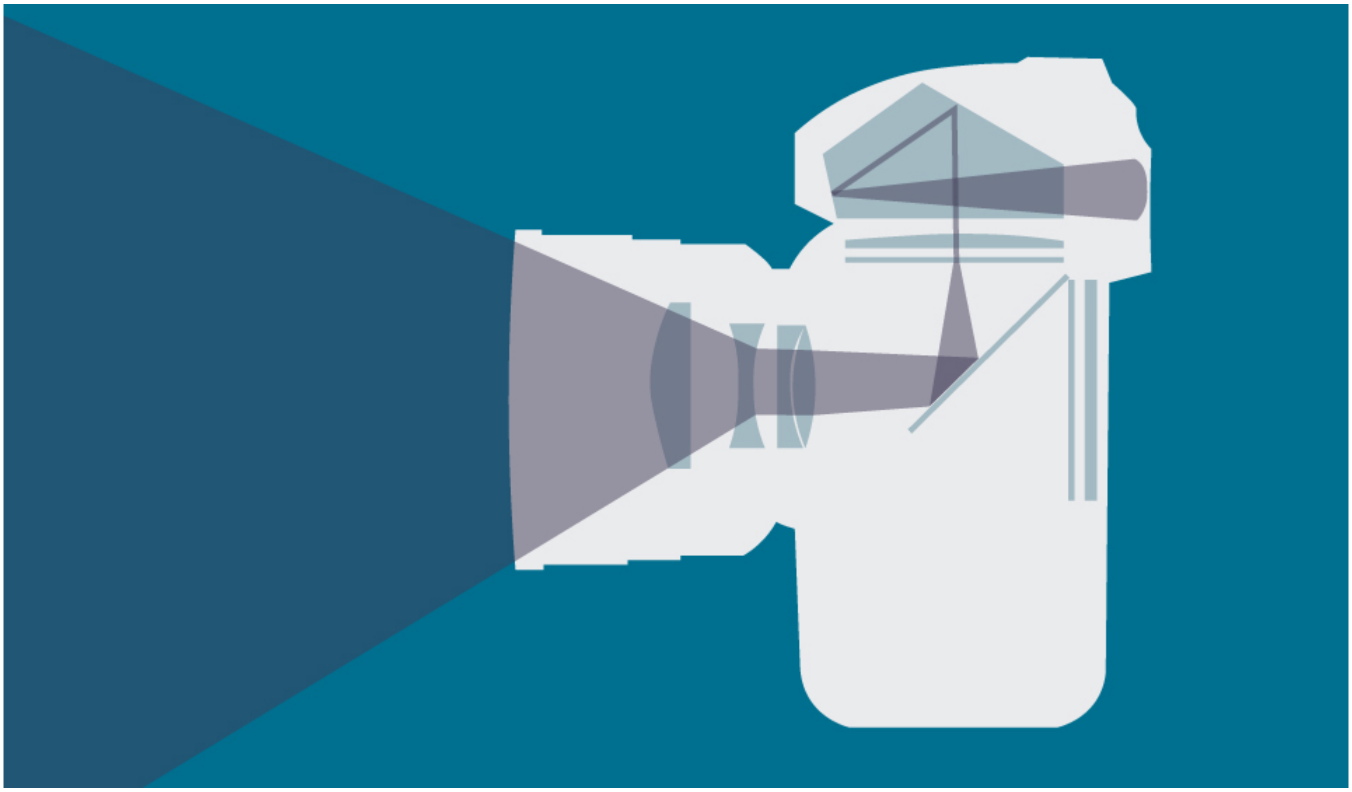
# How Your Digital Camera Works

By Todd Vorenkamp |



Have you ever wondered what is going on inside that picture-taking box that you just held up to your eye, or out at arm's length, to capture a photograph?

**The Basics**

The camera is, in its most simplified terms, a box that allows light to enter and strike a light-sensitive surface. This surface is either a frame of film or a digital sensor. Cameras can accomplish this task in the most simple way—a pinhole camera, for instance. Pinhole cameras may have only one moving part, or none. Or, the camera can have dozens of moving parts like the modern film or digital single-lens reflex (SLR or DSLR) camera.

In this piece, we will discuss the modern cameras popular with today's photographers. We are going to talk about cameras in general terms, so please know that I am aware of dozens of different ways in which different cameras make images. For simplicity's sake, we will keep it simple!

**A Common Path**

Modern cameras, more or less, work similarly to produce a photograph. Obviously, some are more complex than others, but, in general, light travels a similar path once it meets the camera lens.

- Aperture
- Shutter
- Image Plane

How the image is viewed on the camera, through an optical or electronic viewfinder or electronic screen is one thing that differentiates different types of cameras.

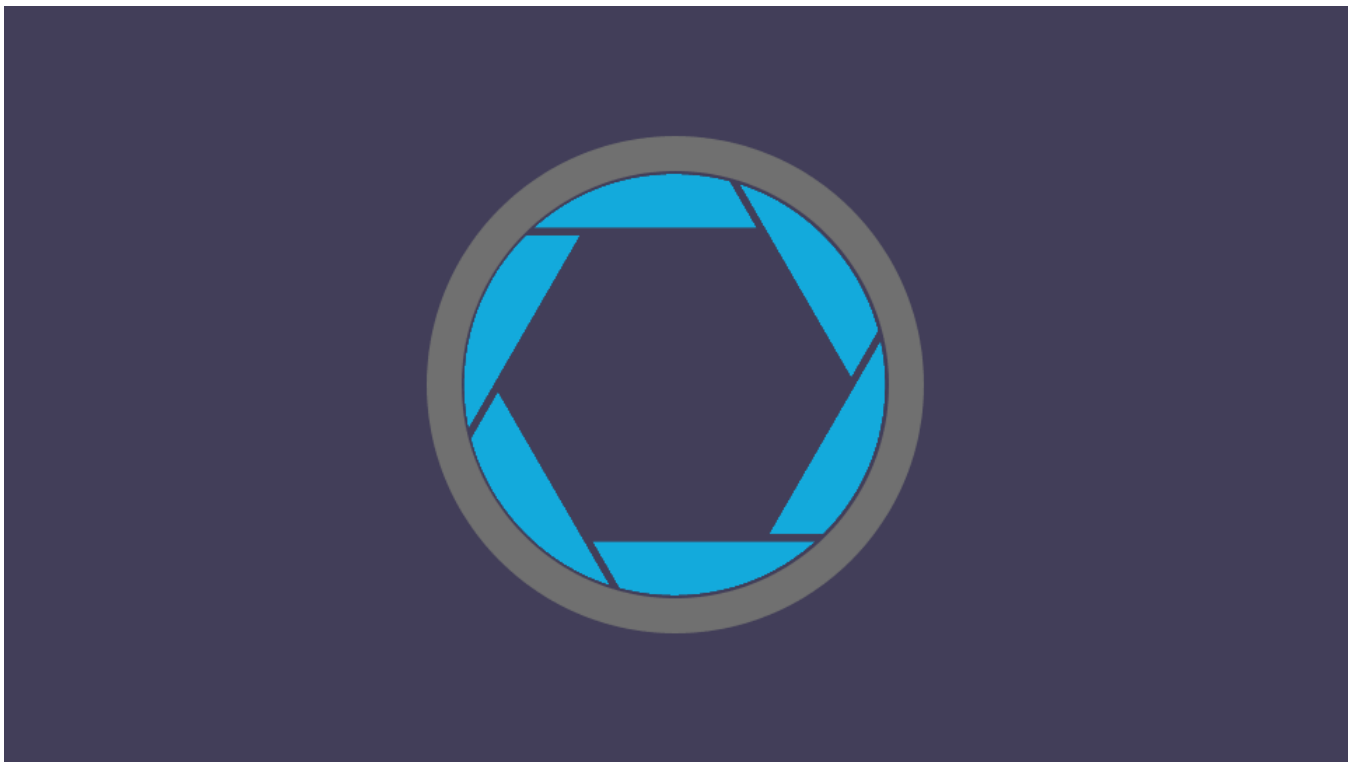
**The Lens**

Light first enters a lens. This is an optical device made from plastic, glass, or crystal that bends the light entering the lens toward the image plane. The lens has a certain number of optical elements. These are arranged together in groups. If you look at lens specifications, you will see a mention of the number of elements and groups in a given lens. Some groups only have one element.

Some lenses have fixed focus; others have movable elements that allow the photographer to control focus. On these lenses, one or more elements can change position to focus the light precisely at the image plane.

The lens's field of view is determined by its focal length. This is the length, in millimeters, from the rear nodal point of the lens to the image plane. Some lenses have fixed focal lengths, while others have adjustable focal lengths. Those that can change focal length are known as "zoom lenses."

**The Aperture**

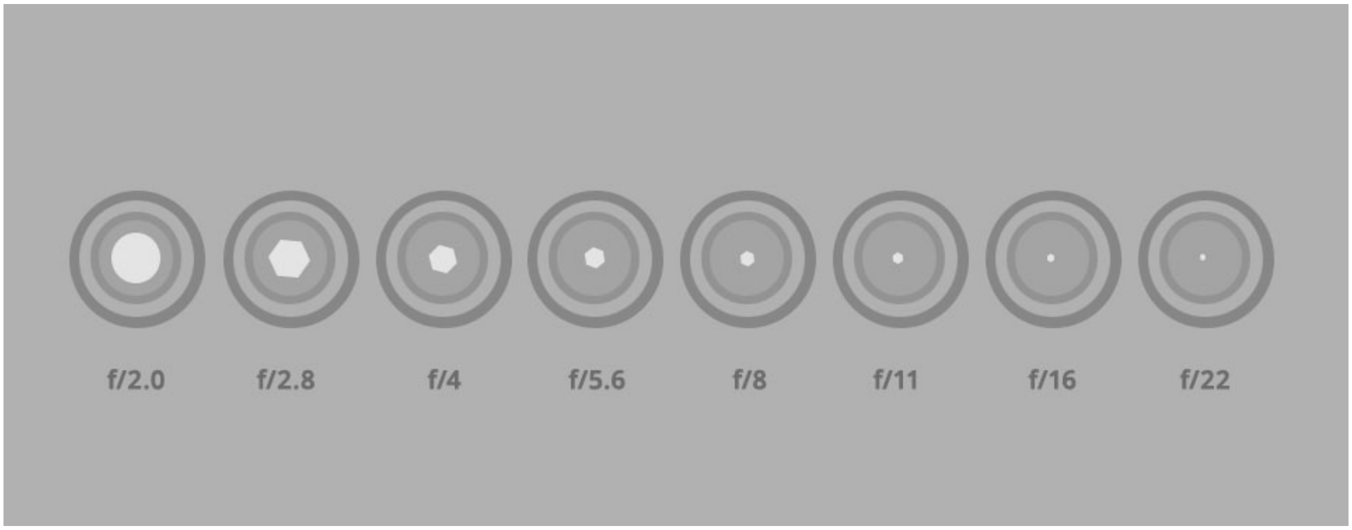


*Aperture is created by a set of blades inside the lens.*

**Aperture**

Aperture is the size of the opening in the lens. Some lenses have fixed apertures, but most photographic lenses have variable apertures in order to control the amount of light entering the lens. This aperture is regulated by a diaphragm made of overlapping blades that can be adjusted to vary the size of the opening through which light passes. The size of the opening also has a secondary effect on the photograph, as the diaphragm also changes the angle at which the light passes through the lens. We will discuss two "side effects" of changing the aperture size after we finish discussing aperture's relationship to exposure.

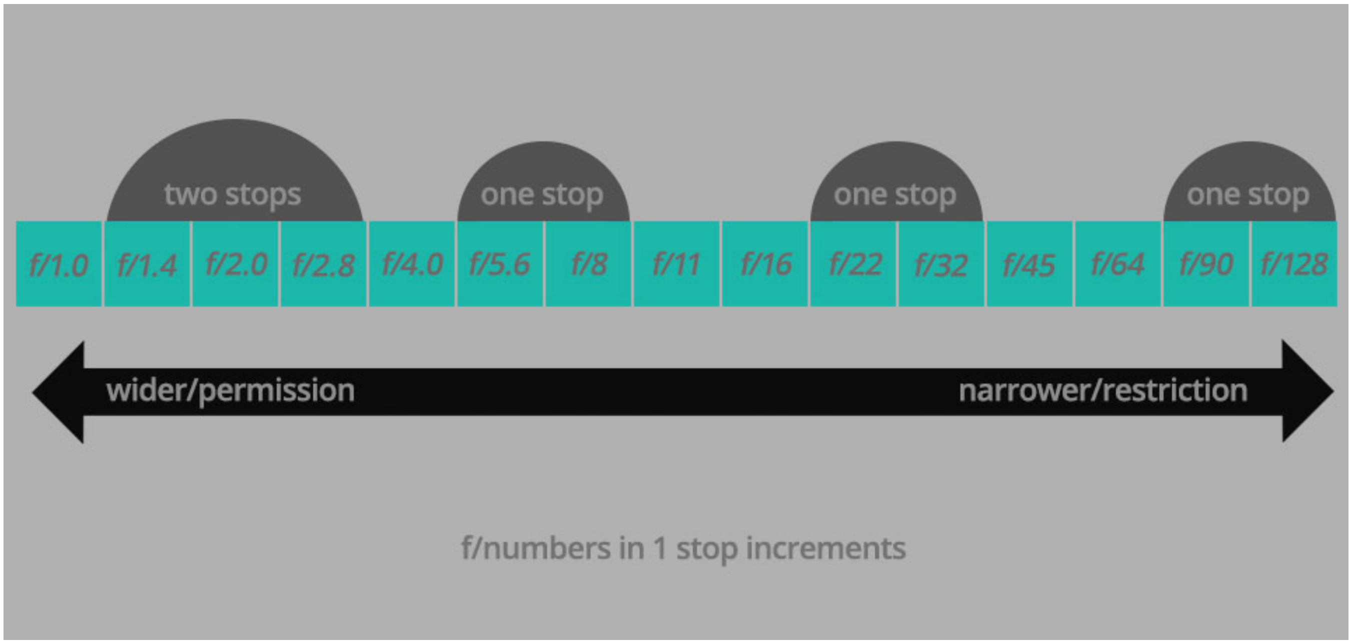
Like the pupil in your eye, the aperture diaphragm opens and constricts to control the amount of light passing through the lens. In order to facilitate a properly exposed photograph, we need to quantify the size of the opening so that we can mathematically incorporate this opening into our calculation for exposure+. Luckily, especially if you have my math skills, this has been done for us already!




**Graphic representation of apertures at different f-stops**

The ratio of the opening of a lens aperture when compared to the size of the lens—not a measurement, but a ratio—is referred to as an f/number, f/stop, focal ratio, f/ratio, or relative aperture. Regardless of the label you use, aperture values are spaced, for mathematical purposes, in stops.

Written on the barrel of your lens, or digitally inside your camera and displayed in the viewfinder or LCD screen, you probably see f/stop markings at one-stop increments.



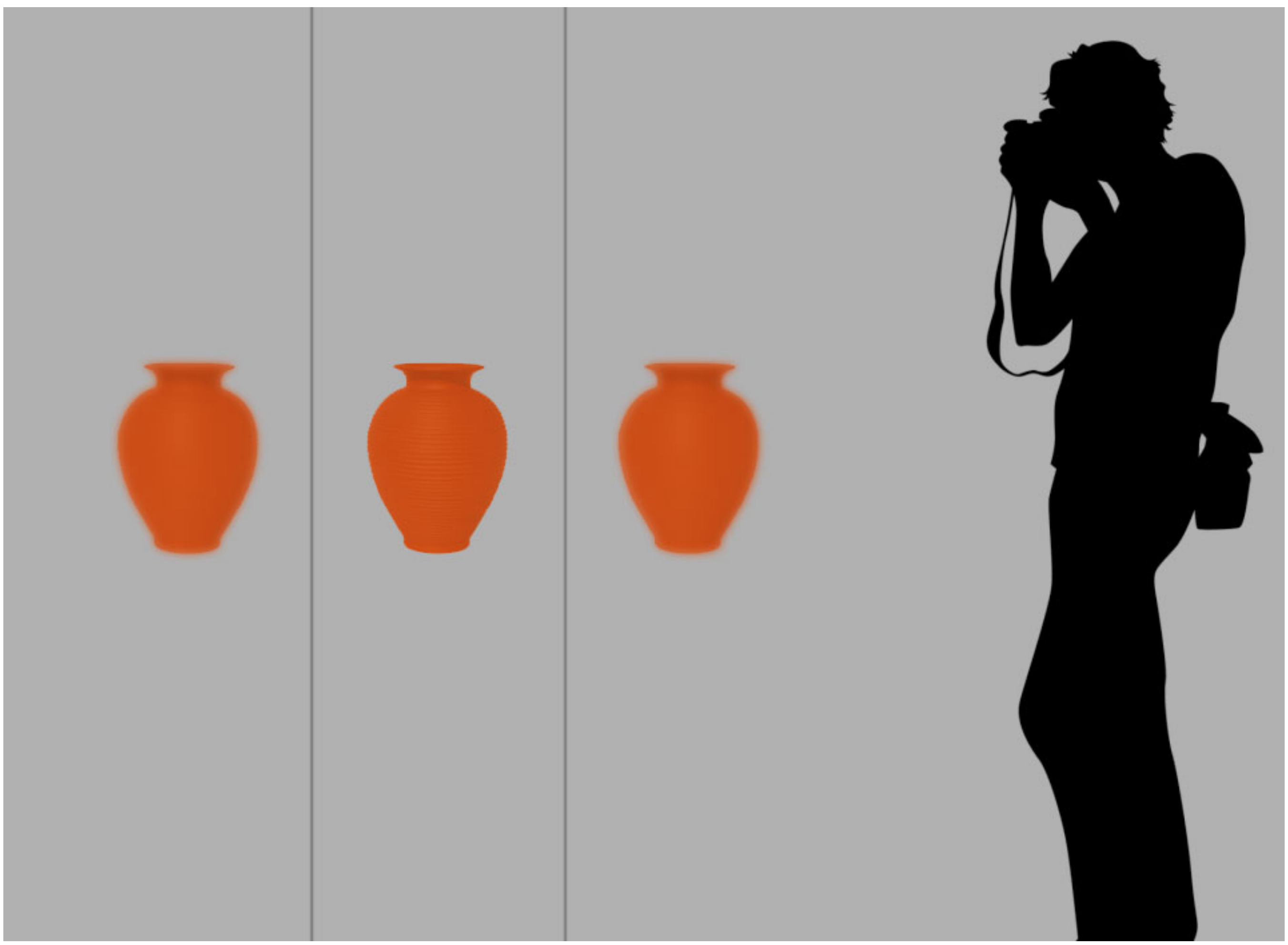

The smaller the number, the wider the opening. Therefore, a lens with a larger-diameter barrel and optics will allow a larger opening represented by a smaller f/stop. Your lens/camera might allow you to "dial up" different numbers than what is shown above; older manual lenses usually "click" at 1/2 stop increments. These numbers, seen on a digital display, like f/3.3 for instance, represent 1/2-stop or 1/3-stop ratios.

So, now that you know how aperture effects exposure, let us talk about those two "side effects" of aperture that we alluded to above. The size of the aperture diaphragm not only affects the amount of light passing through the lens, it also affects image sharpness and is one of several factors that affect something called "depth of field."

Depth of field is defined as the amount of distance between the nearest and farthest objects that appear to be sharply in focus in an image. Without depth of field, the lens's razor-thin focal plane would cause problems for photography. Take a photo of a person and, for instance, the tip of their nose would be in focus but the rest of them would be completely blurry. Depth of field allows that focal plane to have a perceived depth.

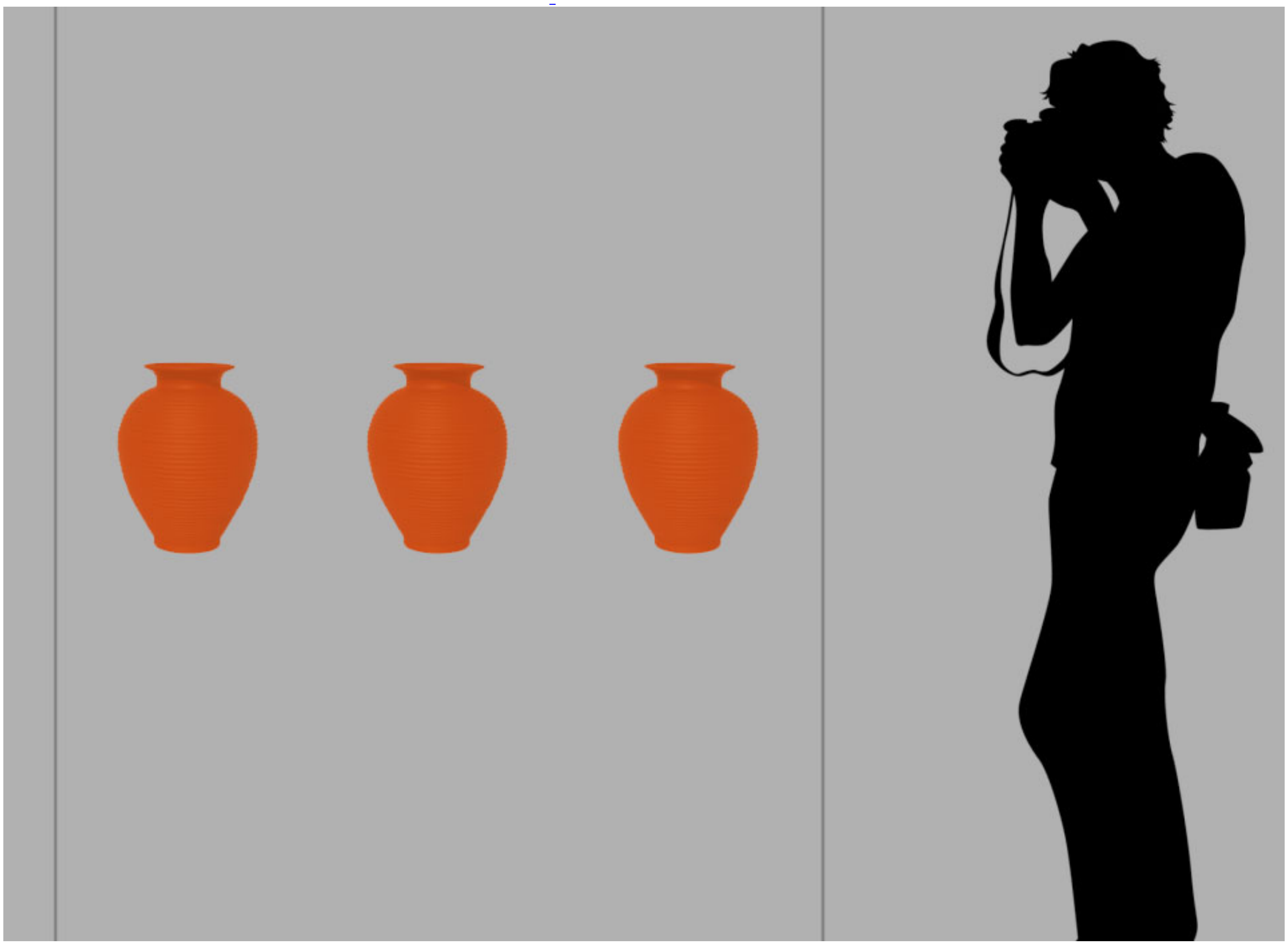
**Example of deep depth of field**

Depth of field is a function of lens aperture size, lens focal length, the distance between the subject and the camera, and something called the circle of confusion. For the purposes of this article, we will keep the depth-of-field discussion relevant to aperture. Depending on your camera and lens, by opening your aperture to its widest settings, you will narrow the range of the focal plane to a very small distance. This can be used in photography for creative compositions with close-up photography and, most popularly, for making distant backgrounds blurry when taking portraits.



**Shallow depth of field (large aperture)**

It is important to note that some camera/lens combinations will not produce appreciably shallow depths of field, so do not think that by simply opening up your aperture diaphragm to its maximum, you will achieve extremely small depth of field. Adjusting your aperture diaphragm the other way, to its most narrow setting, extends the depth of that focus plane and allows a large range of the image to be in sharp focus. Deep depth-of-field techniques are used commonly in landscape images.



**Large depth of field (small aperture)**

Not only does the aperture control the amount of light passing through the lens, it affects the angle of the light rays as they transit the lens. To be clear, we are not talking about how the lenses are bending light, we are talking about how light, when it passes by an object, is slightly bent by that object—in this example, the blades of an aperture diaphragm. This bending of the light is called "diffraction" and is a characteristic of light's wave properties.

When you constrict a lens's aperture diaphragm, you are bringing that diffraction closer to the center of the image. Many photographers, when they are starting to understand aperture, think that the key to maximizing sharpness is a small aperture because of the effect that aperture has on depth of field. However, because of diffraction, this is not true. Although you are increasing your depth of field by constricting the aperture, you are also increasing the amount of diffraction in the image and this causes the image to lose sharpness.

Additionally, even with modern manufacturing precision and computer design, there is no such thing as an optically perfect lens. Because of imperfections in the glass and the way light behaves when it is bent, lenses produce aberrations that have negative effects on an image.

When you open the aperture diaphragm to its maximum size, you allow the maximum amount of light into the lens and, with it, the maximum number of aberrations. By "stopping the lens down," or reducing the size of the aperture diaphragm, you reduce those aberrations and the sharpness of the image created by the lens increases. However, as we discussed above, the downside is that as you make the aperture diaphragm smaller, you will increase the diffraction as the smaller opening causes more bending of the light rays. The middle ground, the region where the aberrations are reduced and the diffraction is manageable, is known as the lens's "sweet spot"—usually in the region between f/4 and f/11 depending on the design of the lens. This sweet spot aperture is where you will get the maximum performance of the lens as far as sharpness and reduced aberrations, as well as getting a middle-of-the-road depth of field.

So, in summary, aperture not only serves to control the amount of light passing through a lens, it also affects the performance of a lens in terms of depth of field and sharpness.

**The Shutter**

Many cameras have a device that opens and closes to let light impact the image plane for a predetermined amount of time. This is the shutter and it works much like your opening and closing eyelids—if you had your eyes closed more than open!

The shutter is a complex mechanical (or electrical) system. Mechanical cameras may have leaf or focal-plane shutters. The leaf shutter opens and closes like the aperture diaphragm and the focal-plane shutter uses “curtains” that work like garage doors.


As we said in our last segment, Understanding Aperture, photography is all about capturing light. In order to expose a photograph, we have to control the amount of light that is exposed to a photosensitive surface, as well as control the sensitivity of that surface to the light.

We compared aperture to the eye's iris that opens and constricts the diameter of its opening to limit the amount of light allowed into the eye. Shutter speed is akin to the duration of time your eye is open to take in the light.

**Shutter Speed**

Shutter speed is a measurement of time that a camera's shutter is open—allowing light, usually after it has passed through a lens and through the aperture diaphragm, to strike a photosensitive surface, like film or a digital sensor.

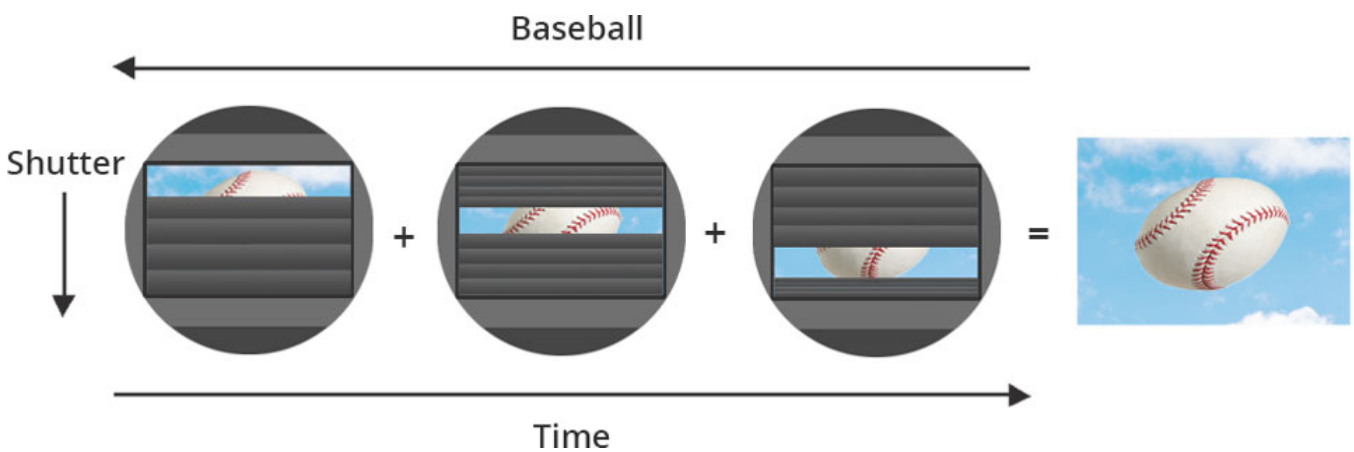
The challenge of the mechanics of the shutter is in designing a device that exposes the entire sensor or film plane to an equal number of photons so that exposure is consistent through the image. Many people think that the shutter works like a miniature garage door. If you can visualize a garage door opening and then closing in front of a photosensitive surface, you can see that the problem with that design is that the bottom of the image will be exposed to more photons of light as it is the first portion of the image to see light as the door begins to open and it is also the last part to be blocked by the door as the door closes. Therefore, a photo taken with a shutter that functions like a door will have an unbalanced exposure.

had lens-cap-type shutters where the lens was exposed to light by removing the cap and then, after a calculated amount of time, the cover was placed back over the lens. Exposures back then took several minutes, and even hours, so the relatively slow opening and closing of the "shutter" was not problematic.

At the inexpensive end of the spectrum, the *simple leaf shutter* appears on many disposable and point-and-shoot cameras of yesterday. This is a mechanized version of the old lens cap "shutter" where a leaf, or two leaves, are mechanically pulled aside to let light through an opening. They generally only operate at one speed.

The *leaf shutter*, also known as a diaphragm shutter, functions very much like the aperture diaphragm of the lens in that a group of metal blades is mechanically opened and closed in rapid fashion. Unlike the blades of the aperture diaphragm that just constrict to a small opening, these blades close all the way until there is no light coming through the shutter. The shutters are designed to open and close extremely fast so that the center of the image does not see an appreciably greater amount of light than the edges. Because of their design, leaf shutters work very well when synchronized with flash strobes, but cannot operate at speeds as fast as the shutter type that we will discuss next.

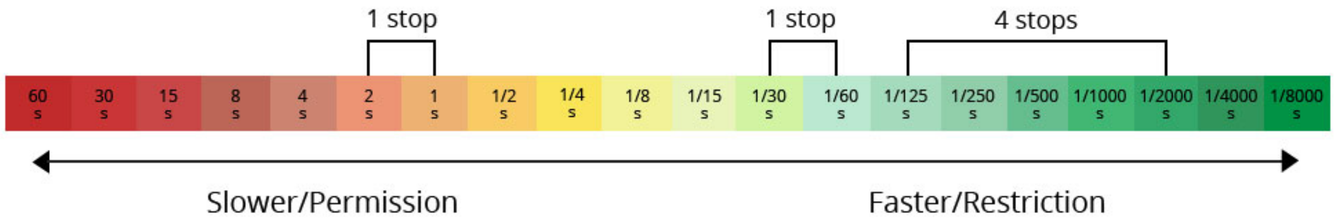
Almost all modern SLR and DSLR cameras employ the *focal-plane shutter*. The focal-plane shutter works more like a garage door, but with a second door, called a *curtain*, that follows behind the first curtain to close the image sensor or film off from light after the first curtain opens. This two-curtain design allows a balance of light across the sensor or film so that exposure is even. This design allows for extremely fast operation, up to 1/8000 of a second, on today's SLR and DSLR cameras. However, focal-plane shutters, due to their complexity and exotic construction, are relatively expensive.




Like most things, the shutter has gone digital. Many modern digital cameras operate an *electronic shutter* that simply powers the digital sensor on for a selected amount of time. Because there is no mechanical function, electronic shutter speeds can be extremely fast. A *global shutter* turns the entire sensor on and off at once, while a *rolling shutter* activates one row of pixels at a time across its width.

Both the focal-plane shutter and rolling electronic shutter, because of their design and function, can cause interesting distortion through an image when there is fast motion across the picture plane.

OK, back to shutter speeds. As I wrote earlier, shutter speed is simply a measure of time that the shutter is open, or, in the case of the electronic shutter, the sensor is powered. The longer the shutter is open, the more light comes through. No inverse square law here (thank goodness!); if you double the amount of time that the shutter is open, you will double the amount of light coming in. Shutter speed is simple, right?




**Shutter speed in 1-stop increments**

Shutter speeds are listed as whole seconds or as fractions of a second. The maximum shutter speed for most SLR cameras is 30 seconds. If you want to take a photo longer than 30 seconds, you can use the *bulb* (B) or *time* (T) functions of the camera, if it is equipped with a specially built shutter release that includes a timer. The bulb function opens the shutter as long as the shutter release is depressed. The time function opens at

There are some "side effects" of shutter speed.

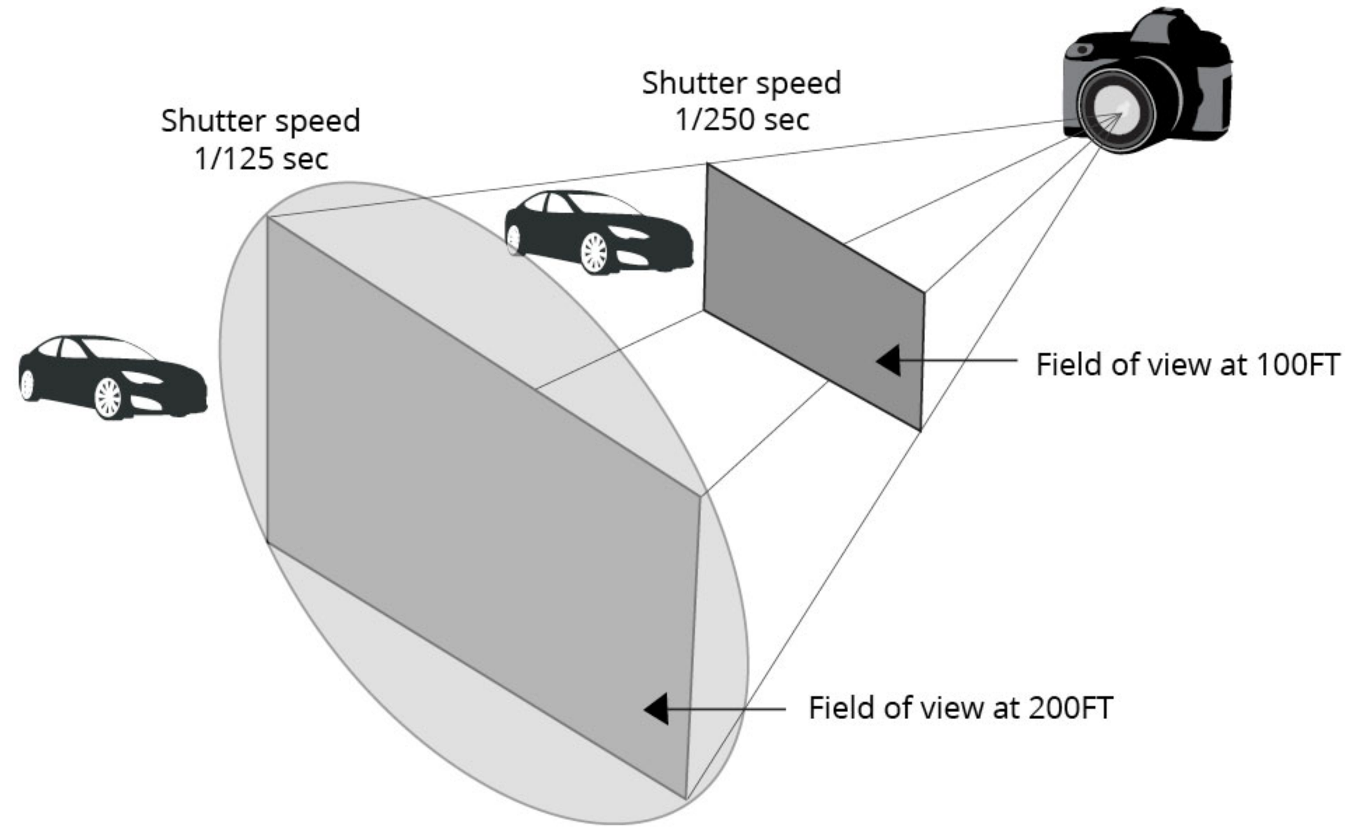
Slow shutter speeds allow movement to be imaged across the photograph. This is not just movement of the subject or subjects, but also of the camera too. It is nearly impossible to hold a camera perfectly steady for any length of time, especially for a few seconds. Therefore, an image taken with a handheld camera that covers any length of time will have blur from camera shake. Definitely keep this in mind when shooting with slow(er) shutter speeds. The other motion the camera sees is movement in the frame. A slow shutter speed will allow moving cars, runners, animals, etc., to change position inside the duration of the image. This movement will show on the photograph as motion blur and can be a really great creative element in a photograph. Another creative technique for slow shutter speeds is intentional panning of the camera, or even random camera movements, while the shutter is open.

Low-light and nighttime photography dictate a slow shutter speed to allow enough photons to reach the sensor or film. The camera is usually stabilized by a tripod, and shutter speeds of great lengths can capture images in very dark places or even trace the stars streaking across the night sky as the Earth rotates.

Fast shutter speeds are used in the opposite fashion—to freeze action versus letting it blur across a photograph. Speeding cars, diving swimmers, racing animals, mischievous kids, and more can all be frozen in time with a fast shutter speed.

Ready for more math? The two biggest factors in how movement is "seen" by the camera are: speed and distance.

If you stand on a sidewalk and stare straight ahead and a car goes past you at 40 miles per hour, a few feet in front of you, it will go through your field of view in a very short amount of time—probably a fraction of a second. If you look out to the horizon and another car going 40 miles per hour is passing you, 4 miles into the distance, you will see that car, going the same speed as the one before it, for a much longer amount of time.




**Shutter speeds for moving objects**

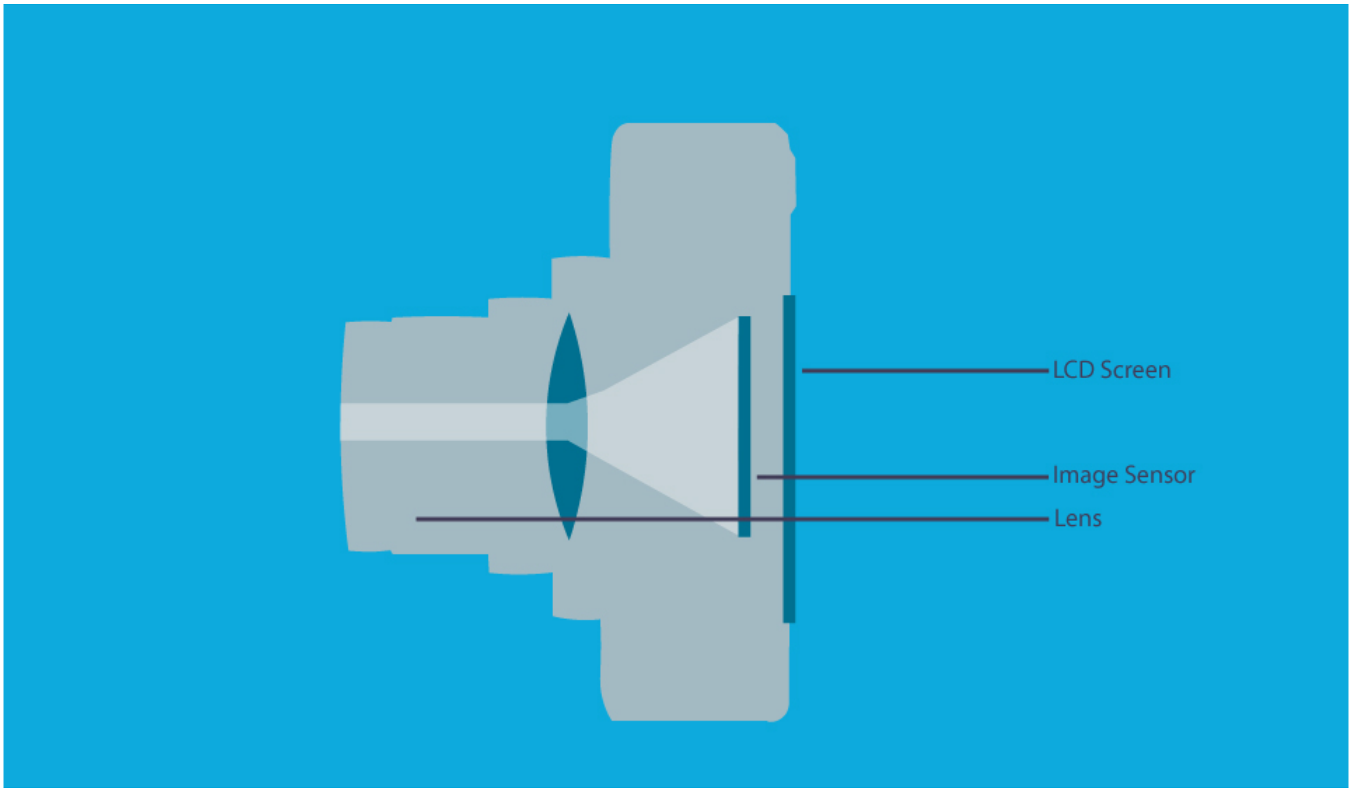
The camera's limited field of view works the same way if the subject is moving or if the camera is moving. If you have ever taken a photo of a distant object from a speeding vehicle, you have seen the same type of effect in your image; the distant snow-capped mountain is clear and sharp, but the fences and fields and Armco next to the road are blurry from the motion. So, applying mathematics once again, we can crunch numbers to help us get the shutter speed effects we want in our images. When you double the distance from the camera to the moving subject, you will half its speed through the frame. Therefore, to get the same blur, you can use half the shutter speed. Conversely, if your moving subject is the same distance away each time you photograph it, but you double the speed of the subject, you will have to halve the speed of your shutter to get the same amount of blur

**The Image Plane**

After light passes through the lens aperture and is allowed to travel through an open shutter, it strikes the image plane. At the image plane is light-sensitive chemical-based film or a digital sensor on which the projected image is recorded. This plane’s position inside the camera is often marked by this symbol: "Φ" painted or engraved somewhere on the camera body, often on the top plate.

**Point-and-Shoot Cameras**

Point-and-shoot (PAS) cameras are generally the most simple of modern cameras. The most basic PAS cameras have fixed focal length lenses, non-adjustable apertures, and a basic shutter design. More advanced PAS cameras may incorporate zoom lenses, variable apertures, and a combination of mechanical focal-plane shutters and electronic shutters.




*The basic components of a typical point-and-shoot camera*

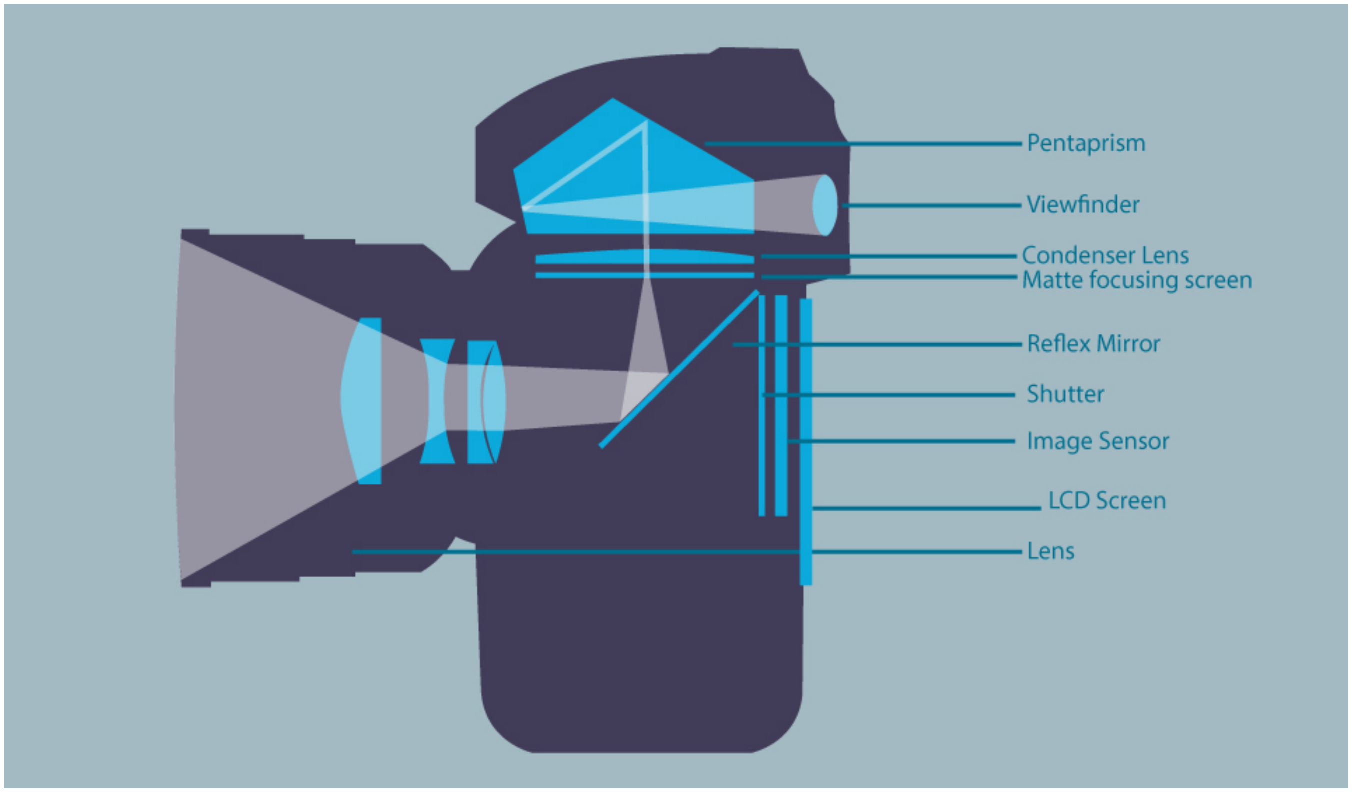
Therefore, the light path through a PAS camera is very simple. To see the light that is coming through the lens, the digital PAS camera will have an electronic screen that shows the true image impacting the image plane. Or, on some digital and film PAS cameras, there is a separate optical viewfinder that, when you look through it, displays a representation of the lens's field of view.

Today, there are several genres of PAS cameras: pocket sized, superzooms, and there are newer PAS cameras that feature "full-frame" digital sensors the same size as 35mm film frames in a compact camera. Some PAS cameras are built to be water-, freeze-, dust-, and shockproof. Smartphone and cellphone cameras are, in fact, very tiny PAS cameras.

**The SLR and DSLR**

One of the primary benefits of the SLR camera is the ability to look through the camera's lens to see exactly what the film or sensor will be seeing when the shutter is opened. How does the SLR "interrupt" the light and redirect it to a viewfinder?

The light path to the image plane is similar to that of other cameras, but in between the lens and the shutter lies a mirror that blocks the light from reaching the shutter. This is the reflex mirror (the "R" in SLR). Light enters the lens and then strikes a silvered mirror inside the camera housing. It is then reflected up toward a prism at the top of the camera and then bent toward the rear of a camera through an optical viewfinder. Below the prism is a focusing screen that can superimpose information over the image.




*The basic components of the DSLR*

The photographer composes the image through the viewfinder, and when the shutter release is depressed, that mirror flips up, out of the light's path, the shutter opens, and then the light travels to the image plane.

When it comes to manual focus, the SLR is easy. Basically, you just determine focus by looking through the viewfinder as it shows the image that is being transmitted through the lens. Autofocus is more complicated and involves a transparent part of the reflex mirror, a secondary mirror behind the reflex mirror, and autofocus sensors in the bottom of the camera.