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Principles of Technical Photography and Photoinstrumentation

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Introduction

The intent of this article is to give the reader an overview of photographic imaging and recording principles and to introduce operating concepts behind various instruments and techniques associated with applied, or applications oriented, photography and techniques particularly suitable for recording and visualization and both qualitative and quantitative evaluation of physical and chemical phenomena.

The paper introduces general image formation principles, camera design, function and selection, time manipulation concepts and specialized camera and lighting systems for industrial and scientific applications.

1. Principles of Image Formation

Photography is a method whereby information in the form of light associated with a particular subject is recorded, stored and analyzed for subsequent interpretation and evaluation of the real subject at a later time.

It is important to note that photographs are not the real subject but rather records of the appearance of a subject based on light emitted, reflected or transmitted by the subject. Therefore, photography is generally not considered an invasive or destructive recording medium since the contact between the record and the subject is simply one associated with light. As such, photography is inherently dependent on image formation principles associated with the field of optics. In this article we will deal with some of the very basic principles and refer the reader to substantive optics discussions for supporting materials.

At the very basis of image formation is the fact that when light is emitted from a source or reflected from a subject, light rays emanate from it in all directions but modified by subject characteristics. These include such things as refraction, reflection, absorption, etc.

For the sake of simplicity we will deal with subjects that are perceived as real by the fact that they reflect light to our eyes and the image they form on our retina is interpreted by our brain as the subject we are looking at whatever that might be.

1.1 Pinhole camera - formation of an image

In principle then, in order for an image to form within our eye or within a camera, and for this subject to be recognized as real, all its parts, every point on its surface, must reflect
incident light rays in varying degrees and modified according to the characteristics of each individual point on the surface of the given subject.

The light rays that leave any point in the subject travel through space in straight lines and wherever they fall they increase the level of local illumination. This fact makes it possible to create a reproduction of the subject tones and distribution of light reflecting points by passing the light rays leaving the subject's points through a limiting aperture generally called a pinhole.

The pinhole aperture intercepts some of the light rays leaving a subject point and these fall on a screen placed some distance from the aperture forming a "blob" of light whose dimensions depend on the distance between the aperture and the screen. If this blob is small enough we call it an acceptable reproduction of the subject point. The size of this fuzzy reproduction of a subject point is affected by diffraction and there is an optimum size beyond which its size actually increases due to diffraction. The optimum pinhole diameter is given by:

\[
C = \frac{2}{\pi} \sqrt{\frac{wD}{wD}}
\]

where
- \(C\) = diameter of Pinhole Aperture
- \(w\) = wavelength of light used
- \(D\) = distance from pinhole to screen

The brightness of the reproduction of the subject point by a pinhole depends on the size of the pinhole, the absolute amount of light available (ie: amount of light incident and portion reflected by the subject point) and the distance from the pinhole to the screen. The larger this distance the dimmer the image "point" becomes according to the inverse square law. Increasing the pinhole diameter has no effect on the brightness or luminance of the spot forming the reproduction of a point. The spot simply gets bigger in size and thus contains more light rays. But since a complete scene is made up of many points, the larger the pinhole diameter the brighter the overall image becomes in direct proportion to the area of the pinhole due to the overlapping of the "blobs" of light associated with each subject point.

Other points also reflect light rays and they are reproduced in the same way on the intercepting screen. The distance between any two image points is a function of the angular displacement between the corresponding subject points and the distance between the pinhole aperture and the screen. This means that images vary in size based inversely on the distance between the pinhole and the subject and directly with the distance between the pinhole and the screen.

1.2 Pinhole camera - capturing the image

While a pinhole can be used as an imaging device to form a representation of the subject the image on a screen, the image is fleeting. In order to retain it for future use the photographic process is generally employed as a recording medium. Photography allows
for fixing the effect of the light image on a photosensitive medium. Thus the pinhole is placed at one end of a light tight container and the pinhole is covered by a removable opaque obstruction (a shutter to control the time over which the light acts on the light sensitive surface) while the photosensitive material is placed opposite the pinhole.

1.3 Pinhole camera - characteristics

A pinhole camera has some advantages over cameras equipped with lenses. 1. It does not suffer from distortion, 2. it has essentially infinite depth-of-field meaning that the camera does not need to be focused, producing equally unsharp images of subjects near or far from the camera, 3. it covers a wide angle of view, 4. it transmits all wavelengths and 5. it is cheap or expendable. To counteract these advantages there are the following problems: 1. The images are generally not very sharp, 2. the images are much dimmer than in cameras equipped with lenses, thus often necessitating relatively long exposure times during which light acts on the photosensitive material.

The number of light rays that are reflected from any point in the subject depends on the number of light rays originally incident on the point and as the number of light rays that falls on a point increases so does the number that are reflected and finally so does also the number that fall on the photosensitive material. Although the total number of rays that passes through the pinhole also is affected by the size of the pinhole it is impractical to alter the pinhole size since it is set to an optimum value. Instead, lenses are used to increase the size of the pinhole and to improve on the general lack of light efficiency and image sharpness of the pinhole camera.

1.4 Simple camera

A simple camera is nothing more than an elaboration of the pinhole camera where a lens is substituted for the pinhole. At a very basic level, a lens, due to refraction, will make the rays that are diverging from any given subject point converge to a particular location in the image side of the lens. The location in the image space where the diverging rays from a specific subject point are reproduced as close to a point as possible varies with the distance between the lens and the subject. When the subject is located at infinity the distance between the lens and the film plane is equivalent to its focal length or F.

Since the cone of light collected from a given subject point by a lens is generally much larger than the cone of light collected by a pinhole (in fact with a pinhole there is no spot where light rays emanating from subject points are actually "focused") the image formed by a lens will be significantly brighter than that made with a pinhole. Therefore, a simple hand-operated shutter is no longer sufficient to control exposure and some simple form of mechanical shutter is built into these cameras. These cameras also incorporate some sort of viewing device to help aim the camera in the correct direction and to give the photographer an idea of what will be included in the final image.

2. Basic definitions and characteristics of lenses used in photography.
2.1 Focal length

While a pinhole does not have a specific distance upon which objects located at infinity are reproduced, given a particular pinhole size there is an optimum distance for the placement of the photosensitive material. In the case of lenses the situation is similar and lenses are characterized by the distance between them and the image plane when the subject is located at infinity. This distance is known as "F" or the focal length. Knowledge of a lens' focal length allows the photographer to determine various outcomes associated with the use of a given lens in various applications.

Generally these have to do with determining the size of the image or subject, the location of the image plane where the image is sharply focused or the location of the subject given a particular distance between image and lens. The fundamental relationship that ties lens focal length, object and image together is:

\[
\frac{1}{F} = \frac{1}{v} + \frac{1}{u}
\]

where 
F = focal length
u = distance from subject to lens
v = distance from image to lens

(Distances are measured to corresponding nodal points - consult references in photographic optics for details but essentially nodal points or planes are special locations in a lens. They can be located and identified using a nodal slide. If rough approximations as sufficient, they are located a distance equal to one focal length from the lens's image planes)

2.2 Image size

As with pinhole imaging, given a particular subject distance its image size is directly proportional to the lens' focal length and inversely proportional to the subject distance. The ratio of image size and object size is known as magnification and it is given by:

\[
M = \frac{I}{O} \quad \text{or} \quad M = \frac{v}{u}
\]

where 
I = image size
O = object (subject) size

2.3 f-number

The ability of a lens to collect light rays from a subject point and thereby control the brightness of the image on the screen or photosensitive material is generally described by its "f number". This is merely the ratio between the focal length (F) and the effective diameter of the light gathering aperture (entrance pupil) of the lens (d).

\[
f\# = \frac{F}{d}
\]
Thus, the smaller the f# the "faster" the lens meaning the images it produces are brighter than another lens of larger f#. "Fast" lenses are important when photography under adverse lighting situations is encountered.

By convention the following set of f#'s has been standardized upon. Starting with f/1 the progression is: f/1.4, f/2.0, f/2.8, f/4, f/5.6, f/8, f/11, f/16, f/22, f/32, f/45, f/64, etc. These f#'s increase or decrease the illumination level of the image by a factor of 2 as one goes from one number to the next. They increase in numerical fashion multiplied by the square root of 2.

2.4 Depth-of-Field

Subject points located at a particular distance from the lens will be reproduced as image points that are usually much smaller than those formed with a pinhole and thus subjects located a specific distance from the lens are reproduced with significantly greater clarity than those formed by a pinhole.

Unfortunately the consequence of this is that subject locations other than those on which the lens is "focused" appear unsharp after a critical degree of unsharpness has been reached. Thus lenses have zones of acceptable and unacceptable rendering of the visual perception of sharpness or, have limited "depth-of-field". This zone of acceptable sharpness can, however, be controlled by selection of the lens aperture or diameter, the larger diameters producing the least depth in sharpness within the scene.

In order to determine the depth-of-field, one needs to first specify how much unsharpness is tolerable in terms of the size of the out-of-focus light spots formed by the lens of a given subject point. This is called the "circle of confusion" (c) and it is based on the ability of the eye to differentiate fine detail. When the size of the circle of confusion associated with a given subject plane (other than the one the lens is focused on) is so small that making it any smaller (by reducing the aperture of the lens) does not produce any further improvement in detecting detail from subjects located in that plane, one can state that the circle of confusion is as large as permissible. It should be noted that the viewing conditions as well as the ability of the observer to distinguish fine detail influence its absolute value.

In practice the maximum allowable size for the diameter of the circle of confusion in a print viewed at a distance of 25 cm is approximately .25 mm under average conditions of illumination. At other viewing distances its size varies directly with distance so at 1m the size is 1mm. It also depends on the visual acuity of the observer and may be somewhat larger or smaller than this for a given individual.

The maximum allowable size for the circle of confusion in negatives must be as many times smaller than the final print as the enlargement ratio and it is also directly related to the viewing magnification with 25cm assumed to be unity. Thus, at a viewing distance of 50cm the permissible size for the circle of confusion in the negative can be twice as large as when the viewing distance is 25cm. If the viewing distance is kept at 25cm but the
negative is enlarged to different magnifications, the negative which is enlarged further will exhibit shallower depth of field. For the depth of field to be the same the larger print must have been made from a negative where the size of the permissible circle of confusion was smaller than that of the negative which was enlarged less.

Determination of the limits of sharpness in a scene when the object focused on is at relatively large distances from the lens can be determined from the following relationships as follows:

\[
\begin{align*}
Dn &= \frac{H \times u}{H + (u - F)} \\
Df &= \frac{H \times u}{H - (u - F)} \\
H &= \frac{F^2}{f \times c}
\end{align*}
\]

Depth-of-field is determined by subtracting \(Dn\) from \(Df\).

Where
- \(Dn\) = Near Distance Sharp
- \(Df\) = Far Distance sharp
- \(H\) = Hyperfocal Distance
- \(c\) = Diameter of circle of confusion on film - see Note
- \(F\) = focal length
- \(f\) = f number

Note: with 35mm cameras \(c\) is usually accepted as .03mm with assumption that the negative will be enlarged up to an 8x10 inch print and viewed at a distance of 25cm.

2.5 Angle of view

The angle of view of a camera is controlled by the lens focal length and the film format. While angle of view is normally given as the field angle covered by the camera along the diagonal of the film. In general terms, for pinholes and non-distorting lenses that cover the film format, the angle of view for any given film dimension (such as height, width or diagonal) is determined by:

\[
\text{angle of view} = 2 \tan \left( \frac{\text{film dimension} \div 2 \times \text{focal length}}{2} \right)
\]

3. Brief Definition of Photographic Exposure and controlling factors.

Photosensitive materials respond to exposure to light by producing, after chemical aftertreatment, a certain degree of darkening or density associated with the strength of the total exposure. Actually the chemical treatment or development, of the photosensitive material serves an amplification function since the mere exposure of the film to light produces a very faint "latent" image. Since most photographic materials darken on exposure to light they are described as negative working systems. In order to make a positive, a reproduction that has the same tonal relationships as the original, a copy of the negative has to be made onto another negative working emulsion. This is commonly the case when B&W (Black and White) negatives are made from which B&W prints are
produced. Sometimes positives appear to be made directly, such as in the case of slides or transparencies, but even in these cases there is usually an intermediate negative stage associated with their production.

3.1 Sensitivity and characteristics of photographic materials

The sensitivity of photographic materials to light is generally based on the minimum exposure necessary to produce a specified density when certain specific development and reproduction characteristics have been met. In practice the speed of standard photographic materials is defined as their ISO (International Standards Organization) speed and is given in a form such as this: 100/21 where the arithmetic speed (100) is the ASA (American Standards Organization) speed component and the 21 is the DIN (Deutsche Industrie Normale) speed component of the combined ISO speed designation of the film. Since both speeds are determined the same way each can be used individually to describe a given film's speed. In many countries a film's speed is simplified to ISO 100 for example while in others reference is made to DIN 21 without use of the arithmetic component. The only correct format to specify this film's ISO speed is ISO 100/21.

Ultimately, however, the less light or exposure that is required to achieve the given standard density the "faster" the material. Since the ASA speed component is arithmetic in nature, a doubling in speed is indicated by a doubling of the number whereas in the DIN component an increase of 3 units indicates a doubling in speed. Film speed is gained at the expense of certain desirable emulsion characteristics. In black and white materials this is generally manifested by an increase in graininess and a decrease in resolving power. In color materials, in addition, there may be a loss in color reproduction fidelity.

3.2 Lens aperture and illuminance

Given a particular scene, the controlling factor that determines the amount of light that will interact with the photosensitive emulsion is the aperture or f# that the lens is set to. Determination of the f# of a lens is covered in section 2.3.

3.3 Shutters and exposure time

Photographic emulsions respond in a cumulative way to the presence of light. That is, the longer a given light level is allowed to act on an emulsion the greater the photographic response. The relationship between response and total exposure is not a linear function but deviations from a linear response generally do not cause a significant problem in terms of appropriately reproducing subject tonalities as long as the range of tones is not excessive.

While the aperture of a lens controls the level of illumination at the image plane, the shutter of the camera controls the length of time over which the light is allowed to act on the emulsion. The two together, along with the light level falling on the scene, determine the total energy or exposure that any given area on the film receives.
3.4 Lighting requirements

Any given scene has an inherent light level associated with it. Whether a successful photograph can be made under the given lighting conditions depends on whether the photographer has a lens of appropriate aperture (speed) available, a shutter that can be adjusted to some desired value and whether the camera is equipped with film having suitable speed. All of these factors together are eventually determined based on the outcome desired by the photographer which in turn are based on the conditions prevailing at a given scene or situation.

3.5 Putting it all together

Whether photographers have the ability to control the amount of light present in a scene or not, there is a relationship applicable to standard photographic materials that connects all the various factors affecting exposure together. It is this:

\[
\frac{25 \times f^2}{ASA \times T}
\]

where Light Level required = given in foot-candles
f = f# chosen or available
ASA = ASA component of the ISO speed of the film
T = exposure time chosen or available
25 = a constant

The constant essentially assures that the relationship assumes that the light level associated with a bright sunny day is 6,400 foot candles.

The non-linear and limited response characteristics of photographic emulsions do cause problems for photographers who attempt to photograph scenes that have a very large range of tones or luminances. Although transparent materials have a potential for being able to deal with scene luminance ranges as high as 1:1000 most photographic papers can only produce a range of tones of maybe 1:100. Therefore, scenes reproduced on paper will exhibit improper reproduction of highlights if the shadows of the scene are reproduced properly and, inversely, the shadows will appear very dense and dark if the highlight of the scene are reproduced properly. The reader is referred to more complete treatments of tone reproduction to explore this subject fully.

Also, emulsions do not respond with the same density when given equal exposures but the components of which are significantly different. Using a very low image illuminance caused possibly by using a small lens aperture and coupling this with a long exposure time would produce the same effective exposure as using a much larger aperture and a correspondingly shorter exposure time. However, even though the exposures in these cases would be the same the photographic response, or density, may not be the same. This is due to a characteristic of emulsions described as reciprocity law failure. It is not the law that fails but rather the emulsions fail to follow it. Manufacturers often provide
appropriate guidelines for accounting for such anomalies in a film's response to long and short exposures.

4. Camera options.

Cameras are available in many different designs each often configured to best suit a particular application. Beyond a simple camera equipped with a lens of modest design and performance, more sophisticated cameras generally include options that allow a given camera to be adapted by the photographer for specialized applications. One of the most common options is that of including the possibility to attach lenses possessing special characteristics onto the camera.

4.1 Function of interchangeable lenses

Interchangeable lenses allow the photographer to remove a given lens from the camera body and attach another one onto it. The primary reason for interchangeable lenses is to have the ability to use lenses of different focal length. As the focal length of a lens is changed the camera's field of view will be altered. Given a subject at a particular distance from the camera a change in field of view will make the subject appear to be larger in the viewfinder of the camera as the focal length is increased and smaller if decreased. Lenses are generally designated as normal, wide-angle and telephoto or long-focus.

The relationship governing the field of view of any non-distorting lens that is attached to a camera was given in section 2.5 earlier. Lenses that are considered "normal" have a focal length approximately equal to the diagonal of the film gate dimension or have a horizontal field of view of about 50 degrees. On 35mm cameras the lens focal length that is considered to have a normal focal length is a 50mm lens.

In addition to fixed focal lengths, lenses are also available in variable focal lengths and they are known as zoom lenses. These offer convenience and economy in terms of having a lens with a variety of focal lengths for a price often not much greater than that of a single focal length lens. On the other hand, zoom lenses may do not achieve the same levels of performance as fixed focal length lenses throughout their range, and typically they are significantly slower. Other shortcomings of zoom lenses are that sometimes they change the effective aperture as the lens is zoomed, they are usually of larger physical size and often exhibit higher levels of flare or non-image forming light.

Manufacturers have to employ the most sophisticated techniques to produce zoom lenses that exhibit high levels of performance including the use of special glasses and precision mechanical components that move the various optical elements in complex movements relative to each other as the focal length is changed. These steps have contributed to the introduction of zoom lenses that compare very favorably with fixed focal length ones.

4.2 Review of shutter designs
Shutters are the devices built into cameras that control the length of time that light will be allowed to act on the film and also determine the degree of blur associated with the image of a subject that was moving while the picture was taken. There are two common shutter designs. The leaf or diaphragm shutter and the focal plane shutter.

The leaf shutter is closely related in design to the aperture adjusting blades or diaphragm built into a lens and it is, in fact, located right next to it. While the lens diaphragm consists of overlapping blades that can be adjusted to leave a variable sized opening or aperture within the lens, the leaf shutter blades are independent blades that operate in unison and can be moved to an overlapping position such that light is completely prevented from passing through to the film.

Although it is not a simple mechanical device, the leaf shutter enjoys popularity in simple fixed lens cameras and in lenses intended for use on cameras not equipped with focal plane shutters (such as studio cameras). Because of the special manner in which this shutter opens and closes, it can accommodate the firing of an electronic flash (or "X" sync) at all speeds. This is of particular advantage when having to use a flash under high levels of ambient illumination.

The focal plane shutter consists of two independently tensioned and released opaque curtains (or stacked blades that in their operation look very much like curtains) that move across the film plane with a time difference equal to the time set on the shutter speed selector dial of the camera. When the time chosen is very short, the distance between the two curtains is less than the length of the film direction along which they are traveling. Thus, one can not fire an electronic flash once such a short time has been chosen because only a partial picture would then be exposed. Thus these cameras have a "X" sync speed indicated on them beyond which electronic flash should not be used.

Otherwise, focal plane shutters can deliver the shortest exposure times and cameras equipped with them allow for easy interchangeability of lenses.

Modern cameras incorporate electronic circuits to time the operation of the shutters focal plane and indeed some leaf shutters and have raised the reliability and accuracy of the shutters to very high levels. Electronic circuits are also built into some cameras for accurately measuring the light level passing through the lens and in some cases falling onto the film while the exposure is actually being made whether by ambient light or by electronic flash. When an adequate exposure is determined by these circuits the exposure is terminated either by closing the shutter and/or extinguishing the flash. Such capabilities have made modern cameras almost foolproof in terms of producing photographs that are properly exposed and that will yield the highest possible quality reproductions.

4.3 Flash synchronization

Photography based on the discharge of a flash of light from short-duration sources, such as an electronic flash, is accomplished by firing the flash at a time appropriate for the
shutter being used. With leaf-type shutters the time at which the flash is ignited depends on the characteristics of the flash. There are two synchronization settings commonly used. The first is the "M" setting. This causes the synchronization contacts to close about 20 milliseconds before the shutter opens to give the flash time to reach peak intensity during the operation of the flash itself. Use of the "M" setting is no longer common since most flash lighting today is provided by flash sources with very fast ignition characteristics and relatively short durations: the "electronic" flash.

The second synchronization scheme, and the one almost exclusively used in cameras today, is that of "X" synchronization. In this scheme the flash contacts close immediately upon the leaf shutter's blades reaching their fully open position or, in the case of focal plane shutter, immediately when the leading curtain has completed its travel across the image gate of the camera. In this case the "delay" is 0 milliseconds.

Normally, electronic flashes can be synchronized with leaf shutters when these are set to any speed. Sometimes, however, the duration of the flash is longer than the exposure time selected on the shutter and this may call for a small adjustment in exposure. This is typically only a factor when the highest shutter speeds are used with leaf shutters in combination with electronic flashes of high power, and consequently of long duration, such as studio flashes.

When focal plane shutters are coupled with electronic flashes, then the exposure time selected must be such that the second, or trailing, curtain does not cut into the image gate before the flash has completely turned off. This results in a minimum exposure time available for use with the flash and is referred to as the camera's "X" sync speed. Since the shutter achieves shorter exposure times by narrowing the separation between the leading and trailing curtain, anytime the distance between them is less than the width of the gate the full frame will not be exposed to the light of the flash and results in partially exposed images.

Proper exposure is determined manually by using Guide Numbers. These are simply a system for simplifying the determination of the exposure required. The Guide Number associated with a given flash depends on the film speed used and the amount of light produced by the flash used under typical conditions:

\[
GN = f\# \times 10
\]

where f# stands for the f number that produces a properly exposed record with a given film speed at a distance between the flash and the subject of 10 feet. Thus, if a flash has a GN of 160 with ASA 100 film and the flash is 10 feet from the subject the required aperture is f/16. At a distance of 20 feet the aperture required is f/8, which is in accordance with the "inverse square law" that states the light falls off inversely with the change in distance squared.

The "inverse square law" only strictly applies to point sources used without any reflectors and when applied to electronic flashes can lead to serious exposure errors. Accurate
exposure when using electronic flashes is best determined with a reliable flash meter or basing it on tests.

Some flashes have built-in light metering circuits that automatically turn off the flash when an appropriate level of exposure has been reached. This capability can be built into the flash or sometimes the flash is controlled by a meter built into the camera itself. This capability of making the meter reading of the light that falls onto the film plane during the exposure itself is called OTF or off-the-film metering.

5. Camera systems - typical systems and their characteristics.

Many different variations exist in terms of the basic light tight box that is used to house the photosensitive material, the shutter and the lens. Each one is best suited to particular applications.

5.1 Miniature or 35mm cameras

These are by far the most popular cameras. They also come in the widest possible range of models and offer the largest variety of accessories and capabilities. The common thread among these cameras is the film format which is actually a size originally designed for use by the motion picture industry. The film is 35 mm wide from edge to edge. The image area is actually only 24 by 36 mm in size, or about twice the size of images made on the same format film by 35 mm motion picture cameras. On either side of the image area about 5mm is devoted to sprocket holes used to advance the film through the camera.

In the popular marketplace the "point-and-shoot" camera is very popular. The level of sophistication of these cameras varies from something not much above that of a simple pinhole camera to complex and sophisticated versions equipped with variable focal length lenses, automatic focusing and exposure capabilities and automatic film advance. Their limitation is generally that they have a viewfinder system that defines the lens' field of view from a slightly different point of view than the actual lens making the picture, and that the lenses are usually not interchangeable.

While the simplest pount-and-shoot cameras have no provision for focusing built in, being simply set to a given distance, some cameras are equipped with automatic focusing devices. These depend on various devices most generally related to standard rangefinding principles. Some autofocusing systems depend on detecting the condition of greatest image contrast.

For the sake of simplicity we will concentrate on the 35mm SLR camera. SLR stands for Single Lens Reflex which means that the viewfinder and focusing mechanism operate through the lens attached to the camera. The image formed by the lens falls on a screen after reflection from a mirror set at 45 degrees to the lens axis. The screen and the film plane are at the same distance from the lens. In this fashion a quasi WYSIWYG (what you see is what you get) condition is set up.
The design of the SLR camera allows for ready interchangeability of lenses since cameras are equipped with focal plane shutters. Focusing is simply a matter of making sure the image on the viewfinder screen is sharp. Proper composition is assured since the SLR viewfinder (unlike viewfinders located to the side of the prime lens and which exhibit parallax) shows the exact same image as will later appear on the film when the picture is made. Focusing can be adjusted manually by examining the image formed on the screen by the lens or, as with the separate optical viewfinder types, done automatically.

Shutters in 35mm cameras can be set to any desired speed manually but in many modern cameras a light meter system is built in which when set to Automatic mode regulates the exposure time and/or the lens aperture to achieve proper exposure. Variations on this metering system allow the photographer to select a given exposure time (possibly to minimize subject motion) while the meter adjusts the aperture automatically - this is called Shutter speed Priority. Or, the photographer may choose a given aperture (to possibly achieve a particular depth of field) and then the meter will automatically adjust the exposure time to maintain proper exposure. This is called Aperture Priority automatic exposure.

The capability for simple interchangeability of lenses allows an operator to easily vary the image size of an object at a fixed distance from the camera or to change the perspective apparent in a finished photograph. Beyond lenses of fixed focal length it is quite common to find cameras with lenses of variable focal length or "zoom" lenses. This same capability allows these cameras to be easily attached to imaging devices such as telescopes or microscopes.

5.2 Medium format or 2 1/4 cameras

While 35mm SLR cameras are of very high quality and versatility indeed the image quality they can deliver is limited by the fact that the image is reproduced on a film area only 24x36mm in size. This means that to get large finished reproductions the film needs to be enlarged a significant amount leading to loss of quality. To overcome this, the 2 1/4 cameras are based on the use of film which is 60 mm wide and onto this film the cameras lay down images varying from 45mm, 60mm, 90mm and 120 or more mm in length. The film is designated as 120 or 220 in size. The 120 film has a paper backing which allows frame numbers printed on this backing to be checked through a window built into the backs of many 2 1/4 cameras. 220 film does not have a paper backing. The spool can thus accomodate a length of film twice as long as when the paper backing is present and therefore the 220 film loads are able to record twice the number of pictures per roll as the 120 size.

Again, the most common type of 2 1/4 camera is the Single Lens Reflex design. Due to the larger film size the cameras are somewhat more bulky than the 35mm models but in terms of number of accessories, metering modes, accessories and choice of lenses, the 2 1/4 cameras are very similar to their 35mm counterparts. Because of the complexity of zoom lens design it is not yet possible to manufacture and sell zoom lenses designed for
the much larger 2 1/4 film format. While automatic exposure systems are fairly common, automatic focusing is also not yet commonly available.

5.3 Large format or 4x5 and larger cameras

Large format cameras typically refer to cameras that are designed to accept film in sheets rather than rolls. The most popular large format camera is the one that accommodates 4x5 inch film sheets. From a mechanical or electronic standpoint, these cameras are possibly the least complex of all formats and approach in simplicity the original "box" camera. In spite of this, large format cameras deliver the most exacting and faithful reproductions due to the large size of the photosensitive material used.

These cameras typically incorporate a rail (essentially a short optical rail) onto which are mounted two carriers. One is designed to hold the lens/shutter assembly and the second carries the film-holder and viewing system. The two are connected with each other by means of a flexible, light-tight, bellows that permits the selection of a large variety of distances between the two carriers.

The lenses are interchangeable and viewing/composition and focusing is accomplished on a groundglass screen. The brightness of the image formed on it by the lens is enhanced by the placement of a fresnel condensing lens below the groundglass.

The lens board or the film carrier can be displaced with respect to each other (while remaining parallel to each other) allowing the photographer to photograph objects located further off-axis than the lens/back combination would allow if they were rigidly fixed in position. Use of the lateral displacement of the front or back standards is called "shifting" the lens or the back. It is a feature particularly useful for architectural situations since it allows photography of elevated subjects while keeping the camera back parallel to a building's facade. This prevents the creation of converging vertical lines which are typically encountered when rigid camera types are used for similar applications.

The lens and film carriers on the camera's "bed" can generally also be adjusted in angle with respect to each other or the "rail" to manipulate the location of the plane of sharp focus of the lens and the shape of the subject's image as reproduced on the groundglass. This is referred to as making tilt and swing adjustments. Making the planes of the lens, subject and film intersect at a common line (the Scheimpflug condition) tilts the plane of sharp focus so that it matches the tilt of the subject plane and thus increases the apparent depth-of-field for the aperture in use. This capability makes the view-camera particularly suited for product photography and preferable in industrial situations over other (smaller format, rigid) cameras where the lens and film planes can not be adjusted.

5.4 Digital cameras

Photographic technology associated with electronic photography is essentially concerned with using an electronic sensor array instead of film. The optical part of the camera is unchanged as well as the need to keep non-image forming light away from the
photosensitive medium during the making of an exposure. The fact that photoelectronic recording methods are becoming prevalent also has meant that shuttering can be accomplished electronically if desired.

The impact of the digital "revolution" is that cameras (point-and-shoot, SLR and medium and large format) are now available with a digital method for capturing and storing images essentially replacing photographic emulsions. The advantages gained by electronic photography systems don't come without drawbacks, one of the least ones being initial expense, which even if very high today promises to drop in the future.

When records are needed fast, the digital camera can deliver images in seconds that then can almost immediately be transmitted to any of a number of locations worldwide for simultaneous distribution. Images, being digital files, can be easily manipulated in a computer. This raises ethical questions. For the researcher, engineer and technician the big advantage is the immediacy of results and the fact that photography can be immediately repeated if not of suitable quality.

The resolution of digital systems, some being cameras in their own right while others are simply accessories that can be attached to existing cameras, is close to that of film (especially in the smaller sizes) and is often of suitable quality for many purposes.

Digital or electronic cameras are available in about as many varieties as standard film-type cameras, whether still of motion picture. At the present time, large format cameras are only available as scanning camera backs which are best used with stationary subjects since they capture the whole image by moving one or more linear arrays of photosensors gradually from one side of the gate to the other. Two-dimaensional array cameras permit instantaneous recording of the whole scene and are thus suitable for imaging objects in motion.

A significant problem associated with digital records is the storage capacity requirement both at the taking stage and the storage stage. Film is an excellent and low cost information storage medium albeit somewhat susceptible to change over time due to environmental conditions. The immediate future, however, will see the two systems coexisting and researchers will be able to decide on the best system for a given application. The future promises development of more hybrid solutions rather than complete elimination of photographic emulsions.


Light meters are devices designed to evaluate the light levels being reflected from the subject (reflected meters) or the light levels falling on a subject (incident light meters). In both cases the general assumption is that the subject has an average reflectance of 18% of the incident light. This reflectance value is considered the visual neutral located between white and a black.
Essentially light meters are photometers and their output is calibrated to read the number of foot-candles or meter-candles being reflected or incident on a scene. These instruments further incorporate a calculator "dial" that then basically solves the exposure equation given in section 3.5 and provide the photographer a series of aperture and shutter speed combinations each potentially capable of making a properly exposed exposure.

Light meters are built into cameras as well as being available as separate, hand-held, instruments. The latter are particularly useful for measuring very low light levels with good linearity while the ones built into cameras are convenient to use and sometimes even measure the light during the process of exposure by "metering" the image-forming light off the film plane as the exposure is taking place. These meters can then accommodate changing illuminance values that may happen during the course of the exposure.

Built-in camera meters often also control the shutter so that when an appropriate amount of light has been collected by the meter's circuit (and thus the film itself) the exposure is automatically terminated.

Separate "spot" meters are invariably of the reflected type and are used to evaluate a subject's luminance range so as to properly place these light values on the characteristic curve of the film being used for a predictable tonal outcome in the final print. This is the principle of the "zone" system of exposure.

7. Light and Color.

Films are generally "panchromatic" meaning they reproduce or react to all color of the spectrum either as tones of grey or as tones bearing not only luminance information but also chromatic information about the subject.

Black-and-white films reproduce subject colors in monochrome. Color negative and color positive films provide for full-color reproductions. Color records are made by making simultaneous red, green and blue records of the subject onto three superimposed black and white emulsions whose sensitivity is more or less restricted to the wavelengths of interest. The red, green and blue records are then transformed into cyan, magenta and yellow dyes. If this "stack" is developed as a positive record of the original then a transparency is produced. A positive shows the subject in its original tonal values. If the film is processed as a negative, where the subject is shown in the opposite tonal and color values of the original scene, then reflection prints (positives) in any desired size are made in a subsequent step by printing onto a similar negative working emulsion but coated on a paper support.

It should be noted that positive paper prints or film transparencies can be produced from both positive transparent film materials as well as negative ones. It is now common practice to scan these film materials with electronic devices, transforming analog density data into digital form, and subsequently adjust or manipulate this data for the photographers purposes. These may include the generation of copy prints or
reproductions that show enhanced detail, color accuracy or which contain other desirable features. Sometimes this process is referred to as Digital Retouching. It is a tool that has great potential for producing high quality reproductions as well as misleading images if used by unscrupulous individuals.

7.1 Filters in B&W photography

It should be stated, however, that while deeply colored filters are not generally used with color films they are often used with black and white films. These films can reproduce a subject of a given color as a light or a dark tone depending on the color of the filter being used over the camera lens. In this manner filters are used to eliminate stains, emphasize particular wavelengths (whether visible or not visually detectable such as in infrared photography) being reflected from the subject, or to increase the contrast between subjects of dissimilar color but similar luminosity.

The principle is that subjects of a given color will be darkened by the placement of filter of the complementary color over the camera lens and lightened by filters of the same color as the subject. To darken blue skies and emphasize clouds against them, a yellow or red filter is used over the lens.

7.2 Filters used in color photography

The use of colored filters with color films generally only results in photographs that acquire the tint of the filter. Generally, therefore, filters are only used for two purposes in conjunction with color films. The first is to eliminate certain wavelengths which would affect the accuracy of color reproduction of color films adversely. These filters eliminate ultraviolet wavelengths and are a pale yellow in color.

Another set of filters is used to alter the spectral energy distribution of light either falling on a subject or reaching a lens in such a manner as to more nearly approximate the spectral quality of the light for which a given film is designed. These are known as color correction or color balancing filters. For example, they allow the use of color films designed for outdoor photography under "cool" daylight illumination to be used with much "warmer" tungsten illumination.

7.3 Polarization filters

Light, in addition to being transmitted, absorbed and reflected from a subject, may also become polarized. Light that becomes polarized by reflection is generally considered to be "glare" light and is particularly bothersome when it appears on otherwise transparent surfaces such as glass or surface finishes thereby obscuring the view of the subject's surface itself. Polarizing filters are used to eliminate this polarized light and thereby improve on the general visibility of subject details hidden by such glare.

It should be pointed out that since many in-camera meters measure light reflected from semi-reflecting mirrors their operation may be adversely affected by the placement of
polarizing filters over the camera lens. This means that linearly polarized light can arrive at a polarizing element within the camera's metering system at various orientations (depending on the orientation of the polarizer on the lens) and thus the meter will give erroneous "readings" of image illuminance.

Cameras equipped with such meters typically require the use of a "circular" polarizer. This does not refer to the shape of the polarizer but to the fact that it is made up of a regular polarizing filter backed up by a quarter-wave plate whose function it is to make the polarized light transmitted by the polarizer become circularly polarized. This essentially removes any specific orientation from the light passing the filter and thus the metering system operates in a satisfactory manner regardless of the orientation of the polarizing filter, which can then perform its function of removing polarized light from the light reaching the filter.

Special Purpose cameras

Beyond standard cameras, scientific and technical photography is often accomplished with highly specialized cameras. In addition to simple records of a scene, high speed events require higher shutter speeds than are normally available on standard cameras, photography in hostile environments calls for cameras ruggedized for such conditions, the motion of subjects over time is sometimes of interest or the desire to record subjects that are too small for the unaided eye to fully appreciate also calls for special camera gear. Cameras are available to deal with most any special scientific purpose.

8. Motion Picture cameras

While standard cameras record the appearance of a subject at a single time, much information can be gained by studying a subject over time. If samples are taken at a sufficiently high frequency and then redisplayed to the viewer at the same frequency, the illusion of motion (and elapsed time) can be perceived from these records.

8.1 Standard motion picture cameras.

Motion picture cameras are available in almost the same variety and based on the same design principles as still cameras however, while still photographs only require the making of a single record of a scene, motion picture photography requires that a large number of photographs be made at a rapid rate. The acquisition of images at a rapid rate and the subsequent replaying of these images at a similar rate enable the subsequent visualization of subject motion in a time frame that matches that of the original event.

The industry standard for image projection systems that include sound is 24 pictures per second. Video, a close relative of the motion picture camera essentially does the same thing but the capture and playback rates are 30 picture per second (or 25, usually depending on the local line frequency).
Standard motion picture cameras acquire photographs at that rate by intermittently placing raw film stock in the camera's gate every 1/24th of a second and while the film is standing still, the camera's shutter exposes it for some time. Typically these cameras couple a rotating disc shutter (with a fixed or adjustable open sector cut into the disc) located just in front of the film plane with the film advance mechanism built into the camera. The exposure time, ET, is a direct function of the size of the opening cut into the shutter and the framing rate as follows:

\[
ET = \frac{\text{shutter opening in degrees}}{360 \text{ degrees} \times \text{framing rate}}
\]

The relationship between the full circle of the rotating shutter disc and the opening cut into it is often referred to as the "shutter factor". If the open sector is 180 degrees, then the shutter factor is 2. Exposure time can also be determined by the reciprocal of the framing rate multiplied by the shutter factor.

This means that at a framing rate of 24 pictures per second and with a shutter opening of (for instance) 180 degrees, the exposure time is 1/48 second. What is more significant, however, is that the film advance mechanism must then move a new piece of film into the gate of the camera also in 1/48th second.

Standard motion picture cameras can move and expose film in such intermittent fashion up to a rate of about 64 pictures per second.

Since the objective in motion picture photography is to essentially duplicate the events that took place in front of the camera, the time factor on playback generally matches the time that an event took place at the time it was recorded. That is, under normal conditions one can say that films have a Time Magnification of "1". Thus Time Magnification is determined by dividing the Image Acquisition Rate by the ultimate Projection Rate and standard motion picture cameras and video cameras acquire images at the same rate as is used later to project them.

8.2 High speed intermittent motion picture cameras

By increasing the acquisition rate to rates higher than the eventual projection rate, time can essentially be "magnified" on playback. If a camera operates at 48 pictures per second and is later replayed at 24 pictures per second, the time on the screen will last twice as long as it took the event originally. To examine at leisure smaller and smaller time periods it is necessary to operate cameras at ever increasing framing rates.

Two reasons that motion picture cameras can not operate at higher framing rates than about 64 pictures per second both relate to mechanical failure. For one, the perforations, or sprocket holes which the film transport mechanism engages to move the film one frame at a time, can not tolerate the acceleration forces involved and tear above a certain rate. Second, when higher framing rates are involved, the film does not achieve the
condition of being completely motionless during the exposure time and this leads to blurred records.

Cameras that can achieve higher framing rates beyond the 64 pictures per second are equipped with advance mechanisms that engage up to from four to eight film perforations at a time and when the film is advanced it is also placed over a set of pins that match the film's perforations before the shutter exposes the film. Thus not only are these cameras intermittent but they are also "pin registered" which means the film is about as motionless as it can get during exposure. Cameras of this type are available that regularly reach recording rates of up to 500 pictures per second. This means the film is moved a distance of one frame in a time of close to 1/1000 second.

The rotating shutter in these cameras can be adjusted to select exposure times as long as 1/1000 second (at the top framing rate) to exposures in the range of 1/25,000 second. In addition, the cameras often have the ability to be synchronized with high-speed repeating stroboscopes for even better action-stopping ability.

At their top framing rates these cameras are able to magnify time by a factor of approximately 20 times. Typical motion picture cameras of this type are the Milliken, the PhotoSonics 1PL and the RedLake Locam.

8.3 Rotating prism cameras

When the framing rate of the intermittent motion picture camera is not high enough, camera designers compromised somewhat with the sharpness of the records obtained and designed cameras in which the film is in constant motion during the filming process. Since the film never comes to a standstill, the image of the subject must be moved at a rate that matches as well as possible the rate at which the film is moving. Then a simple segmenting device allows the moving film to periodically record the appearance of the subject.

The enabling device that accomplishes the above requirement simultaneously is a glass block that rotates and is placed between the lens and the moving film. The image forming rays pass through the rotating block and are deflected so that the image formed by the lens moves approximately at the same rate as the film. As the critical angle between the incoming light rays and the glass block is exceeded the illumination at the film plane decreases (essentially "shuttering" the view) until such time as the next facet of the block starts to transmit the next view of the subject onto the film. More often than not the glass block is also placed in a surrounding, metal, cage that further sharpens the division between one frame and the next.

With interdependent gearing, the glass block and the film maintain a relatively stable relationship to each other as the film is pulled through the camera from a supply spool onto a take-up spool. Cameras are available that accept film loads from 100 to 2,000 feet of 16mm film (4000 to 80,000 frames) and the framing rate is essentially dependent on
the rate at which the film can be moved through the camera. Special circuitry is available in some models to reach and keep desired framing rate as constant as possible.

Ultimately, accurate timing can only be accomplished by the fact that timing lights, flashing at known time intervals (generally 100 or 1000 flashes per second) are incorporated into the cameras and these leave a periodic mark on the edge of the film. If the time between marks is known then the number of frames between marks is an indicator of what the camera's framing rate was at the time the timing marks were impressed on the film.

Framing rates up to about 10,000 full frame 16mm film images per second can be reached for relatively long times. At such framing rates the time magnification ability of these cameras is about 400 times.

When even higher framing rates are desired these cameras can be equipped with prisms containing a larger number of facets and this allows doubling or quadrupling the full frame capability of the camera by making the height of the individual frames 1/2 or 1/4 their full frame dimension.

Refinements of this basic concept of glass-block motion compensation include cameras where the compensating device is a multifaceted mirror ground onto the same shaft that advances the film through the camera. Cameras of this general type include the Fastax, Hycam, Nova, PhotoSonics 1b, etc.

8.4 Rotating drum and prism cameras

Again, physical limitation put a ceiling on the rate at which film can be transported through a camera and when still higher framing rates are needed than those reached by the rotating prism cameras, then cameras that reach higher speed but at an additional compromise on image sharpness are available.

In these cameras the image forming rays are deflected by a rotating multifaceted mirror driven by a rotating drum that also holds the film during exposure. The mirror turns at a particular rate set by the camera design parameters but it is just right so that the image moves close to the same rate as the film, located along the inside periphery of a rotating drum, moves. The motion-inducing rotating mirror also deflects the image of a "stop", through which the image forming rays pass, across a physical replica of the stop and because the stop's image is moved more rapidly the subject's image the shuttering of such a camera is quite remarkable in terms of duration.

Cameras like this only hold enough film for about 200 separate full-frame 16mm pictures but can achieve recording rates of up to about 35,000 pictures per second at exposure time of less than a microsecond. Such a relationship obviously means that the camera is out of film in less than 1/100 second when running at full speed but the framing rate is uniform along the film.
Unlike most other cameras, drum-type cameras generally do not need any sort of synchronization scheme between the camera and the event as long as the event is self-luminous. They are "always alert". This is a result of the camera running the same film past the image gate over and over at the desired framing rate. The drum is simply brought up to the desired speed. When an event happens it gets recorded by the film. One only needs to close a shutter before the drum has made a complete turn to prevent multiple exposures.

Although their framing rate, and thus time magnification capability, is high the images captured by these cameras can generally not be conveniently viewed with a projector. They are, instead, viewed as a series of still images or are "animated" by duplication onto standard motion picture stock. Cameras of this type include the Dynafax by the Cordin Corporation.

8.5 Rotating mirror framing cameras

When even higher framing rates are desired a further compromise is typically made in terms of the total number of images acquired. For photography at rates of millions per second, the film is actually held still and the image of the subject is moved to successive positions by means of a rotating mirror. The primary image collected by the camera's objective is brought to a focus and then imaged on the surface of a rotating mirror surrounded by an array of lenslets which in turn reimage the subject's image formed in the mirror onto film which is held in an arc at the appropriate distance from each lenslet.

Since each lens can only "see" the image of the subject reflected by the rotating mirror when the mirror is lined up at a particular angle, as the mirror rotates each lens records the view of the subject at a slightly different time than the other ones. The time between lenslets recording their respective images is a function of how fast the main, rotating, mirror can be made to turn. With rotation rates on thousands of revolutions per second, framing rates of millions of pictures per second are possible, albeit for only a few microseconds duration or only a dozen to a few dozen frames. Again, framing rate with these cameras can be increased by making the frames small when measure in the direction of mirror rotation.

To prevent multiple exposures, that would be caused by the main mirror making more than one revolution, a variety of capping shutter are employed both before event initiation (in case of a non-self-luminous event) and post-event. These include mirrors or glass windows that are explosively shattered as well as surfaces explosively coated with various materials. Timing and synchronization are significant problems when using these cameras.

8.6 Image dissection cameras

When even higher framing rates are desired it is possible to employ cameras that sacrifice spatial resolution for temporal resolution by using the same piece of film to store information about the appearance of the subject at more than one time. This solution to
high speed recording depends on the fact that it is possible to demonstrate that one can often make do with images of low spatial resolution and still have enough information to deduce various subject behavior parameters.

By placing a grid consisting of a fine opaque/clear lines in front of a piece of film, and assuming the clear lines to be 1/10 the size of the opaque ones, it can be readily understood that if a picture is made through the grid only 1/10 the film's surface area. If the grid lines are small enough a fairly good representation of most subjects can be achieved with only 1/10 the total image content information possible.

Then, by moving the grid a distance equal to the width of the opaque grid it is possible to record additional records of a subject. It the subject is in motion the as the grid moves the image information will occupy different locations with respect to the film.

Once the film is processed, placing the real grid on the film registering it with the location of the grid when the picture was made, movement of the grid along across the grid lines presents the viewer with essentially a brief "motion picture" of the subject's action during the time the grid moved while the "sequence" of pictures was being made. Cameras of this type are quite rare but are able to achieve very high framing rates at relatively low cost.

8.7 Electrostatic image tube cameras

An alternative to high speed rotating mirror framing cameras and image dissection cameras is the high speed framing electrostatic camera based on the use of an image tube, sometimes equipped with an auxiliary micro-channel plate image intensifier. A camera of this kind is the Hadland Imacon.

In these cameras, capable of making images with a time separation of the order of a few nanoseconds, images are electrostatically shuttered and moved to various locations eventually recorded on a sheet of film (often Polaroid sheet film) such that eight to ten images appear on a single sheet. This means that while the framing rate of these cameras is the fastest among all high speed cameras, the number of records is among the fewest. At the highest framing rates cameras like this only make sequences lasting tens of nanoseconds.

9. High speed video and CCD systems

The high speed industry was to a large extent stagnant in terms of new developments in instrumentation until recent developments in electronic imaging detectors and integrated systems made significant inroads into a field long dominated by film-based cameras.

Early high speed video cameras were no match for the workhorse of the high speed industry: the rotating prism high speed camera. This situation changed dramatically with the introduction of the Eastman Kodak Ektapro system which is capable of capturing and storing 1,000 full frame video images per second with a sensor made up of 192x240
pixels. At first novel tape transport methods allowed the system to store images on videotape. While the system captures Black and White images at a significantly lower resolution than film the immediate availability of the data and the fact that the equipment does not required a highly skilled operator made it a highly desirable imaging tool in the manufacturing industry.

A newer version of the system, the EM, stores several thousand full frame images in RAM digital memory. This enables the camera to achieve something that the high speed industry has sought to accomplish since the advent of photography. This is the recording of random events at a high recording rate and the visualization of a subject's state just prior to, as well as during and after, catastrophic failure.

This is accomplished by erasing the oldest images recorded into RAM memory while continually adding new images to the "image stack" loaded into the camera. By monitoring the event the camera made to stop recording at some suitable time after a random event happens and the stored images are then played back from a time prior to the initiation of the event or failure.

Advances continue to be made in the area of solid-state imaging and high recording rates at brief exposure times are currently achieved in a similar fashion. Often microchannel image intensifiers are used to boost the light sensitivity of these high speed imaging systems.


Although there is no hard and fast definition for what a panoramic photograph is it is commonly accepted that the photographs generally encompass and angle of view not achievable by standard cameras. Recently panoramic cameras have also been classified by the fact that their width to length aspect ratio is large, regardless of the actual angle of view of the camera.

10.1 Fixed lens panoramic cameras.

Panoramic photographs can be made by overlapping exposures made by rotating the camera (best when done around the front nodal point of the lens) and assembling the individuals prints into a continuous whole by carefully matching up the details on the edge of one print with those on the opposite edge of the next print. Recent developments in this area enable electronic imaging programs to assemble a series of photographs by electronically "stitching" one image to the next one.

Fixed lens panoramic cameras base their claim to being panoramic by virtue of the aspect ratio of the film format they use. They may or may not be equipped with wide angle lenses although most are. Typically the cameras use 120 size (about 60mm wide) roll film. The length of the negatives varies from 9cm to 17cm. These cameras are essential nothing more than regular cameras that have been fitted with the means for making pictures that exhibit a large aspect ratio of something up to about 1:3.5 or so.
10.1 Rotating lens panoramic cameras

When angles of view in excess of 100 degrees are desired, there is a class of panoramic camera that is capable of covering up to about 140-150 degrees in one direction while covering about 40 degrees in the other (for an aspect ratio of about 1:4. They accomplish this by compromising on the instantaneous exposure capability of standard cameras. They scan the object scene with a slit located near the film plane, which is curved around the axis of rotation of the lens. The lens, rotating around its rear nodal point produces an image of the scene that remains stationary with respect to the film even while the lens is sequentially oriented towards different directions. Since the image plane produced by the lens is quite flat, one need to restrict the area of the image that falls onto the curved film plane at any given time. This is done by adding a funnel shaped "horn" behind the lens that gradually sweeps the image of the surrounding onto the film.

Due to the scanning nature of the exposure the image may be distorted if the camera is moved during the relatively long time it takes the lens to swivel from one side of the scene to the other. If the camera is not help level the horizon line will appear curved in the final record. Furthermore, since the image distance is the same throughout the scanning action of the lens, parallel lines extending along the scan direction of the lens will exhibit "panoramic distortion", meaning that equal sized objects in a plane in front of the camera such that this plane would be parallel to the film plane of a standard flat film type camera, then those objects farther from the lens will appear smaller than those objects directly in front of the camera.

Panoramic "distortion" can be corrected to a large extent at the viewing stage by displaying the image on a curved surface and placing the viewer's eyes at the center of curvature of the print surface.

11. Streak and Strip cameras

The imaging scheme used in cameras of standard design is that the film remains stationary with respect to film gate the at the time of exposure. A significant number of specialized applications employ cameras in which the film is in motion at the time of exposure. In their simplest manifestation film is simply moved past a stationary slit and the exposure itself takes place during the transit of the film across this opening.

Unlike normal cameras that make photographs that have two spatial dimensions, these "strip or streak" cameras always display time as one of their dimensions and one subject spatial dimension as their other dimension.

When cameras of this type are used to make records of subjects whose images don't move across the shutter-slit they are basically simple time-recording instruments. When images move along the slit then the photographic record can be reduced to image velocity or acceleration.
Cameras that employ this scheme for making photographs but whose output resemble the subjects they are photographing rely on moving the image of the subject at the same rate as the film moves past the stationary, slit, shutter.

11.1 Streak Cameras

In its simplest form, the camera system described above basically behaves as a light-based strip chart recorder where a physical pen is substituted by many light "pens" operating along the open slit-shutter of the camera while the moving film is the recording medium. As such, the instrument is capable of making precise measurements of event duration, simultaneity, velocity, acceleration, frequency, etc.

The time resolution of the camera is first a function of the rate at which the film can be moved past the slit and secondarily on the width of the shutter-slit itself. When the upper limits to film transport methods are reached, the image of the slit can be quickly wiped across stationary film. Rotating mirror streak (or velocity recording) cameras have been made with time resolutions of better than 1 cm per microsecond and slit sizes as small as 1/10 of a millimeter and less.

Electrostatic streak cameras are also available in which an image line is deflected electrostatically across the face of an image tube for time resolutions that enable researchers to determine the duration of events in the picosecond time realm.

11.2 Strip Cameras

When it is desired to make records of a scene so that it resembles its appearance to the eye, the image of a subject can be made to move across the slit-shutter of the streak camera, instantly converting it into a strip camera. Images can be made to move across the slit of the camera by several methods. The easiest by far is to simply have the subject move in linear fashion across the field of view of the lens.

11.3 Photofinish cameras and Synchroballistic cameras

One of the major problems in photography at racetracks is the determination of the order of finish of participants in a race. Many years ago this was attempted by using high speed motion picture cameras. The invariable problem was that important finishes happened between frames and that film costs became considerable.

The strip camera is the perfect solution to the photofinish photography problem since one of the film's dimension, that in which the film moves, it the dimension of time itself. Photofinish cameras are simply aligned so that the slit in the camera lines up with the wire or poles across the track and then, a few seconds before the racers arrive to the finish area, is set in motion at the estimated speed of the image of the horses at the film plane.

Electronic strip cameras are currently being installed at many racetracks. They are "linear" array cameras where a single row of CCD sensors doubles for the slit of the film-
type strip camera. The results are similar to what was traditionally achieved but the darkroom is no longer needed and several linear array cameras can be installed along the track for basically instantaneous readings on the elapsed time for any given racer between the start and the arrival at a given location as well as obtaining accurate, almost real time, time-between-racers information even as the race is developing.

The same camera design, but with film moving at a higher rate of speed, can be used to photograph subjects moving at such high rates of speed that, in order to perceive detail in them sharply, they would normally require exposure times so short that most shutters are not capable of achieving them. By "synchronizing" the rate of motion of the film with that of the rate at which the image of the moving subject (typically a missile) moves the image is essentially motionless on the film and a sharp record can thus be secured. The rate of image motion can be determined by multiplying the expected subject velocity by the magnification of the camera optical system.

11.4 Rotating Panoramic Cameras

When angles of view in excess of 150 degrees are required, then a different version of the panoramic camera is used. In this design the camera itself rotates. Since this induces image motion at the film plane, the film is moved by any one of several schemes, at the same rate as the image appears to move at the image plane. This is often restricted to a narrow "slot", sometimes of variable width to allow some measure of control over exposure time. Angles of view up to 360 degrees are possible with such a system. The photographs exhibit panoramic distortion just as the swing-lens types do and due to the sequential nature of the exposure subjects that are moving at the time they are "scanned" by the sweeping camera will be distorted in relationship to their normal appearance.

11.5 Peripheral cameras

When records of the exterior or interior surface of (generally) cylindrical objects is required, the panoramic camera referred to in section 2 above can be held stationary and a rotating stage is placed in front of the camera such that its shutter slit is aimed at the center of rotation of the turntable. If the subject of interest is now placed on the turntable, various aspects of its surface will appear sequentially on the slit. The moving film now records those changing features and, over time, a complete 360 degree record of the subject's surface is recorded on the film.

Since the film can only accommodate one particular subject diameter (in terms of image velocity at the shutter slit) at a time, any diameters that are not the same as that for which the film velocity is adjusted will be either stretched or compressed compared to their normal dimensions. With perfectly cylindrical subjects perfect reproduction is possible.

Interior surfaces can also be reproduced by arranging a series of mirrors to look at the interior surface of a cylinder.

12. Underwater cameras.
The technology of photography has found particular application when it is desired to visualize phenomena in hostile environments, such as underwater. Recent advances in camera design make photographing underwater about as effortless, at least from a technical point of view, as it is above water.

When the subject can be isolated and placed in a controlled environment, such as in a tank, standard cameras can be used to photograph through suitable windows. When the photography must take place in uncontrolled situations, then the photographer will most likely be equipped with scuba gear and a standard camera system will be installed in a watertight housing or the photographic equipment itself will be watertight. A large number of manufacturers provide equipment suitable for very basic underwater photography through camera systems such as those made by Nikon and Sea and Sea which equal in performance and sophistication those of the very finest above-water cameras.

Nevertheless, it should be noted that the quality of color reproduction of subjects is affected by the spectral absorbance characteristics of water.

Beyond depths reachable by humans remotely controlled equipment is also available to photograph to the greatest depths of the ocean.

**Additional Photographic Techniques**

**13. Time Lapse for events of extended duration**

In high speed motion picture photography small time periods are magnified to extend over relatively long times, giving the human brain a chance to visualize events that are essentially invisible because they happen so quickly that the brain does not have a chance to reconstruct the event in detail. A similar situation occurs if the event happens over a long period of time.

In this case motion picture cameras (or standard cameras for that matter) can make a record at a rate much lower than the playback rate, thus compressing time and again making the projected series of images present a the event in a time frame that the human brain can more easily relate to.

Time-lapse is the general term that describes this approach to motion picture photography. The cameras often are quite standard in terms of general features but they are equipped with an intervalometer that trips the shutter and advances the film. The time between exposures can be determined by taking any one of a number of approaches:

\[
\text{Time Between Exposures} = \frac{\text{Time Magnification}}{\text{projection rate}} = \frac{\text{Real Event Time}}{\text{On-Screen Event Time}} = \frac{\text{Event Time}}{\text{Total Number of On-Screen Frames}} \text{ and others.}
\]
Major problems occur with light sources (the sun for example) changing the illumination level and lighting direction throughout a scene. Elaborate settings are constructed to contain the event in a controlled environment. Stationary standard lighting is provided either by tungsten lamps turning on for the brief moment during which the exposure takes place or electronic flash is synchronized with the camera's shutter.

In very sophisticated time-lapse installations the camera itself is sometimes moved, the lens zoomed, the lighting position or color quality is gradually changed, etc.. These are all actions that are written into a script and usually programmed into a computer. The planned script is then automatically carried out without human intervention.

Much significant time-lapse work, however, is still carried out by painstaking manual operation of cameras and lights and control of the environment.

14. High Speed flash photography.

The exposure time necessary to limit blur in a subject moving at a particular rate can be estimated from the following relationship:

\[
ET = \frac{\text{Maximum Allowable Blur}}{K \times \text{Rate of Subject Motion} \times \cos A}
\]

where

- \( K \) is a "quality" constant equal to 2-4
- \( A \) is the angle between the subject's direction of motion and the film plane.

The Maximum Allowable Blur is often taken as a percentage of subject size, typically something like 10% of subject size. This means that one must accurately predict what the smallest part of a given subject one desires detail in for this then becomes the real subject of the photograph and 10% of which will be assigned the "maximum allowable blur" factor in the above equation.

When the action stopping ability of a mechanical shutter is not sufficient to achieve blur-free images, short duration flash illumination sources are usually used to achieve desired results. The lighting units are referred to as electronic flashes and their duration ranges from milliseconds to less than a microsecond.

An electronic flash is a device that stores electrical energy in capacitors over an extended period of time and then discharges it in a brief period of time through a tube most often filled with Xenon or by a simple discharge over an air gap.

Electronic flashes are described by their watt-second rating, their lighting efficiency and also by their duration. The watt-second rating is arrived at simply by taking into consideration the operating voltage of the circuit and the capacitance of the main capacitors.
Raising the voltage is a very efficient way of increasing the power level because it is a factor that raises the power quadratically while capacitance increases raise the power linearly.

A simple watt-second rating of electronic flashes does not completely account for the photographic efficiency of a given flash since it does not take into account the reflector that typically surrounds a flash tube. A better comparison of the photographic effectiveness of electronic flashes is a comparison based on their Beam Candle Power Seconds (BCPS) rating or their effective guide numbers when used with the same film under similar conditions.

The duration of a given flash unit can be approximately determined by taking into account the resistance of the circuit while the discharge is taking place plus the capacitance of the main capacitors.

\[
\text{Duration (seconds)} = \frac{\text{Capacitance (Farads)} \times \text{Resistance (ohms)}}{\sqrt{2}}
\]

Since it is impractical to raise the voltage beyond certain safe-to-handle limits further gains in power must be achieved by increasing capacitance. On the other hand, since it is not possible to drop circuit resistance below certain limits, achieving short exposure times must be done by dropping the capacitance of the main capacitors. Thus high power and short duration can not be achieved simultaneously and are a matter of compromise in any given flash design.

The illumination efficiency of any given flash can be affected by the gas used in the discharge tube and also the reflector associated with the lamp. Therefore it is possible to encounter two flash units with the same watt/second rating but one be more efficient in terms of providing useful light on the subject than another simply by the differences in reflector efficiency.

Electronic flashes tubes can be disconnected with suitable solid state switches from the power capacitors so that only a fraction of the power available in the capacitors is used at any given time. This increases the life of batteries used to power portable units and also shortens the duration of a given flash discharge while also providing less light. When action stopping capability is required the fractional power settings of many common flash units provide an effective means to achieve relatively short durations suitable for many high speed applications.

15. Stroboscopic Photography.
An often neglected form of motion analysis is the application of stroboscopes to the study and visualization of high speed events. If these events are repetitive in nature, then a stroboscope often is a low cost instrument that enables the researcher to gather significant data without having to make permanent records of the subject at all. And if records are needed, the instruments can also be used for that purpose in a variety of ways.

A stroboscope can be either mechanical or electronic. The latter is usually used for event visualization but there is a lot to be said for the mechanical variety as well. While the mechanical stroboscope is generally nothing more than a rotating disc with one or more "slots" cut into the disc at regular intervals, the electronic stroboscope is nothing more than a short duration electronic flash that has a very fast recycling time allowing it to be triggered at variable and calibrated time intervals.

When the time period of a repeatable event is the same as that of the time between light flashes of the stroboscope the event seems to appear motionless if the ambient light level is low in comparison to the light produced by the flash. Since in such a case our eyes can only see by the light of the flash, and the flash of light (usually lasting only microseconds) happens when the subject is in the same position, the illusion that is given is that the event is stationary. The event could, however, make more than one cycle between light flash periods. To determine the frequency of any cyclic event all that is needed are two consecutive frequency "readings" (made off the stroboscope's frequency dial) where the event appears to be standing still. The event frequency (FE) can then be found from:

\[
EF = \frac{\text{Frequency 1} \times \text{Frequency 2}}{\text{Difference between Frequency 1 and Frequency 2}}
\]

Photographs that can give insight into the motion characteristics of a moving subject can be recorded onto a frame of film by having the subject, illuminated by the flashing stroboscope, perform its motion against a dark background while the shutter of the camera is open for a brief period of time. Those parts of the subject that are in different locations at the time of each light flash are recorded on different locations on the film. By knowing the frequency of the strobe and (by incorporating a scale in the scene) the distance a subject moved, the average rate of motion from one point to another can be relatively easily determined.

Unfortunately, stationary parts of a subject overexpose the film in their locations. Also, if a subject parts return to a previous location it may be difficult to determine the actual sequence of the images recorded by the film. To deal with this eventuality stroboscopes are sometimes coupled with cameras that are simply shutterless film transport mechanisms. They are either transport film from a supply roll onto a take-up spool or are cameras equipped to carry film either on the inside or outside surface of a rotating drum.

In these cases, with each flash of light from the stroboscope not only is the subject in a new location but there is (mostly) unexposed film available to record the image associated with each flash. Since there is a period of darkness between flashes,
sometimes the subject has attached to it a continuously glowing lamp to enable the researcher to easily track subject position over time.

**Basic Flow Visualization Techniques**

Photography is widely used to visualize phenomena that are invisible to the eye by virtue of the fact that they hardly alter the environment from a visual point of view. Such events are associated with density gradients formed in liquids or gases as a result of non-homogeneous mixing or the by-product of local heating, cooling or compression of gases. To visualize these gradients several basic techniques are used.

16. **Shadowgraph method**

The shadowgraph is nothing more than the result of interposing a subject containing density gradients between a small (sometimes referred to as a "point") light source and a screen (often plain photographic film or paper). The gradients present in the subject cause light rays to fall in different locations than they would if the disturbing medium were not present and therefore the effect of the gradients on the light distribution on the screen can be then associated with the gradients themselves.

If a plain screen is used a standard camera can be at the screen from the front or, if the screen is translucent, from the rear. High reflectivity (3M's Scotchlite (R)) materials allow the visualization of shadowgraphs in daylight conditions.

When photographic materials are used as the screen, the system is set up under laboratory conditions in a darkened room and the lamp is placed in a shuttered enclosure or a flash is used as the source. Advantages of this simple system are its ability to deal with large subjects, and the low cost. A disadvantage is its relatively low sensitivity.

17. **Schlieren methods**

When a higher level of sensitivity is desired optical elements are incorporated into the shadowgraph system (thus practically limiting the size of the subjects that can be photographed) and deviations in the path of light rays caused by density gradients (or departures from surface flatness in reflective systems) cause these deviated rays to interact with various physical obstacles (knife edges) emphasizing the appearance of these gradients compared to their appearance in a shadowgraph system.

17.1 single pass systems

In a popular layout, a small light source is placed at the focal point of an astronomical-quality spherical or parabolic mirror (lenses can also be used but the system costs go up dramatically). The light emerges from the mirror in a parallel beam intercepted some distance away by another similar mirror. It collects the light rays from the first one and brings them to a focus at its focal point where a real image of the light source is formed.
The light then continues into a camera where the image of the second mirror's surface appears to be filled with light. Introducing a "knife edge" into the image of the source causes an overall drop in the light level of the mirror's surface. When the image of the source is moved by refractive index gradients in the space between the source and its image, local variations in light level appear in the image of the second mirror's surface.

Photography is almost secondary to the process although just about every industrial Schlieren system is designed with a camera of some sort incorporated in the system.

17.2 Double pass Schlieren systems.

When the sensitivity of the above design is not sufficient, light can be made to pass through the density gradients twice and thus the sensitivity is increased. This is commonly accomplished by using a single mirror and placing the camera and the source close to each other at both located approximately two focal lengths from the mirror's surface. In this fashion, again, a life-sized image of the source is formed just in front of the camera lens.

The light from the source again proceeds into the camera lens where it contributes to making the mirror's surface appear to be fully luminous. Intercepting some of the light rays at the image of the source leads to an overall, uniform, darkening of the image of the mirror's surface (as if the source itself had been reduced in.

If the knife-edge remains fixed in position and, instead, the image of the light source is moved (by density gradients) then those areas in the image of the mirror's surface made up of light rays that moved away from the knife edge will appear brighter and those made up of rays that moved towards the edge will appear darker than the brightness level associated with a steady-state condition.

Replacing the opaque, solid, knife edge with transparent, colored, filters opens up the possibility of introducing color into the images although color systems, while visually more appealing, are often of lower sensitivity than black-and-white systems and do not generally yield additional data.

17.3 Focusing schlieren.

An interesting schlieren scheme that overcomes the relatively high cost and complexity of mirror systems, while not loosing much in terms of sensitivity to them is the focusing schlieren system. This system is particularly well suited for dealing with windows (in wind tunnels for example) of relatively low quality and has the advantage of being highly sensitive to the location of the gradients in the scene, unlike mirror systems which are influenced by the effect on light rays over the entire distance from source to knife edge.

A basic focusing schlieren system consists of a grid of opaque and transparent lines placed in front of a broad light source. A camera lens, although focused at some distance between the it and the grid (where the subject will be located) nevertheless forms an
image of the grid located some distance on the opposite side of the lens. The image of this grid will be distorted to some extent and may be rather badly distorted if low quality windows are placed between the grid and the lens. Whatever the quality of the image is, a reproduction (negative) of it is made onto high contrast film.

After processing, the photographic negative is then replaced in the same exact position that it had when the image of the (distorted) grid was made. The consequence is that the negative image of the grid prevents any light rays from proceeding onto the camera's groundglass and the field is completely (or mostly) dark.

The subject giving rise to, or containing, the refractive index gradients is now placed between the grid and the camera lens. Since it is closer to the lens than the grid an image of it is formed beyond the distance at which the image of the grid was brought to a focus.

As disturbances in the path of light rays are now induced at the subject location, these will cause some of the light rays making up the image of the grid to move relative to the obstructing negative and those areas on the groundglass will gain brightness, again identifying a subject with non-homogeneous refractive index distribution. If direction changes are caused in locations outside the plane of sharp focus of the lens they tend to move the image of the grid over a much larger area and thus they simply slightly degrade the overall contrast of the image but can not be identified with a particular location.

17.4 Reflection Schlieren System

Generally only transmission schlieren systems are used but a significant tool for determining surface flatness of reflecting or semi-reflecting surfaces can also be investigated with a reflection schlieren system.

In this scheme the light source and camera lens are again next to each other but located one focal length from a "field" lens. Since the source is at the focal point of the lens a parallel beam of light emerges from it. If this falls on a flat surface and is reflected directly back to the lens, then an image of the source is formed again at the focal point of the lens. Since the lens and source can't generally made to occupy the same location they are each slightly off-axis.

If the surface is not flat then it changes the direction that the light rays are reflected from the surface. When these changes are at right angles to the orientation of the knife-edge this causes variations in light intensity at the image of the lens' surface. The change in direction can be caused by either the surface not being flat or by refractive index gradients being present in the space between source and image. One attempts to isolate the changes to a known location, generally as close to the flat mirror as possible.

Surface qualities of multiple surfaces can be visualized by offsetting slightly the angle of tilt of each individual surface. Each will produce an image of the source and thus multiple knife edges are used.
18. Close-up photography.

It is often desired to make records of objects at a large scale of magnification, where the record equals or even surpasses the size of the original subject. Under these conditions special problems arise for the photographer.

The term photomacrography is applied to the making of records where images are about 1/10 the size of the subject and extend to a magnification of about 20x or so. Optical magnification or scale of reproduction (m) is simply determined by:

\[
\text{Magnification (m)} = \frac{\text{Image size (on negative unless otherwise stated)}}{\text{Object size}}
\]

18.1 Auxiliary lenses

By far the simplest method for making macrophotographs involves the use of simple supplementary lenses attached to the front of a given camera's lens. These generally are available in strengths of 1, 2 and 4 diopters, meaning their focal lengths are 1, .5 or .25 meters. If such a lens is added to a camera's lens focused at infinity, the supplementary lens will cause light rays from a subject placed at its focal point to exit towards the camera lens as a parallel beam and thus the image in the camera will be sharply focused.

Actually the focal length of the camera lens is altered by the addition of the supplementary lens but for photography the important thing is that cameras can be made to focus relatively easily on close-up subjects by simply placing a lens with a focal length equal to the required distance over the normal camera lens.

18.2 Lens Extension Method

Another method for making macrophotographs is to simply extend the distance between the lens and the camera body. With interchangeable lens cameras this is generally done by placing either rigid extension tubes or a variable length "bellows attachment" between the lens and the body while with large format cameras the bellows is simply extended to allow the camera to focus at ever closer distances.

Once the magnification starts to exceed about 1/10x the increase in lens to film distance starts to influence the amount of light reaching the film for a given f number. That is, when a lens is focused at infinity an aperture of f:8 produces a particular light level at the image plane. As the image distance increases, the light level drops due to the fact the lens is farther from the image plane while the lens opening remains the same. A compensation in exposure needs to be made. Thus adjustment can be made either with the lens aperture control or the exposure time. To determine the factor by which exposure needs to be increased one simply need to determine the distance the lens is moved away from the
image plane with respect to its distance when imaging objects at infinity. Then the Exposure Increase Factor or EIF is equal to:

\[
EIF = \frac{\left(focal\ length + additional\ extension\right)}{2} \times \frac{2}{\left(focal\ length\right)}
\]

For example, when a lens is moved from the infinity position so that life-sized images are produced at the film plane, then an additional distance equal to the focal length of the lens needs to be introduced between body and lens. In the case a 50 mm focal length lens is used, the extension would also be 50 mm and the sum of 50 + 50 would be 100 which squared is 10,000. The focal length of 50 squared is 2500. Divided into 10,000 the exposure factor is 4. This stands for two "stops" or an increase of two aperture stops (eg: f:16 to f:8) or a quadrupling of the exposure time that would be used had the lens not been extended.

Another approach, based on magnification \(m\) is:

\[
EIF = \left(1+m\right)^2
\]

Some improvements in performance can be obtained by reversing a lens so that the longer conjugate is facing the front of the lens. This often disables any coupling between camera body and lens and features such as automatic aperture stop-down prior to exposure may become inoperative.

Special "macro" lenses with extended focusing mounts are available. These allow continuous focusing to about 1/5 life size at which time an extension tube is added which then takes the focusing capability of the lens helicoid down to life size. Also, short focus, highly corrected barrel mounted macro-lenses are available for mounting onto bellows units for magnifications from life size to 20 times life size or more.

18.3 Effective f-number

The f number of a lens is used (along with the exposure time) to determine proper exposure under given lighting conditions. Since f numbers are computed based on the focal length of the lens rather than image distance, f numbers can only be relied upon only when object distances are relatively large compare to the lens focal length. Sometimes the term "relative" f number is used when referring to the f number determined based on the focal length of the lens.

Since in photomacrography the image distance is significantly larger than the focal length, an "effective" f number needs to be determined and used for exposure determination purposes. There are many ways to determine it but maybe the simplest one is based on the f number selected on the lens and the magnification \(m\) of the image as follows:
f (effective) = f (m+1)

When the photograph is made at life-size, or 1:1, magnification the effective f number is double the f number set on the lens.

18.1 Sharpness in depth

As in the case of pictorial photography, a lens only strictly brings one subject plane to a sharp focus on the film surface. Planes in front and behind those on which the lens is focused will appear slightly out-of-focus and fuzzy. This is due to the increase in size of the circle of confusion as the image is increasingly defocused. Determination of the region of acceptable sharness in depth over the subject can be determined in a variety of ways but in the realm of photomacrography, the following relationship is often most useful:

\[
\text{Depth of field} = \frac{2 \times c \times f (m+1)}{2m}
\]

Where

- \( f \) = f number selected on the lens
- \( c \) = diameter of acceptable circle of confusion on negative
- \( m \) = magnification of image

While the above formula can be used to predict the total depth of field, it gives no indication of its distribution over the subject. When operating at life size or 1:1 magnification the depth of field is exactly the same in front as behind the object plane focused upon and at magnifications less than unity the depth is slightly larger behind the subject.

This relationship indicates that greater depth of field can be achieved by using a smaller initial magnification and enlarging the negative when printing. However, the limitations of the negative material become more obvious when magnified and so the increase in depth of field based on this approach is often quite modest.


Increasingly, all kinds of imaging instruments are being designed with image capture capabilities, such as a camera, built-in. Nowhere is this more prevalent than in astronomical "photography" where telescopes are almost never used for visual observation but rather the images captured or displayed by cameras are recorded and studied at leisure.

Similarly, in the field of microscopy, most research grade microscopes are available with photographic capabilities built-in. However, one can simply place a regular camera, or a video camera or digital still camera, over the eyepiece of a microscope and make rudimentary records. Another approach is to remove the lens from the camera body and
project either the primary image formed by the microscope's objective onto the film or
the secondary image projected by the eyepiece.

Whether the camera is added to the microscope or built-in, one of the most important
steps to ensuring high quality results is how the lighting is set-up. The most common
lighting method is Koehler lighting. In this scheme the light source filaments are imaged
at the diaphragm of the microscope's condenser which, in turn focuses the light source
condenser onto the subject plane. It's image size is adjusted until it just fills the aperture
of the objective lens.

Cameras equipped with automatic exposure control are easiest to use since external light
meters can not be used. Some compensation may be necessary due to unusual subject
tonalities. If a subject is very light or transparent and does not exhibit a uniform
distribution of tones slight overexposure may be called for. This is best achieved by
simply "downrating" the film speed by some amount. If a subject is supposed to be quite
dark, then the opposite step may be necessary. Finally, the light quality should match the
spectral quality for which the film is designed.

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