Basic Photographic Materials and Processes

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Focal Press
Boston London

Focal Press is an imprint of Butterworth–Heinemann.
A member of the Reed–Elsevier group.

Cover design: Instructional Media Services/Rochester Institute of Technology
Cover photograph: Barbara Morgan. *Cadenza.* 1940. Courtesy of the Willard and Barbara Morgan Archives.
Illustrations: J. Wesley Morningstar

Library of Congress Cataloging-in-Publication Data
Basic photographic materials and processes / Leslie Stroebel . . . [et al.].
p. cm.
ISBN 0-240-80026-5
1. Photography. I. Stroebel, Leslie D.
TR145.B25 1989
771—dc20 89-36389

British Library Cataloguing in Publication Data
Basic photographic materials and processes.
1. Photography
I. Stroebel, Leslie
770

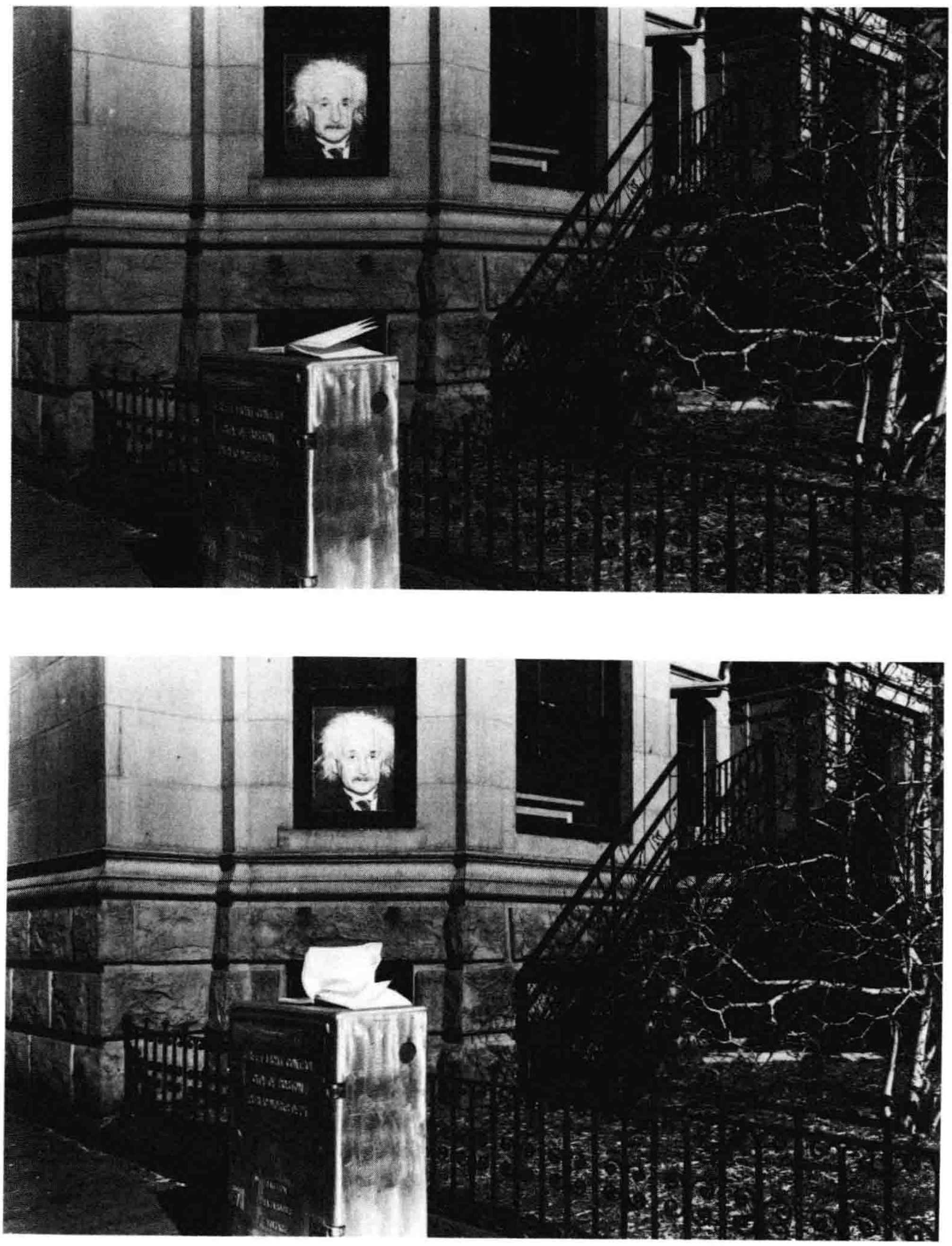
ISBN 0-240-80026-5

Butterworth–Heinemann
313 Washington Street
Newton, MA 02158–1626

10 9 8 7 6 5 4 3 2

Printed in the United States of America

Preface



Nathan Lyons.

Since the invention of the Daguerreotype process in 1839, the procedure for making photographs has become progressively easier. With the automated photographic equipment now available, there are some who claim it is no longer necessary to know anything about the technology of photography to make good photographs. This thought is not new. Over a hundred years ago, George Eastman used the slogan "You press the button, we do the rest." Serious photographers, however, have always known that knowledge of how photography works enables them to better achieve the results they want. This book was designed to be used as a textbook by college level students, but it also is appropriate for anyone who wants to learn more about how the photographic process works.

Evaluation of the esthetic attributes of photographs is considered to be subjective in nature since feelings play a more important role than logical reasoning, and different viewers can rightfully reach different conclusions. Technical aspects of photographs, on the other hand, are considered to be objective in nature since they can be measured, and different persons should obtain approximately the same measurements.

Although this book does not deal with photography as an art form, it does deal with esthetics in two important ways. First, by providing the knowledge needed to control the various components of the photographic process, technology enables the photographer to achieve desired image effects. For example, graininess of a photographic image can be affected by every step of the process from choice of subject to choice of printing paper. Information on how to control graininess is presented without value judgment, leaving it to the photographer to vary the graininess as seems appropriate.

Second, by providing the photographer with data that have previously been correlated with viewer responses to photographs representing systematic variations of a factor, technology reduces the number of photographs that are unacceptable due to related esthetic considerations. For example, published film speeds enable photographers to obtain a high proportion of correctly exposed photographs. Exposure failure occurs due to deviation from one or more of the conditions under which the tests were conducted. When picture-making conditions differ from the test conditions, technological procedures can be used to enable the photographer to arrive at an adjusted or personalized exposure index.

Photographic technology has evolved from traditional scientific disciplines that include mathematics, physics, chemistry, psychology, and physiology. Most of the technical material in this book is related to the process of making photographs, as distinct from the study of photographic theory for its own sake. It should be noted, however, that many students who earn a college degree in photography are attracted to photographic careers that do not have a major emphasis on working with a camera. Many of these positions require the same understanding of the photographic process as is expected for professional picture-making photographers.

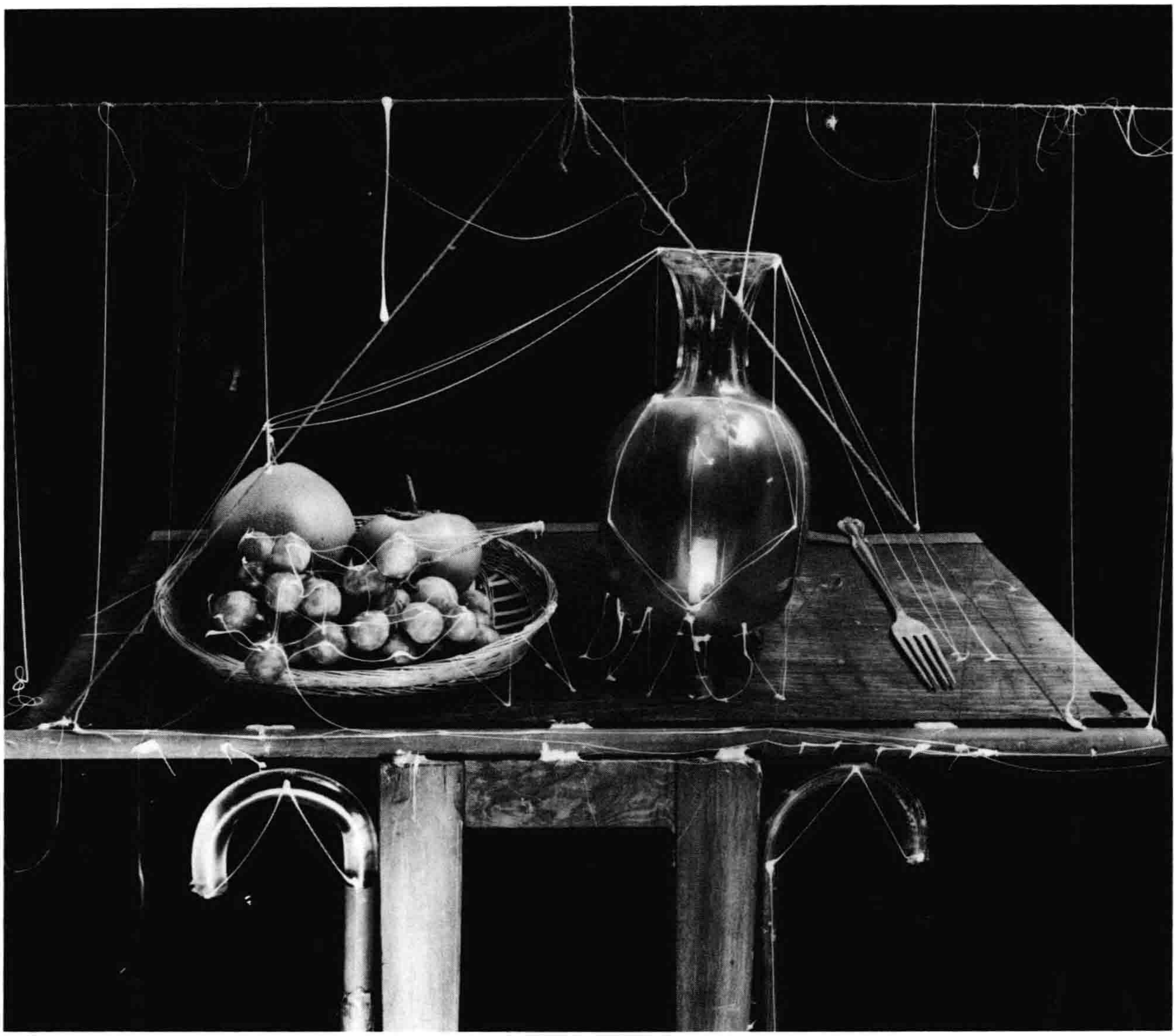
The authors' objectives are that this book will enable the reader to

1. understand and apply published information about photographic equipment and materials (such as manufacturers' data publications),
2. learn how to obtain reliable information about the subject, equipment, materials, and processes involved in making photographs (such as how to determine the accuracy of an exposure meter),
3. learn to solve technical problems involved in the production of photographs (such as how to use controlled fogging to change image contrast),
4. build a technical foundation for the more advanced formal or informal study of photography and related imaging systems (such as video, computer imaging, and photomechanical reproduction), and
5. learn the basics of how the process of visual perception operates, and learn to anticipate and compensate for variations in visual perception (such as those associated with adaptation and defective color vision.

Concise and practical marginal notes have been used throughout the book to provide the reader with highlights of important concepts and to serve as a preview of each section.

Sample questions are included at the end of each chapter so that readers may check their understanding of the material.

Contents



Zeke Berman. Untitled. 1984.

1 Light and Photometry

Andrew Davidhazy.

THE NATURE OF LIGHT

Light is fundamental to photography. The function of photographic materials is to record patterns of light. The function of photographic equipment used for taking pictures is to produce light (lamps), to measure light (exposure meters and color-temperature meters), and to control light (lenses, shutters, apertures, and filters). It is therefore desirable for the photographer to possess some understanding of the nature of light.

Light is defined as the form of radiant energy that our eyes are sensitive to and depend upon for the sensation of vision. The obvious importance of light has resulted in it being the object of an enormous amount of experimentation and study over many centuries. One of the first persons to make significant headway in understanding the nature of light was Isaac Newton. In the seventeenth century he performed a series of experiments and proposed that light is emitted from a source in straight lines as a stream of particles. This theory was called the "corpuscular theory."

Light travels about 25,000 miles in 1/10 of a second. Sound would require about 33 hours to travel the same distance.

However, the facts that light bends when it passes from one medium to another, and that light passing through a very small aperture tends to spread out, are not easily explained by the corpuscular theory. As a result, Christian Huygens proposed another theory called the "wave theory." This theory holds that light and similar forms of electromagnetic radiation are transmitted as a waveform in some media. (This theory was elaborated considerably by Thomas Young in the nineteenth century after he performed a number of experiments.) The wave theory satisfactorily explained many of the phenomena associated with light that the corpuscular theory did not, but it still did not explain all of them.

One of the more notable of these unexplained effects was the behavior of "blackbody radiation." (Blackbody radiation is radiation produced by a body that absorbs all the radiation that strikes it, and emits radiation by incandescence, depending on its temperature.) In 1900 Max Planck suggested the hypothesis of the "quantization of energy" to explain the behavior of blackbody radiation. This theory states that the only possible energies that can be possessed by a ray of light are integral multiples of a quantum of energy. In 1905, Einstein proposed a return to the corpuscular theory of light with light consisting of photons, each photon containing a quantum of energy. These suggestions, along with others, gradually developed into what is known today as "Quantum Theory" or "Quantum Electrodynamics." This theory combines aspects of the corpuscular and wave theories, and satisfactorily explains all of the known behavior of light. Unfortunately, this theory is difficult to conceptualize, and can be rigorously explained only by the use of sophisticated mathematics. As a result, the corpuscular and wave theories are still used to some extent where simple explanations of the behavior of light are required.

LIGHT WAVES

If the idea that light moves as a wave function is accepted, it becomes necessary to determine the nature of its waves and the relationship of light to other forms of radiation. Actually, light is but a fractional part of a wide range of radiant energy that exists in the universe, all of which can be thought of as traveling in waves. These forms of energy travel at the same tremendous speed of approximately 186,000 miles (3×10^8 meters) per second, differing only in wavelength and frequency of vibration. These waves have been shown to vibrate at right angles to their path of travel. The distance from the crest of one wave to the crest of the next is termed the wavelength, with the Greek letter λ (lambda) used as the symbol. Figure 1–1 illustrates this concept. The number of waves passing a given point in a second is called the frequency of vibration; the symbol f is used to specify it. The wavelength multiplied by the frequency of vibration equals the speed or velocity (symbol v) of the radiation. Thus, $\lambda \times f = v$.

Since the wavelength of radiant energy can be determined with far greater accuracy than the frequency, it has become common practice to specify a particular type of radiation by its wavelength. Because of the extreme shortness of the wavelengths encountered with light sources, the most frequently employed unit of measure is the nanometer (nm) which is equal to one-billionth of a meter. A somewhat less commonly used measure is

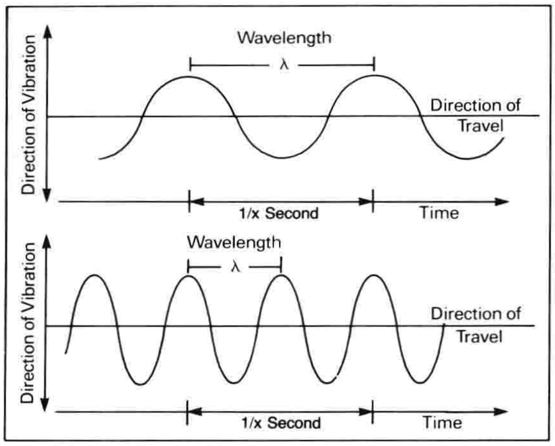


Figure 1–1 A simple form of a light wave, illustrated in a longitudinal cross section. In reality, the wave is vibrating in all possible right angles to the direction of travel. The second wave has a wavelength one half that of the first and, therefore, a frequency twice as great.

the Angstrom (Å), which is equal in distance to 1/10 of a nanometer (e.g., 400 nm equals 4,000 Å). Table 1–1 summarizes these measurement concepts.

THE ELECTROMAGNETIC SPECTRUM

When the various forms of radiant energy are placed along a scale of wavelengths, the resulting continuum is called the *electromagnetic spectrum*. Although each form of radiant energy differs from its neighbors by an extremely small amount, it is useful to divide this spectrum into the generalized categories shown in Table 1–2. All radiations are believed to be the result of electromagnetic oscillations. In the case of *radio waves*, the wavelengths are extremely long, being on the order of 10^{10} nm, and are the result of long

Table 1–1 Units of length

Unit	*Symbol*	*Length*
Meter	m	3.218 ft. (38.6 in.)
Centimeter	cm	0.01m (10^{-2}m)
Millimeter	mm	0.001m (10^{-3}m)
Micrometer	μ (mu)	0.000001m (10^{-6}m)
Micron	"	"
Nanometer	nm	0.000000001m (10^{-9}m)
Millimicron	mμ	"
Angstrom	Å	0.0000000001m (10^{-10}m)

Table 1–2 The electromagnetic spectrum

Frequency Hertz (cycles per second)	*Wavelength nm*		*Type of Radiation*
	10^{15}		
10^4	10^{14}		Maritime radio communications
	10^{13}		
10^6	10^{12}	1 km	AM radio
	10^{11}		
10^8	10^{10}		
	10^9	1 m	FM radio
10^{10}	10^8		Radar
	10^7	1 cm	TV
10^{12}	10^6		Microwave
	10^5		
10^{14}	10^4		Infrared
	10^3		Light
10^{16}	10^2		
	10^1		Ultraviolet
10^{18}	10^0	1 nm	
	10^{-1}	1 Å	
10^{20}	10^{-2}		X-rays
	10^{-3}		
10^{22}	10^{-4}		
	10^{-5}		
	10^{-6}		Gamma rays

electrical oscillations. The fact that such energy permeates our environment can easily be substantiated by turning on a radio or television receiver in any part of the technologically developed world. This form of radiant energy is not believed to have any direct effect upon the human body. Radio waves are customarily characterized by their frequency, expressed in hertz (cycles per second).

The portion of the electromagnetic spectrum that is sensed as heat is called the *infrared region*. The origin of this form of radiant energy, which is shorter in wavelength than radio waves, is believed to be the excitation of electrons by thermal disturbance. When these electrons absorb energy from without, they are placed in an elevated state of activity. When they suddenly return to their normal state, electromagnetic radiation is given off. It has been shown that all objects at a temperature of greater than −273°C give off this type of radiation. The temperature of −273°C is referred to as absolute zero or 0° Kelvin (K), after Lord Kelvin, who first proposed such a scale. Thus, all the objects we come into contact with give off some infrared energy. In general, the hotter an object, the more total energy it produces and the shorter the peak wavelength.

If the object is heated to a high enough temperature, the wavelength of the energy emitted will become short enough to stimulate the retina of the human eye and cause the sensation of vision. It is this region of the electromagnetic spectrum that is termed *light*. Notice that it occupies only the narrow section between approximately 380 nm and 720 nm. Because the sensitivity of the human visual system is so low at these limits, 400 and 700 nm are generally considered to be more realistic values. Objects with very high temperatures produce *ultraviolet* energy, which is shorter than 400 nm in wavelength.

To produce radiant energy shorter in wavelength than about 10 nm requires that an object be bombarded by fast-moving electrons. When these rapidly moving electrons strike the object, the sudden stopping produces extremely short wave energy called X-radiation, or more commonly, *X-rays*. Still shorter wavelengths can be produced if the electron bombardment intensifies, as occurs in a cyclotron. In addition, when radioactive material decomposes, it emits energy shorter in wavelength than X-rays. In these two cases the energy is referred to as gamma rays, which are usually 0.000001 nm (10^{-6} nm) in wavelength and shorter. These forms of electromagnetic energy are the most energetic, penetrating radiation known.

Thus it can be seen that the wave theory of radiant energy provides a most useful system for classifying all the known forms of radiation.

THE VISIBLE SPECTRUM

Although the terms "UV light" and "black light" are commonly seen in print, "UV radiation" is a more appropriate term.

Light occupies a very small part of the electromagnetic spectrum.

Located near the middle of the electromagnetic spectrum are the wavelengths of energy referred to as light. It is important to note that the location of this region is solely dictated by the response characteristics of the human eye. In fact, the international standard definition states: "Light is the aspect of radiant energy of which a human observer is aware through the visual sensations which arrive from the stimulation of the retina of the eye." Stated more simply, light is that energy which permits us to see. By definition, all light is visible, and for this reason the word *visible* is an unnecessary (and perhaps confusing) adjective in the common expression *visible light*. This definition also may be interpreted to mean that energy which is not visible cannot (or should not) be called light. Thus it is proper to speak of ultraviolet radiation and infrared radiation, but not ultraviolet light and infrared light. The popular use of such phrases as *black light* and *invisible light* to describe such radiation makes it impossible to determine what type of energy is being described, and they should be avoided.

To understand more about light, it is necessary to become familiar with the way in which the human eye responds to it. The graph in Figure 1–2 represents the results of testing 100 observers with normal color vision for the perception of brightness in respect to different wavelengths of energy. The plot comes from the average of all observers and shows the sensitivity of the eye to different wavelengths (or colors) of light. In this case, sensitivity is similar to a film speed. These data indicate that the sensitivity of the eye drops to near zero at 400 nm and at 700 nm, thus specifying the limits within which radiant energy may be referred to as light. It also shows that the response of the eye is by no means uniform throughout the visible spectrum. In fact, if equal physical amounts of different colors of light are presented to an observer, the curve shows that the middle (green) portion of the spectrum would appear the brightest, and the extreme (blue and red) parts would look very dim. It is for this reason that a green "safelight" is used when processing panchromatic film. Since the eye

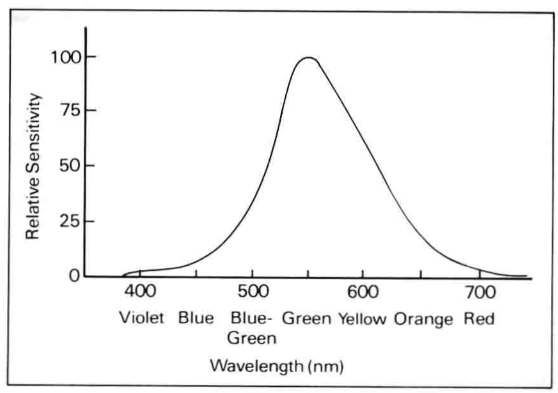


Figure 1–2 The sensitivity curve of the human eye. The plot indicates the relative brightness of the energy at each wavelength. Note that the curve is asymmetrical.

is more sensitive to green light, it takes less of it to illuminate the darkroom than any other color of light.

The plot shown in Figure 1–2 has been accepted as an international standard response function for the measurement of light. Therefore, any meter intended for the measurement of light must possess a sensitivity function identical to it. Most photoelectric meters used in photography have response functions significantly different from the standard and are not properly called light meters, although the international standard curve can be approximated by the use of appropriate filters with some meters. (It should be noted that the determination of the proper f-number and shutter speed for a given photographic situation does not require a meter with this response function.)

When all of the wavelengths between 400 nm and 700 nm are presented to the eye in nearly equal amounts, the light is perceived as white. There can be no absolute standard for white light because the human visual system easily adapts to changing conditions in order to obtain the perception of whiteness. For example, the amounts of red, green, and blue light in daylight are significantly different from those of tungsten light; however, both can be perceived as white due to physiological adaptation and the psychological phenomenon known as color constancy. Thus our eyes readily adapt to any reasonably uniform amount of red, green, and blue light in the prevailing illumination. This means that our eyes are not to be relied upon when judging the color quality of the prevailing illumination for the purposes of color photography.

If a beam of white light is allowed to pass through a glass prism as illustrated in Figure 1–3, the light is dispersed into a series of colors termed the *visible spectrum*. This separation of the colors occurs as a result of the light of various wavelengths being bent by varying amounts. The shorter-wavelength blue light is bent to a greater extent than the longer-wavelength green and red light. The result is a rainbow of colors that range from a deep violet to a deep red. Experiments indicate that human observers can distinguish nearly 100 different spectrum colors. However, the visible spectrum is often arbitrarily divided into the seven colors listed in Figure 1–3. For the purpose of describing the properties of color photographic systems in simple terms, the spectrum is divided into just three regions: red, green, and blue. The color of the light may be specified at a given wavelength, thereby defining a spectral color. Such colors are the purest possible because they are unaffected by mixture with light of other wavelengths. It is also possible to specify a certain region or color of the spectrum by the bandwidth of the wavelengths. For example, the red portion of the spectrum could be specified as the region from 600 nm to 700 nm.

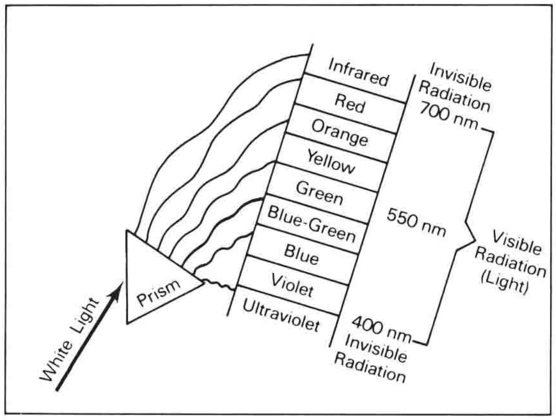


Figure 1–3 The dispersion of white light into the visible spectrum.

SOLID-OBJECT SOURCES AND THE HEAT-LIGHT RELATIONSHIP

Light is a form of energy that can only be produced from some other form of energy. The simplest and perhaps most common method is from heat energy, a process called *incandescence*. Whether the source is a filament in a tungsten lamp, a candle flame, or anything that has been heated until it glows, incandescence is always associated with heat. In fact, the amount and color of light produced by an incandescent source is directly related to the temperature to which it is heated. Consider, for example, an iron poker, one end of which is placed in a fire. Initially the poker feels somewhat cold; but as it is left in the fire, its temperature rises and it begins to feel warm. By increasing the temperature of the poker, we can become aware

Leonardo da Vinci discovered that white light contains different colors 200 years before Newton, but he identified only five colors.

All objects emit radiation at room temperature, but objects must be heated to a temperature of approximately 1200° Fahrenheit before visible radiation is emitted.

of a change in its radiating properties through our sense of touch, although it looks the same. Soon the poker will become too hot to touch and we will be able to sense its radiation as heat at a short distance. As the temperature is raised even higher, the poker reaches its point of incandescence and begins to emit a deep red glow. If the poker is allowed to get hotter still, the color of the light it produces will become more yellowish, and the light will become brighter. At extremely high temperatures, the end of the poker will look white, and ultimately blue, in addition to becoming still brighter. All of this illustrates the fact that a solid object, when heated to its point of incandescence and higher, produces light that varies in color as a function of its temperature. When describing the temperature of such sources, it is common practice to employ the absolute or Kelvin scale for reasons discussed earlier.

The best solid-object radiator is an absolutely black body, as it absorbs all the energy that strikes it. All light sources are radiators, some of which are more efficient than others. Thus, since a perfectly black object would absorb and emit energy but not reflect it when heated, it would be the most efficient source. A blackbody source is achieved in practice by the design shown in Figure 1–4. An enclosure surrounded by a boiling material becomes the source. Since the interior surface of the object is darkened and everywhere concave, any light that enters will be absorbed, either immediately or after one or more reflections. Consequently the hole will appear perfectly black. As the walls of the oven are heated, they will emit radiant energy in all directions; that which escapes through the hole is called blackbody radiation. When such an experiment is performed and the blackbody is heated to a variety of temperatures, the characteristics of the radiant energy it produces change systematically, as shown in Figure 1–5.

As discussed previously, every object emits energy from its surface in the form of a spectrum of differing wavelengths and intensities when heated to temperatures greater than −273°C (absolute zero). The exact spectrum emitted by the object is dependent upon its absolute temperature and its *emissivity* (the flow of radiation leaving a small area divided by the area). Since the blackbody has perfect emissivity, the temperature in degrees Kelvin becomes the only important factor. It can be seen in Figure 1–5 that as the temperature increases, the curves are everywhere higher, indicating that the amount of energy at each wavelength increases. Additionally, as the temperature increases, the wavelength at which the peak output occurs becomes shorter. The peak position shifts from the long-wavelength end of the infrared region

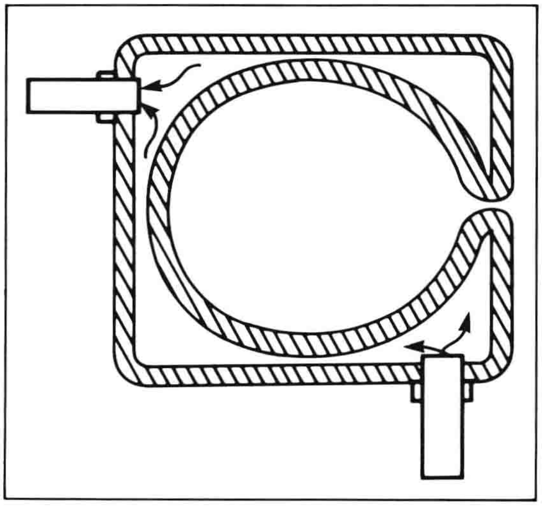


Figure 1–4 Cross section of a simple blackbody radiator consisting of an enclosure surrounded by boiling or molten material.

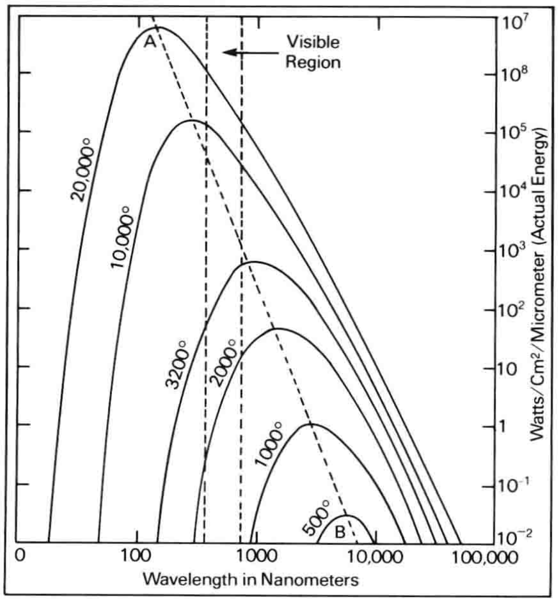


Figure 1–5 Spectral-energy curves for a blackbody heated to various temperatures.

toward the short-wavelength end of the ultraviolet region as the temperature increases. The portion of emitted energy that would be perceived as light is contained within the narrow band between the broken lines.

Some observations are now in order. First, since all of the objects with which we come into contact are at temperatures greater than −273°C, they are emitting some form of radiant energy, principally in the long-wavelength infrared region. For example, the human body at a temperature of 98.6 F (40 C, 313 K) emits infrared energy from 4000 nm to 20,000 nm, with the peak output at approximately 9600 nm. Second, most objects must be heated to a temperature of greater than 1000 K (727 C, 1340 F) in order to give off energy short enough in wavelength to be sensed by the human eye. For example, iron begins to glow red when it is heated to a temperature of about 1200 K, and a typical household tungsten lamp operates at a filament temperature of nearly 3000 K. Both sources will emit large amounts of infrared energy in addition to the visible energy. Third, in order for it to emit ultraviolet energy, a solid-object source must be heated to extremely high temperatures. Since tungsten steel melts at 3650 K, incandescent sources are not typically used when large amounts of ultraviolet energy are needed.

VAPOR SOURCES AND THE EFFECT OF ELECTRICAL DISCHARGE

A fundamentally different method for producing light makes use of radiation emitted from gases when an electrical current is passed through them. Such sources are called discharge lamps and generally consist of a glass tube containing an inert gas, with an electrode at each end. An electrical current is passed through the gas to produce light and ultraviolet energy. This energy may be used directly or to excite phosphors coated on the inside of the glass tube, as in a fluorescent lamp.

The basic process involved in the production of light is the same for all vapor lamps. The light emission from the vapor is caused by the transition of electrons from one energy state to another. When the electrical current is applied to the lamp, a free electron leaves one of the electrodes at high speed and collides with one of the valence electrons of the vapor atom. The electron from the vapor atom is bumped from its normal energy level to a higher one and exists for a short time in an excited state. After the collision, the free electron is deflected and moves in a new direction at reduced speed. However, it will excite several more electrons before it completes its path through the lamp. The excited electron eventually drops back to its former energy level and, while doing so, emits some electromagnetic radiation.

The radiation emitted may be at any of several wavelengths, depending primarily upon the properties of the vapor in the tube. Each type of vapor atom, when excited, gives off energy at wavelengths determined by its structure. Some gases emit radiation only at a few wavelengths, while others emit energy at many different wavelengths. These sources are said to show a discontinuous or line spectrum. For example, the spectrum of sodium vapor shows a bright yellow line near 600 nm, as shown in Figure 1–6, while mercury vapor produces energy at many different wavelengths, both in the ultraviolet region and in the visible region, as illustrated in Figure 1–7.

Solids emit continuous spectrums. Gases and vapors emit discontinuous spectrums.

The pressure under which the vapor is dispersed in the tube has a significant effect upon the amount of energy that will be emitted. The terms *low pressure* and *high pressure* are often used to describe such lamps; low pressure indicates some small fraction of atmospheric pressure, while high pressure is

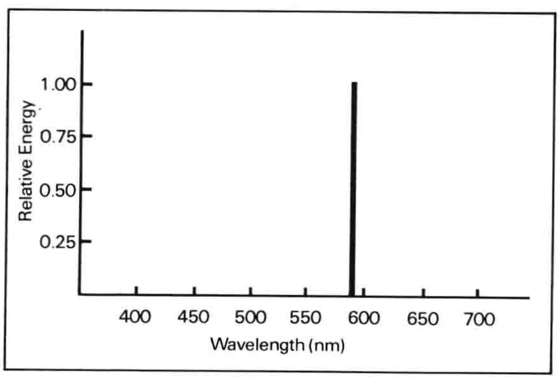


Figure 1–6 Spectral-energy distribution of a low-pressure sodium-vapor source. Such sources appear yellow.

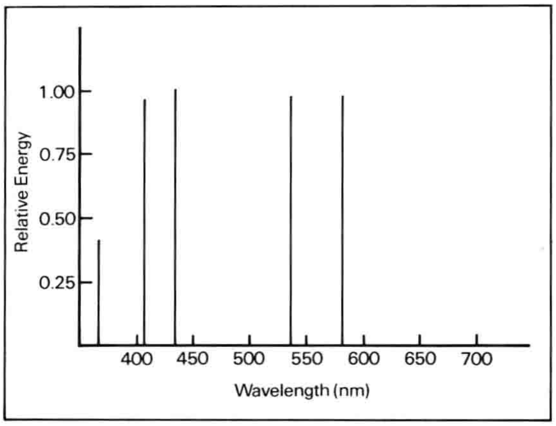


Figure 1–7 Spectral-energy distribution of a low-pressure mercury-vapor source. This source would appear violet.

applied to sources working above atmospheric pressure. High-pressure sodium-vapor lamps are often used for illuminating streets at night. Low-pressure sodium-vapor lamps are often used as safelights in photographic darkrooms when working with orthochromatic materials because they produce light in regions of the spectrum where the emulsion shows low sensitivity. High-pressure mercury-vapor sources are often used when making blueprints, while low-pressure mercury-vapor sources are used in greenhouses as plant lights because the ultraviolet energy they emit is beneficial to plant growth. It is important to note that the spectral characteristics of the radiation emitted by these sources is dependent primarily upon the properties of the vapor in the tube.

Perhaps the most commonly encountered vapor source is the fluorescent lamp. These are typically low-pressure mercury-vapor tubes that have phosphors coated on the inside of the glass envelope. When bombarded by the large amount of ultraviolet radiation emitted by the mercury vapor, these phosphors begin to glow and give off visible energy at all wavelengths in the visible spectrum. Thus, the light emitted by a fluorescent lamp is the result of both the discontinuous energy emitted by the vapor and the continuous energy emitted by the fluorescing phosphors.

There are many classes of phosphors that can be used for this purpose, with each phosphor emitting its own color of light. Figure 1–8 illustrates the spectral energy distribution for a typical cool white fluorescent lamp. The light that corresponds to the discontinuous line spectrum produced by the mercury vapor may not be apparent to a human observer because of the ability of the visual system to adapt to variations in the color balance of "white" light. Photographic films do not have this capability. Therefore, color transparencies made on daylight type color film with "daylight" fluorescent illumination tend to have a greenish cast unless an appropriate filter is used.

LUMINESCENCE

Luminescence can be described as the emission of light due to causes other than incandescence. It is generally caused by the emission of photons from atoms by exciting them with energy of relatively short wavelengths. As the electrons return to a lower energy level, energy of longer wavelengths is released. The rate at which this occurs can be affected by the presence of an *activator*, which is made up of ionized atoms that trap, then release the electrons slowly for recombination. The exciting energy is usually in the ultraviolet region, but can be caused by energy in the visible and infrared regions. There are many forms of luminescence. *Bioluminescence* is the result of biochemical reactions, and is typically seen in fireflies and glowworms. *Chemiluminescence* occurs as the result of some chemical reactions. *Gal-*

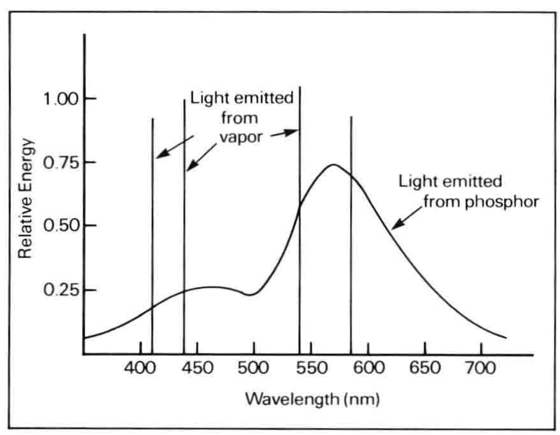


Figure 1–8 Spectral-energy distribution of a cool white fluorescent lamp.

vanoluminescence occurs as the result of galvanic action (the result of the flow of an electrical current) and, in the days when vacuum-tube rectifiers were common, could be seen as a "glow" when they were operating. *Triboluminescence* occurs when a material is ground; an example would be the grinding of sugar with a mortar and pestle. Solid substances that luminesce are called *phosphors*. Photographers are most concerned with the luminescence that occurs as a result of excitation with ultraviolet energy and light.

Fluorescence is luminescent emission of electromagnetic radiation in the visible region that occurs during the time of excitation. Thus, phosphors that are radiated with ultraviolet energy fluoresce. When the excitation is stopped, the fluorescence ceases within about 10^{-8} seconds; but it sometimes continues for as long as 10^{-1} seconds, depending on the activator.

Phosphorescence is the emission occurring after the excitation has been stopped, and which continues for somewhat more than 10^{-8} seconds up to several hours. The duration is strongly dependent on temperature. Phosphorescence is similar to fluorescence, but has a slower rate of decay.

Some dyes fluoresce, including fluorescein, eosin, rhodamine, and a series of dyes (and other materials) that are used as brighteners in substances such as paper and cloth. Photographic papers may contain brighteners to give them "cleaner" and more brilliant "whites." Most modern papers are treated with brighteners, a distinguishing characteristic when comparing modern prints to those made 30 or 40 years ago, without brighteners. The occurrence of brighteners in fabrics and similar materials can present problems in color photography when the ultraviolet component of electronic flash energy (or other light sources) causes them to fluoresce, most often in the blue region of the spectrum. This has a strong effect on the reproduced color of the material, often rendering it "blue" or "cyan" when the other materials in the scene have been reproduced satisfactorily in the photograph. The effect is minimized or eliminated by the use of an ultraviolet-absorbing filter over the electronic flash, or other source, to prevent it from exciting the fluorescing dyes or pigments in the material. An ultraviolet filter over the camera lens in this case would not correct for the fluorescence.

Fluorescent lamps excite gas molecules within the tube by means of electrons, to produce energy of discrete wavelengths, or lines, largely in the blue and ultraviolet regions (but dependent to a great extent on the gas elements in the tube). Some of this energy is absorbed by phosphors coated on the inside of the tube and is converted to longer-wavelength (visible) radiation. The color of the fluorescent emission is highly dependent on the phosphor material, and the activators incorporated in it.

Fluorescing screens are extensively used in radiography. In this application, they are called *intensifying screens*. They fluoresce when activated by the X-rays used for exposure, and the visible radiation from the screens is considerably more effective in exposing photographic emulsions than the X-rays themselves. The screens are placed in contact with both sides of the film, in the film holder, during exposure.

Brighteners in photographic papers fluoresce to produce whiter whites.

Brighteners in clothing, paper products, hair rinses, etc., can adversely affect the color of the objects in color photographs.

THE USE OF COLOR TEMPERATURE

As discussed previously, the amount and color of radiation emitted by a solid-object source is very much temperature dependent. In fact, the color of light being emitted from such a source can be completely specified by the Kelvin temperature (K) at which it is operating. Such a rating is referred to as the *color temperature* of the source. A color temperature may be assigned to any light source by matching it visually to a blackbody radiator. The temperature of the blackbody radiator is raised until the color of its light visually matches that from the lamp, and the Kelvin temperature of the blackbody is then assigned as the color temperature of the lamp. Thus, the use of color-temperature ratings in photography presumes that the lamp being described adheres to the same heat-to-light relationship as does the blackbody radiator. For incandescent lamps, this presumption is correct. However, the color of light emitted by some sources, such as fluorescent lamps, has no relationship whatever to the operating temperature. In these cases, the term *correlated color temperature* is used to indicate

As color temperature increases, the color balance of the light shifts from reddish to bluish.

Tungsten color film can be used in daylight by using a filter that converts daylight to tungsten-quality light.

***Light Conversions.* An orange 85B filter converts daylight to tungsten quality. A bluish 80A filter converts tungsten light to daylight quality.**

that the color of light emitted by a blackbody radiator of that temperature produces the closest visual match that can be made with the source in question. It is important to note here that a visual match of two sources does not ensure a photographic match. In fact, in most cases, the photographic results will be different.

The color temperatures of a variety of light sources are given in Table 1–3. It is apparent that photographers are faced with a tremendous range of color temperatures, from the yellowish color of a candle at about 1800 K to the bluish appearance of north sky light, rated at 15,000 K. Notice that as the color temperature increases, the color of light emitted from the source shifts from red to white to blue in appearance. In order for photographers to produce excellent photographs under widely varying illuminant conditions, color films are designed for use with three different color temperatures. Type A color films are designed to produce images having optimum color balance with light rated at 3400 K, while Type B films are intended for a source rated at 3200 K. Daylight-balanced color films are designed to be used with 5500 K light, which is often referred to as photographic daylight. The actual color temperature encountered from a lamp in practice can vary significantly as a result of reflector and diffusor characteristics, changes in the power supply and the age of the bulb. Consequently, it is often necessary to measure the color temperature of the source with a color-temperature meter when using color films. Most color-temperature meters employ photoelectric cells used in conjunction with color filters to sample specific regions of the spectrum being produced. These instruments measure the blue energy compared to the red energy output and give a reading directly in color-temperature values, or indirectly through the use of calibration charts. Such meters can be successfully used in both daylight and tungsten lighting conditions, where the source is producing a continuous spectrum. However, when used with vapor sources that produce a discontinuous spectrum, the results may be very misleading because of significant differences in this response compared to the visual response.

When the color temperature of the light from a solid-object source does not match the response of the film, light-balancing filters must be used over the camera lens. If the color temperature is too high, a yellow filter over the camera lens will lower the color temperature of the light that the film receives. If the color temperature of the light is too low, a blue filter can be used to raise it. If the filters are desaturated in color, then the changes to color temperature will be relatively small, while saturated filters will give large changes in color temperature.

The filters necessary to properly correct the color of light from vapor sources, such as fluorescent lamps, must either be determined from manufacturer's literature or from tests performed with the color film itself.

Table 1–3 The color temperatures of some common light sources

Source	*Color Temperature (°K)*
Candle	1800
60-watt tungsten lamp	2800
100-watt tungsten lamp	2900
250-watt photographic lamp	3200
250-watt studio flood lamp	3400
Flashbulb (uncoated)	4000
Direct sunlight	4500
Photographic daylight (sunlight plus sky light)	5500
Electronic flash	6000
Sky light (overcast sky)	8000
North sky light	15,000 (approximately)

THE MIRED SCALE

Although color temperature provides a useful scale for classifying the light from continuous-spectrum sources, it does have some limitations. For example, a 500 K change at the 3000 K level does not produce the same visual or photographic effect as a 500 K change at the 7000 K level. This is because there is a nonlinear relationship between changes in a source's color temperature and the changes in the color of light it produces, which is illustrated in Figure 1–9.

This awkwardness in the numbers can be eliminated if the reciprocal of the color temperature is used, because of the more nearly linear relationship existing between this value and the effect. Since this number would be