

Principles of Photographic Exposure

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Introduction

A camera works by focusing light rays through a lens onto a piece of plastic film substrate coated with an emulsion made of light-sensitive chemicals or silvers. In the case of a digital camera, the film is replaced with an electronic device called a CCD chip.

Photographic film is manufactured in varying degrees of sensitivity. Film that is intended for use in sunlight, for example, is not usually sensitive enough for pictures taken under indoor lighting.

Two mechanisms in the camera control how much light falls onto the film. There is an aperture, a device very much like the iris of the human eye, which opens or closes to allow more or less light to pass through to the film. Photographers call the aperture setting the "f/stop." The higher the f/stop number, the smaller the aperture and the less light admitted.

There is also a shutter, with a timer to control how long it remains open. The longer the shutter is open, the more light falls on the film. Photographers state shutter speeds in fractions of a second, such as 1/250.

Manipulating these mechanisms to produce meaningful photographs is called exposure. This document will attempt to explain these basic principles in a logical manner, without using complicated mathematics or jargon.

Elements of Exposure

Each of the three ways of controlling exposure (film sensitivity, f/stop, shutter speed) has its own side effects. It is up to the photographer to decide which is most important. For instance, very sensitive film is usually unable to record fine-grain details. Opening the aperture limits how much of the image will be in focus. Very large or very small apertures may also degrade the sharpness of the image, depending on the optical quality of the lens. Using a slow shutter speed may blur the photograph if the subject or camera moves during the exposure.

Camera Controls

The two basic camera controls for exposure are aperture and shutter speed. Both exposure controls run through a sequence of settings, which involve doubling and halving the amount of light reaching the film.

Aperture – As previously mentioned, the aperture works like the iris of the human eye, and can be opened or closed to adjust the amount of light allowed through the lens. The control unit is called an f/stop. Simply put, an f/stop is a way of quantifying the size of the opening of the aperture. The following series represents the standard sequence of f/stops from f/1.4 to f/22:

1.4 2.0 2.8 4 5.6 8 11 16 22

Although it doesn't seem intuitive at first, in this sequence the f/1.4 setting lets in the most light, while the f/22 setting lets in the least. Each of these f/stops has the effect of halving or doubling the amount of light allowed through the lens. In other words, moving from f/2.0 to f/2.8 halves the amount of light that comes through the lens.

The f-number itself is fraction representing the effective number of times the aperture diameter will divide into the lens focal length. For example, an f4 aperture diameter is 1/4 the focal length (i.e. 25mm aperture diameter in a 100mm focal length lens, or a 12.5mm aperture diameter in a 50mm lens). Each marked aperture is referred to as a “stop,” and since aperture stops are measured as a fraction of the focal length, these stops are called f/stops.

The “Sweet Spot” – Due to various physical factors and design compromises, most lenses will display some image degradation at very large and very small apertures. The lens will be at its sharpest somewhere near the middle of its aperture range. So, if a lens has an aperture range of f/2.8-f/22, the “sweet spot” will be around f/8-f/11.

Shutter Speed – Shutter speeds are a bit easier to understand. Shutter speeds are measured in seconds and fractions of a second and so the doubling and halving is self-evident. One quarter second is half as long as one-half second but is twice as long as one-eighth. One second is twice as long as half a second and half as long as 2 seconds. It's pretty easy, and this works through the whole sequence of shutter speeds. On most 35mm SLR cameras, for instance, the shutter speed sequence is:

2 1 1/2 1/4 1/8 1/15 1/30 1/60 1/125 1/250 1/500 1/1000

Stops and “Stopping Down” – The word “stops” has more meaning than just f/stops, and this can be a source of some confusion. The term is used in every aspect of photography to represent a relative change in the brightness of light. Just think of it as handy “shorthand” for other doubling/halving relationships when referring to exposure.

“Stopping down” is another term for selecting a smaller aperture and therefore less light. Going from f/8 to f/11 is stopping down. While “stopping down” usually refers to changing the aperture, changing your shutter speed from 1/125 to 1/250 has the same effect on the exposure.

ISO Film Speed

Film speed refers to the sensitivity of the film to light. In the past, this film speed rating was referred to as its ASA film speed. ASA stands for American Standards Association. In other parts of the world, the film speed was rated as a DIN number. In recent times, the ASA and DIN numbers have been phased out in favor of ISO ratings. ISO stands for the International Standards Organization. When the film ratings were converted, the ISO adopted the ASA rating scheme.

As we've seen with apertures and shutter speeds, the relationship between each “stop” on the control ring or dial doubles or halves the amount of light allowed to reach the film. Film speeds do the same thing, with regard to the sensitivity of the film. The lower the number, the less sensitive the film is to light.

The doubling goes like this in the common range of film speeds:

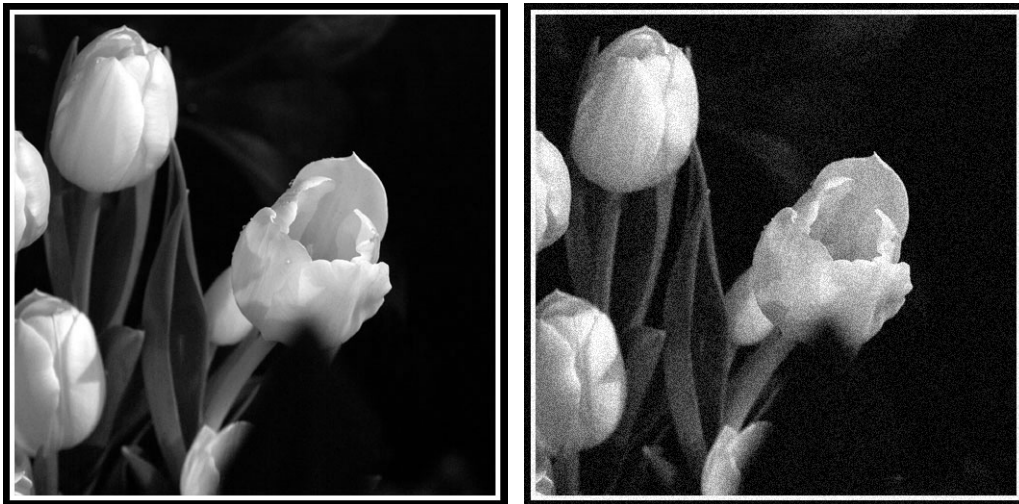
25 50 100 200 400 800

Each step here is a doubling/halving of the film's sensitivity to light. Thus, an ISO 100 film requires twice as much light to be correctly exposed as an ISO 200 film but

only half as much as an ISO 50 film. You would say it was a stop slower than the ISO 200, a stop faster than the ISO 50.

Choosing an Appropriate Film Speed – Generally speaking, the lighting conditions will suggest the best film speed to use in a given photographic situation. If you'll be shooting in low light, say, indoors without a flash, choose a higher ISO film (400, 800 or higher). If you'll be shooting outdoors in bright sun, or in a studio with lots of light, a lower film speed is appropriate.

Be aware that there is a trade-off for high film speeds. In order to make more sensitive film (higher ISO), the particles of chemicals or silvers in the emulsion must be physically larger. The result, at its extremes, can be a grainy photograph. If you require very fine grain for extreme enlargements, it is better to use a slower film.



These two images show the effect of grain in a photograph. The picture on the left represents the results of using a fine-grained, slow speed film. The picture on the right represents the results of using a high-speed film.

Film Speed and digital cameras – In a digital camera, an electronic device called a CCD replaces the film. The sensitivity of the electronics in a digital camera can be varied to make the CCD more or less sensitive to light. In electronic terms, this is called gain. Digital camera manufacturers have calibrated the gain settings to react similarly to film. Most digital cameras offer at least three ISO settings – 100, 200 and 400. More advanced models offer a wider range of effective ISO settings.

As with film, increasing the sensitivity of the CCD has the disadvantage of decreasing the image quality by introducing digital “noise.” This noise is a by-product of increasing the gain, and can sometimes resemble film grain. Other times, it's just ugly. Again, if you are planning to make large prints from your digital files, select a lower ISO setting.

1/3-Stops

So far, we've only discussed the “standard” series of f/stops, shutter speeds and film speeds. We've said that each full stop either doubles or halves the amount of light that reaches the film during exposure, or, in the case of film speed, doubles or halves the sensitivity of the film. While this method of exposure control is very good, there is still some margin of error.

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For many years, film has been available in film speeds that fall outside of the “standard” series of ISO ratings. One of the most famous films of all time, Kodak’s Kodachrome, has an ISO rating of 64. This is 1/3 stop more sensitive than an ISO 50 film. Other common film speeds include ISO 32, ISO 125 and ISO 160. So, an expanded, 1/3-stop listing of film speeds would look something like this:

25 32 40 **50** 64 80 **100** 125 160 **200** 250 320 **400** 500 640 **800**

It is important to note that the same relationship exists between the film speeds on “the thirds.” A film with an ISO rating of 64 is twice as sensitive to light as an ISO 32 film, and half as sensitive as an ISO 125 film, for example.

As the exposure systems in cameras have become more sophisticated, 1/3-stop increments have been added to the aperture and shutter speed series, affording much more precise control of exposure.

Our expanded aperture scale looks like this:

1.4 1.6 1.8 **2.0** 2.2 2.5 **2.8** 3.2 3.5 **4.0** 4.5 5.0 **5.6**
6.3 7.1 **8.0** 8.7 9.8 **11** 12.7 14.3 **16** 17.5 19.6 **22**

Each 1/3-stop down reduces the amount of light by approximately 20%.

In a 1/3-stop system, our shutter speed series looks like this:

2s 1.6s 1.3s **1s** 0.8s 0.6s **1/2** 0.4s 1/3 **1/4** 1/5 1/6 **1/8** 1/10 1/13 **1/15**
1/20 1/25 **1/30** 1/40 1/50 **1/60** 1/80 1/100 **1/125** 1/160 1/200 **1/250**
1/320 1/400 **1/500** 1/640 1/800 **1/1000**

Each 1/3-stop down reduces the amount of light by approximately 20%.

It is interesting to note that many old cameras have a slightly different shutter speed range than modern cameras do. These shutter speeds are typically 1/3-stop slower than modern cameras.

Important Relationships

We’ve already seen how apertures relate to each other, and that the same relationship exists between shutter speeds and ISO film speeds. It follows that aperture, shutter speed and ISO film speed should interact in a logical manner.

Aperture and Shutter Speed – The first relationship pair we’ve already covered, but not directly. We know that the shutter speeds and f/stops both double and halve the amount of light reaching the film. Thus, we know that we can open up an f/stop (letting in twice the light) and move the shutter speed one step faster (cutting the time in half) and have the same amount of light on the film.

For example, if we meter a scene and find that 1/125th at f/8 is the correct exposure, it holds that any of the following combinations would also work:

Shutter Speed	1/15	1/30	1/60	1/125	1/250	1/500	1/1000
f/stop	f/22	f/16	f/11	f/8	f/5.6	f/4	f/2.8

Why would we care about this relationship? Why not just set the camera for 1/125 and f/8 and take the picture, and be happy knowing that our exposure should be correct for the scene?

Aperture and shutter speed affect more than just the exposure.

Aperture and Depth-of-Field – To this point, we've only discussed aperture in the way it relates to the amount of light allowed through the lens. Aperture affects another important photographic element, called depth-of-field.

A photograph is a two-dimensional representation of our three-dimensional world. In other words, a photograph has height and width. The real world also has depth. In high-school geometry, we referred to these dimensions as X (width, left to right), Y (height, bottom to top) and Z (depth, front to back). Depth-of-field refers to the amount of the third dimension, or "Z" that appears in focus in the photograph.

Higher f/stops increase the depth-of-field, and lower f/stops decrease the depth-of-field, thus controlling how much of the photograph is in focus. This effect can be useful for creating visual separation between a subject and the background, effectively isolating and emphasizing a single element.



A very large aperture was used to create a very limited depth of field in this photograph. Notice that the depth of field is shallow enough that even the petals of the flower are not sharp in the background.

In portraiture, for example, it is very common to limit the depth-of-field, making the subject's face the dominant element in the photograph. In landscape photography, on the other hand, it is generally preferable to make as much of the scene as possible appear in focus to convey a sense of space and scale.



In these two photographs of the same scene, you can see the effects of different apertures. The image on the left was made at f/2.0, while the image on the right was made at f/22. Notice that in the image on the left, only the girl is in focus.

Shutter Speed and Motion – Shutter speed also affects more than just the amount of light entering the camera. A photograph captures a relatively brief moment in time. By varying the shutter speed, we can control just how long “brief” is.

Higher shutter speeds have the effect of stopping motion, while lower shutter speed will allow a fast moving subject to blur. This effect is particularly evident when the subject is moving across the frame.

Blurring can be used to very effectively communicate the apparent speed of a subject. For instance, selecting a slow shutter speed (1/8 second, for instance), and panning with a moving subject such as a speeding car, can cause the car to be very sharply focused, while the background and other elements in the photograph are blurred.



In this photograph of a local performer, a very slow shutter speed was necessary. The picture was made by opening the shutter and panning the camera to follow the performer as she moved across the stage.

Another example of using a slow shutter speed to display a subject in motion is to photograph a waterfall using an extremely low shutter speed, say ½ second or slower. For this to work effectively, you must use a tripod or other suitable camera support. You may also need to use a slow-speed film or a neutral-density filter.



These two images illustrate the effects of shutter speed on motion. The image on the left was made with a relatively fast shutter speed, while the one on the right was made at a very slow shutter speed.

Film Speed and Exposure – We’ve seen that the ISO rating of a film is an indicator of its sensitivity to light, and, that the relationship between film speeds is exactly the same as the relationship between shutter speeds and apertures. Let’s look back at our hypothetical exposure of f/8 and 1/125. This time, we’ll assume that the original exposure reading was with ISO 100 film.

In our first example, we see how using a different film speed affects the aperture setting:

Film Speed	25	50	100	200	400	800
Shutter Speed	1/125	1/125	1/125	1/125	1/125	1/125
f/stop	f/4	f/5.6	f/8	f/11	f/16	f/22

Leaving the shutter speed at 1/125, we can see that as we increase our film ISO rating by one stop, we close the aperture down by one stop. For each stop we decrease the film ISO rating, we must open the aperture by one stop. So, for a given level of light, a higher film ISO rating will allow us to gain greater depth of field.

In our second example, we see how using a different film speed affects the shutter speed:

Film Speed	25	50	100	200	400	800
Shutter Speed	1/30	1/60	1/125	1/250	1/500	1/1000
f/stop	f/8	f/8	f/8	f/8	f/8	f/8

This time, we’ll leave the aperture at f/8. In this case, as we increase our film ISO rating by one stop, we must move to the next higher shutter speed. Decreasing our film ISO rating one stop decreases our shutter speed by one stop. So, a film with a higher ISO rating will allow us to use higher shutter speeds to reduce motion. We call films with a high ISO rating, such as ISO 400, a “high-speed film” because it allows us to use higher shutter speeds.

In practice, when using a film camera, we can’t adjust film speed from one frame to the next. Except under very special circumstances, once a roll of film is loaded into the camera, the entire roll should be exposed using one ISO rating. Generally speaking, this is the ISO rating indicated by the manufacturer. Most modern cameras will set this automatically when the film is loaded.

Digital cameras, on the other hand, can use a different ISO rating for each picture, if desired. In fact, most digital cameras now have an ISO AUTO setting, which will adjust the ISO rating as needed. As mentioned previously, the higher ISO ratings on a digital camera will introduce noise, so it is advisable to manually set the ISO, if possible.

Camera Exposure Modes

Many modern cameras incorporate several exposure modes, with more or less of the exposure controlled by the camera’s on-board computers. It should be noted that the on-board computers and exposure meters in modern cameras are incredibly sophisticated, and usually set just the right exposure to get the correct amount of light to the film or CCD sensor, allowing the photographer to concentrate on the aesthetics of composition when creating an image. However, exposure control can

be an important aesthetic element in a photograph, so it's important to know what the camera's computer is doing when using the various exposure modes.

Following is a brief synopsis of the exposure modes found on many modern cameras.

Manual – With manual exposure control, it is up to the photographer to select the correct aperture and shutter speed, using a light meter or other method of calculating the correct exposure. This allows complete control of both shutter speed and aperture.

Aperture Priority – Aperture Priority is an automatic exposure mode, which allows the photographer to set the aperture while the camera calculates the correct shutter speed. This allows the photographer to control depth-of-field without worrying about shutter speed. Of course, it is important to monitor the shutter speed in this mode, to be sure that the shutter speed is not too slow to hold steadily.

Shutter Priority – Shutter Priority is an automatic exposure mode in which the photographer sets desired shutter speed to control appearance of motion. The camera then sets appropriate aperture based on conditions and film speed.

Program – In Program Mode, the camera sets both aperture and shutter speed based on conditions and film speed.

On most cameras with this mode, the photographer may utilize “program shift” to “weight” the resulting exposure settings to control depth-of-field or control appearance of motion. This is usually accomplished by turning a control dial, which causes the camera to step through the various pairs of apertures and shutter speeds chosen as correct for the lighting conditions. In this manner, the photographer can quickly choose the correct settings for the desired result.

Some cameras will allow program mode to vary the weight of the shutter speed based on the focal length of the lens – with longer focal length lenses, the camera will use a higher shutter speed. (Nikon calls this “Dual Program”)

Some cameras will allow program mode to always try to choose a higher shutter speed. (Nikon calls this “Program High”)

Program AE – Program AE is sometimes referred to as “point-n-shoot” mode. Here, the camera sets both aperture and shutter speed based on conditions and film speed. The photographer cannot override camera exposure settings in this exposure mode.

“Creative Modes”

In addition to the exposure modes listed above, some “consumer-oriented” cameras include several “creative exposure modes.” These programs are designed to do a good job with exposure (and other) camera settings in specific circumstances. Usually, the photographer cannot override the settings provided by these exposure modes.

Portrait – This is a special Program AE mode designed to give a good result when shooting portraits. Portrait mode is optimized to create sharp images of the subject with a soft background. Most portraits look best at a medium-telephoto setting. Use “fill flash” with strong direct sunlight or backlight to reduce harsh shadows.

Sports – Sports is a special Program AE mode designed to give a good result when shooting sporting events or other fast-moving subjects. The camera uses the fastest possible shutter speed to stop motion and an auto-focus camera will continually adjust focus to track the subject. The use of high-speed film is recommended.

Landscape – Landscape mode is designed to give a good result when shooting landscapes. It is optimized to create sharp landscape photographs, while maintaining a shutter speed fast enough to prevent blurring from camera shake. For best results zoom to a wide-angle setting or use a wide-angle lens. Include a foreground subject or detail to create a feeling of depth in the picture. It is generally advisable to use a tripod when shooting landscapes.

Night Portrait – This special Program AE mode is designed for photographs of people in low-light conditions, especially when it is desirable to see the background scene as well. The camera generally balances the ambient light exposure with electronic flash exposure (either using a built-in or external flash) so the background appears in the image. The use of fast film is recommended. Use a tripod to reduce camera shake. The shutter will stay open longer than usual to expose the background properly.

Close-up – Close-up, or Macro, is a special Program AE mode designed for macro photography. The camera selects the optimum aperture and shutter speed combination to photograph small objects at very short distances. For best results use a macro lens or a macro capable zoom lens. The use of a tripod is recommended.

Other Methods of Determining Exposure

The most common method of determining exposure is to use the light meter and associated electronics that are built into the camera. However, there are several other excellent methods. While an in-depth discussion of these methods is outside the scope of this discussion, we'll quickly address some of the more common.

The “Sunny-Sixteen” Rule – One of the oldest and simplest rules for determining exposure doesn't involve using any equipment at all. The “Sunny-Sixteen” rule is especially suited to landscapes, but works well with almost any subject for a quick exposure setting.

Simply put, Sunny-Sixteen states that, on a sunny day, your exposure should be the reciprocal of the ISO film speed at f/16. So, if you have ISO 100 film loaded in your camera, the exposure should be 1/100 at f/16. Since many cameras don't have 1/100 as a selectable shutter speed, you could choose the closest available, which would be 1/125. The image would be only slightly (1/3-stop) under exposed.

Hand-held Light Meter – Hand-held light meters come in several forms – reflected, incident, spot and combinations thereof. A hand-held light meter can be used to take exposure readings, instead of the built-in meter. As with anything in photography, there are pros and cons to this approach.

Inexpensive hand-held meters can only measure reflected light from the entire scene. Often, this is a fine method of measuring light. However, some situations require more precise measurements. For these situations, a spot or incident meter is

preferable. Spot meters measure only a small portion of the scene, while incident meters measure the light falling on the subject, rather than the light reflected from it.

Many hand-held meters have the advantage of displaying the appropriate shutter speed/aperture combinations on a dial or display, allowing the photographer to easily choose the desired pair at a glance. However, most hand-held meters cannot account for the light lost to any filters applied to the camera lens.

Zone-system – The zone system for black-and-white photography is a method of thinking as much as a light metering method that states, in general, that a light meter assumes that your subject is a medium gray. The meter will likely improperly expose a subject that is equally reflective to an object that is a medium gray color. Using the zone system, you analyze nine different reflective levels to determine your exposure.

The basic rule is to expose for the shadows, and print for the highlights. This is all well and good, if you have plenty of time to analyze the scene and make the appropriate calculations. Many modern cameras have built-in expose meters that are capable of doing this work for you, using a multi-segment metering mode.

Bracketing Exposure – While this is not really a method of determining exposure, it is a method that will help to ensure that you have the best choice of exposures available when you print your picture. Many professional photographers will shoot a series of the same picture, but at slightly different exposures. Usually, a photographer will make three exposures. The first exposure is the “correct” exposure, according to the meter. The second exposure is 1 stop over the correct exposure (slightly over exposed) and the third is 1 stop under the correct exposure (slightly under exposed). Many modern cameras can accomplish this task automatically, in either full stops or 1/3-stops.

More Information

The Internet contains many web sites dedicated to photography and exposure. Some particularly interesting links are listed below:

<http://www.photonhead.com/beginners> - The Beginner's Guide to Photography. This site covers many topics, and includes several interactive features, including a program called SimCam that will show the effects of various apertures on depth-of-field.

<http://www.silverlight.co.uk/tutorials/toc.html> - Silverlight is a British site that covers a wide range of photographic topics. Their tutorials are complete, and easily understandable.

<http://www.fredparker.com/ultexp1.htm> - Fred Parker's excellent article on what he calls the ultimate exposure computer and how to use it. He also gives an excellent explanation of exposure control, including the math involved.

<http://rob.novak.net/content/archives/Individual/000335.php> - Rob Novak offers another way to look at the mathematics involved in calculating standard apertures.

<http://photospot2004.blogspot.com/2004/07/f-number-demystified.html> - Saanga at Photospot explains the mathematics involved in calculating 1/3-stop apertures.

<http://www.artsmia.org/get-the-picture/abbott/depth4.html> - An excellent depth-of-field simulator. Simply click on the f/number to see the result.

QUIZ

1. An aperture and shutter combination of $f/11$ at $1/125$ th of a second will produce the same exposure, using the same film speed, as which of the following?
 - A. ____ $f/8$ at $1/60$ th
 - B. ____ $f/8$ at $1/250$ th
 - C. ____ $f/16$ at $1/30$ th
 - D. ____ $f/5.6$ at $1/250$ th
2. If a combination of $f/16$ at $1/30$ th of a second yields the correct exposure, what effect will be seen by increasing the aperture to $f/8$?
 - A. ____ Underexposure
 - B. ____ Overexposure
 - C. ____ Nothing
 - D. ____ Reduced film speed
3. My light meter tells me I need an aperture of $f/11$ using 400 ASA film. If I am actually using 100 ASA film what aperture should I set?
 - A. ____ $f/16$
 - B. ____ $f/22$
 - C. ____ $f/8$
 - D. ____ $f/5.6$
4. If I change my shutter speed from $1/250$ th of a second to $1/60$ th of a second how much more light will reach the film?
 - A. ____ Half as much
 - B. ____ Twice as much
 - C. ____ Four times as much
 - D. ____ Three times as much
5. What is the difference, in stops, between $f/4$ at $1/60$ th of a second and $f/16$ at $1/60$ th of a second?
 - A. ____ 2 stops
 - B. ____ 4 stops
 - C. ____ 6 stops
 - D. ____ 8 stops
6. What is the difference, in stops, between $f/4$ at $1/60$ th of a second and $f/8$ at $1/30$ th of a second?
 - A. ____ 1 stop
 - B. ____ 2 stops
 - C. ____ 3 stops
 - D. ____ 4 stops
7. A film with a speed of 400 ASA is:
 - A. ____ Twice as sensitive as 800 ASA film
 - B. ____ Half as sensitive as 200 ASA film
 - C. ____ Twice as sensitive as 200 ASA film
 - D. ____ Twice as sensitive as 100 ASA film

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8. If I wanted to give my film 2 stops more exposure I could do which of the following?
- A. ____ Increase the size of the aperture (smaller f-number)
 - B. ____ Reduce the size of the aperture (larger f-number)
 - C. ____ Increase the shutter speed (faster)
 - D. ____ Any of the above
9. A setting of f/8 at 1/125th of a second using 100 ASA film would be equivalent to which of the following?
- A. ____ f/11 at 1/125th of a second using 200 ASA film
 - B. ____ f/4 at 1/500th of a second using 100 ASA film
 - C. ____ f/11 at 1/30th of a second using 50 ASA film.
 - D. ____ None of the above
10. Which is the faster lens?
- A. ____ 50 mm f/2.8
 - B. ____ 300mm f/2.8
 - C. ____ 90mm f/2
 - D. ____ 50mm f/1.4

Answers: 1. B 2. B 3. D 4. C 5. B 6. A 7. C 8. A 9. C 10. D