Camera Basics

A camera is a device used to form images on film. Light from the object being imaged is allowed to enter the camera through a hole and expose the film for a certain length of time. The diameter of the hole is called the *aperture* (D); its value depends on the lens being used to focus light onto the film. The exposure time (t) is controlled by a shutter in the camera; the *shutter speed* of the camera is the time during which the shutter is open.

The amount of light required for a correct exposure is determined by the brightness of the object being imaged and the type of film used (see below). To control the amount of light reaching the film from the object, the photographer sets the aperture and the shutter speed to an appropriate combination. The settings for these controls are more or less standardized.

Shutter speed settings are fairly straightforward; typical choices are shown, along with the corresponding exposure times. This range may be extended or truncated in some cameras. Note the approximate ratio of 2 between adjacent settings.

The 'B' setting means that the shutter will remain open as long as the shutter button is held down. This allows for long time exposures.

Setting	Exposure time
1000	1/1000 s
500	1/500 s
250	1/250 s
125	1/125 s
60	1/60 s
30	1/30 s
15	1/15 s
8	1/8 s
4	1/4 s
2	1/2 s
1	1 s
B	(variable)

Aperture settings are somewhat more mysterious. They involve the aperture (D) and the focal length (f) of the lens -- the distance required for the lens to bring parallel rays to a focus. These two properties are often combined in a parameter called the *photographic speed* (or the *f-ratio* or the *f-number*) which is the ratio f/D. This dimensionless ratio has no special symbol in general use; for this discussion, let the f-number = # = f/D. Note that as # *increases*, the aperture of a lens of a given focal length *decreases* (D = f/#).

Camera lenses are specified by their focal length (f) and by their *maximum* aperture, except that the aperture is written as f/#. A 50 mm f/2 lens has a focal length of 50 mm, an f-number of 2, and a maximum aperture of 50/2 = 25 mm. This aperture can be 'stopped down' to reduce the amount of light by changing the aperture setting. These settings are labeled by the f-number (#) and are often called f-stops. Typical f-stops are shown, along with actual apertures for a 50mm lens. Note the approximate ratio of √2 between adjacent settings.

f-stop (#)	aperture (D)	D for f=50mm
1.4	f/1.4	35.7
2	f/2	25.0
2.8	f/2.8	17.9
4	f/4	12.5
5.6	f/5.6	8.9
8	f/8	6.2
11	f/11	4.5
16	f/16	3.1
22	f/22	2.3

The role of the focal length of a lens is -- as in a telescope -- to determine the magnification. Lenses with longer focal lengths produce greater magnification, with larger images and smaller fields of view; short focal lengths yield lower magnification, smaller images, and wider fields of view. Because enlarged images spread light over a greater area, increasing the focal length will normally increase the required exposure time.

The amount of light needed to create a proper exposure also depends on the film speed. Film speeds are rated by the ISO (formerly ASA) number; a higher ISO means a faster film -- meaning a faster shutter speed and/or a smaller aperture can be used to achieve the same exposure. Films typically available include ISO values of 25, 64, 100, 200, 400, 800, 1600, etc. 400-speed film is twice as fast as 200-speed film and four times as fast as 100-speed film. Fast films are generally preferable for low-light situations.

Obtaining a proper exposure becomes a matter of determining the correct exposure time (t) to use for a given focal length (f), aperture (D), and film speed (ISO). Faster film (higher ISO) reduces the exposure time; larger aperture (higher D) decreases the exposure time; and for most photographic objects, higher magnification (longer f) increases the exposure time. This relation can be expressed in the following equation:

1. $t = (C1)\,(f/D)^2 / ISO$ [where the constant C1 is determined by a proper exposure, which has values indicated by the subscript (o): $C1 = (t_o)\,(ISO_o) / (f_o/D_o)^2$]

Both f and D are squared in this equation because the light needed to form an image is proportional to the area of the image, and the light passing through the aperture is proportional to the area of the aperture. Increasing f increases the magnification, and because both dimensions of the image are magnified, the area of the image increases as the square of f. Also, because the area of a circle is $\pi D^2/4$, the light passing through the circular aperture increases as D^2.

Now note that because f/D = #, we can rewrite equation 1 as follows:

1a. $t = (C1)\,(\#)^2 / ISO$ (for extended objects, sky brightness) [$C1 = (t_o)\,(ISO_o) / (\#_o)^2$]

This form of the equation is useful for camera settings, which use the f-number to specify the aperture. For example, if a good exposure of the moon (an extended object) is obtained using ISO 400 film and 1/125 second at f/11, any of the following combinations (and many others) should work. The 'constant' (C1) in equation 1a is also shown.

ISO	D = f/#	t	C1
400	f/16	1/60	0.02604
400	f/8	1/250	0.02500
200	f/11	1/60	0.02755
200	f/4	1/500	0.02500
100	f/11	1/30	0.02755
100	f/5.6	1/125	0.02551

Most astrophotography is done at night, when the sky is relatively dark. However, ambient light may increase the sky brightness significantly, causing the sky to appear noticeably bright in the photograph. In some types of astrophotography, sky brightness can easily provide an upper limit on the exposure time. For these cases, equation 1a can be used to determine limiting exposures.

Equation 1a is good for extended objects but not for point objects, such as stars. Because points cannot be magnified, light from a star will *not* be spread out more as the focal length is increased. Thus, the focal length of the lens has no effect on the proper exposure time. For point objects, equation 1 is modified by simply removing the dependence on f, yielding equation 2:

2. $t = (C2) / [(D)^2\,(ISO)]$ (for point objects) [$C2 = (t_o)\,(ISO_o)\,(D_o)^2$]

As can be seen, the brightness of a star image depends only on the film speed, the exposure time, and the aperture of the lens or telescope used to form the image. (A 'good' exposure of a star is generally one in which the star image is sufficiently bright to be measured; overexposure of star images is generally not a concern.)

Alternatively, equation 2 can be rewritten with the substitution D = f/# producing equation 2a:

2a. $t = (C2)\ (\# / f)^2 / ISO$ (for point objects) $[C2 = (t_o)\ (ISO_o)\ (f_o/\#_o)^2]$

In each case above, the constant is evaluated using the settings for a good exposure. In practice, it is often more convenient to simply use ratios as shown:

3. (from 1a.) $t = t_o\ (\# / \#_o)^2\ (ISO_o / ISO)$ for extended objects, sky brightness

4. (from 2.) $t = t_o\ (D_o / D)^2\ (ISO_o / ISO)$ for point objects or

5. (from 2a.) $t = t_o\ (\# / \#_o)^2\ (f_o / f)^2\ (ISO_o / ISO)$ for point objects

This ratio format can easily be employed to create equations to answer other questions about astrophotography:

Star trails: How long will the trails be?

The length of a star trail depends on three factors:

a) How long was the exposure? Longer exposures produce longer star trails.
b) How much magnification was used? Higher magnification makes the star trails appear longer; magnification is proportional to the focal length of the lens being used.
c) Which star is making the trail? Stars closer to the celestial poles move in smaller circles about the poles and thus make shorter trails in any time interval. Stars with declinations closer to 0° will make longer trails.

For a particular star, the declination is constant and thus factor (c) can be ignored. Then if an exposure t_o with a lens of focal length f_o gives a star trail of length x_o, the length of the trail of the same star for a different exposure t and a different focal length f will be given by equation 6:

6. $x = x_o\ (t / t_o)\ (f / f_o)$

Deep sky photography: How large will the image be?

When photographing faint celestial objects through a telescope, normally a long exposure is used. As the telescope tracks the object across the sky, the light builds up to make the image brighter. Because the telescope is tracking on the object, there will be no trail formed. The size of the image will depend only on the angular size of the object and on the magnification being used.

For a particular object, if a telescope of focal length f_o produces an image of diameter x_o, then a telescope of focal length f will produce an image of diameter x given by equation 7:

7. $x = x_o\ (f / f_o)$