$; the ratio b_1/b_0 is called its *modulation*, M , and its spatial frequency is measured in cycles/mm.

At each spatial frequency tested, the modulation transfer factor or MTF for the film is found. This is given by the ratio

$$\text{MTF} = M_1/M_0;$$

where M_1 is the modulation of the developed image on the film, and M_0 is the modulation of the test object measured at the film.

The modulation transfer function of the film is found by plotting MTF against spatial frequency, as shown in Fig. 9.16. At low values of spatial frequency, the image amplitude is reproduced in accordance with the normal density/exposure characteristics of the film. At higher frequencies, the image amplitude is considerably less than predicted by these characteristics, and the change is reflected by the continuing fall in MTF with increasing frequency.

The determination of M_1 is shown in Fig. 9.17. The trace of the density variation with distance in the developed image is produced by a microdensitometer. The modulation of the image is measured, not from the variation in image density, but from the variation in $\log E$. A characteristic curve, produced from a test strip printed on the film when the tests are made, enables density

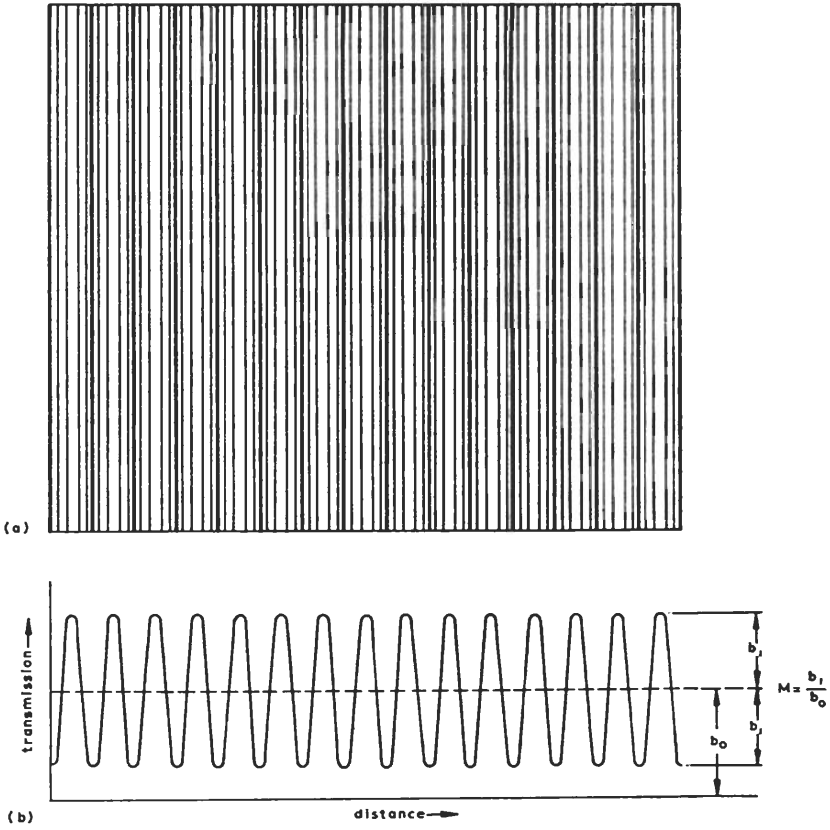


Fig. 9.15. (a) Typical Test Object and (b) Variation of Transmission with Distance Along It

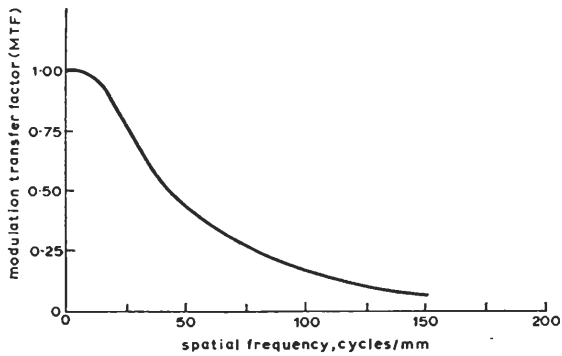


Fig. 9.16. The Modulation Transfer Function or Sine-wave Response of a Film

measurements to be transferred to the $\log E$ axis as shown; results obtained in this way are almost independent of the mean density level and amplitude of the image and are hardly affected by nonlinearity of the $D/\log E$ curve.

Comparison of the transfer functions for a heavy and a light exposure, resulting in average densities of say 1.70 and 0.35, shows that provided adjacency

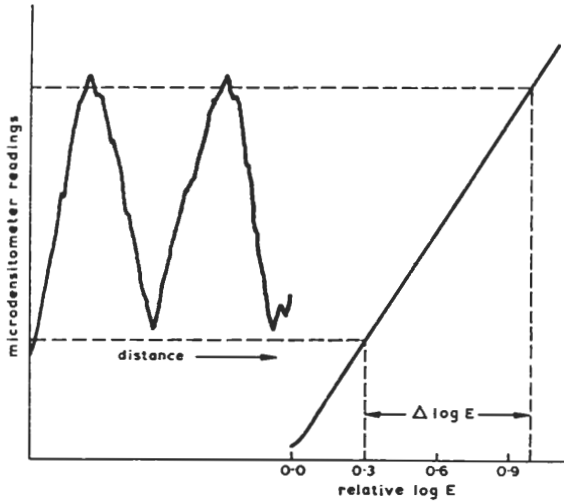


Fig. 9.17. Determination of Image Modulation in Terms of $\Delta \log E$

effects are reduced to a minimum there is very little change over a reasonable range of exposures, and the same applies to development times.

Modulation Transfer Function of a Lens

In practice, the “test object” used to determine the MTF of a film is an image produced by a lens system like the one shown in Fig. 9.18.

A modulation transfer function can be produced for a lens in the same way as for a film. The MTF of a lens is the relationship at any one spatial frequency between the modulation of the test object and the modulation of the image, and the curve of MTF with spatial frequency gives the modulation transfer function as usual.

Multiplicative Property of Modulation Transfer Functions

An important property of transfer functions is that they can be combined by simple multiplication; this may be demonstrated by the systems shown in Fig. 9.18. If, at a given frequency, the modulation of the test object is M_1 and

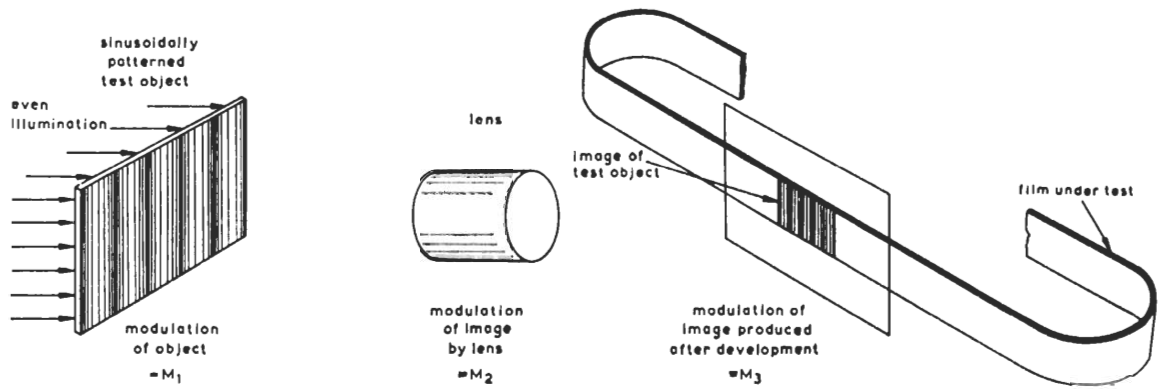


Fig. 9.18. System for Determining the MTF of a Film

the modulation of the image produced by the lens is M_2 , then the modulation transfer factor MTF_1 for the lens at that frequency is given by

$$MTF_1 = M_2/M_1.$$

Now the test object for the emulsion is the image produced by the lens, which itself has a modulation, M_2 . If the modulation of the developed image is M_3 , the modulation transfer factor MTF_2 for the emulsion is therefore given by

$$MTF_2 = M_3/M_2.$$

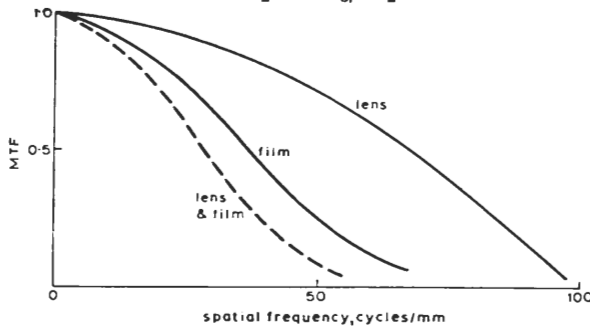


Fig. 9.19. Transfer Functions, showing Cascading Property

The modulation transfer factor MTF_3 for the whole system is given by

$$MTF_3 = \frac{M_3}{M_1}.$$

If the top and bottom of the right-hand part of the above equation are both multiplied by M_2 , we get

$$\begin{aligned} MTF_3 &= \frac{M_3}{M_1} \times \frac{M_2}{M_2} \\ &= \frac{M_2}{M_1} \times \frac{M_3}{M_2} \\ &= MTF_1 \times MTF_2. \end{aligned}$$

This process, repeated ordinate by ordinate, establishes the multiplicative or “cascading” property of the modulation transfer function.

The cascading principle can be used for any number of elements, provided that the various objects and images are scalar quantities; the system cannot be used when the object is an aerial image unless a diffusing screen is placed at the image position.

The response of a lens-and-film combination such as shown in Fig. 9.18 is illustrated in Fig. 9.19.

The modulation transfer function can be plotted on log/log scales, as shown in Fig. 9.20. When MTFs are expressed in dB, they can of course be simply added.

The modulation transfer function is a very sensitive indicator of adjacency effects. These are shown up in Fig. 9.20 by the peaking of the curve above 100% at very low spatial frequencies.

A full description of the performance of an emulsion requires three-dimensional presentation, because of the nonlinearity of the $D/\log E$ curves, and

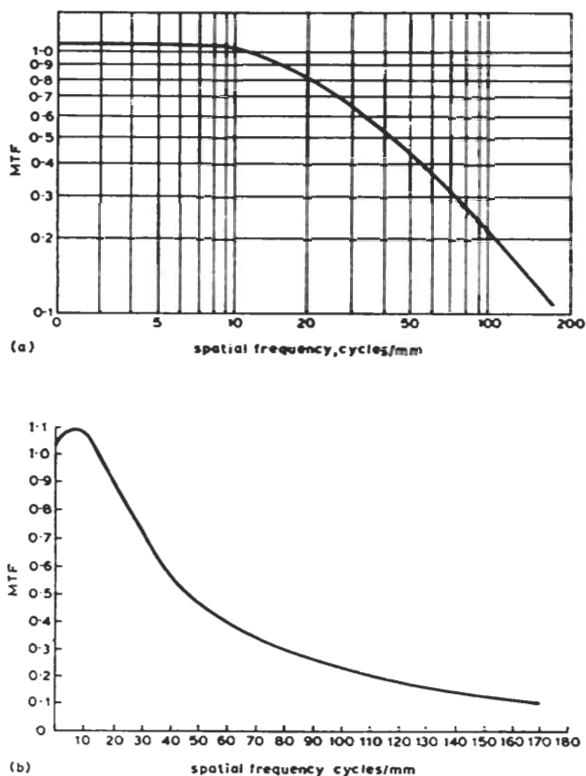


Fig. 9.20. The Modulation Transfer Function drawn on (a) log/log and (b) linear/linear Scales. (The diagrams show a typical high-speed negative film)

a surface representing the transfer characteristic including exposure effects is drawn in Fig. 9.21.

Spread Functions

Two spread functions are defined, the point spread function and the line spread function.

The *point spread function* is the image produced by a lens or a film of a point source of light, as shown (for a film) in Fig. 9.22. It is a basic unit of image

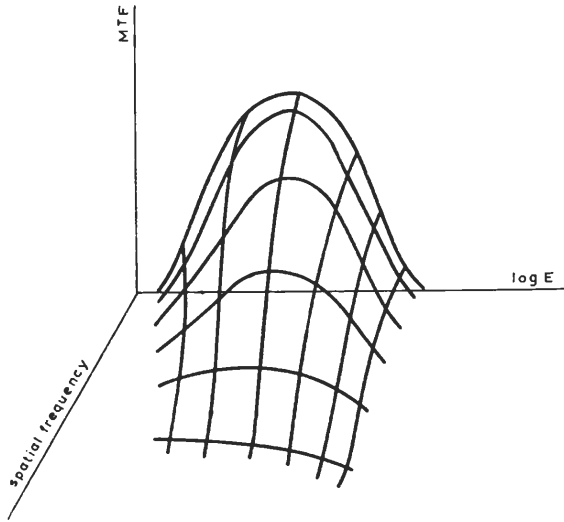


Fig. 9.21. Three-dimensional Transfer Characteristic for Photographic Emulsion

formation, because any scene can be considered to be made up from a large number of point sources. Fig. 9.23 shows how a film image can be built up from the summation of its spread functions, the size of each of which is determined by the exposure intensity of the appropriate element. This process,

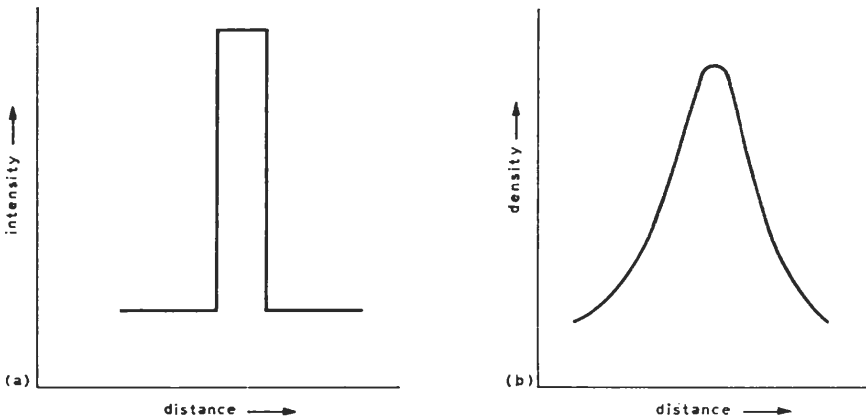


Fig. 9.22. The Spread Function: (a) 'Point' Light Source, and (b) Resulting Image on Film

which is called *convolution*, is very time-consuming and it is more usual to consider the sine-wave response of the film, which can be obtained by Fourier analysis from the spread function. The spread functions for two films are shown in Fig. 9.24(a) and the corresponding modulation transfer functions are shown in Fig. 9.24(b).

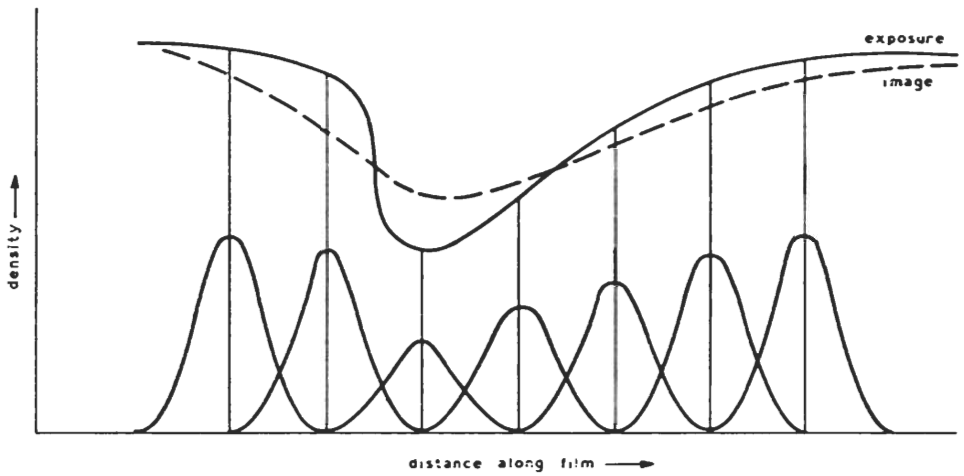


Fig. 9.23. Image Formation by Summation of Spread Functions

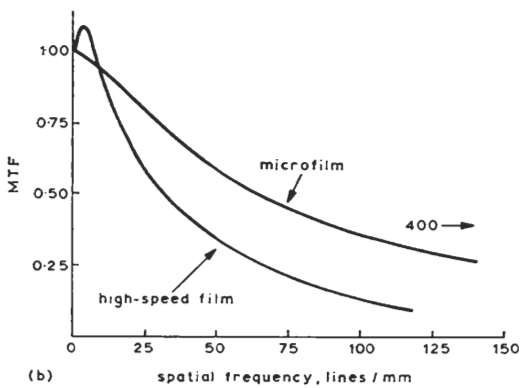
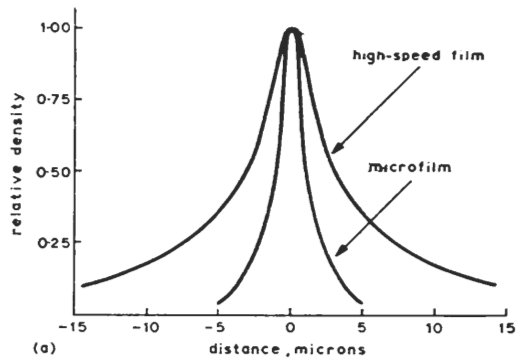


Fig. 9.24. The Spread Function and corresponding Modulation Transfer Function for Two Contrasted Types of Film

(Courtesy of D. Van Nostrand Company, Inc.)

The spread function of a film emulsion is symmetrical, as shown in Fig. 9.24(a), and the modulation transfer function shown in Fig. 9.24(b) represents it completely. The spread function of a lens, on the other hand, is asymmetrical, and the corresponding modulation transfer function must for completeness have both magnitude and phase. An example is shown in Fig. 9.25.

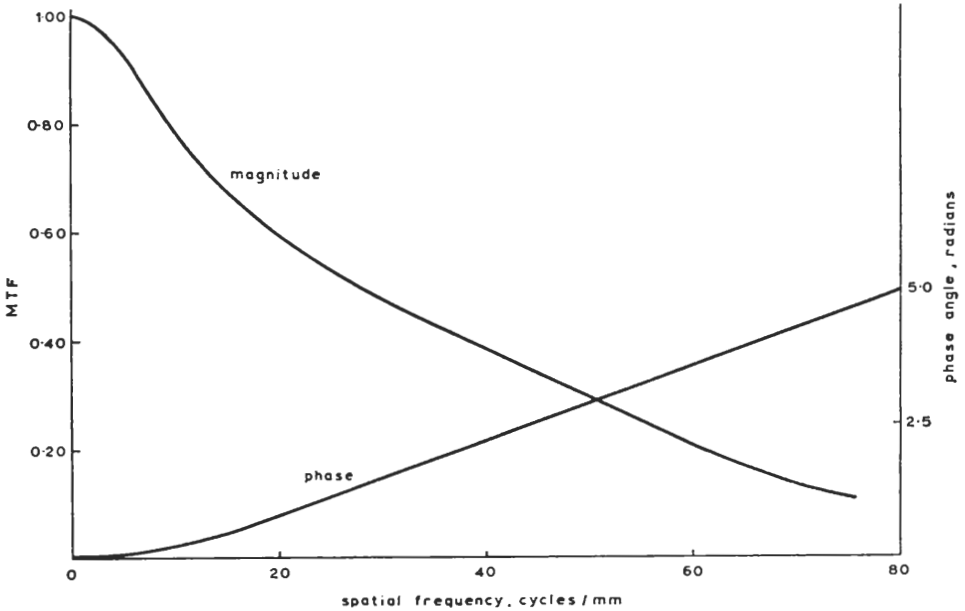
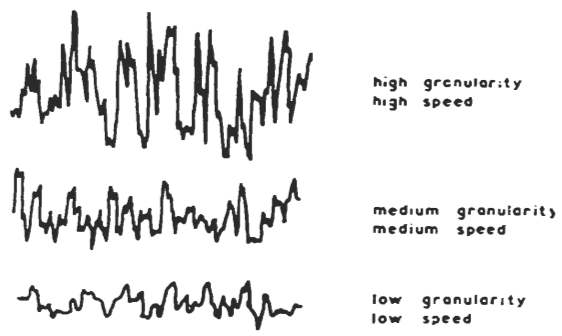


Fig. 9.25. Modulation Transfer Function of Lens showing Magnitude and Phase

Measurements of a true point spread function are very difficult to perform and practical work is usually carried out using a thin line source; the resulting function is essentially the integration of the point spread function along the length of the slit, and is called the *line spread function*.

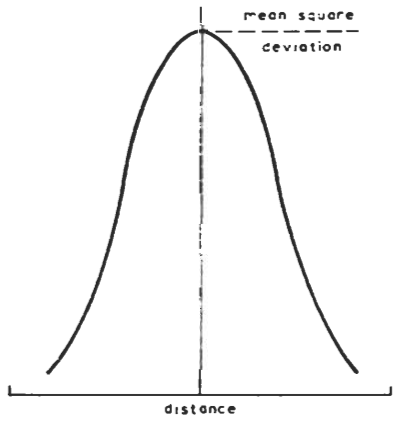
Signal-to-noise Ratio

Fig. 9.26 shows the density fluctuations due to granularity which occur along three typical uniformly exposed and developed films. Each of the waveforms illustrated may be represented statistically by an *autocorrelation curve* similar to Fig. 9.27(a). The height of the curve gives a measure of the film density fluctuations and the width of its skirts is an indicator of the type of fluctuation, which is determined by the grouping properties of the grains. Coarse-grained emulsions have wider-skirted curves than fine-grained ones. The autocorrelation function can be transformed by Fourier analysis into a

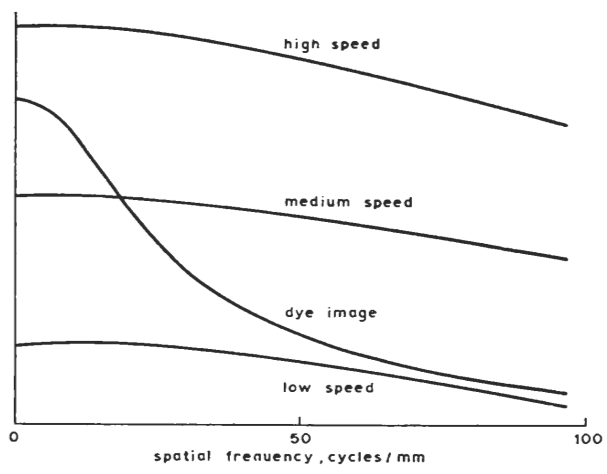


distance along film →

Fig. 9.26. Film Density Fluctuations due to Granularity



(a) Autocorrelation Curve



(b) Noise Spectrum

Fig. 9.27. Autocorrelation Curve and Noise Spectrum

spatial frequency function which here represents a noise spectrum, and Fig. 9.27(b) shows the noise spectra of the granularity waveforms in Fig. 9.26.

The signal-to-noise ratio can be determined after assessing the frequency range applicable, as discussed under the next heading. The amount of noise

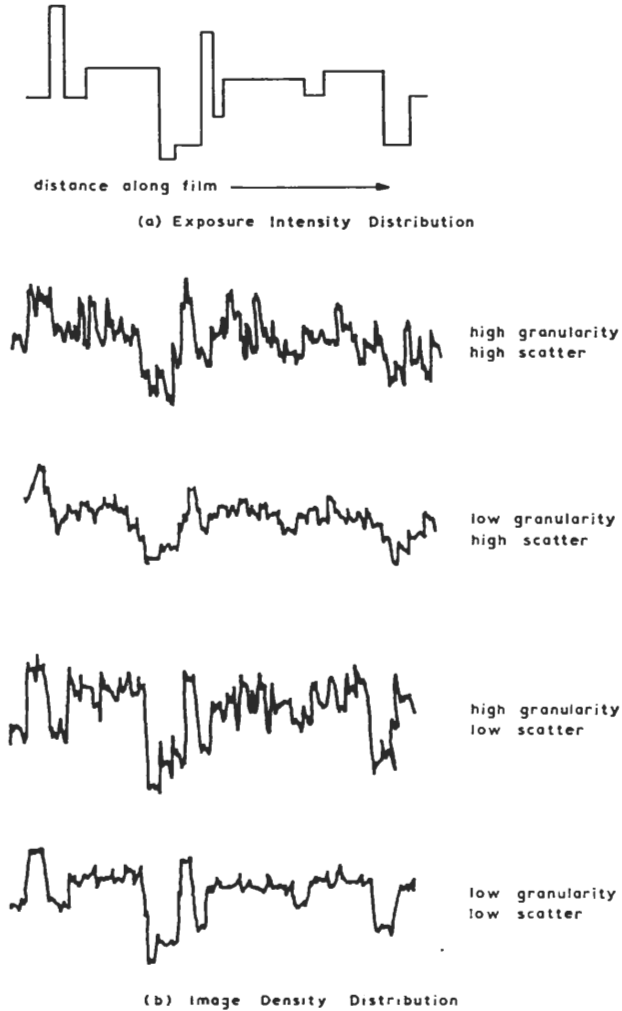


Fig. 9.28. Image Characteristics in the Presence of Varying Degrees of Scattering and Granularity

can be calculated from the noise spectrum and the size of the signal can be determined from the modulation transfer function.

The effect of photographic noise on the image produced by a low value of exposure is shown for a number of typical cases in Fig. 9.28.

Bandwidth-restricted Systems

The modulation transfer function shown in Fig. 9.29 is plotted to very high values of spatial frequency, where the MTF is almost zero. Television broadcasting systems, however, are bandwidth-restricted and the high-frequency

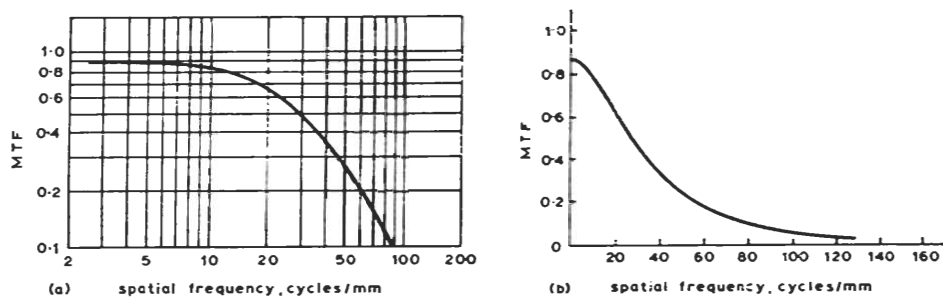


Fig. 9.29. Modulation Transfer Function, illustrating Low MTF Values at Very High Spatial Frequencies. (Diagram (a) is drawn with log/log and (b) with linear/linear scales. The diagrams show a typical motion-picture fine-grain positive film)

information passed by the lens or the film is later discarded. The minimum useful size of the image depends on the overall size of the image format and on the limiting frequency of the system concerned. Tables 9.2 and 9.3 show the

TABLE 9.2
SPATIAL FREQUENCIES EQUIVALENT TO 3-Mc/s
SIGNAL IN 405-LINE TELEVISION SYSTEM

<i>Application</i>	<i>Image Size</i>	<i>Horizontal Definition cycles/mm</i>	<i>Vertical Definition cycles/mm</i>
4½-in. Image Orthicon	1.28 × 0.96 in.	7.4 (8)	7.7 (8)
1-in. Vidicon	1.28 × 0.96 cm	18.75	19.65 (20)
35-mm film recording	0.816 × 0.612 in.	11.6	12.1 (12)
16-mm film (quick pulldown)	0.392 × 0.285 in.	24	26
Number of active lines: 377		Active line time: 80 μs	

limiting spatial frequencies for the more usual formats used in the 405-line and 625-line television systems.

From the above, it would seem reasonable to assume that the only region that need be considered on the modulation transfer characteristic (Fig. 9.30) is the shaded area between a spatial frequency of zero cycles/mm and the cut-off

TABLE 9.3
 SPATIAL FREQUENCIES EQUIVALENT TO 5.5-Mc/s SIGNAL
 IN 625-LINE TELEVISION SYSTEM

<i>Application</i>	<i>Image Size</i>	<i>Horizontal Definition cycles/mm</i>	<i>Vertical Definition cycles/mm</i>
4½-in. Image Orthicon	1.28 × 0.96 in.	8.8	11.9 (12)
1-in. Vidicon	1.28 × 0.96 cm	21.2	30.4 (30)
16-mm film recording	0.816 × 0.612 in.	13.8	18.8 (19)
35-mm film (quick pulldown)	0.392 × 0.285 in.	28.8	40.4 (40)
Number of active lines: 585		Active line time: 52 μs	

Note to Tables 9.2 and 9.3

These tables are prepared on the assumption that a camera tube can register a sharp black/white transition in one line. In practice, this is not so, and the 4½-inch Image Orthicon can be quoted as an example. In the 405-line system, it requires 1.1 lines to record the change, which is as if there were only 342 active lines. In the 625-line system it requires 1.6 lines, corresponding to a 365 active-line system.

frequency f_{∞} . The validity of this assumption has been investigated, mainly in connection with lenses, but the results should also be applicable to films.

One thing that has been found is that there is a linear correlation between (1) the "normalized area" below the modulation transfer curve of a lens between zero cycles/mm and the cut-off frequency, and (2) the subjective impression of image sharpness received by an observer. The "normalized area", which may be explained by reference to Fig. 9.30, is the ratio of the area *aecd* beneath the curve over the frequency range considered to the area *abcd* beneath the corresponding curve for a perfect lens over the same frequency range.

This normalized area expresses the objective *sharpness factor*, *S*, for the lens, which is therefore given by

$$S = \frac{\text{area } aecd}{\text{area } abcd}$$

and subjective estimates of image sharpness are directly related to *S* values.

It has also been found that, as supposed, no property possessed by the lens above the cut-off frequency need be considered. Thus, of the three response curves shown in Fig. 9.31, that of lens (a) is the best for television purposes, in spite of its limited response in cycles/mm, whereas lens (c), with the widest response, is by far the worst for television.

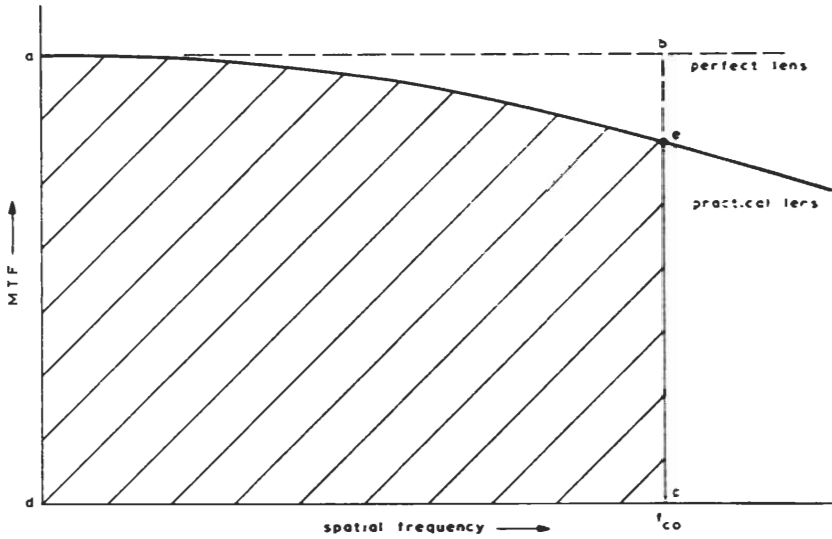


Fig. 9.30. Modulation Transfer Function of Lens, showing System Cut-off Frequency and Method of Calculating Sharpness Factor

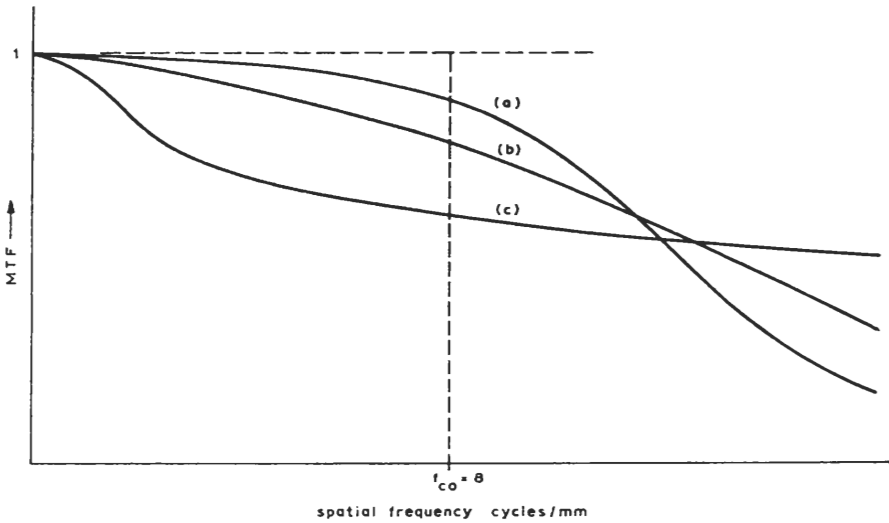


Fig. 9.31. Modulation Transfer Functions of Three Lenses intended for use on $4\frac{1}{2}$ -inch Image Orthicon working in 405-line System

Bibliography

[1] MEES, C. E. K. and JAMES, T. H., *The theory of the photographic process*. Third edition. Macmillan, New York, 1966.

[2] JAMES, T. H. and HIGGINS, G. C., *The fundamentals of photographic theory*. Second edition. Morgan and Morgan, New York, 1960.

[3] NEBLETTE, C. B., *Photography*. Sixth edition. Van Nostrand, 1962.

[4] FERRIN, F. H., Methods of appraising

photographic systems. *Journal S.M.P.T.E.*, volume 69, pages 151–156.

[5] LAMBERTS, R. L., Application of sine wave techniques to image forming systems. *Journal S.M.P.T.E.*, volume 71, No. 9, pages 635–640.

[6] SHAW, R., Modern methods of evaluating the quality of photographic systems. *Visual (Ilford Journal)*, volume 1 (1963), No. 2, pages 19–24.

X. PRINTERS

Types of Printer

Printers are used to make positive copies from negative or negative copies from positive film. Some printers just make simple copies, whereas others have many applications, including printing 16-mm film from 35-mm film, titling, editing and the creation of zooms, fades and special or trick effects. Various types of printer have been developed for particular applications, but all types have certain common requirements. These are

1. They must ensure that every frame is given an even and consistent exposure.
2. The amount of exposure must be adjustable, so that a well-balanced print can be produced from negatives of varying densities.
3. The film transport mechanism must ensure that exact synchronism is maintained and that no slip occurs between the two films.

Printing action may be of either the *intermittent* or the *non-intermittent* (i.e., continuous) type. Printers with either type of action may be further subdivided into *contact printers* and *optical printers*. Special effects printers are usually of the optical intermittent type.

Intermittent Contact Printers

A typical example of an intermittent (or “step”) contact printer is shown in Fig. 10.1. In this machine, a claw mechanism draws both films through the printing gate a frame at a time, usually with their emulsion faces in contact. As soon as the film movement has ceased, a shutter opens, making an exposure through the negative onto the positive film. When the exposure is complete, the shutter closes, the claw moves the films on to the next frame, and the process continues.

Intermittent Optical Printers

In optical printers, the negative and positive films are not in contact, the image of the negative being focused onto the positive by a lens system such as the one shown in Fig. 10.2. Each film is stepped through its printing gate by a separate claw mechanism, and the two claw mechanisms are synchronized to a shutter which governs the exposure as in the previous example.

The whole of the printing aperture must be evenly illuminated by the condenser lens. Light from the lamp is directed by the condenser towards the node of admission of the projection lens; the cone of light which emerges from the projection lens has then the same angle as the one that enters it, and passing

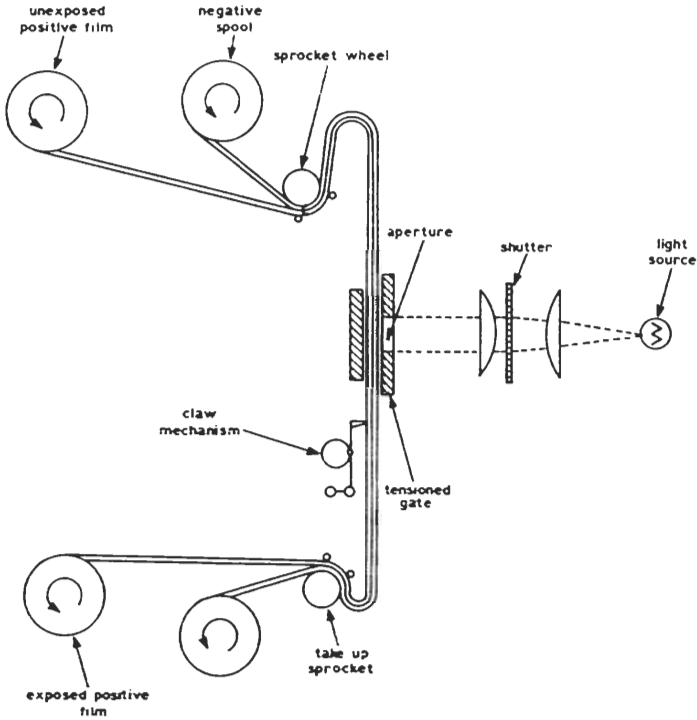


Fig. 10.1. Intermittent Contact Printer

through the first printing aperture, the specular component of the light is thus directed through the second.

The projection lens shown in the diagram is the usual single system, which inverts the image. The positive and negative films must therefore be moved in opposite directions to compensate.

Optical printers have several advantages over contact printers. These are

1. The speed of scenic action on the positive can be altered from the speed of action on the negative by *stretch printing*. For instance, if successive frames of the positive are printed from negative frames

1, 2, 2, 3, 4, 4, 5, 6, 6, and so on,

a negative taken at 16 frames per second can be used to make a positive suitable for projection at 24 frames per second. (In verification of this, it may be

observed that, for the sequence given, nine frames of positive are produced from six frames of negative.)

2. The spacing of the printer heads can be made variable. If a variable focus projection lens is used, zoom effects can be created or selected enlargements made.

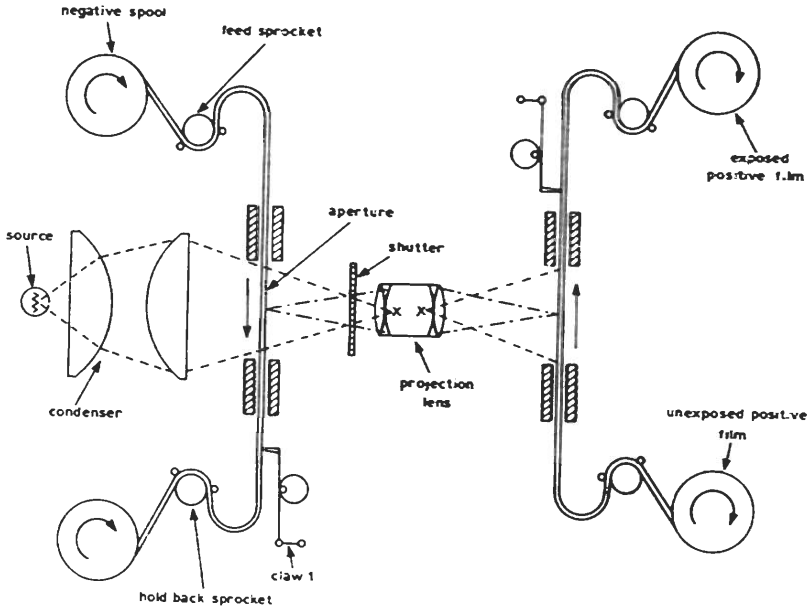


Fig. 10.2. Intermittent Step Optical Printer

3. Reduction printing, optical mixing, special fades and various trick effects are possible.

The disadvantages of optical printers are

1. Higher image contrast than on contact printers.
2. An increase in the apparent graininess of the print.
3. An increase in the visibility of dust and scratches on the negative.
4. Higher cost due to lower operating speed of intermittent mechanism and to higher maintenance charges.

These disadvantages occur mainly because the optical printer has a specular/specular optical system, whereas the contact printer has a specular/diffuse system.

One of the disadvantages of the optical printer—the prominence of scratches on the negative—can be overcome by dipping the film base in a liquid whose

refractive index approaches that of the base. This layer of liquid is levelled by gates and is optically indistinguishable from the base. Clean scratches on the back of the negative do not therefore appear on the print, and even scratches through the emulsion may be reduced in prominence.

Non-intermittent or Continuous Printers

Continuous printers are used where speed is important, as where a large number of prints are to be made from each negative. The films pass through

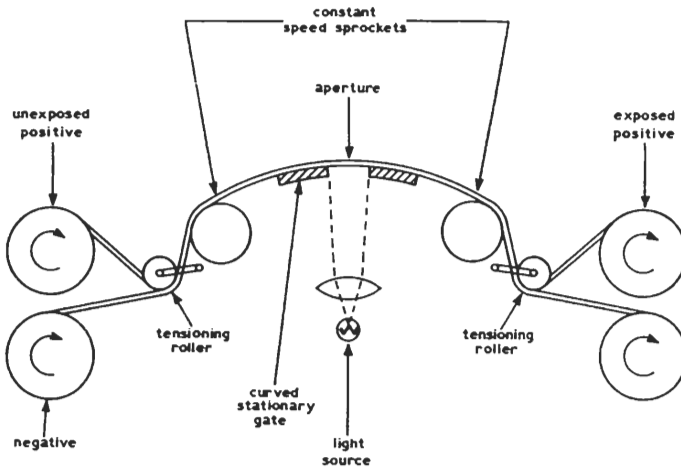


Fig. 10.3. Stationary-gate Continuous Contact Printer

the machine continuously at a constant speed, and consequently the negative is not subjected to the heavy wear-and-tear produced by a claw mechanism after a large number of runs.

Fig. 10.3 illustrates a stationary-gate continuous contact printer and Fig. 10.4 illustrates a rotating-gate continuous contact printer. In each machine, both films are drawn continuously past an illuminated printing aperture, the exposure given depending on the light intensity, the aperture width and the film speed. The disadvantages of continuous contact printers are

1. Slipping between the two films occurs as they pass over the gate, because of the difference in shrinkage between the processed negative and the unprocessed positive, and because the inside film on the sprocket has a lower velocity than the outside film. The shape of the sprocket-wheel teeth which drive the films is usually designed so as to prevent any abrupt change in speed as each

new tooth engages; however, some slipping is bound to occur, with a resultant loss of print sharpness.

2. The printers can only be used for simple contact work.

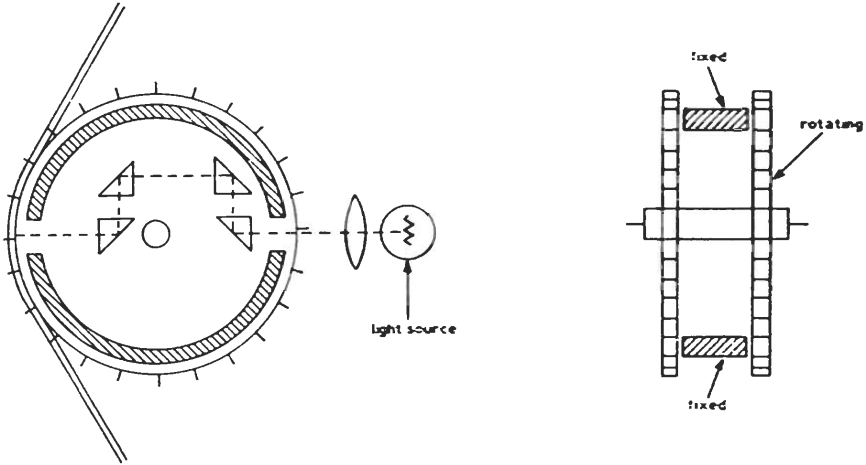


Fig. 10.4. Rotating-gate Continuous Contact Printer

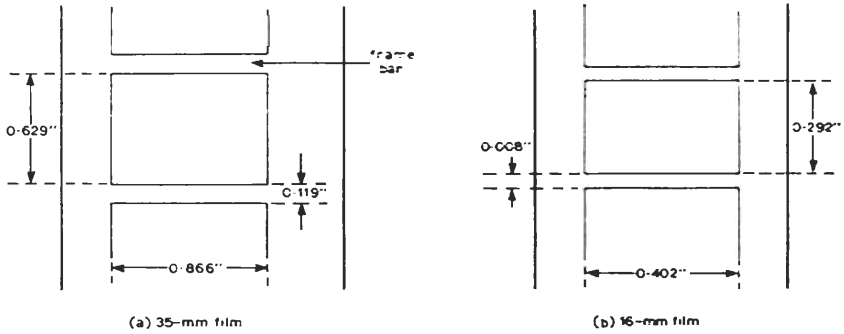


Fig. 10.5. Picture Area and Frame Bar on 35-mm and 16-mm Film

Continuous optical printers are used for sound-track printing, particularly when reduction is involved.

Reduction Printing

It is often necessary to print down from 35-mm film to 16-mm film, a process known as "reduction printing".

The dimensions of the 35-mm and 16-mm pictures are shown in Fig. 10.5. It can be seen that

1. The picture dimensions have to be reduced by a factor of 2.15 to 1, from a size of 0.866 by 0.629 inches for 35-mm film, to 0.402 by 0.292 inches for 16-mm film.
2. The spacing between two adjacent pictures (the *frame bar*) has to be reduced by a factor of 14.5 to 1, from 0.119 inch on 35-mm film to 0.008 inch for 16-mm film.

As the two reduction ratios are different, reduction is carried out using two different features of the intermittent optical printer: the optical arrangements

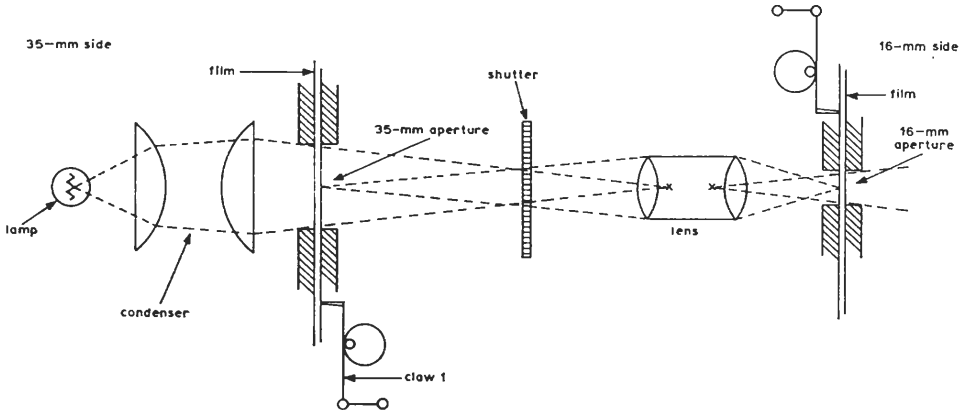


Fig. 10.6. Optical Printer used as Reduction Printer

provide the 2.15:1 step-down ratio for the picture and the film transport mechanism produces the 14.5:1 step-down ratio for the frame bar.

These points are illustrated in Fig. 10.6, which shows an optical printer similar to the one previously discussed. The position of the positive film has been moved towards the projection lens, so that the ratio between the image distance and the object distance is 1:2.15. When the projection lens is suitably focused, the reduction in the frame bar is achieved by making claw 1 step the 35-mm film and claw 2 step the 16-mm film forward by an amount appropriate to each film gauge.

To carry out the reverse operation to reduction, that is, printing up from 16-mm film to 35-mm film, the direction of the light must be reversed. The print produced is called a *blow up*.

Light Control

All printers have some means of controlling exposure; some use a variable iris or aperture, whereas others use rheostats, but whatever the method, there are commonly 21 steps of exposure provided. A skilled grader examines the

negatives before printing, in order to assess the density of each and to estimate the printer exposure required; this is to ensure that the final print, which may be made up from many different scenes, is of uniform density. This does not mean to say that dark scenes and light scenes are printed to look alike; the skill of the grader lies in his ability to assess the mood of each take and to programme accordingly.

“Contact”, “S.M.P.T.E.” and Other Prints

Fig. 10.7 shows two types of 16-mm sound-positive film. The type shown in Fig. 10.7(a) is projected with its emulsion face towards the light source, and is

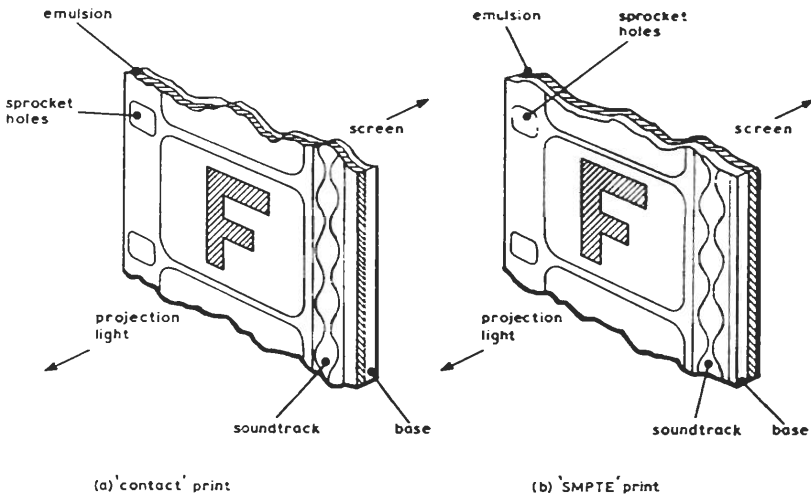


Fig. 10.7. 'Contact' and 'S.M.P.T.E.' Prints

called a *contact print*; the type shown in Fig. 10.7(b) is projected with its emulsion face away from the light source, and is called an *S.M.P.T.E. print*. It can be seen that there is no lateral inversion of the image and that the soundtrack and the sprocket holes are on the same side in both types of print; the altered position of the emulsion face is the only difference between the two.

“Contact prints” are produced when a normal negative is contact-printed on a positive with both emulsions together; this is the usual method, and produces the best results. They are also produced by optical printers when the two emulsions are facing. “S.M.P.T.E. prints” are produced when a print is made from a reversal original via an intermediate negative, or when a print is made with both emulsions turned towards (or away from) the printing light in a contact printer.

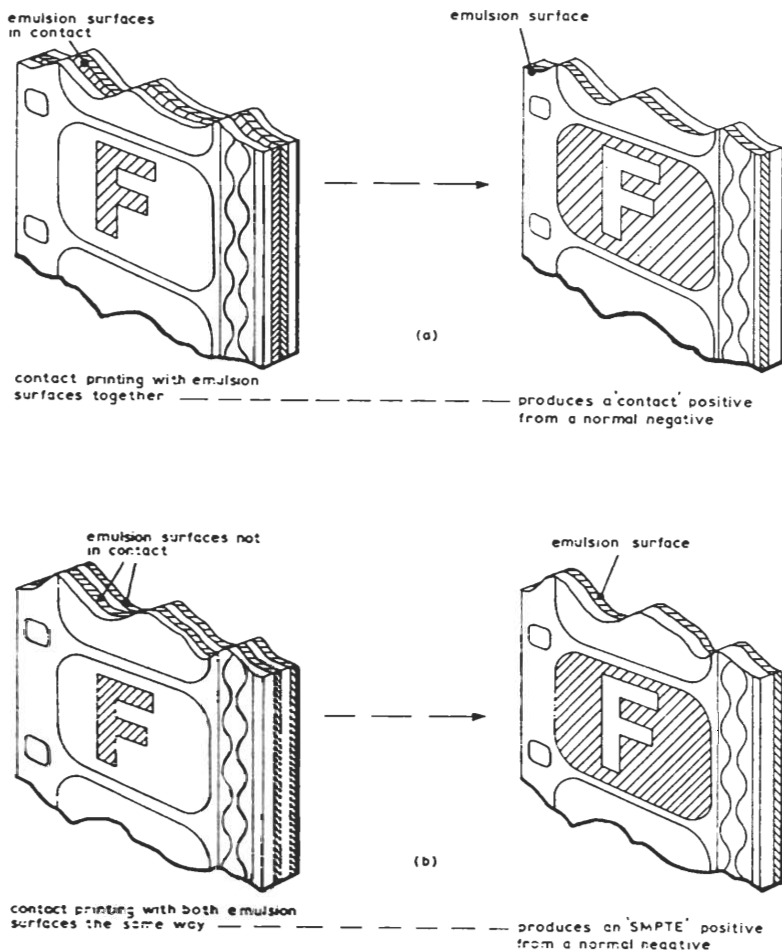


Fig. 10.8. Methods of Contact Printing

The prints produced by various methods are shown in Figs. 10.8 and 10.9.

Sometimes non-standard negatives are encountered, such as would be made by contact printing from a reversed negative. A negative which produces, on emulsion-to-emulsion contact printing, a "contact positive", is called a *contact negative*, whereas a negative which produces an "S.M.P.T.E. positive" is called an *S.M.P.T.E. negative*: all normal negatives are therefore "contact" negatives.

A further form of print is used on the continent; it is called a *D.I.N.* print, and the image is laterally reversed with respect to "contact" and "S.M.P.T.E." prints.

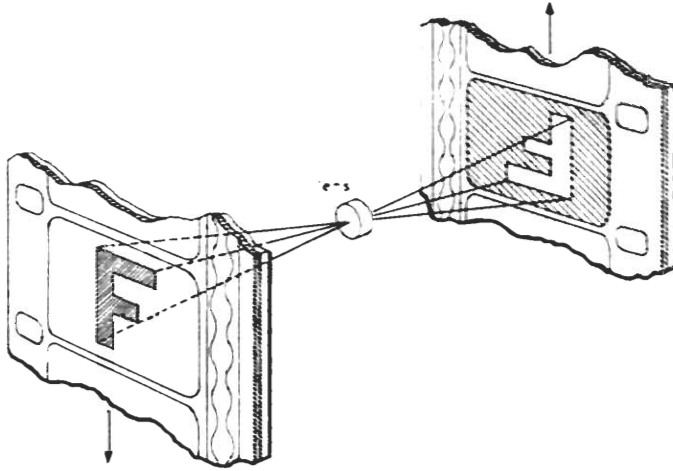


Fig. 10.9. Optical Printing. A print made on an optical printer, with both emulsion surfaces towards the projection light and using a single-system projection lens, produces an inverted 'contact positive'. The negative and positive films must be run through the machine in opposite directions; otherwise, when the print is projected the right way up, the action will take place backwards

Sprocket-holes in 16-mm Film Leaders

The wide variety of types of print mentioned under the previous heading obviously tends to make for complications, with resulting confusion. In the case of 16-mm film, it is possible to guard to some extent against errors due to this cause which might arise on television transmissions. A 16-mm sound film has only one set of sprocket-holes, whereas a 16-mm silent film has two, and to insure against lateral inversion in the projector, all 16-mm films for transmission are provided with correctly-attached single-perforated leaders.

Bibliography

[1] WHEELER, L. J. *Principles of cinematography*. Third edition. Fountain Press, 1963.

XI. FLARE—THE QUADRANT DIAGRAM— REVERSAL PROCESSING

Flare

The image formed in the camera does not have the same scale of illumination as the scene being photographed, owing to the effect on the image of light scatter or *flare* caused by the lens and lens assembly.

If I_t is the total image illumination at any point, I_i is the illumination resulting from focused image-forming light, and I_f is the illumination resulting from unfocused flare light alone, then

$$I_t = I_i + I_f.$$

The unfocused flare light is produced largely by reflection at the glass/air interfaces and by dirt, dust and scratches on the lens. Additional flare can come from the lens barrel, the iris diaphragm and the shutter mechanism.

Surface coating of the lens greatly reduces reflection at the glass/air interfaces. Usually, the coating is a quarter-wavelength deposit of a material having a refractive index as close as possible to the geometric mean for the glass and air. A modern zoom lens, however, is given multiple layer coatings, because of the very large number of glass/air interfaces it contains; these coatings reduce the light scatter caused by surface reflection to a level comparable to that in a good fixed-focus lens.

Flare light compresses the tonal scale, because it has proportionately more effect on the shadows than on the highlights. For example, the uniform addition of 1 per cent flare to an image with a contrast ratio of 100 to 1 reduces the ratio to 101 to 2, thereby almost halving the contrast range. The 1 per cent of flare hardly affects the highlights, but it doubles the shadow illumination.

The magnitude of flare depends not only on the equipment used, but also on the type of scene. The effect is sometimes expressed in terms of a *flare factor*, which is defined as the ratio of scene brightness range, B_r , to image illumination range, I_r . This definition can be illustrated on the flare curve given in Fig. 11.1, which shows the relationship between scene brightness, B , and image illumination, I , in a typical case. The curve is normally drawn with logarithmic scales as here, so that it can be used in conjunction with emulsion characteristics. From the diagram,

$$\text{Flare factor} = B_r/I_r = (B_2 - B_1)/(I_2 - I_1),$$

where B_2 and B_1 are the maximum and minimum scene brightnesses, and I_2 and I_1 are the corresponding image illuminations.

Curves such as that shown can be determined experimentally by measuring and photographing a grey scale placed in the scene, the image brightness figures being derived from a knowledge of the emulsion behaviour. In one experiment, measurements were made on 126 different scenes, photographed

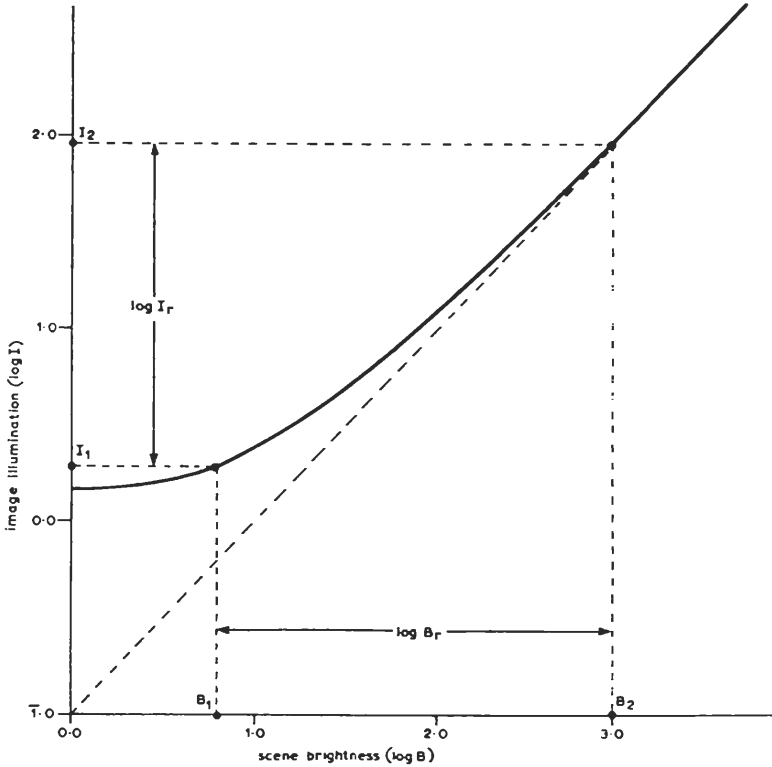


Fig. 11.1. Flare Curve

using a first-class camera with a coated lens; the results gave a flare factor varying between 1.15 and 9.50, the average figure being 2.35.

The Quadrant Diagram

GENERAL PRINCIPLES. The flare curve for a camera lens and the sensitometric curve for a film can be combined by means of a transfer diagram (Fig. 11.2), to give a density/brightness relationship. The scene brightness range is transferred to an image illumination range via the flare curve; this in turn is transferred to a negative density range by means of the $D/\log E$ curve of the film.

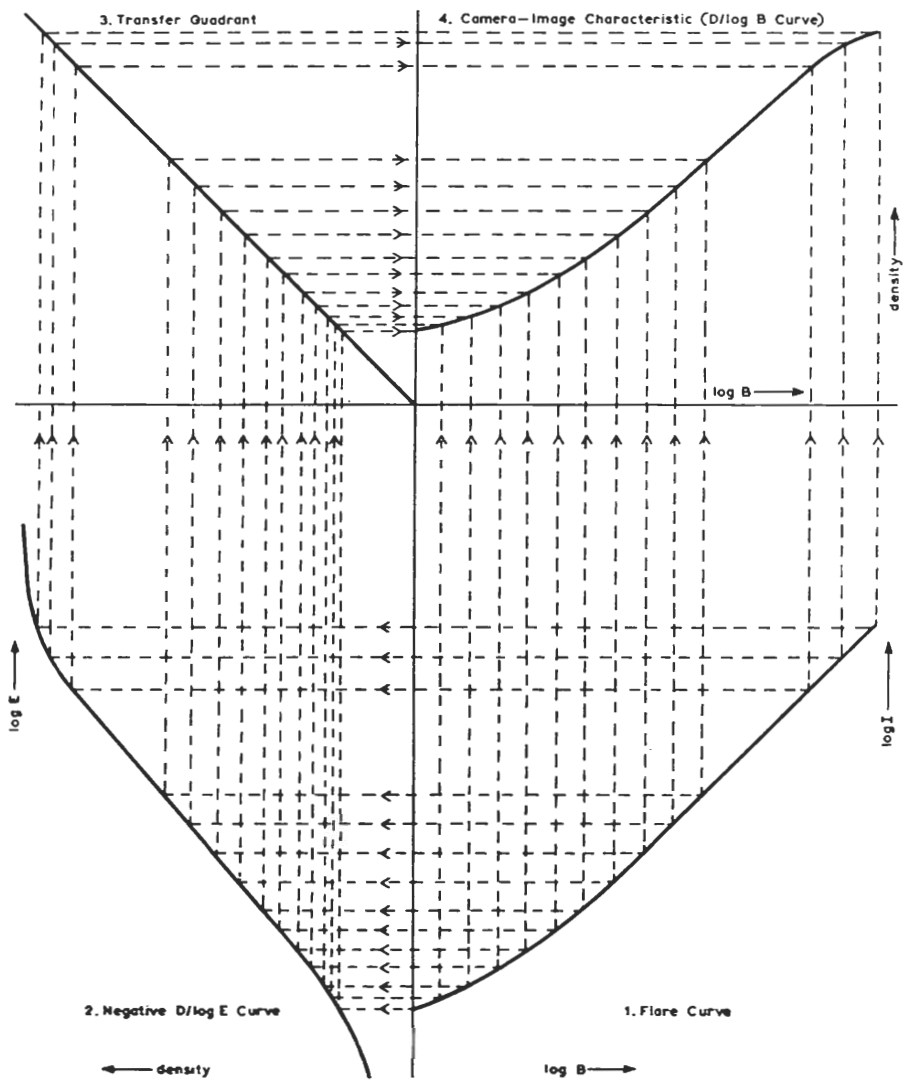


Fig. 11.2. Construction of Camera-image Characteristic or $D/\log B$ Curve

The resulting combined $D/\log B$ curve which is produced is often called the *camera-image characteristic*.

This method can be extended to the description of the transfer characteristics of the combination of any number of photographic stages; by following the photographic process through in detail, the effect of each stage can be assessed, and the final reproduction compared to the original. In the example which

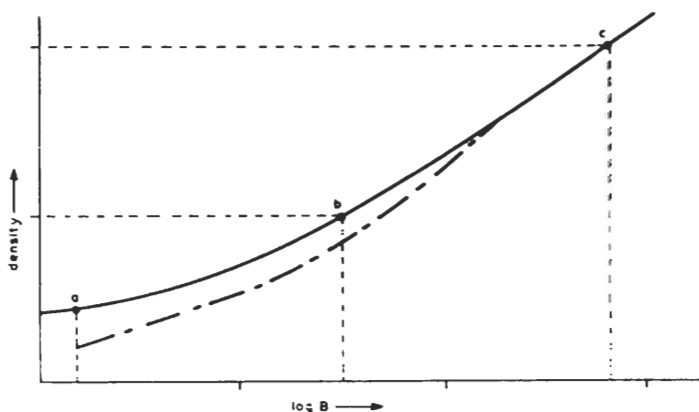


Fig. 11.3. Camera-image Characteristic (continuous line) and Negative Film Characteristic (chain line)

follows, it is assumed that the photographic process consists of the following steps:

1. The production of a negative photograph of a scene.
2. The use of a printer of known characteristics to produce a projection positive on a photographic material of known characteristics.
3. The projection onto the screen of the positive, the overall projection-screen plus viewing-room characteristics being known, and the final reproduction being placed so that it can be compared with the original scene.

Figs. 11.3, 11.4 and 11.5 show the camera-image $D/\log B$ characteristic, the printer characteristic and the positive film characteristic. The printer characteristic includes the effects both of lens flare and of the rest of the printer optical system on the effective printing density of the negative.

Fig. 11.6 shows how these individual characteristics are combined to determine the characteristic of the positive print. Two transfer quadrants are used; the first is required to avoid rotating the printer characteristic, while the second, which has a negative slope, indicates the negative-positive reversal. The points a , b , c on the $D/\log B$ characteristic represent three points in the scene whose log brightness values differ by equal amounts. These points are carried through the process, so that their relationships in the final result can be compared to their relationships in the original scene.

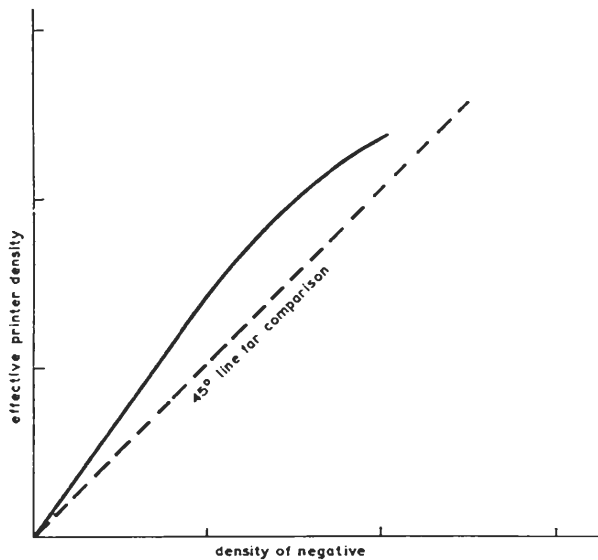


Fig. 11.4. Printer Characteristic

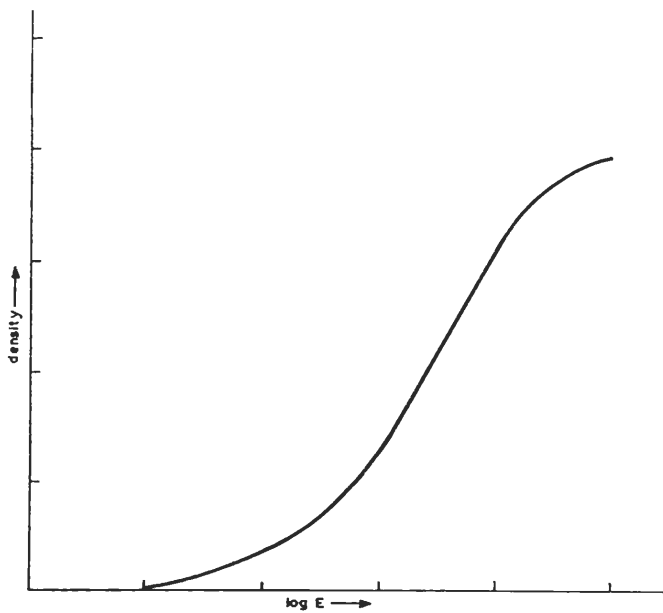


Fig. 11.5. Positive Film Characteristic

The characteristic of the combined projection and viewing conditions is shown in Fig. 11.7. From this and the positive print characteristic, determined in Fig. 11.6, the overall characteristic can be obtained as indicated in Fig. 11.8. In this last diagram, the negative characteristic is included for comparison.

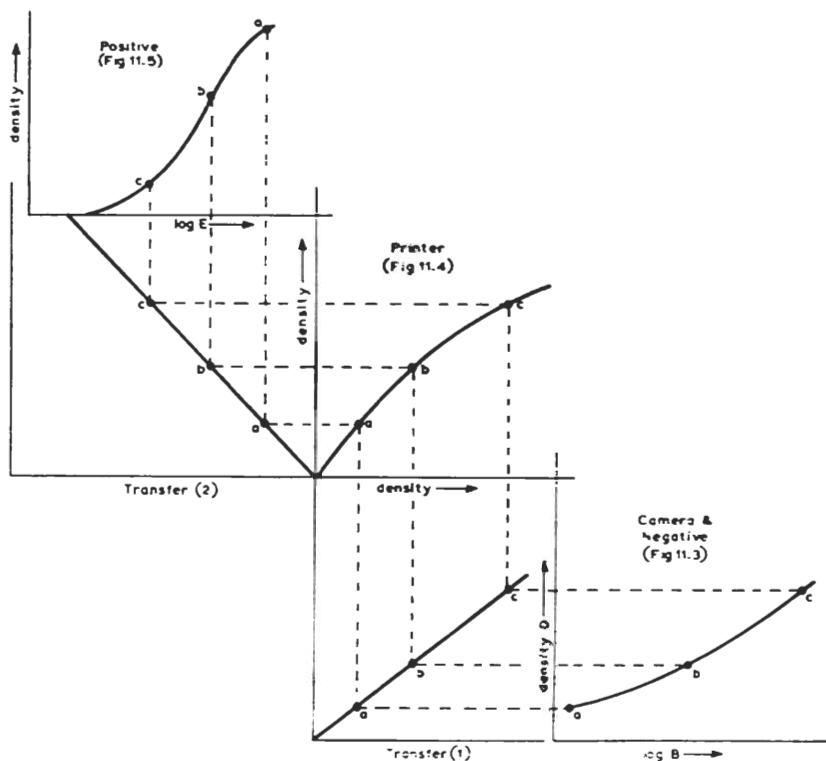


Fig. 11.6. Production of Positive Print. (The transfer quadrants are linear transfer devices (with gamma = 1), introduced to avoid having to rotate the characteristics of Figs. 11.4 and 11.5. The reverse slope of transfer line (2) indicates the negative-positive reversal)

By reorientating the various characteristics, the whole process can be telescoped, as shown in Fig. 11.9. The same result is obtained as from Figs. 11.6 and 11.8 combined, and only one transfer quadrant is required.

The principles of the quadrant diagram can be applied to any photographic process, provided that the transfer characteristic of each stage is known.

When only the straight-line portions of the transfer characteristics are used, the gamma of the final result is the simple product of the gammas of the individual stages.

DUPLICATE NEGATIVES. Most photographic processes use the nonlinear portion of the characteristic curve, but only the straight-line portion must be

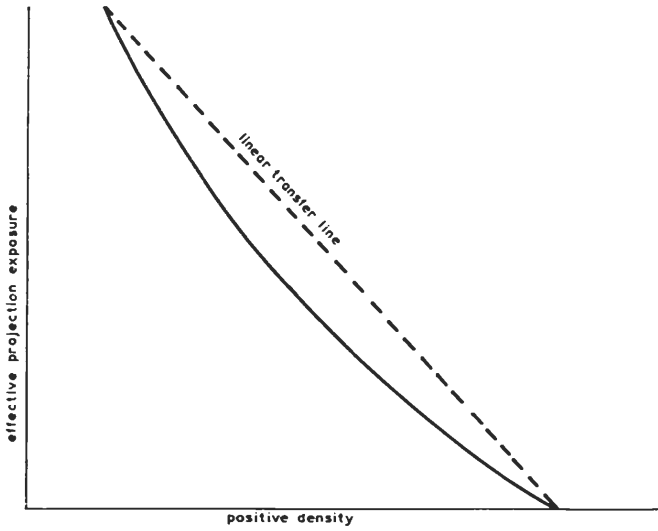


Fig. 11.7. Projection and Viewing Characteristic

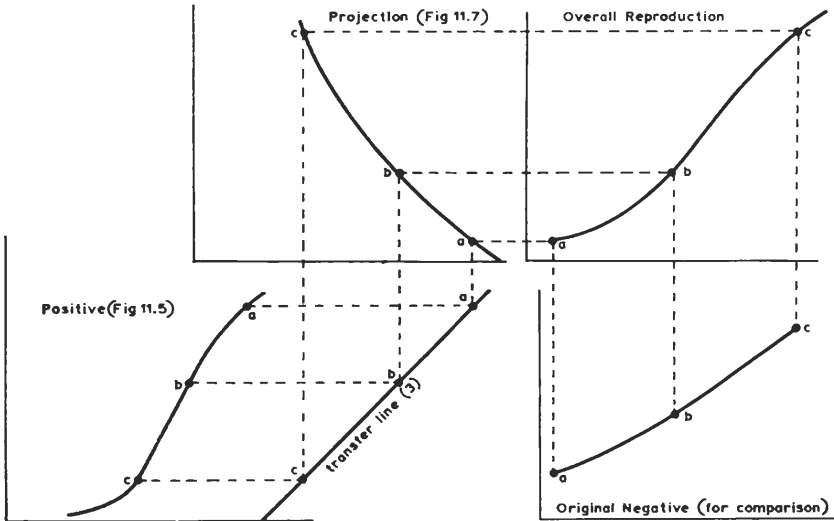


Fig. 11.8. Determination of Overall Reproduction Characteristic from Positive and Projection Characteristics

used if duplicate negatives are to be produced without tonal distortion. The development at each stage must be adjusted so that the gamma of the final print produced from the duplicate negative is as close to the gamma of the print from the original negative as possible.

The original negative is used to produce a master positive, developed to γ_{MP} . From this a duplicate negative is made, developed to γ_{DN} . The condition

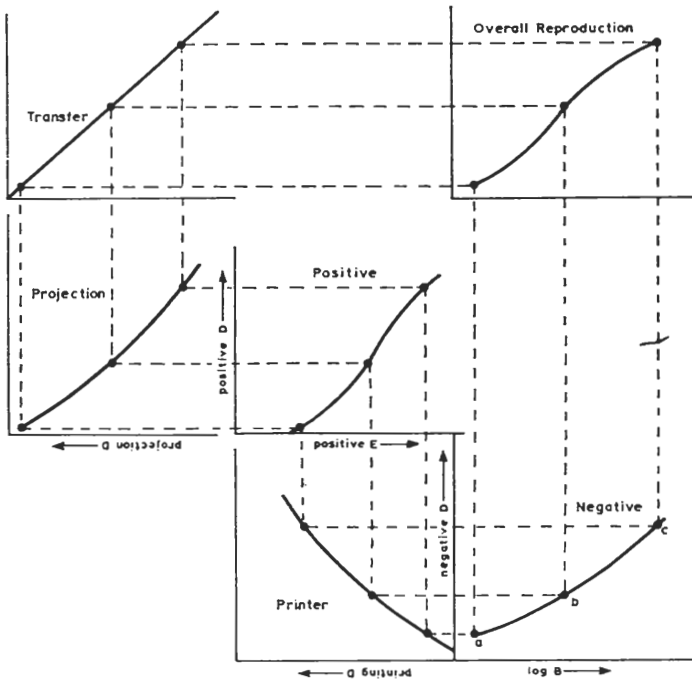


Fig. 11.9. Combined Transfer Diagram

required in order that these two intermediate stages shall not introduce tonal distortion is that

$$\gamma_{MP} \times \gamma_{DN} = 1.$$

In practice, this condition is modified slightly by the transfer characteristic of the printing equipment, which can be allowed for by an experienced operator.

PRINT TRANSFER CHARACTERISTIC. The shape of the print transfer characteristic required for television film recording is discussed fully in a BBC Film Recording Instruction entitled "The Print Transfer Characteristic", by A. G. Warren.

Reversal Processing

A normal emulsion can be made to produce a positive result instead of a negative result by reversal processing. This is useful when a positive is wanted quickly and only one copy is required.

The method is simple in principle, and consists of four stages.

1. **FIRST DEVELOPMENT.** The film is exposed in the usual way, and given a first development. As a result, highlight areas are largely converted to metallic silver, while shadow areas remain relatively unchanged as silver halide. The amount of silver halide in the highlights therefore decreases and what remains on the film, largely in the shadows, forms a potential positive image.

2. **BLEACHING.** The potential positive image formed by the silver halide is rendered permanent by three subsequent stages, the first of which is the bleaching stage. In this the silver forming the negative image is removed by a bleach such as an acid permanganate solution which leaves the silver halide image unchanged.

3. **SECOND EXPOSURE.** The film is next exposed to light, making the remaining silver halide developable.

4. **SECOND DEVELOPMENT.** The second development converts the silver halide which formed the potential positive image into a permanent silver positive image.

In addition to the steps listed, there are rinse and stop baths between the various stages and a final hardening-fixing stage which toughens the emulsion layer and removes any unsensitized silver halide which may be left in the highlights.

The reversal process is very much more critical than the negative-positive process, because the control introduced by the printing operation in the latter cannot be used. In addition, the initial exposure has to be correct, with very little latitude. This is because the highlights should produce a just-clear positive; anything more gives washed-out highlights on projection; anything less gives over-dense highlights.

Bibliography

[1] MEES, C. E. K. and JAMES, T. H., *The theory of the photographic process*. Third edition. Macmillan, New York, 1966.

[2] S.M.P.T.E., *Control techniques in film processing*. 1960.

[3] WARREN, A. G., *The print transfer characteristic*. BBC Film Recording Instruction.

XII. PROCESSING EQUIPMENT

Introduction

The following Chapter, which covers the design of processing equipment in general, includes the practical application of much that has already been said in previous chapters.

Basic Requirements

The processing operations for motion picture film are basically the same as for any other film, namely developing, rinsing or stopping, fixing, washing and drying. The main difference is that cine film must be handled in much greater lengths and that processing must be carried out to a uniform standard.

Early Apparatus

In the early days, when cine cameras commonly used 100-foot lengths of film, a widely used processing apparatus consisted of a wooden frame which closely resembled one half of an old-fashioned domestic clothes horse, several wooden tanks (usually made of teak, and big enough to permit complete immersion of one or more frames), and a large-diameter drum constructed by spanning two disks of wood with slats as on a water-wheel.

The exposed film was wound round the frame, and the ends were secured by elastic or a spring. The frame was then immersed in each of the solution tanks in turn for an appropriate time, until the processing was complete.

Drying was accomplished by mounting the frame, pivoted about its centre, in a crude yoke which allowed the frame to rotate within it; one end of the film was then detached from the frame and secured to the drum, rotation of which caused the film to be transferred and wound up spiral fashion with the celluloid base inwards, thereby exposing the outer, emulsion, surface to the air for drying.

This type of equipment, although crude, provided considerable flexibility and, as long as enough tanks were available to contain the various solutions, enabled every type of operation—negative, positive and reversal processing, as well as reducing, intensifying and tinting—to be carried out simply and cheaply.

Continuous Processing Machines

As the demands and standards of the industry rose, the need for more sophisticated methods of processing led to the use of continuous processing machines. In these, the film is caused to pass in a continuous length through tanks containing the necessary solutions and then on without interruption through the drying stages. The requirements of such a system are clear, and stated briefly comprise a means of attaching and removing reels of film while the machine is in motion, means to control the flow and chemical activity of the solutions, and adequate speed regulation to control development time.

The design and layout of a machine based on the foregoing requirements can be varied widely, and in the early days most machines were specially designed to fit into the space that happened to be available in a particular building. They were large, and frequently extended through three rooms, the first being a darkroom in which development and fixing took place, the second a wash room (normally lit) and the third a drying room. The ancillary equipment, including air compressors, temperature control gear, and chemical replenishment tanks, together with suitable pumps, was housed in yet another area. Today, with the increasing use of 16-mm film, particularly in television, many machines are manufactured as complete freestanding daylight-loading units, and only need connecting to suitable power and water supplies and drains.

Design Considerations

In a practical machine, containing different liquids in separate tanks, only two basic film paths are possible. In the first (Fig. 12.1), the film is guided by upper (coaxial) and lower sets of rollers into a series of long nearly upright loops, and moves along a flattened spiral. In the second (Fig. 12.2), the film is guided by upper and lower sets of parallel rollers into vertical loops and moves along a path at right-angles to the axes of the rollers.

The second method, using straight loops, is not favoured, because either the upper or the lower rollers must touch the emulsion side of the film. In a more acceptable modification of this arrangement, the film is twisted to keep the base in contact with the rollers, as in fact shown in Fig. 12.2.

Machine Leader

In any continuous motion machine, the films to be processed are joined end-to-end, and are guided and driven by rollers on their path through the machine. To establish the path, a specially tough film known as *machine*

leader is used to “lace” or thread the machine. The story film is joined to the end of this leader. When the last film to be processed is passing through, the leader is attached to its rear end, leaving the machine threaded ready for use again later.

Machine Output Speed

The size of a machine is largely determined by the output required from it. The factors which determine output are the following:

- (a) The development time, T minutes, required at a given temperature.
- (b) The path length, L feet, of one complete loop.
- (c) The number of loops, N , in the tank.

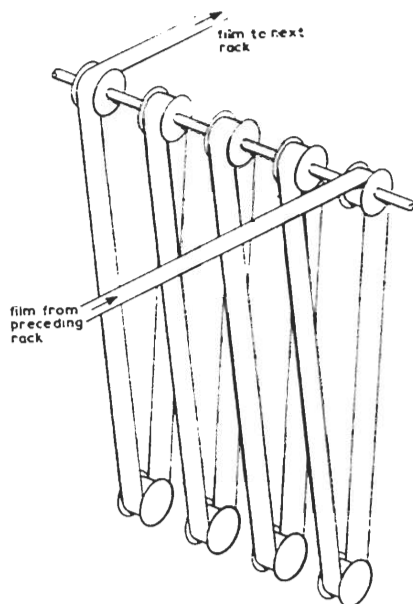


Fig. 12.1. Spiral Film Path

A simple formula enables the output speed, V , of the machine to be calculated.

$$V = LN/T \text{ ft/min.}$$

Thus, if a given developer achieves the required contrast in a time of say four minutes, and each loop measures 10 feet, then with 10 loops the machine speed in feet per minute needs to be

$$(10 \times 10)/4,$$

or

$$25 \text{ ft/min.}$$

In like manner, if a machine speed of 100 feet per minute is required, then clearly, since

$$T = LN/V,$$

the path length will need to be multiplied by four to maintain the required development time.

Development has been used for the foregoing example, but the same reasoning can be applied to all the processes, to ensure that sufficient time is available

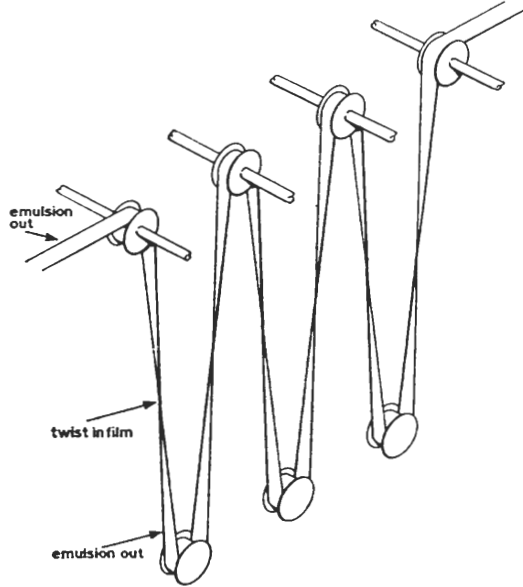


Fig. 12.2. Undulating Film Path

under all conditions. The relationship between the variables can also be manipulated to achieve the same result in different ways. Using the previous output of 25 feet per minute, the depth of the tanks and likewise the loop length could be doubled and the number of loops could be halved, giving

$$V = (20 \times 5)/4,$$

or

$$25 \text{ ft/min},$$

or conversely, the loop length could be halved and the number of loops doubled, giving

$$V = (5 \times 20)/4,$$

or

$$25 \text{ ft/min}$$

again.

In practice, very deep tanks are usually avoided, because they are cumbersome and difficult to house, and also difficult to clean.

Film Transport

GENERAL. Film is normally driven and guided along the chosen path by rollers, and there are two principal ways of doing this. The first is to drive the film via its sprocket holes, such a drive being known as *positive drive*. The second is to drive the film by friction; this is known as *tendency drive*. Often a combination of both methods is used, loosely known as *semi-tendency drive*.

POSITIVE DRIVE. In this first method, a driven shaft carrying the required number of sprockets is positioned horizontally across a tank. A loop of film is produced between the first and second sprockets and a large flanged weighted roller called a *diabolo* is placed within the loop. Since the film is engaged by the teeth on two adjacent sprockets which are driven with the shaft, the loop remains of constant size and successive loops spiralling (say) from left to right are thus formed. The film is then directed across to the next tank, where the procedure is repeated but with the film spiralling from right to left. Although this method is not widely used on large machines today, it does have the advantage of compensating automatically for changes in film length which may be caused by stretching or shrinking. Furthermore, it permits the diabolo to assume an optimum angle between the two sprockets, thereby reducing stress on the film to a minimum. Its disadvantages are:

1. The large numbers of loose components involved.
2. The danger that (due to a bad join, for example) one loop may rise and an adjacent loop fall, see-saw fashion, causing the flange of one diabolo to touch the emulsion on the next loop. This necessitates frequent adjustment to the levels of the diabolos.

TENDENCY DRIVE. In this method of drive, which is sprocketless, two shafts carrying rollers are positioned one at the top and one at the bottom of each tank. One shaft is driven and the rollers on this rotate with the shaft. On the other shaft the rollers are free to rotate independently. In a typical construction, the two shafts are held apart by two channel-section vertical side members, between which the top shaft is carried in fixed bearings, and the bottom shaft in bearing blocks which are free to move up and down guided by the channel sections forming the sides. These constructions are known as *racks*, and each tank is equipped with one or more of them. The drive is transmitted to the top shaft by friction, which enables the speed to vary between one rack and the next in order to accommodate stretching or shrinking of the film. Many ways exist to effect this differential drive, but only two will be considered here.

1. *Orthodox Principle of Operation of Tendency Drive.* To describe the orthodox principle of operation of tendency drive, it is only necessary to consider the behaviour of two complete loops of film, the first loop (Fig. 12.3) being the last on its shaft in Tank 1, and the second being the first on its shaft in the adjacent Tank 2. The primary drive is rotated positively by gears or chains. This rotation is transmitted to the top film roller in Tank 2 via a smooth belt which transmits the drive only when it is tensioned by a roller connected to the sliding bearing-block assembly in Tank 1.

In operation, if the drive to the roller in Tank 2 is too fast, the bottom roller in Tank 1 rises, carrying the connecting rod A and tension roller upwards, and

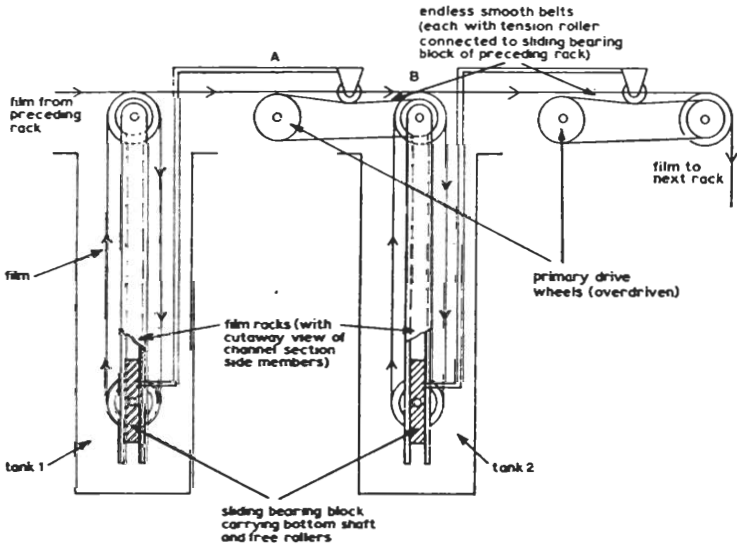


Fig. 12.3. Orthodox Tendency Drive

If the drive in Tank 2 is too fierce, the rack in Tank 1 rises, reducing the pressure of the tensioning roller. This permits sufficient belt slip to make the rack in Tank 1 descend

thereby reducing the tension in the smooth belt until the speed of roller B is reduced. This in turn permits the bottom roller in Tank 1 to descend and tension the belt, so that in practice a state of equilibrium is reached in which the film traction speed via the friction drive equals the feed rate from the preceding tank.

Thus the speed of drive to each film rack is automatically controlled and maintained by the position of the bottom shaft in the rack preceding it. The actual mechanical arrangements are not necessarily as shown and usually involve levers, springs and counterweights.

2. *Variation on the Orthodox Principle.* In another type of tendency drive (Fig. 12.4), the tension of each individual film loop is automatically controlled.

A fixed spindle is mounted across the tank, and on this is mounted a row of rocker arms pivoted about their centre. Each arm carries a film roller at one end and a counterweight at the other. The flanges of the film roller are knurled around their periphery and can be brought to bear on a plain rubber drive roller which is situated immediately beneath and parallel to the row of film rollers. The lower rollers are free and are mounted on a shaft with its centre fixed close to the bottom of the tank.

At the output end of the machine, there is a single sprocket or pinch roller, which effectively provides a slip-free drive and is called a *pacer roller* or *come-along roller*. The relationship in speed between the maximum drive possible

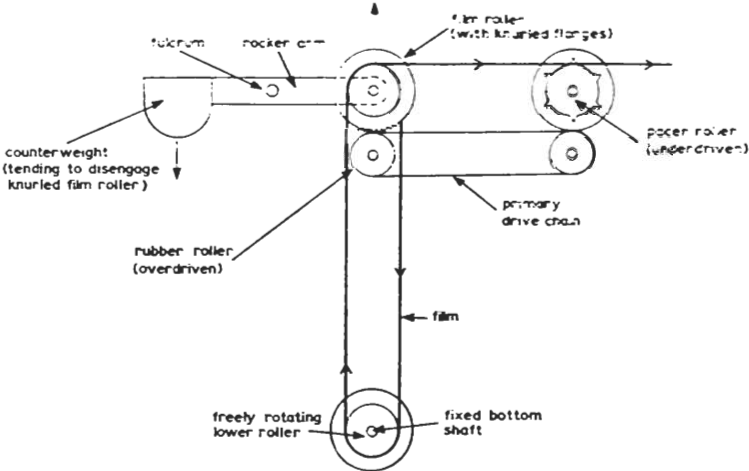


Fig. 12.4. Modified Tendency Drive

The pacer roller is underdriven and the rubber roller overdriven, so the length of film connecting the knurled film roller to the pacer roller always tends to be slack. Whenever the film slackens, however, the counterweight disengages the knurled roller, allowing the pacer roller to restore the tension and engaging the knurled roller once more

from the rubber rollers across the tanks and the pacer roller is fixed so that the output of the pacer roller is always effectively the lower. When the machine is at rest the counterweight on each rocker arm tends to disengage the knurled film roller from the rubber driving roller. This is contrived in the following manner:

When the machine is started, the pacer roller rotates and increases the tension on the first film loop, thereby pulling the knurled film roller into contact with the rubber driving roller. This imparts a drive which in turn increases the tension on the next loop, and so on throughout the length of the machine.

Consider now the reverse reaction. When a single film roller overdrives, it tends to produce a slack loop of film which allows the counterweight on the

rocker arm to disengage the drive until equilibrium is restored. Thus, throughout the length of the machine, the rocker arms are constantly oscillating as they engage and disengage the rubber driving rollers.

In practice, the difference in speed between the pacer roller and the speed of a fully engaged knurled film roller is very small, just enough to ensure that the film roller is never slower than the pacer roller.

This form of drive has the advantage of controlling the tension on each single loop, whereas the type described under heading (1) only controls the tension between adjacent racks.

Film Reservoir or Storage Unit

GENERAL. For a machine to operate continuously, it is necessary to attach and remove rolls of film while the machine is in motion. As before, only two practical film paths are possible, the spiral configuration being again the more usual.

PRINCIPLE OF OPERATION. The basic principle of operation is similar to that of a block and tackle, and the equipment in simplest form consists of two parallel horizontal shafts (Fig. 12.5), one below the other, on which freely rotating rollers are mounted. The distance between the upper and lower shafts can be varied over a range of several feet.

CAPACITY. The storage capacity of the reservoir is determined by the number of film loops accommodated and the effective length of each loop.

Consider one loop of film formed between the top rollers on a fixed axis and a single bottom roller hanging free. If one end of the film is anchored and the other end is pulled x feet, then the bottom roller rises $x/2$ feet.

Now suppose 10 loops are formed by passing the film over 10 rollers on a fixed-axis top shaft, and the single bottom roller is replaced by a guided shaft also carrying 10 rollers. Then it follows that if 20 feet of film are pulled out, the bottom shaft rises towards the fixed top shaft by

$$20/(2 \times 10) \text{ feet,}$$

i.e., by 1 foot.

If the top and bottom shafts are initially separated by seven feet, then five feet of effective travel can certainly be made available, thus permitting 100 feet of film to be pulled out without moving the anchored end. The time taken by this is the *storage time* of the reservoir, and must be long enough to change a magazine and join the film plus a healthy safety margin. One minute is usually adequate.

Reservoir Design

In a practical machine, the foregoing factors are used to determine the number of loops and the height of the reservoir cabinet. It is preferable to use a tall cabinet with a few loops, rather than a short cabinet with many loops, because the total friction of all the rollers required for a large number of loops puts considerable stress on the film.

The method by which one shaft is guided parallel to others is a matter of convenience and in some cases the top shaft has a fixed axis with the bottom one rising towards it, and in other cases vice versa. In one widely used method,

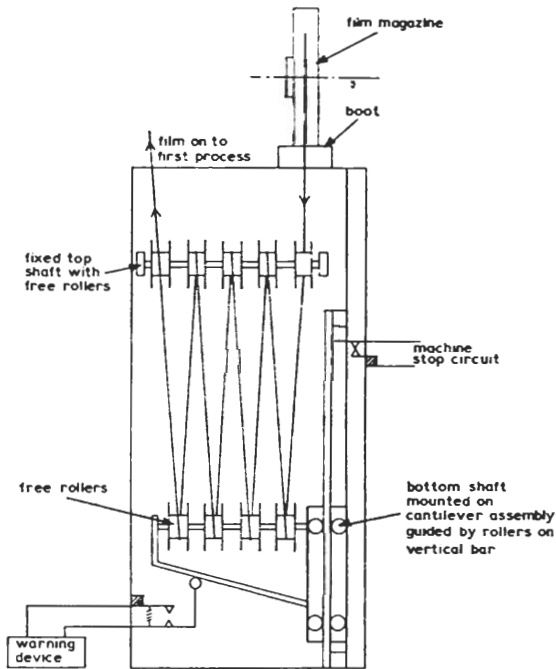


Fig. 12.5. Film Reservoir or Storage Unit

the bottom assembly is of cantilever construction, and moves upwards guided by rollers which bear on a single vertical rectangular bar; this arrangement effectively maintains the bottom shaft parallel to the fixed axis of the top shaft. A microswitch at the lower end of the bar actuates a warning device when the bottom assembly starts to rise, and another microswitch near the top limit of travel cuts off the machine drive motor when all the stored film has been used.

Magazines

In a daylight operated machine, exposed film is loaded into light-tight magazines which are then fixed to the input end of the storage unit via a light-tight device (often called a *boot*) which also traps the end of the film when a magazine is removed.

The magazines must be loaded in a darkroom and, in one method, the exposed film is positively anchored and wound onto a core which is secured to a backplate. The backplate is then placed inside the magazine, and the end of the film is fed out through a light trap, so that a foot or so is available for joining. After the magazine lid has been secured, the remaining operations may be carried out in daylight.

Film Joining

Two basic ways are used to join film for passage through a processing machine:

1. An overlapped joint,
2. A butt joint.

Either of these can be achieved with appropriate metal staples, or with the special adhesive tapes which have recently become available. The main requirements are that the joints should be made in the minimum of time, and that they *must* be reliable. Several proprietary devices exist and they all serve to align the film accurately while the joint is made and, where appropriate, align the perforation holes as well.

Operation of Reservoir

While the film from a magazine is passing freely into the reservoir, the lower assembly is held by gravity in a position close to the bottom of the reservoir cabinet. In this position the two shafts are spaced at their greatest distance and the reservoir is fully charged.

On reaching the end of the roll, the film tail remains positively anchored to the core which is secured to the backplate in the magazine. Since the machine is still running, the lower part of the storage unit must rise to maintain the feed to the first processing tank. As it ascends it actuates a device, usually a bell or buzzer, to warn the operator.

The operator disengages the magazine from the light-tight boot, which automatically retains the end of the roll. He breaks the film, replaces the magazine with a full one, joins the film and, on fully engaging the magazine in the

boot, automatically releases the entrapped film, permitting it to flow freely into the reservoir again.

At this stage, if no restraint is applied to the lower assembly, it will descend very rapidly and hit the bottom of the cabinet. To prevent this, some sort of braking must be applied as it approaches the end of its travel.

One very effective braking method is an air dashpot, which is rather like a bicycle pump with the air outlet restricted to a pinhole. In use, this device is positioned vertically, and is arranged so that it is extended when the lower assembly ascends, and compressed as it descends. The rate of descent is progressively arrested by the build-up of air pressure, and is controlled by adjusting the size of the hole.

Speed Control

To ensure satisfactory operation of a processing machine—which must handle several different types of film—the development time must be variable. This can be achieved by altering the path length or, more usually, by altering the speed. With large machines it is common to use variable-speed d.c. motors having high torque at low speed, which are fed from the regulated d.c. supply usually available in large film laboratories.

With compact machines, such a supply is not always available, and they normally operate from the a.c. mains. A.C. variable-speed motors must therefore be used, although these are liable to speed changes caused by small variations in input voltage; such variations can occur, for example, when the heaters of the processing machine are switched off or on. In addition, the mechanical load on the machine may vary.

A very satisfactory alternative to the variable-speed a.c. motor is a mechanical speed “*variator*” driven by a brushless induction motor. One such unit, the Kopp Variator, is widely used and has a speed range of 9:1.

Solution Distribution and Control

To maintain a satisfactory and consistent standard of processing, the agitation, temperature and chemical activity of the developer must be kept within certain limits. In a practical system, the needs for agitation and temperature control are interdependent, as clearly a large volume of developer cannot easily be maintained at a given temperature unless it is kept thoroughly mixed.

With large machines, solutions are mixed in separate tanks, and passed to main reservoirs where the temperature is held at a nominal value. From these they are pumped as required through a heat exchanger to the processing tanks, from which they flow back to their respective reservoirs.

In some of the smaller compact machines, the solutions are mixed in the processing tanks, and the pumps and temperature control form an integral part of the machine.

Temperature Control

GENERAL. In all but the very simplest machines, some attempt is made to maintain the temperature within certain limits. For the developer, it is desirable to maintain a control of $\pm 0.5^\circ\text{F}$, but many machines operate satisfactory with a variation of $\pm 1.0^\circ$. Other solutions are more tolerant, and $\pm 5^\circ$ is usually satisfactory. Many control systems exist, but all in principle use a temperature sensor placed in or near the solution tank. This sensor operates a control unit which heats or cools the solution as required.

TEMPERATURE CONTROL IN LARGE INSTALLATIONS. In a large machine, the solutions are passed through a heat exchanger. This is usually a long coil of piping housed inside a large tube. The large tube is connected to hot and cold water supplies which are differentially controlled by information from the sensor. When the temperature of the solution tanks falls, more hot and less cold water flows, and vice versa. The solution is passed through the long coil which is immersed in the temperature-controlled water in the large tube, and is therefore heated or cooled as necessary.

The actuating mechanism for this form of control may be electromechanical or pneumatic, and many systems also record temperature variations as well. Such installations are expensive, and much simpler methods are employed in compact machines.

TEMPERATURE CONTROL IN COMPACT MACHINES. One very interesting unit is manufactured by Techne of Cambridge. This device, called a *Tempunit*, has a bimetallic helix which acts as the sensor. The unit also includes a 1-kW heater and a small electric motor driving a suction-pump which works a pneumatic amplifier. The whole unit is self-contained and its operation is as follows:

One end of the bimetallic helix is anchored and the other is connected to a thin rod which passes through its axis, and is then bent at 90° to form an actuating lever. A change in temperature causes the helix to deflect, thus rotating the rod and hence the lever. This mechanism is not very powerful, but is made to control a pneumatic amplifier. This it does by actuating a flop valve which controls the flow of air through a small hole which bleeds a vacuum system.

The vacuum system consists of a rubber bellows unit which is continuously exhausted by the motor-driven pump and is replenished with air via the bleeder

hole. When the flop valve is closed, the bellows therefore collapses. This closes a microswitch and operates the heater.

As the temperature rises, the bimetallic helix deflects, rotating the rod and moving the lever. This in turn opens the flop valve, releases the vacuum and allows the bellows to extend again, thus switching off the heater. Since only a very small movement is required to open the flop valve, the device is extremely sensitive, and in fact will easily control the temperature to within $\pm 0.25^{\circ}\text{F}$.

COOLING ARRANGEMENTS. To ensure the correct functioning of a temperature control system, it is necessary to provide for cooling as well as heating. On large machines, a separate refrigerator is normally employed to ensure an adequate supply of cold water to the heat exchanger. With smaller machines refrigerators are also used, but they are usually part of the machine and often cool the solutions via a cooling coil or a brine pack. If climatic conditions permit, a cheaper alternative is simply to circulate the wash water through a cooling coil before using it for the wash.

Recirculation and Agitation

NEED FOR DEVELOPER MOVEMENT. To achieve consistent and even development of motion picture film, it is necessary to ensure that fresh developer is continuously supplied to the emulsion surface. Failure to do this results in uneven development, streaks and directional effects, particularly where high density areas are adjacent to low ones. The basic requirement, therefore, is to produce sufficient turbulence at the surface of the film to ensure that exhausted developer is washed away and replaced by fresh. The movement of the film itself provides some of this agitation and, of course, the faster the movement the more effective it is. In most machines film movement alone is insufficient and supplementary agitation must be provided, usually in one of the following ways:

1. Recirculation,
2. Submerged Sprays,
3. Cascade,
4. Inert Gas Bursts.

RECIRCULATION. This method is probably the most common of all the systems because it is simple, relatively inexpensive and is easily applied to the compact machines. With large installations there are two variations on its use.

The first of these variations uses a large centrifugal pump, which takes developer from the main reservoir and passes it through the heat exchanger into the processing tank. The developer then overflows, via a float valve (or similar device to prevent air being drawn in), back to the reservoir.

The second variation employs two pumps. The first pump, with a much slower flow rate than the other, injects fresh developer from the reservoir; the second pump, which operates a closed circuit, takes developer from near the top of the solution tank and pumps it back near the bottom. This latter system allows the use of smaller-diameter pipelines to connect the overflow between the developer tank and the reservoir while still maintaining a high flow rate through the tank.

Smaller machines, with no reservoir, use just one pump operating on the closed circuit principle.

The required degree of agitation is hard to define, but should be at least that flow beyond which any further increase produces no change in the density, gamma, or uniformity of the developed image.

SUBMERGED SPRAYS. This system differs from the recirculation method in that the output from the pump is directed through small submerged jets onto the emulsion surface of the film. The jets, to be effective, must be positioned close to the film, and must give an even flow of developer across the whole film width.

The velocity of the emerging jet often makes it necessary to provide back-up rollers behind the film, to prevent it from being driven away by the jets of developer.

This method utilizes the output of the pump to the greatest effect, because all the flow is onto the film and not into the tank. However, it also not only involves the expense of supplying and fitting all the jets, but also often requires more space in a compact machine.

CASCADE. This method of agitation is confined to machines designed specifically for it. There are no tanks as such, the film being enclosed in splash-proof cabinets. Thus, the loops can be made longer than usual—quite often up to 10 feet. The bottom of the cabinet consists of a shallow trough, somewhat like that used for a shower bath. The solutions are pumped at a high rate through large orifices onto the strands of film as they pass over the top rollers; the liquid then cascades down the film into the trough below, and so back to the reservoir.

For obvious reasons, this method is not often used on compact machines, but some very large and fast machines in laboratories use it most successfully for processing positive film.

INERT GAS BURSTS. This method is more commonly used in colour processing and often employs nitrogen as the gas.

The system is arranged to release bursts of bubbles at regular intervals from the bottom of the tank. These bubbles agitate the solution as they rise.

Solution Replenishment

Whenever a chemical reaction takes place, active constituents are consumed and by-products are released. From a practical point of view, two alternatives are possible to cope with the resultant gradual change in the composition of a solution. The first method is to use the solution to a point where its performance is no longer acceptable, and then to replace it completely. This is the practice generally adopted with compact machines. The second method is to analyse the solution constantly, and try and maintain its activity within acceptable limits. The latter method requires a chemist with elaborate metering and measuring equipment, and is therefore only economic where large volumes of solutions are involved, as in a major laboratory.

The successful operation of a full replenishment system is really divided into three parts:

1. Analysing the working solution.
2. Determining the required composition of the replenisher.
3. Controlling the addition of the replenisher to the working solution.

Clearly, it would be unsatisfactory to check the solution once a week and add several gallons of replenisher in one lot. The best control is achieved by constantly metering the developer through a flow meter and adding fresh solution at intervals as determined by experience with the particular installation so that chemical activity is maintained; an amount nearly equal to the make-up must be bled off to keep the working volume constant and to ensure that the by-products are kept at a calculated level.

Initially, this involves a lot of testing and checking, but eventually it is possible to arrive at a suitable flow rate for each material, and it is not unusual for big laboratories to work for many months without replacing the bulk solution. In some instances the control is taken to the point of automatically reducing the flow of replenisher when machine leader is passing through the solution, as apart from the carry-over from the previous tank, this material causes no chemical reaction because it has no emulsion.

In practice, the replenisher is usually introduced into the return pipe from the processing tank, so that it is well mixed with the bulk solution. It is also necessary for the flow rate between the reservoir and the processing tank to be sufficiently high to avoid local exhaustion and excessive build up of by-products in the actual processing tank.

Air Knives and Squeegees

GENERAL. When film passes from one tank to another, it carries on its surface a significant quantity of liquid, which contaminates or (if water) dilutes

the liquid in the next tank. To minimize this carry-over, *air knives* or *squeegees* are fitted between tanks to remove the surplus liquid.

AIR KNIFE. This name is usually applied to a unit comprising two chambers, one on either side of the film, which are arranged with narrow slits spanning the film width and inclined against the direction of its travel. Air at a pressure of several lb/in² is fed through the slits, so that a high-velocity wall of air pushes the liquid back along both sides of the film as it travels through the

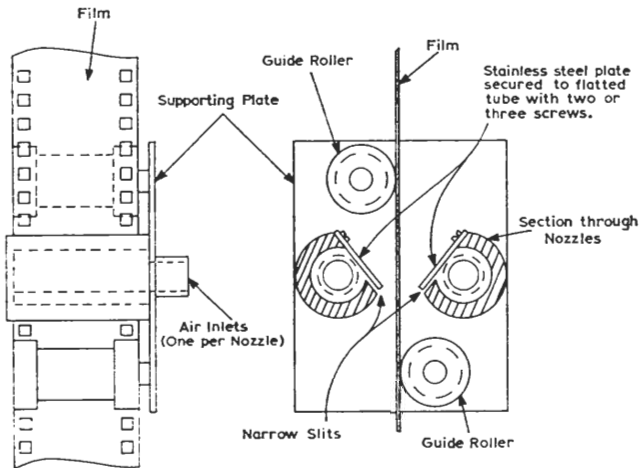


Fig. 12.6. Simple Air Knife

unit. Suitable rollers are provided to guide the film centrally through these jets so that joints do not foul them.

The design of air knives is a compromise between cheapness and efficiency. The crudest design (Fig. 12.6) uses two short tubes of small (say half-inch) diameter. These have a flat machined down their length which breaks into the bore. A stainless steel plate is screwed to the flat, and is adjusted to leave a slit a few thousandths of an inch wide. One end of the tubes is blocked in and air is fed in at the other end.

More efficient designs use chambers which are shaped to utilize the Venturi principle, in order to increase the air velocity without an increase in the total quantity of air required. A machine employing several air knives requires a very large compressor to supply it, because each unit may well use 3-5 cubic feet a minute, depending on the pressure.

The high-velocity air flow atomizes the liquid it is blowing off, and the droplets produced could find their way into other solutions. In an enclosed daylight operated machine, provision must therefore be made to vent or extract this contaminated air.

SQUEEGEE. A squeegee is really a mechanical wiper, like a windscreen-wiper blade. In this application the blade is kept stationary and the film provides the movement. Squeegees are commonly used on compact machines because they need no air supply, but they are potentially scratch-making devices and unless strict cleaning and adjusting routines are observed they can be troublesome.

SUCTION SQUEEGEE. This is a variation on the wiping squeegee and is extensively used by some commercial laboratories. The unit comprises a suction box through which the film passes and in which a partial vacuum is maintained by the close proximity to the film of rubber-lipped blades. The blades are arranged in pairs on opposite sides of the suction box and are adjusted to not quite touch the film, i.e., with a gap of 0.006 in., so that they provide a suction seal without scratching. The required pressure reduction in the system is maintained by a vacuum pump, and separators or traps are included to keep the sucked-off liquid out of the pump.

This system is more economical in terms of power than the compressor required for the air knife, but demands greater diameter pipe lines for the low-pressure air flow. It also has the big advantage of not spraying particles of solution into the free air to contaminate other solutions.

The Drying Process

INTRODUCTION. When the film has passed through all the wet processes, the surplus water is removed by either an air knife or a squeegee. If these units are operating efficiently, both sides of the film will then be free from droplets of water, but the emulsion side, which is effectively a micro-sponge, will still contain a significant amount of water entrapped in the swollen gelatin layers. Most of this water has to be dried out (i.e., evaporated), so that the film is left with a specified uniform moisture content, or is normalized with the surrounding air. Such an operation is usually carried out in a drying cabinet, in which several loops of film are exposed to a warm air flow for the necessary time.

DESIGN CONSIDERATIONS. The most important consideration in the design of a drying system is the air temperature/velocity combination. It is clear that warm air dries film more rapidly than cold air and it is equally clear that a high-velocity air flow produces quicker drying than a gentle breeze.

In practice, the best combination is a lot of air with the minimum of heat, and on the large installations where space is not at a premium, this method is generally used.

EARLY DESIGN. The very simplest design comprises a cabinet, or room, which effectively encloses the banks or racks of film. A heater is provided, and a large fan fitted with a filter. The air is drawn through the filter, passes over the heater and is directed into the cabinet so that it blows from the dry toward the wet end.

Although this method is widely used, it is not very efficient, because a fairly large proportion of the available air never touches the film.

COMPACT MACHINES. With the increasing use of compact machines, there is less footage of film, and therefore less time, available for drying. To achieve the required result in the time available, there are two alternatives, either to increase the air velocity, or to raise the temperature.

HIGH TEMPERATURE DRYING. A significant increase in temperature leads to softening of the gelatin and loss of the plasticizer in the base. This causes both shrinkage and brittleness. Furthermore, since the heat is usually provided by electric elements, this method is expensive by virtue of the power it consumes.

HIGH VELOCITY DRYING. A better method is to direct the air so that it is all brought into contact with the film. This is achieved by the use of a *plenum*, a hollow rectangular chamber shaped to fit between adjacent banks of film. Air is fed into this chamber and emerges from both sides through rows of slits positioned to direct the air straight onto the film.

Thus, the film path is closely followed by rows of air jets, and all circulating air impinges on the film. In this way film can be dried quickly within a short path length.

APPEARANCE OF DRYING FILM. Film is made up of two parts, the base, which is usually cellulose tri-acetate, and the emulsion which consists of silver halide grains suspended in gelatin. When the film is wetted the sponge-like gelatin absorbs more water than the base and in consequence swells more. This action causes the emulsion side to become relatively longer than the base and the film curls with the emulsion on the outside. As the film dries, the gelatin contracts, first causing the film to flatten and then to curl the other way, so that the emulsion side is concave.

This change of curl makes it easy to observe the pattern of drying and to determine the exact point in the cabinet where the film is dry. In practice, the film *appears* dry after about half the total drying time actually required.

Silver Recovery

FIXING. When a latent image is developed, the exposed silver halides are converted to metallic silver, but the unexposed areas are left unaffected. The

unexposed halides are converted into soluble compounds and are removed from the film in the fixing process. The amount of silver removed in this way varies according to the type of film, there being more silver in negative than in positive, but as a rule-of-thumb it may be assumed that about 1 oz of silver is released into the fixing bath from each 1000 ft of 35-mm film. In large installations, which process millions of feet of film, the recovery of this silver is a worthwhile operation.

METHODS OF SILVER RECOVERY. There are three practical methods of recovering silver from a fixing bath:

1. Chemical Precipitation,
2. Metallic Replacement,
3. Electrolysis.

1. *Chemical Precipitation.* In this method, the soluble silver compound in the bath is converted to an insoluble compound, by adding a suitable precipitating agent. Many such agents exist, but the most common is sodium sulphide. Unfortunately, when sodium sulphide is added to the fix, very unpleasant hydrogen sulphide fumes are produced. However, the reaction also produces silver sulphide, which is precipitated and after settling, washing and drying can be refined

2. *Metallic Replacement.* If a penny is placed in a well-used fixing solution, the copper surface appears to become plated with silver. In fact, however, the copper is not plated with silver, but is replaced by it.

In practical silver recovery, it is more common to use zinc than copper. Powdered zinc is introduced into the discarded bath and effectively changes place with the silver, which is precipitated and forms a sludge. A further variation of this method uses steel wool; here the silver atoms change place with iron atoms, so that the steel wool becomes transformed to "silver wool". The efficiency of this method depends on presenting to the silver-laden solution the largest possible surface area of the substitute metal.

3. *Electrolysis.* If two electrodes are immersed in an aqueous solution of silver salts and a current is caused to flow, silver is deposited on the negatively charged electrode, which is called the *cathode*.

The application of this principle to the recovery of silver from a fixing solution has the following advantages: (1) It is clean and free from unpleasant odours, (2) it produces almost pure silver and (3) if properly controlled, it can be introduced into an active fixing bath to reduce the build-up of silver compounds, thereby considerably extending the useful life of the fixing solution.

In practice certain requirements must be fulfilled to achieve a satisfactory system. The biggest problem is to prevent the formation of sulphide due to electrolytic decomposition of the hypo. There must be a reasonable amount

of silver present in the fix, and the current density must not be too high, if the deposition of silver is to occur before the sulphide is formed.

There are two basic approaches to the problem. The first is to use electrodes with a very large area, combined with a very low operating voltage; the second is to use smaller electrodes, a higher current density and very efficient agitation to prevent local desilvering of pockets of hypo which would give rise to the formation of sulphide.

Ideally, some form of automatic current control might be used which would increase the current when the silver content was high and reduce it as it became lower. At present this is not practicable, and in most large installations, samples are analysed at regular intervals and the current is adjusted so that the silver content is maintained just above the level at which sulphide formation would occur.

Several manufacturers produce units for recovering silver in this way, and continuous processing machines are well suited to their use.

SUBJECT INDEX

- Accelerator 105
Acid fixing bath 120
Acids, alkalis and salts 45
Acutance 114, 166
Acutance developers 116
Adjacency effects 115
Adsorption 67
After-ripening 70
Agitation, Developer 114, 218
Air knife 220, 221
Alexandra Palace 140, 144
Alkali 45, 105, 106
American Standards Association 135
Antifoggant 111
A.S.A. fractional gradient system 135
A.S.A. new speed system 137
Astatine 48
Atom 41
Atomic number 41
Atomic structure 41
Atomic weight 41
Auto-accelerated reactions 104
Autocorrelation 181
Average gradient 87
- Bandwidth-restricted systems 184
Barrier layer cells 151
Base density 85
Base material 50
BBC Engineering Division Monograph No. 33: 103
Benzotriazole 111
Bibliography 40, 65, 81, 103, 123, 146, 163, 187, 196, 205
Binder, Gelatin 66
Black body 15, 37
Blow up 193
Boot 215
Border effect 115
Brightness or luminance 25
Brightness units 39, 40
Brightness, Spot 159
British Standard 677: 11, 52-54
Buffering ability 46
- Callier coefficient 29
Camera-image characteristic 200
Cascade development 219
Cation 43
- Characteristic curve 82 *et seq.*
 Gradient of 85
Chemical change 43
Chemical compounds 42
Chemical developer 104
Chemical development 72
Chemical formula 42
Chemistry, Organic 48
Clear-base film 57
Clearing time 122
Colloids 47
Colour sensitivity 73
Colour temperature 15
 correction 35
Come-along roller 212
Commag 59, 60
Comopt 59, 60
Comparison photometers 159
Compounds, Chemical 42
Conductivity, Ionic 79
Contact negative 196
'Contact' prints 194
Continuous processing machines 207
Conversion factors for light units 39
Convolution 179
Cores and windings 55
- Dark current 150
Densitometers 91, 98
Density 28, 72
 Base 85
 Diffuse 30
 Double-diffuse 30
 Fog 85
 Specular 30
Deutsche Industrie Norm 134
Developer:
 agitation 114, 218
 Chemical 104
 Composition of 105
 constituents 112
 constituent variation 118
 exhaustion 117
 Physical 104
 replenisher 118
 Types of 112
Developers, Acutance 116
Developing agent 105
Development:
 Cascade 219

- Development (*contd.*)
 - Chemical 72
 - Control of 124
 - Fine grain 113
 - of latent image 72
 - Physical 73
- Diffuse density 30
- Dimensional changes 53
- Dimensions, Film 52
- D.I.N. system 134
- Double-diffuse density 30
- Drive, Film 210
- Drying 123, 222
- Duplicate negatives 202
- Dyed-base film 57
- Dye-sensitizers 73

- Eberhard effect 116
- Effective film speed 139
- Electrolysis, Silver recovery by 224
- Emulsification 69
- Emulsion:
 - colour sensitivity 73
 - constituents 66
 - preparation 69
 - speed increase 110
 - structure 70
- Equipment, Processing 206
- Exhaustion of developer 117
- Exposure 23
- Exposure index 136
- Exposure meters 157
 - Intergrating 157, 162
 - Narrow-angle 159
- Exposures, Stepped 96
- Exposures, Wedged 96

- Film:
 - Clear-base 57
 - construction 51
 - dimensions 52
 - Dyed-base 57
 - joining 215
 - magazine 215
 - reservoir 213
 - transport 210
- Film leader:
 - BBC 60
 - Kodak 59
 - Sprocket-holes in 16-mm 196
- Film stock markings 57
- Film storage 55
- Filters, Light 33
- Fine grain development 113
- Fixing 119, 121
- Fixing bath 119, 122
 - Acid 120

- Fixing time 122
- Flare 197
- Flare factor 197
- Flux, Luminous 21, 37
- Fog density 85
- Formula, Chemical 42
- Fourier analysis 179, 181
- Fractional gradient:
 - point 136
 - system, A.S.A. 135
- Frame bar 193
- Frenkel defects 79
- Fringe effect 116
- Full radiator 15, 36
 - temperature 19

- Gamma 85
 - Point 89
- Gel 47
- Gelatin binder 66
- Gelatin, Effects of 77
- Gradient of characteristic curve 85
 - Average 87
- Grain structure of image 164
- Graininess 164, 165
- Granularity 165
- Green film 123
- Gurney-Mott hypothesis 80

- Halation 52
- Halogens 48
- Halide, Silver:
 - crystals 68
 - precipitate 74
- Halides, Silver 48
 - Electrical conductivity of 79
- Hardening bath, 120
- Hurter and Driffield system 132
- Hydroquinone 106

- Identifying markings 57
- Illumination 21
- Image:
 - Grain structure of 164
 - Latent 72, 74
 - Sub-latent 81
- Inert gas bursts 219
- Inertia point 128
- Inertia, Regression of 128
- Infra-red emulsions 74
- Integrating exposure meters 157, 162
- Integrating sphere 31
- Intensity, Luminous 21, 37
- Intensity-scale modulation 89, 94
- Intermittent contact printers 188
- Intermittent optical printers 188
- Inverse square law for light 23

- Ionic conductivity 79
- Ions and ionization 42
- Irradiation 52
- Joining film 215
- Kostinsky effect 116
- Lambert surface 26
- Latent image 72, 74
 - Development of 72
- Lawley Junior continuous processing machine 140
- Leader film, BBC 60
- Leader film, Kodak 59
- Leader, Machine 58, 207
- Light:
 - filters 33
 - meters 147
 - radiation 13
 - sources 15
 - units and measurements 20, 26, 28, 39
- Line spread function 181
- Luminous flux 21, 37
- Luminous intensity 21, 37
- Luminance 25
 - units 39, 40
- Machine leader 58, 207
- Machine output speed 208
- Mackie lines 116
- Magazine, Film 215
- Markings on film stock 75
- Marks, Static 57
- May and Baker method 122
- Measurements, Light 20
- Meters:
 - Exposure 157
 - Light 147
- Metol 105
- Mired values 36
- Modulation 173
- Modulation transfer factor 173
- Modulation transfer function:
 - of a film 173
 - of a lens 175
 - Multiplicative property of 175
- Moisture content 53
- Molecule 42
- Monomethylpaminophenol sulphate 105
- Narrow-angle exposure meters 157
- Negative:
 - 'Contact' 196
 - S.M.P.T.E. 196
- Neutron 41
- Non-intermittent printers 191
- Opacity 28
- Optical printers 188
- Organic chemistry 48
- Orthochromatic emulsions 74
- Ostwald ripening 70
- Output speed of processing machine 208
- Oxidation 47
 - Prevention of 108
- Pacer roller 212
- Panchromatic emulsions 74
- Parahydroxybenzene 106
- Paraphenylenediamine 106
- Perforation holes 52-55, 196
- Phenidone 106
- 1-phenyl-3-parazolidone 106
- pH values 46
- Physical developer 104
- Physical development 73
- Photocells, Comparison of 155
- Photoconductive cells 154, 157
- Photoconductivity 79
- Photoemissive cells 147, 155
- Photographic shelf life 55
- Photometers, Comparison 159
- Photometric units 39
- Photopic curve 15
- Photovoltaic cells 151, 156
- Planckian radiator 37
- Plenum 223
- Point gamma 89
- Point spread function 178
- Positive drive 210
- Precipitate, Silver halide 74
- Precipitation 69
- Preservative 105, 108
- Printers:
 - Intermittent contact 188
 - Intermittent optical 188
 - Non-intermittent 191
 - Types of 188
- Printing, Reduction 193
- Prints:
 - 'Contact' 194
 - S.M.P.T.E. 194
- Print transfer characteristic 204
- Processing equipment 206
- Processing machines 207
- Proton 41
- Purkinje shift 15
- Quadrant diagram 198
- Radiation, Light 13
- Radiator, Full 15, 36
- Radiator, Planckian 37
- Radical 43

Reciprocity failure 81, 89
Recirculation 218
Reduction, Chemical 47
Reduction printing 192
Regression of inertia 128
Replenisher for developer 118
Replenishment of solution 220
Reservoir, Film 213
Resolving power of emulsion 168
Restrainer, Developer 105, 109, 110
Reversal processing 205
Rinsing 119
Ripening 69
Roller, Come-along or pacer 212

Salts 45
Scheiner system 133
Schwarzschild coefficient 90
Scotopic curve 15
Semi-tendency drive 210
Sensitivity centres 71
Sensitivity, Colour 73
Sensitizers, Dye 73
Sensitometers 91
Sensitometric working tolerances 144
Sharpness 166
 factor 185
Shelf life 55
Shoulder 85
Shrinkage, Film 53
Signal-to-noise ratio 181
Silver halides 48
Silver halide crystals 68
 Defects in 79
 Electrical conductivity of 79
Silver halide precipitate 74
Silver recovery 224
S.M.P.T.E. negative 196
S.M.P.T.E. prints 194
Sol 47
Solution control 216
Solution replenishment 220
Sound on film 58
Sources, Light 15
Spatial frequency 171
Specular density 30
Speed control of processing machine 216
Speed, Effective 139
Speed measurement 128, 132
 systems, Comparison of 139
Speed point 131, 132
Speed rating:
 Specialized methods of 142
 Subjective 134

Sphere, Integrating 31
Spot brightness 159
Spray, Submerged 219
Spread functions 178
Sprocket-holes 52-55
 in 16-mm film leaders 196
Square law, Inverse 23
Squeegee 220, 222
Stainers 109
Standard eye 13
Static marks 57
Stepped exposures 96
Stop bath 119
Storage of film 55
Storage time of film reservoir 213
Storage unit, Film 312
Streamers 116
Stretch printing 189
Structure, Grain, of image 164
Sub-latent image 81
Submerged spray 219
Suction squeegee 222
Superadditivity 111
Suspensoid 47
Swell and shrinkage 53
Symbols, Light 28
Sync cross 60

Temperature:
 Changes due to 53
 Colour 15, 35
 control in processing machines 217
 Full radiator 19
Tempunit 217
Tendency drive 210
Threshold frequency 147
Threshold, Sensitometric 85
Time-scale modulation 89, 94
Toe of characteristic 85
Tolerances, Sensitometric 144
Transfer characteristic, Print 204
Transmission 28, 173

Units, Light 20, 26, 39, 40

Valency 44

Washing 119, 120, 123
Wedged exposures 96
Winding, Film 55
Woodnorton Hall 9
Work function 147
Working solution 113
Working tolerances, Sensitometric 144

AUTHOR INDEX

Amos, S. W. 40

Baines, Dr E. C. 12, 67

Birkinshaw, D. C. 40

Bomback, E. F. 12

Dubois, M. 103

Higgins, G. C. 11

Horder, A. 11

James, T. H. 11

Lamberts, R. W. 12

Lobell, L. 103

Mees, C. E. K. 11

Neblette, C. B. 11

Nelson, C. N. 12

Perrin, F. H. 12

Rieck, G. D. 11

Shaw, R. 12

Sheppherd, J. C. 11

Smith, J. W. W. 11

Sommer, A. 11

Stevens, W. R. 11

Todd, H. 11

Verbeek, L. K. 11

Walsh, J. W. T. 11

Warren, A. G. 205

Wheeler, L. J. 12, 103

Zakia, R. D. 11

*The Science and Technology of
Photography, Cinematography, Sound
and Image Recording*