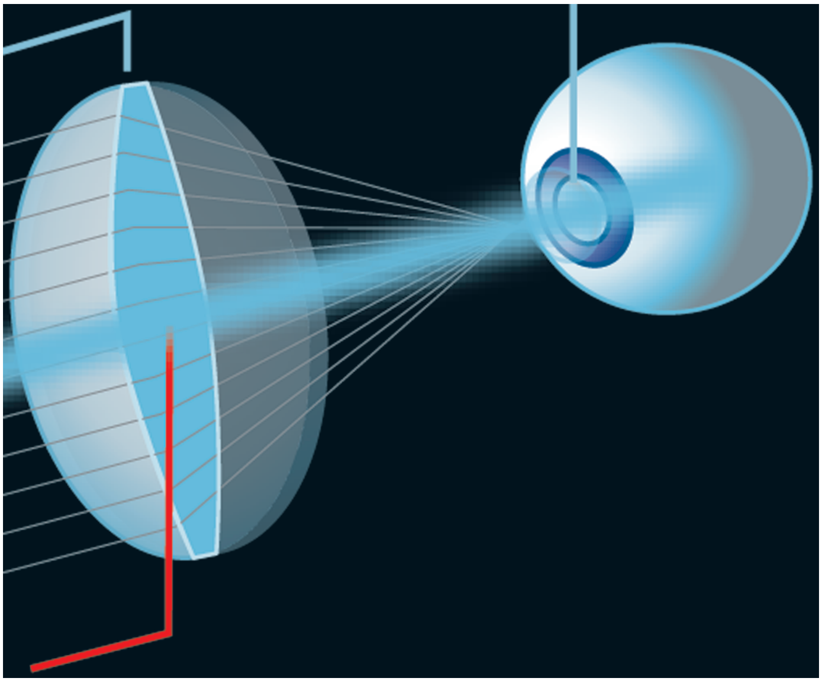
CHAPTER 3

How Lenses Work



If your pictures aren't good enough,
you aren't close enough.
Robert Capa

Best wide-angle lens? Two steps backward.
Look for the "ah-ha."
Ernst Haas

IT'S possible to make a camera that has no lens. It's called a pinhole camera. You can make one in just a few minutes. All it takes is a box with a tight-fitting lid that won't let light in. Punch a small hole—a pinhole, made with a straight pin or needle—in the center of one side of the box. You can even make a pinhole digital camera by putting a hole in the center of the body cap that that goes on a camera when its lens is removed. Because light enters the box or the pinhole digital through such a small opening, it does not spread out and become diffused the way light does, say, entering a room through a window. The result is a focused image striking the other side of the box. A pinhole camera is not only a fun project, but serious photographers use it to create excellent photographs. (For more information, including how to build your own pinhole camera, check out Bob Miller's Light Walk at http://www.exploratorium.edu/light_walk.)

Pinhole cameras aside, the image deposited on film or a digital sensor is only as good as the image that emerges from the lens. The use of glass or plastic, how many pieces of plastic or glass elements make up the lens, and the precision with which its focusing and zooming mechanisms work all determine the quality and price of a camera. The most important function of the lens is to focus the light entering the camera so that it creates a sharp image when it hits the back of the camera.

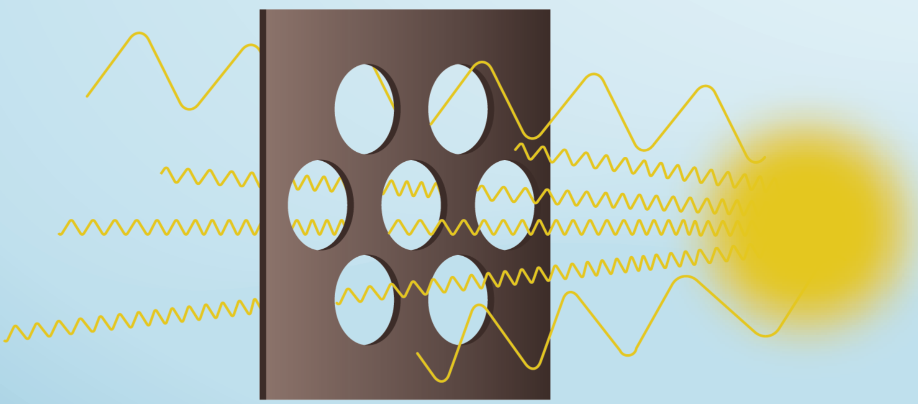
You may control the focus by turning a ring running around the barrel of the lens as you check the focus through the viewfinder. Or you might have nothing to do with it at all. The lens might focus automatically, or it might not change its focus at all. The cheapest cameras—digital or film—have fixed-focus lenses that bring into definition everything in front of the lens from a few feet out to infinity. This is not as good a deal as it might seem at first glance. Everything is somewhat in focus, but nothing is sharply in focus. Plus, a good photographer doesn't always want everything to be focused. Blurred images have their place in photography, too.

The lens is not the only player in the focus game. The elements of the exposure system, the image sensor, and the processing a digital camera does to a picture before depositing it on a memory chip all influence how crisp or mushy the final photo is.

How Light Works

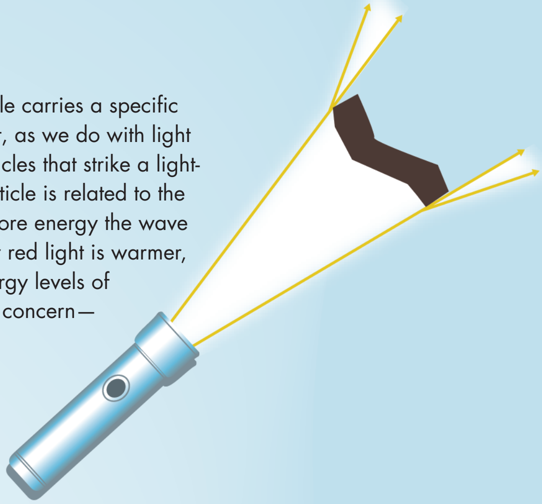
Photography is all about light—light bouncing off pigments and dyes, light shining through gels and filters, and the shadows and depth that come with the absence of light. Light is one of the basic influences in life. In fact, it brings life. Without light there would be no energy on the planet except that lurking deep in its bowels. And yet we're not exactly sure what light is. The scientific answers at times contradict each other, and if you start to peer at it too closely, the physical nature of the universe develops cracks. So we're not going to do that, but we will look at it in less intimate terms.

1 Light is a form of energy. It is just a small segment of the vast energy that fills the universe in the form of the **electromagnetic spectrum**. Energy moves through space as waves. The distance from the peak of one wave to the peak of the next is the **wavelength**, which determines many of the characteristics of a particular form of energy. The only energy we can see is a narrow band of wavelengths in the middle of the spectrum. We call this band light. We sense other wavelengths in the form of heat, and we've created various devices that detect energy with wavelengths longer than those of light—infrared—and shorter wavelengths, such as ultraviolet.



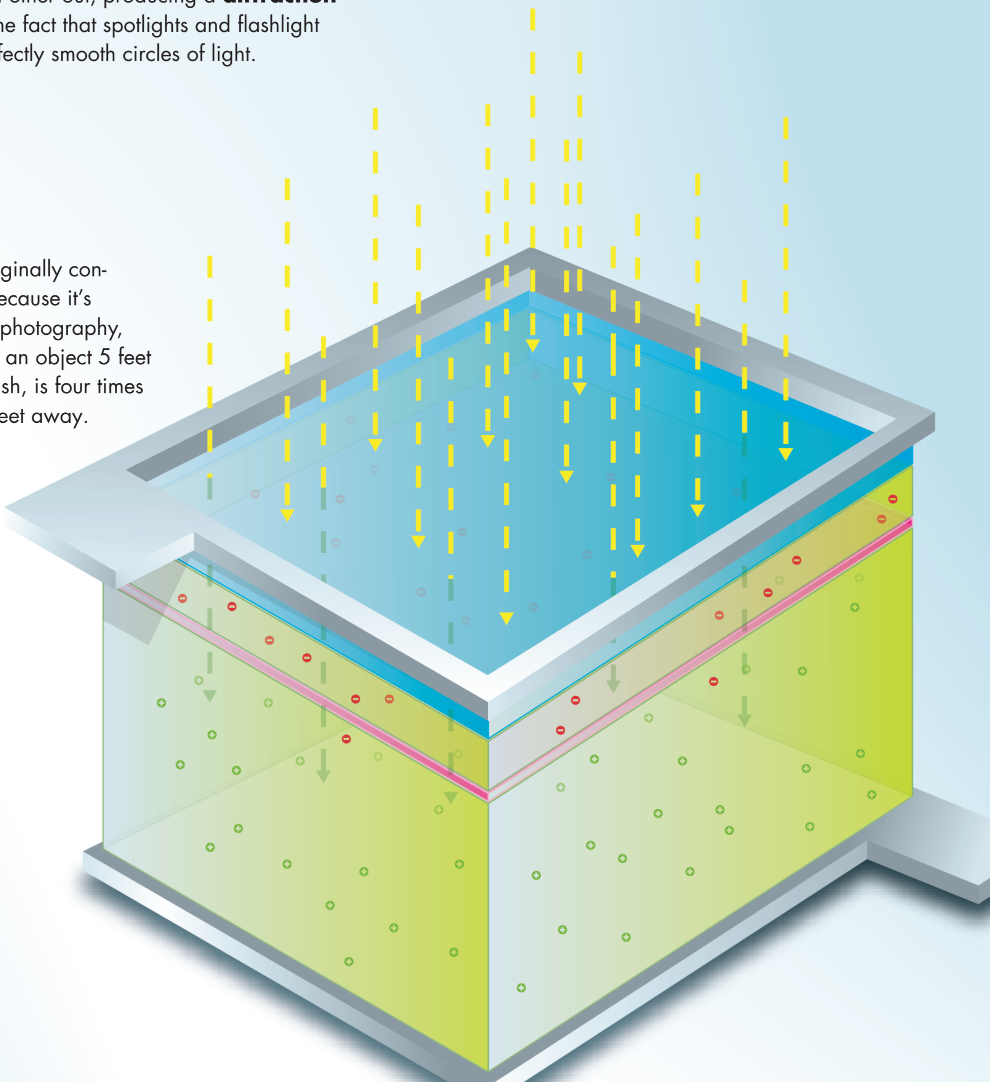
2 The wave characteristics of the spectrum account for several useful aspects. Waveforms give energy size and shape. Microwaves are blocked by the screen filled with small holes in the window of a microwave oven because the waves are too large to pass through the holes. Light, however, is small enough to pass through easily.

3 Light can also take the form of a particle. Each particle carries a specific amount of energy. This is useful when measuring light, as we do with light meters. A meter essentially counts the number of particles that strike a light-sensitive surface. The amount of energy in a light particle is related to the light's wavelength. The shorter the wavelength, the more energy the wave contains. (Most of us would probably say a yellow or red light is warmer, but a blue light actually packs more energy.) The energy levels of different colors of light are not so different as to be a concern—or use—in photography.



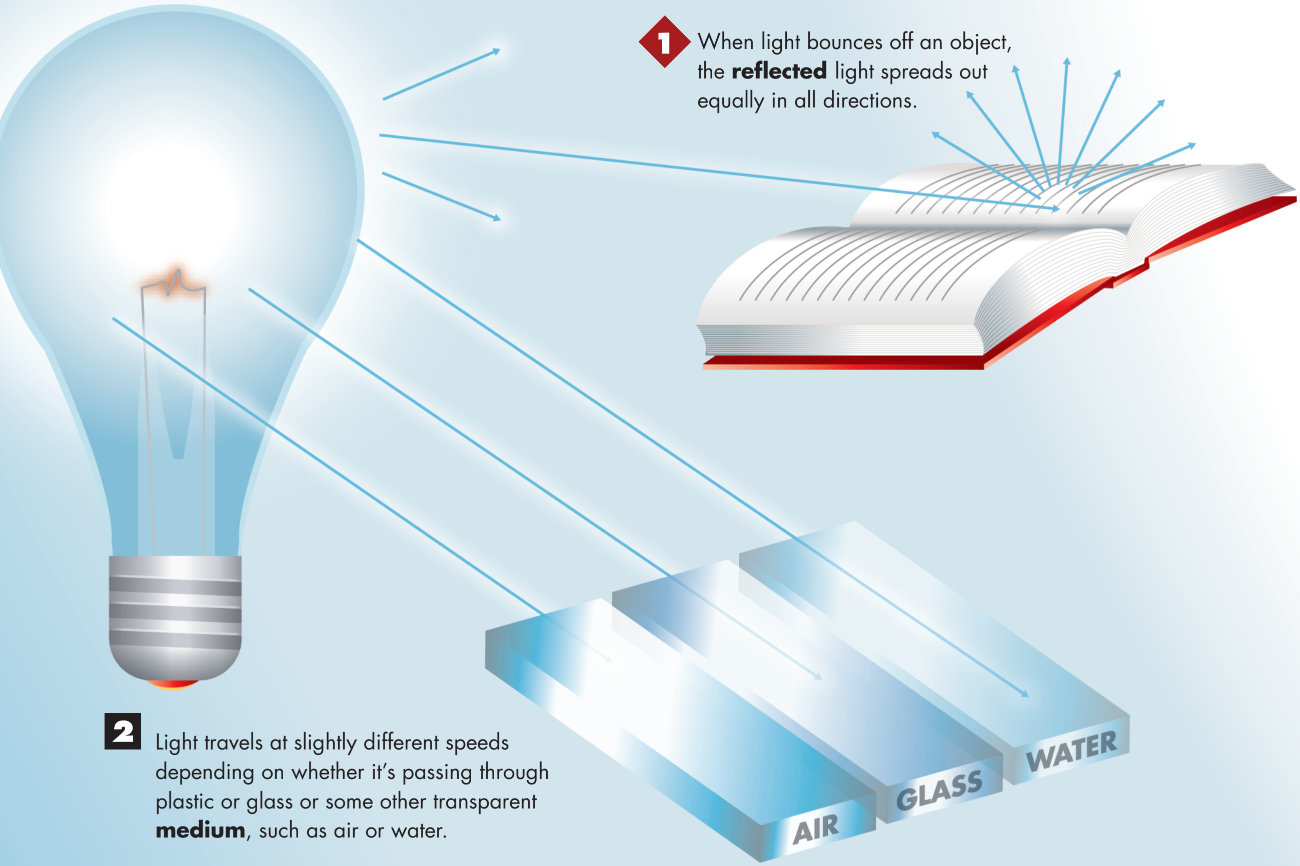
4 Light spreads as it travels, like the ripple on a pond. If light passes through a hole or past the edge of some obstacle, it will spread out from those points. The waves of light are not perfectly in step. The peaks of some waves will meet the troughs of other waves, with the effect that they cancel each other out, producing a **diffraction** pattern. This accounts for the fact that spotlights and flashlight beams do not produce perfectly smooth circles of light.

5 As light waves spread, the energy originally contained in the light becomes weaker because it's spread thinner over a larger area. In photography, this is particularly significant because an object 5 feet away, being photographed with a flash, is four times as brightly lit as the same object 10 feet away.



How a Lens Bends Light

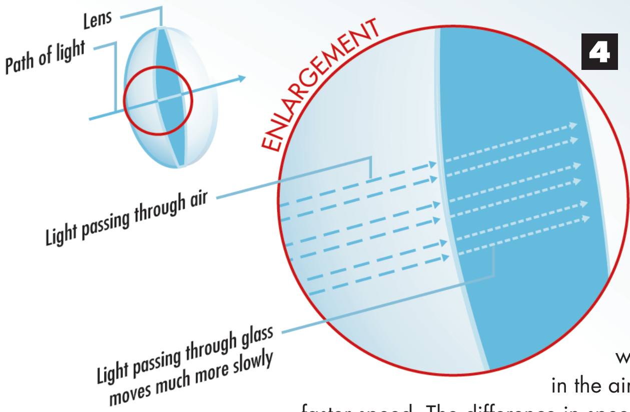
The lens performs multiple jobs when it comes to gathering the light that the camera then shapes into a photograph. The lens frames all the subject matter and determines how close or how far away it seems. The lens controls how much light passes through it, and which subjects are in focus. Framing with a viewfinder and the zoom controls still needs your aesthetic judgment. But with most digital cameras, the lens is happy to do all the focusing entirely on its own. Whether you focus the camera manually or let autofocus do the job, focusing works because of what happens when light passes through glass or plastic.



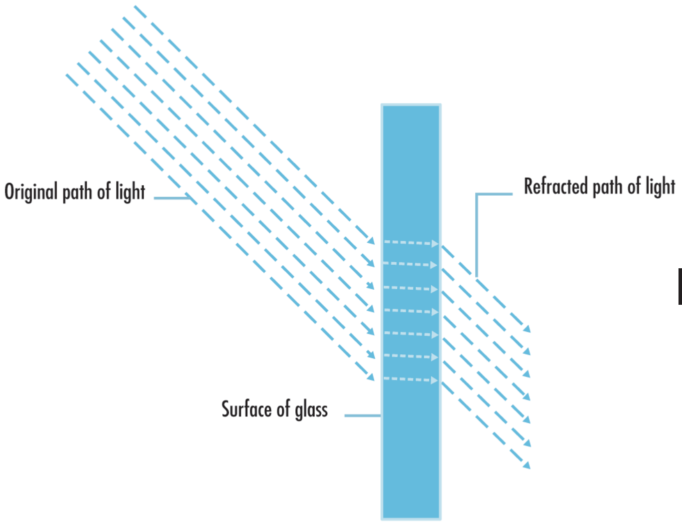
1 When light bounces off an object, the **reflected** light spreads out equally in all directions.

2 Light travels at slightly different speeds depending on whether it's passing through plastic or glass or some other transparent **medium**, such as air or water.

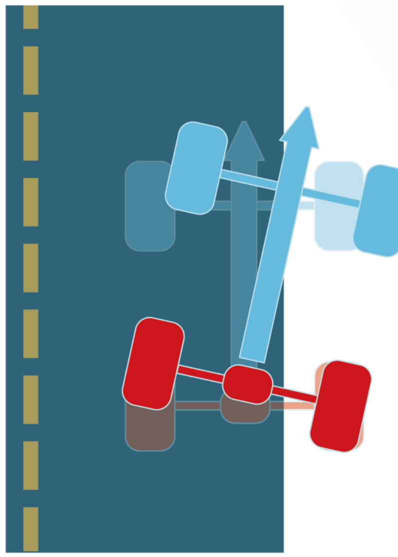
3 When a ray of light passes from the air into glass or plastic—the most common materials used for lenses—the light continues at an infinitesimally slower speed. It's like a speed limit enforced by the laws of nature.



4 But if the ray of light is at an angle to the plane where air and glass meet, not all parts of the ray move at the same speed as they cross from air to glass. The edge of a light beam that hits the glass first slows down while the opposite edge, still in the air, continues to move at a faster speed. The difference in speed results in the beam of light traveling in a different direction. The effect is similar to a car that has its right wheels in sand and the left wheels on pavement. The right wheels spin without moving the car forward much. The left wheels, with more traction, push the car forward more than the opposite wheels, causing the car to skid to the right.



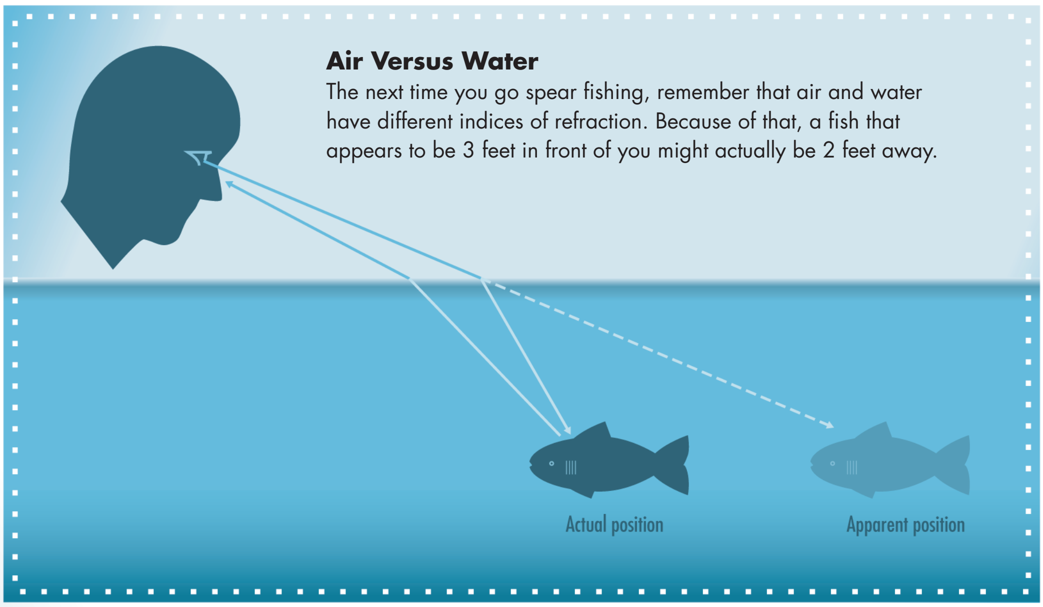
5 The process of bending light to travel in a new direction is called **refraction**. How much a substance causes light to bend, or **refract**, is called its **index of refraction**. Refraction is the principle that allows a camera lens to create a sharp, focused image.



Left wheels continue to move forward while right wheels in sand fail to move

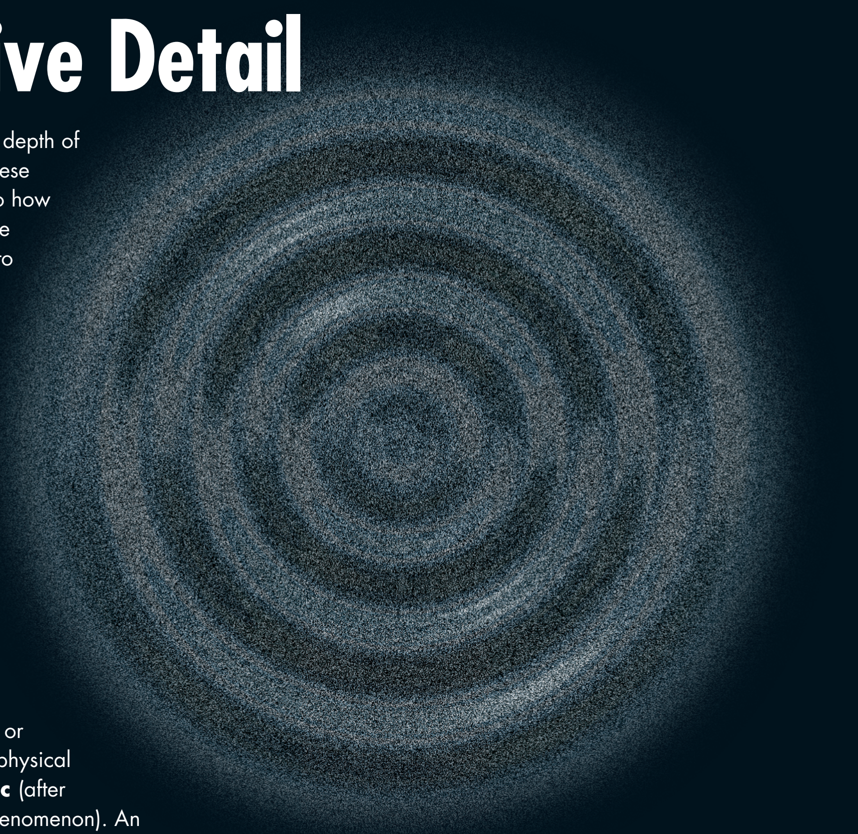
Air Versus Water

The next time you go spear fishing, remember that air and water have different indices of refraction. Because of that, a fish that appears to be 3 feet in front of you might actually be 2 feet away.



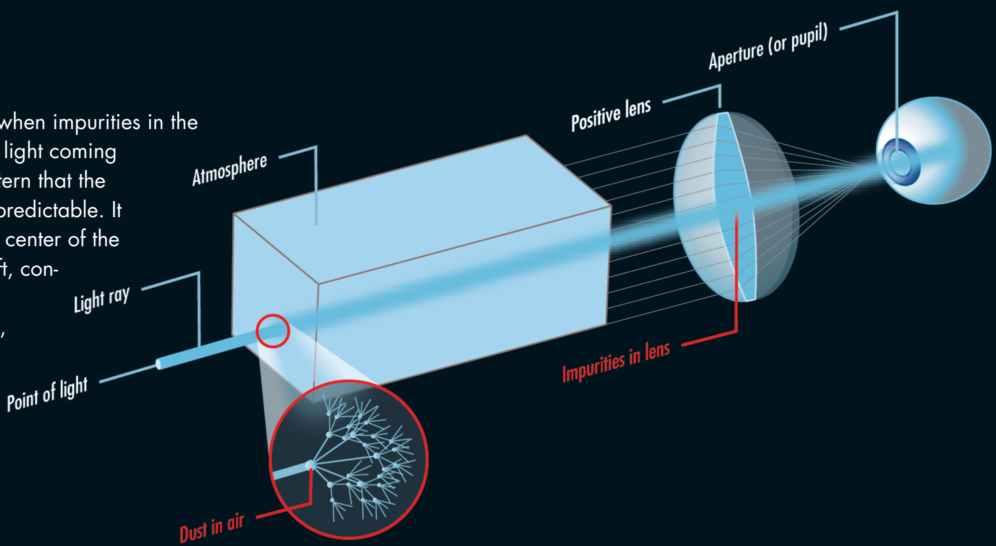
How We Perceive Detail

In all the photographer talk about resolution, focus, and depth of field—which we'll get to after we lay a foundation on these pages—it's easy to lose sight of the ultimate restriction to how much detail you can see in a photo—the human eye. The biggest asset in seeing detail is imagination, the ability to make logical connections to fill in the details that are smaller than digital film can capture or photo printers can reproduce or the eye can discern. The tricks our perceptions pull on us are particularly important in digital photography because the technology squeezes the size of digital "film" to an area smaller, usually, than even the 35mm frame. That pushes the concepts of resolution and detail into even finer distinctions and even smaller realms. That's where human vision encounters the, no kidding, Airy discs and circles of confusion…strap yourselves in and keep your hands inside the cart at all times for this one.

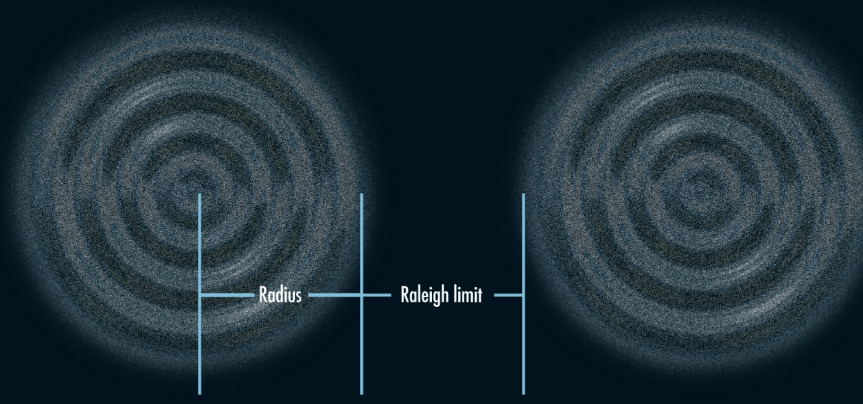


1 A point of light, like other points having no width or breadth, is an abstraction. The closest thing to a physical point of light is a spot of light called an **Airy disc** (after astronomer George Airy, who first noticed the phenomenon). An Airy disc is an artifact. It doesn't exist in nature, but instead is created by the interaction of light diffraction and human vision. What began as a point of light changes when it passes through air, a lens, and an aperture. (That includes the eye's lens and pupil. An Airy disc doesn't exist at all unless someone or something looks at it.)

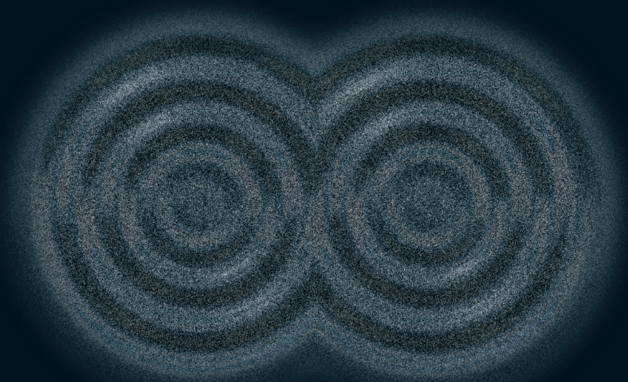
2 Diffraction is caused when impurities in the air and lenses scatter light coming from a point. The pattern that the diffraction creates is predictable. It is concentrated in the center of the disc, fading out in soft, concentric circles until it reaches the disc's rim, where the light is again concentrated.



3 If you back away from any two objects, perspective makes them appear to move closer together. As two Airy discs approach each other, they reach a point where the distance between them is equal to the radius of one of the discs, about 0.27 microns (µm). This is called the Rayleigh limit.



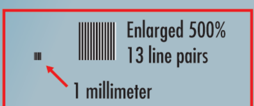
4 When objects cross the Rayleigh limit, they can no longer be distinguished as separate objects. They lose visual information in the form of detail, but they might produce new, gestalt information. If you look closely at a brick wall, you'll see that it is made up of individual bricks with rough textures and a mixture of reds, all surrounded by mortar of a different color and texture.



5 Back off from the wall and the points of light from the bricks cross the Rayleigh limit, blending their visual information. First the wall's color becomes more uniform. Back off farther, and the individuality of the bricks blurs into one solid wall. Although you might lose visual information, such as the type of bricks used in the wall or even that it is made of bricks at all, you now know that the wall is of a two-story building, something that even a close knowledge of the parts of the wall couldn't tell you.

So What Do We Mean by Focus?

Based on the physics of Airy discs, lens makers have established a standard for measuring resolution based on pairs of black and white lines. This, of course, assumes ideal lighting conditions, 20/20 vision, the distance from an object to the eye, and various details concerning brightness and contrast. In photography, the assumptions also include how much a photo will be enlarged from a negative or digital image. Studies on human visual acuity indicate that the smallest feature an eye with 20/20 vision can distinguish is about one minute of an arc: 0.003" at a distance of 10". Optics, dealing as it does with human perception, is in many ways the most imprecise of the sciences that abound with measurements and complex math and formulas.

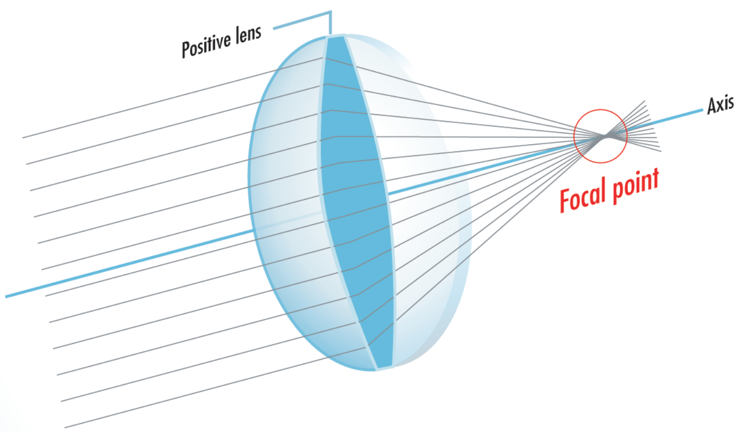


1. The standard that optical engineers use, regardless of human acuity tests, is that 13 pairs of black and white lines per millimeter is the finest resolution that can be seen. More lines than that take the viewer into the gray Rayleigh territory. That's equivalent to about 30µm (.03mm).
2. A point of light can undergo the Airy disc distortion and be enlarged in a photographic print, and as long as it does not exceed 30µm, it is still perceived as sharp. But if the point of light grows larger than that, it's considered blurry; the larger it gets, the blurrier it is. It is this visual definition of sharpness that we're looking for when we say a picture is in focus.

How a Lens Focuses an Image

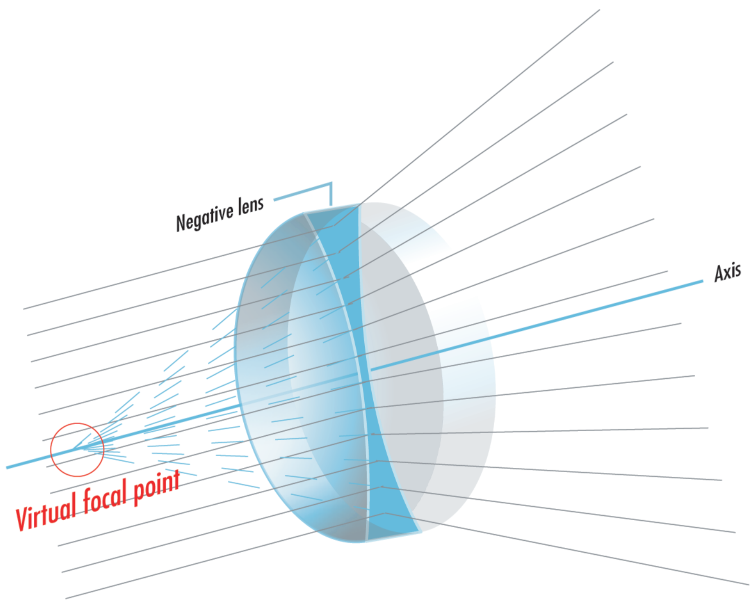
You must remember boring, sunny summer days in your childhood when you took a magnifying glass outside looking for anything flammable. Having spied a dry leaf, you held your magnifying glass between the leaf and the summer sun. Moving the magnifying glass back and forth with the precision of a diamond cutter, you found the exact point where the magnifier's lens concentrated the sunlight to form an image of the sun on the hapless leaf. Within seconds, the concentrated rays of the sun caused a thin wisp of smoke to rise from the leaf. Then, suddenly, it burst into flame. You had just done the work involved in focusing a camera's lens, though with more dramatic results.

1 To create an image inside a camera, it's not enough that light bends when it goes through glass or plastic. A camera also needs the bending to apply to each and every beam of light that passes through the lens. And it needs the bends to be precise, yet different, for each separate light ray.



2 To make beams of light converge to a **focal point**—like the hot spot on the leaf—the beams have to pass through the glass at different angles from each other. A **positive**, or **converging**, lens uses a smoothly curved surface that bulges so it's thick in the middle and thin at the edge, creating a **convex** surface. One beam of light that passes dead-on through the center, along the **axis** of the lens, doesn't bend because it doesn't enter the lens at an angle.

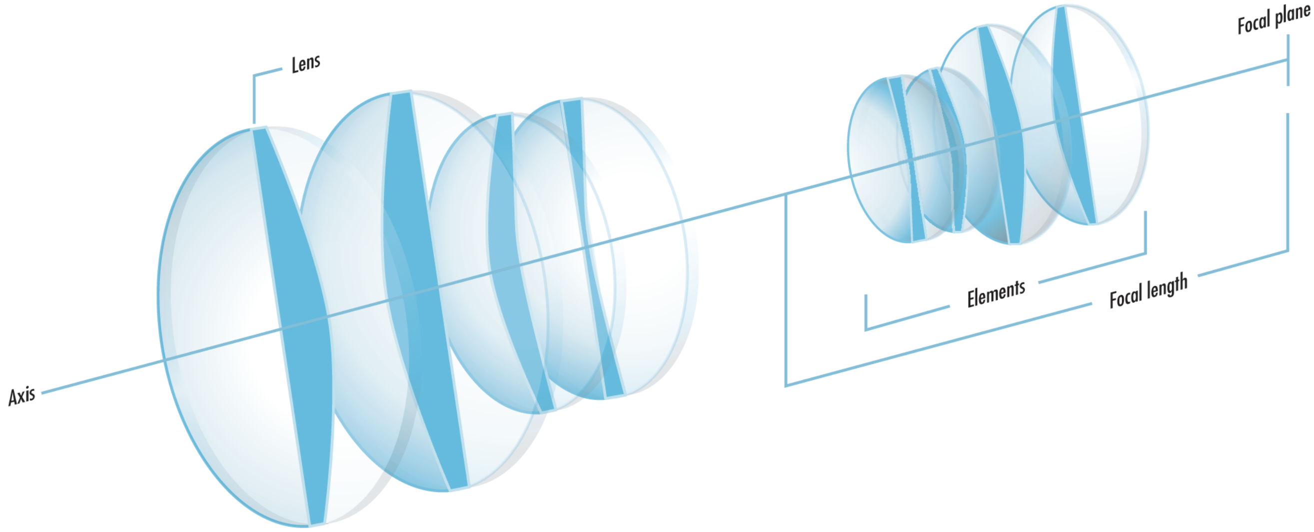
3 All other rays of light traveling parallel to that center beam hit the surrounding curved surface at an angle and bend. The farther from the center that the light beams enter the lens, the more they are bent. A **positive lens** forces light rays to converge into a tighter pattern along the axis until they meet at a common focal point, where the energy in sunlight is concentrated enough to ignite a dry leaf. Positive lenses are also called **magnifying** lenses; they're used in reading glasses to magnify text.



4 A **negative**, or **diverging**, lens does just the opposite. It has **concave** surfaces that make the lenses thicker on the edges and thinner in the middle. Glasses for people who are nearsighted (who can't see distant objects well) use negative lenses.

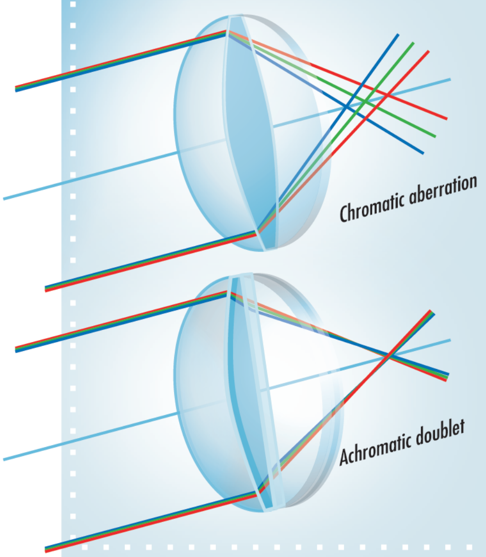
5 Light waves passing through a negative lens spread away from the lens's axis. The light waves don't meet, so there is no focal point that a leaf need fear. There is, however, a **virtual focal point** on the front side of the lens where the bent rays of light would meet if they were extended backward.

6 Focusing a clear image is a complex job that isn't done well by a single lens. Instead, most lenses consist of collections of different lenses grouped into **elements**. Together, they are able to focus objects at a multitude of distances from the lens with simple adjustments. Together, the elements determine the **focal length** of a lens. The focal length is the distance from the focal plane to the rear nodal point when the lens is focused at infinity. The **rear nodal point** isn't necessarily in the rear. In fact, it can be in front of the lens.



The Bend in the Rainbow

Not all colors of light bend at an angle when they pass through a lens. Different colors have different **wavelengths**, the distance between the high point of one wave in a beam of light to the high point in the next wave. That makes each color bend at a different angle, as shown in the drawing.



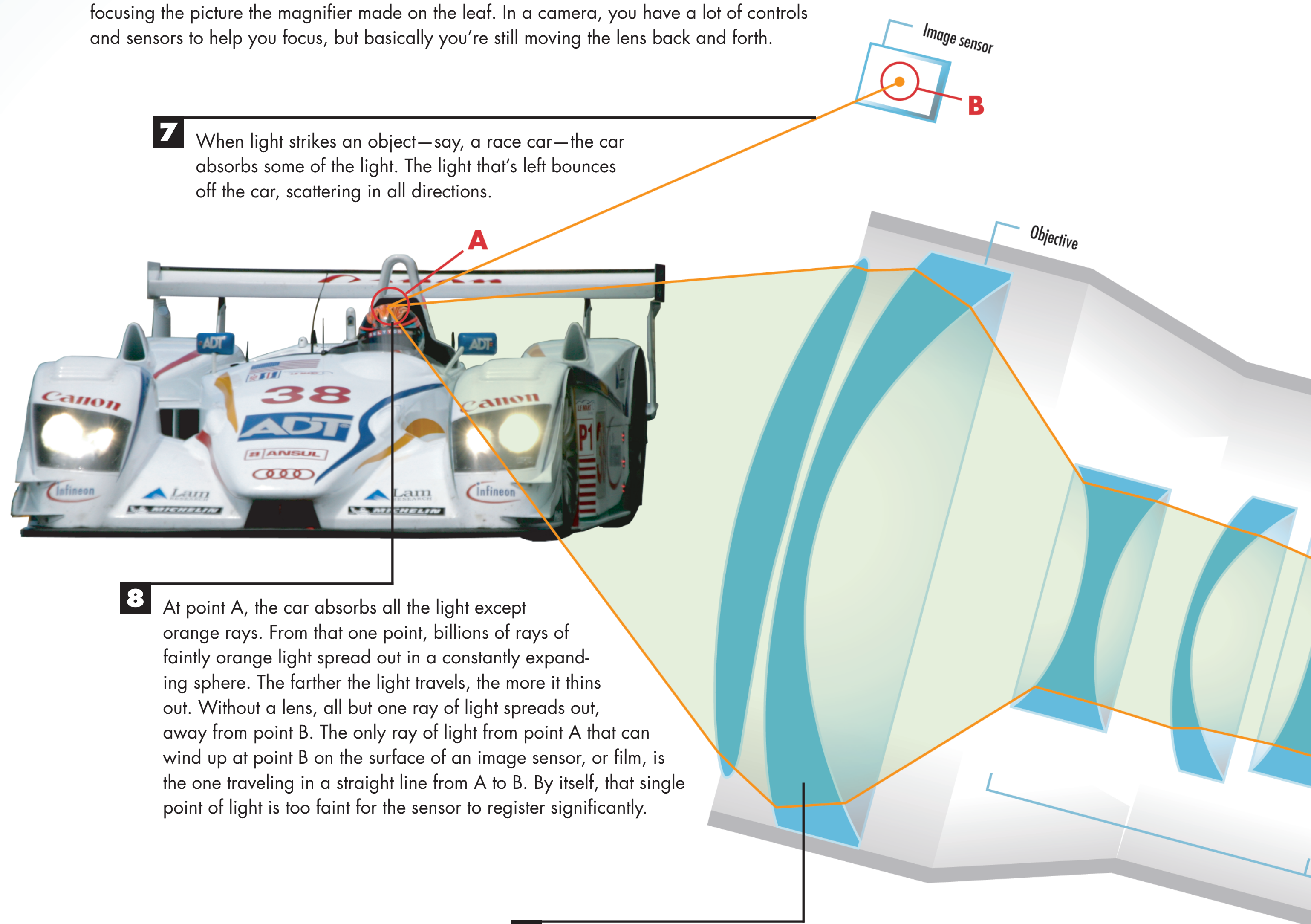
When light passes through raindrops, the drops act as lenses and break sky light into the colors of the spectrum. We call that a rainbow; when something similar happens in a camera, we call it chromatic aberration. In a photograph, it shows up as fringes or halos of color along the edges of objects in the picture, as in the photo shown here.

The aberration is prevented by an **achromatic doublet**, or **achromat**, a single lens made of two materials that are bonded together. Because each material has a different refractive index, their chromatic errors tend to cancel each other. The aberration is also corrected with image editing software, as was used on the second photo shown here.

Photos courtesy of Robert Tobler, who demonstrates the latter method at http://ray.cg.tuwien.ac.at/rft/Photography/TipsAndTricks/Aberration.

The Magnifying Glass Effect

Let's go back to that childhood fascination with magnifying glasses that set the scene for the previous illustration. Take a closer look at the hot spot of light created by the magnifying glass. You'll see that the spot is actually a picture, a small image of the sun. Now, remember how you moved the magnifying glass back and forth until it was just the right distance to start a flame? You were focusing the picture the magnifier made on the leaf. In a camera, you have a lot of controls and sensors to help you focus, but basically you're still moving the lens back and forth.



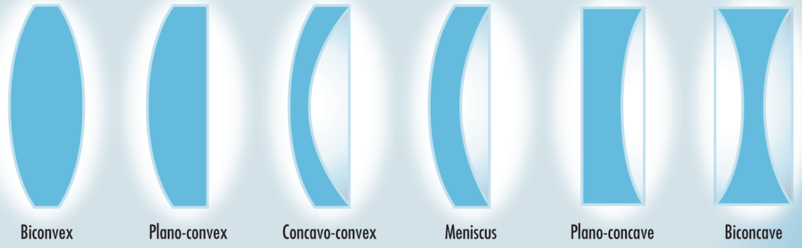
7 When light strikes an object—say, a race car—the car absorbs some of the light. The light that's left bounces off the car, scattering in all directions.

8 At point A, the car absorbs all the light except orange rays. From that one point, billions of rays of faintly orange light spread out in a constantly expanding sphere. The farther the light travels, the more it thins out. Without a lens, all but one ray of light spreads out, away from point B. The only ray of light from point A that can wind up at point B on the surface of an image sensor, or film, is the one traveling in a straight line from A to B. By itself, that single point of light is too faint for the sensor to register significantly.

9 That changes when a camera's lens is put between A and B. Millions of other rays from A enter a camera's lens through the millions of points on the surface of the **objective**. The objective is the first of the half dozen or so **simple lenses** that make up the camera's **compound lens**. The simple, single lenses are distributed along the same line among separate groups called **elements**. The multiple lenses, which might mix **positive** and **negative** lenses, compensate for each other's defects in the way that two lenses fix chromatic aberration, which was shown in the previous illustration. Also, as you'll see, the compound lens design allows precise focusing and zooming.

Curves Ahead

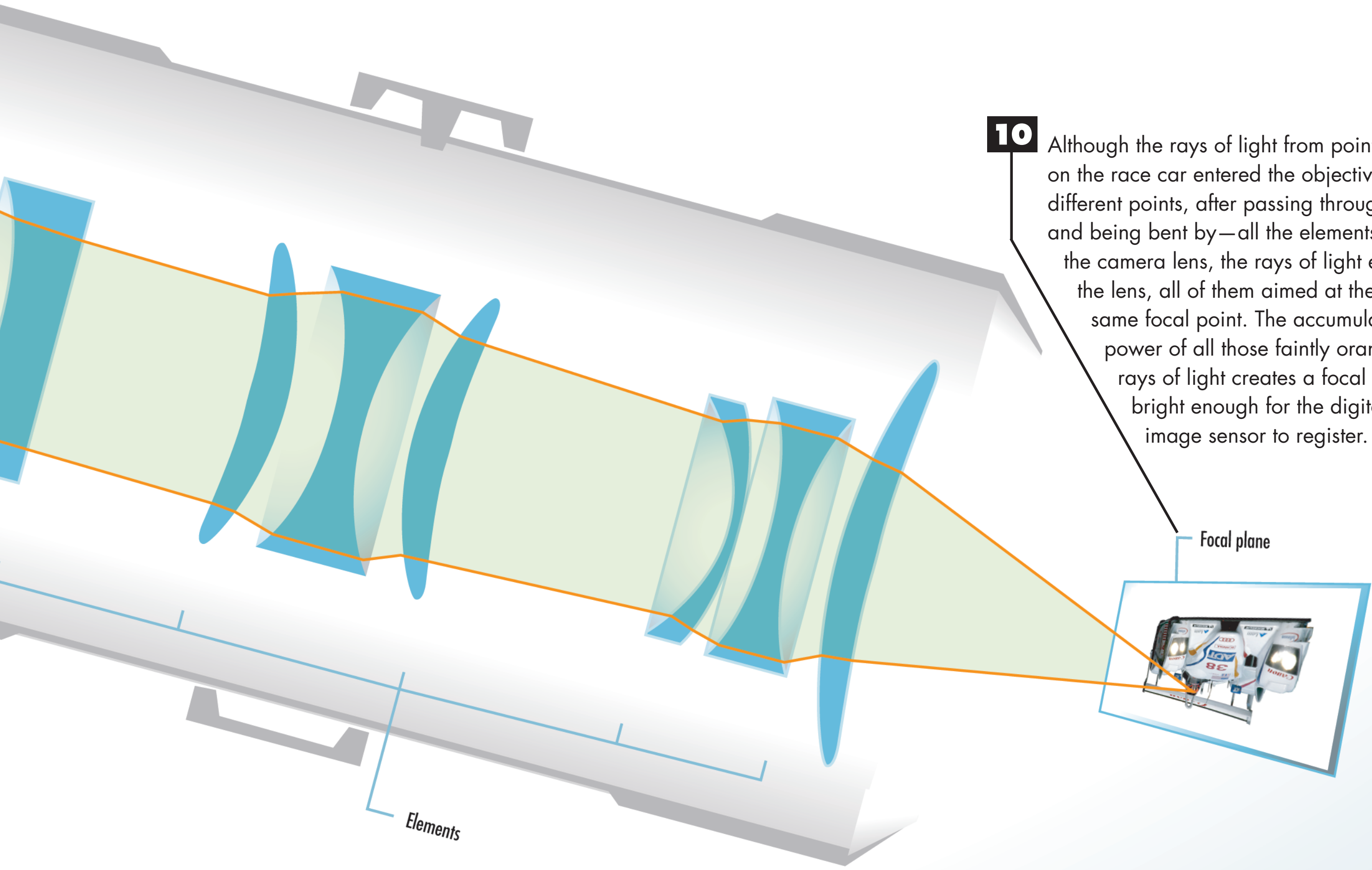
There are two basic types of **simple lenses**: positive and negative. A **positive convex lens** causes parallel light rays entering one side of the lens to converge at a focal point on the other side. A **negative concave lens** causes parallel rays to emerge moving away from each other, as though they came from a common focal point on the other side of the lens.



With these two basic shapes, optical engineers have engendered a variety of **multiple lenses**, which bond two simple lenses with a transparent glue. Simple and multiple lenses go into making **compound lenses**, which use different combinations of lenses to herd light rays into the corrals of film, eyes, and imaging sensors. Here are some variations on combinations of simple lenses, all of which can show up in the same camera lens.

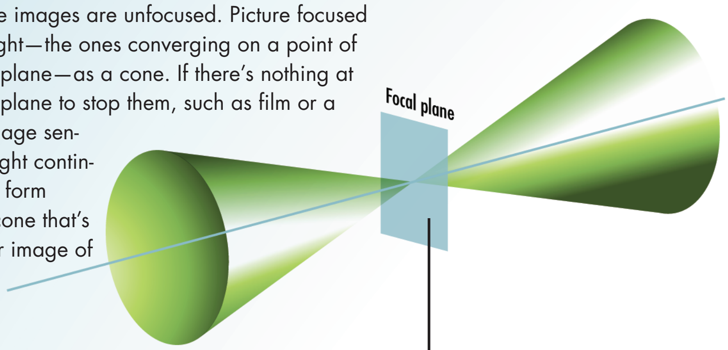
11 The same process occurs for every point on the car that can be "seen" by the camera lens. For each point on the race car, there is a corresponding focal point for all those light rays that bounce off those points. All together, those focal points make up a **focal plane**. The plane is where you find the surface of a digital imager or a strip of film. Light that is focused on that plane produces a sharp, focused photo.

10 Although the rays of light from point A on the race car entered the objective at different points, after passing through—and being bent by—all the elements in the camera lens, the rays of light exit the lens, all of them aimed at the same focal point. The accumulated power of all those faintly orange rays of light creates a focal point bright enough for the digital image sensor to register.

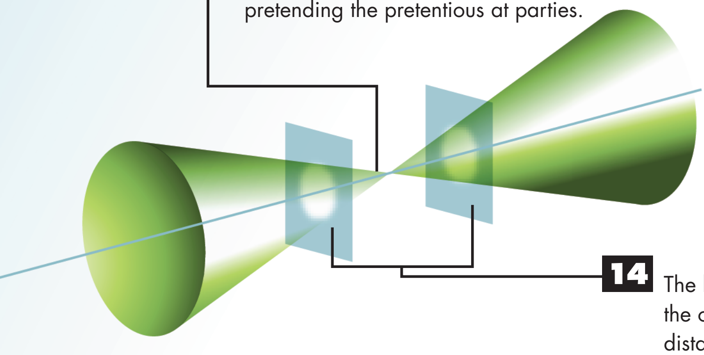


How Lenses Don’t Focus

12 You can more easily understand focus if you see why some images are unfocused. Picture focused rays of light—the ones converging on a point of the focal plane—as a cone. If there’s nothing at the focal plane to stop them, such as film or a digital image sensor, the light continues on to form another cone that’s the mirror image of the first.



13 The tips of the two cones meet at the same point on the focal plane. If an image sensor were located either in front or in back of the focal plane, the light would form not a point of light, but a circle. It would be **unfocused**. Because the rays of light would not be concentrated, the circle would be hazy, and dimmer than a focused point of light. The unfocused parts of the image, particularly when they contribute to an artistic effect, are called the **bokeh**, a great word for Scrabble and out-pretending the pretentious at parties.

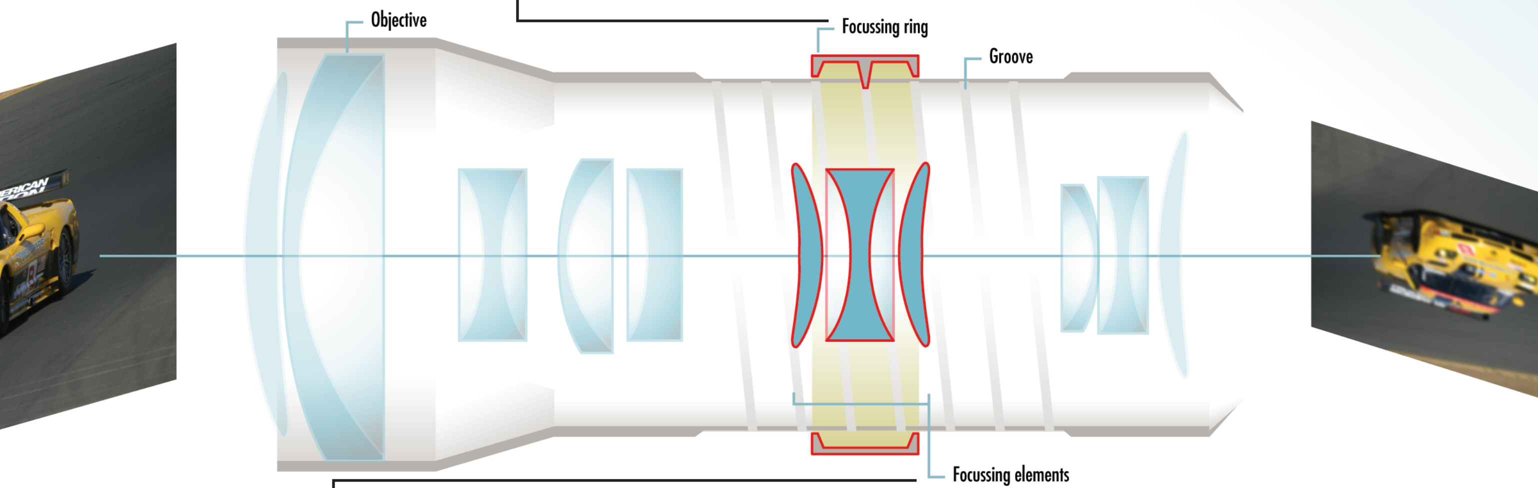


14 The location of a focal plane is partly the result of the optical characteristics of the lens and of the distance from the lens to the subject. Objects at different distances, some too close to the lens and some too far away, will be out of focus.

Broken Fixed Focus

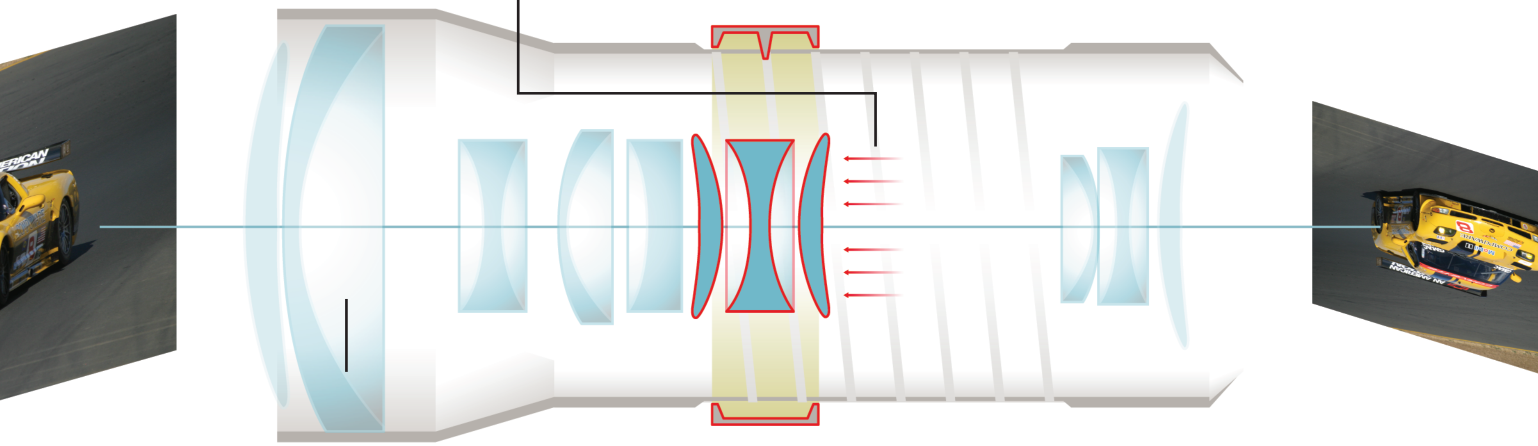
Some cameras have **fixed-focus** lenses that don’t require adjustments for each shot. This type of lens tries to get everything in focus from a few feet in front of the camera to infinity, but it’s a poor compromise. Nothing is in truly sharp focus, and you can forget about close-ups.

15 Rather than bring an object into focus by walking toward or away from it, the photographer turns a **focussing ring** that runs around the barrel of the lens. (Virtually all digital cameras also provide **autofocus**, which adjusts the lens without the aid of the photographer. That's the subject of the next two illustrations.)



16 Attached to the ring is a part of the lens's barrel with a spiral groove cut into it. As the groove turns with the focussing ring, it moves a pin from another part of the barrel. The groove-pin arrangement translates the focus ring's circular motion into linear motion.

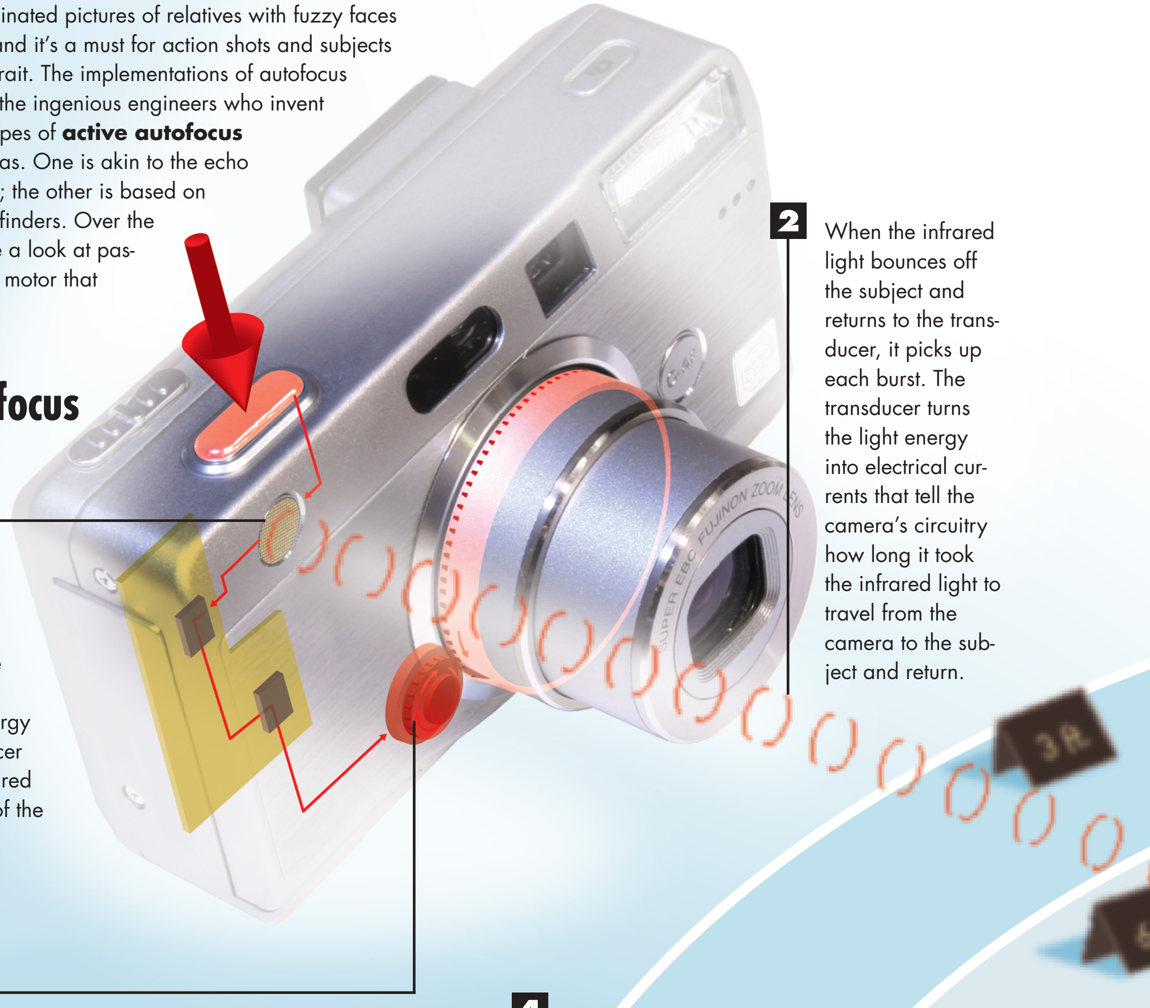
17 That motion, in turn, moves the lens elements toward and away from one another. The different distances among them change the optical effect they have on each other and shift the paths that light beams take as they careen through the lenses. When the light rays reach the digital image sensor, the optical changes now bring to focus a part of the scene that's closer or farther away.



How Active Autofocus Makes Pictures Sharp

Photographers can't always rely on automatic focusing because it's subject to the vagaries of any mechanism that cannot see but pretends it can. For the most part, autofocus has all but eliminated pictures of relatives with fuzzy faces and blurred birthday bashes, and it's a must for action shots and subjects who won't stand still for a portrait. The implementations of autofocus are as diverse as the minds of the ingenious engineers who invent them. We'll look here at two types of **active autofocus** found on less expensive cameras. One is akin to the echo technology of radar and sonar; the other is based on the triangulation used in rangefinders. Over the next few pages, we'll also take a look at passive autofocus designs and the motor that makes them all work.

Echo Active Autofocus



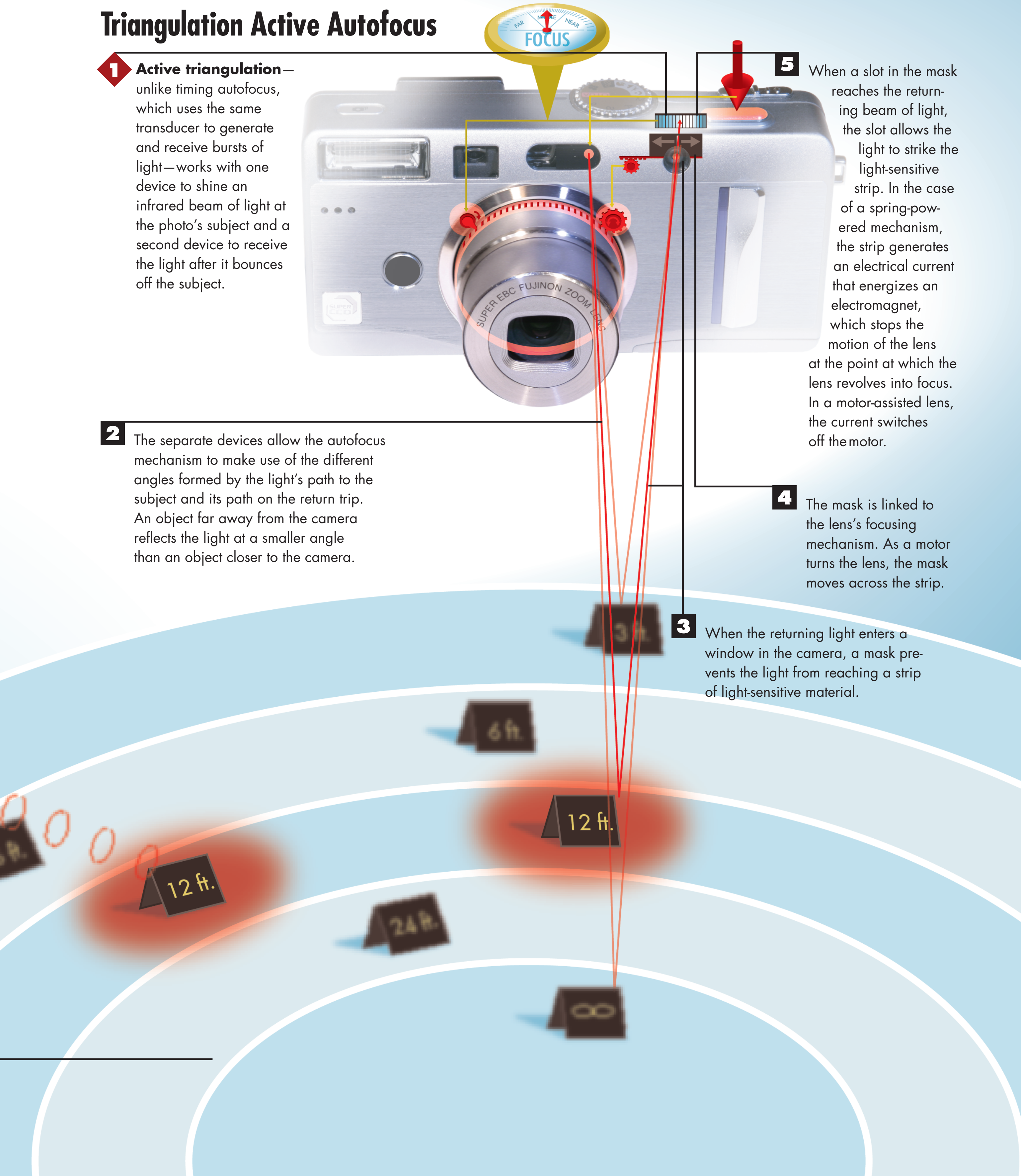
1 When a photographer presses the shutter button, it sends a burst of electricity to a **transducer** on the front of the camera. A device that changes one form of energy into another, the transducer generates volleys of infrared light toward the subject of the photograph.

2 When the infrared light bounces off the subject and returns to the transducer, it picks up each burst. The transducer turns the light energy into electrical currents that tell the camera's circuitry how long it took the infrared light to travel from the camera to the subject and return.

3 The round-trip time for the light takes a little under 2 nanoseconds for each foot from the camera to the subject. The measurement of that time goes to a microprocessor that controls a small motor built into the lens housing. The motor rotates to a position that's been calibrated to focus on an object at the distance determined by the infrared bounce.

4 This type of autofocus works with subjects no more than about 30 feet from the camera. With any subject farther than that, the returning light is too faint to register. In that situation, the camera sets the lens to **infinity**, which brings into focus any subject from 30 feet to the farthest star.

Triangulation Active Autofocus



1 **Active triangulation**—unlike timing autofocus, which uses the same transducer to generate and receive bursts of light—works with one device to shine an infrared beam of light at the photo's subject and a second device to receive the light after it bounces off the subject.

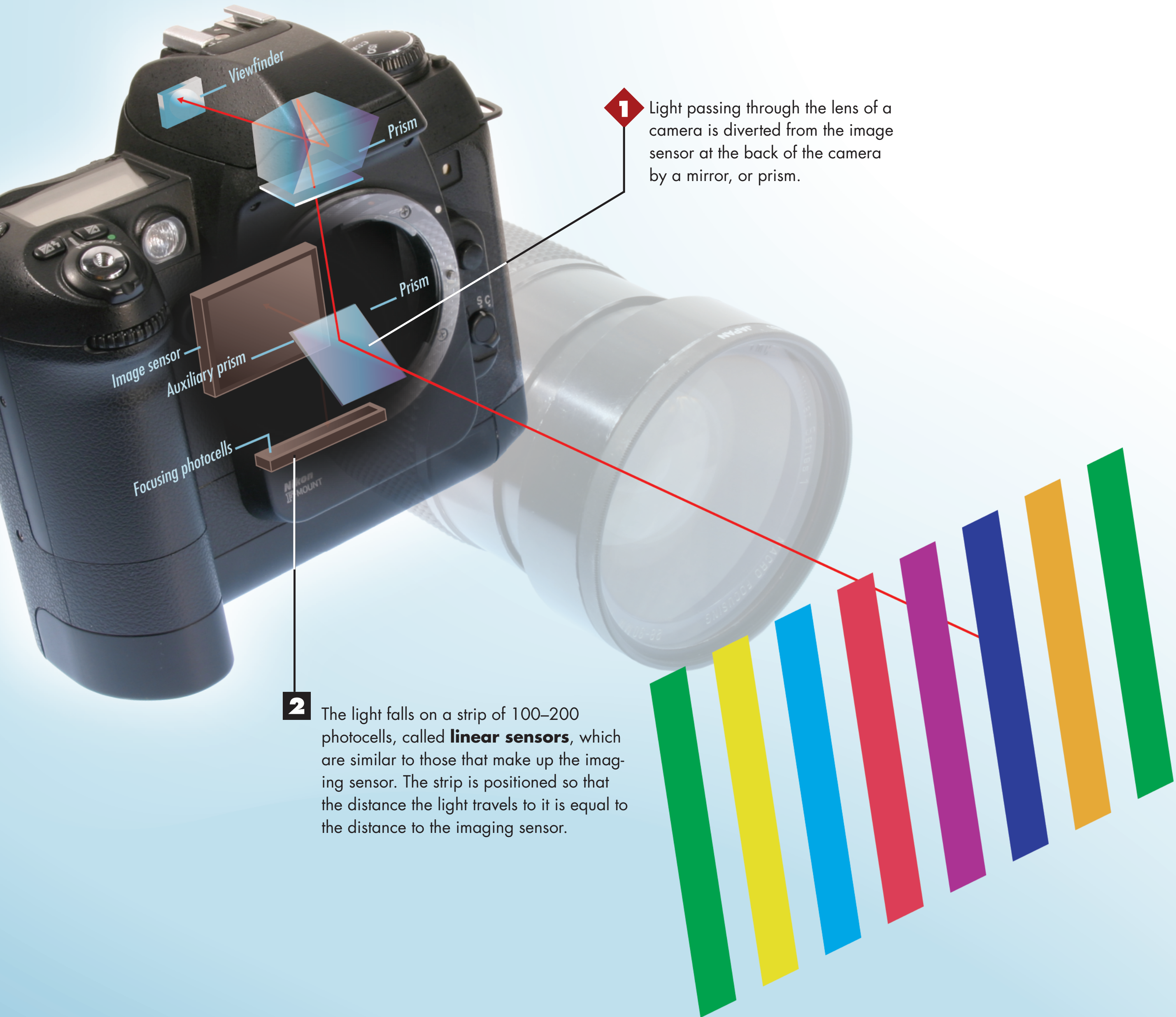
2 The separate devices allow the autofocus mechanism to make use of the different angles formed by the light's path to the subject and its path on the return trip. An object far away from the camera reflects the light at a smaller angle than an object closer to the camera.

3 When the returning light enters a window in the camera, a mask prevents the light from reaching a strip of light-sensitive material.

4 The mask is linked to the lens's focusing mechanism. As a motor turns the lens, the mask moves across the strip.

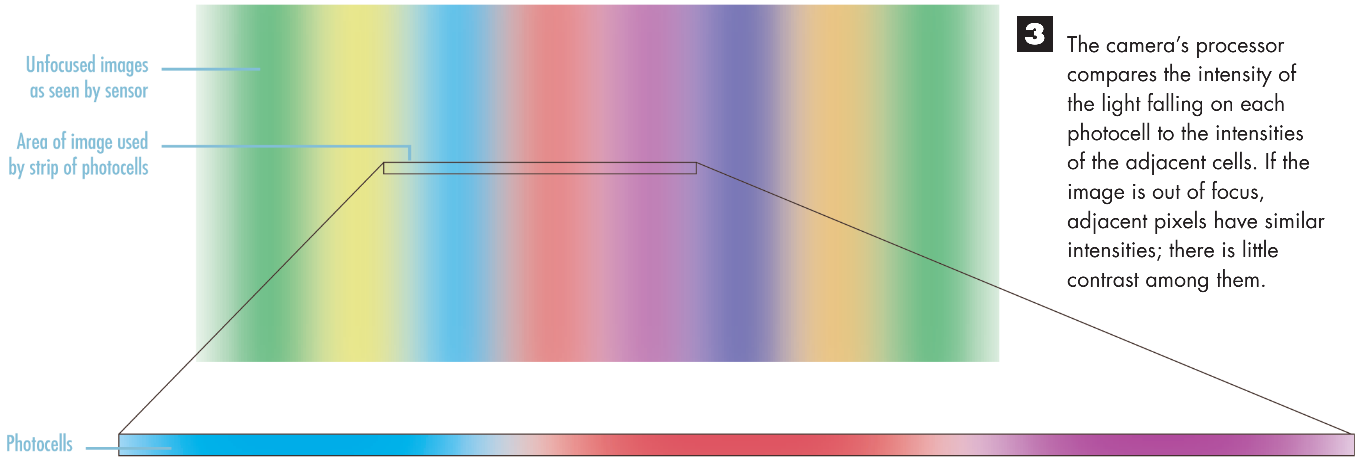
5 When a slot in the mask reaches the returning beam of light, the slot allows the light to strike the light-sensitive strip. In the case of a spring-powered mechanism, the strip generates an electrical current that energizes an electromagnet, which stops the motion of the lens at the point at which the lens revolves into focus. In a motor-assisted lens, the current switches off the motor.

How Passive Autofocus Sees Sharp and Fuzzy



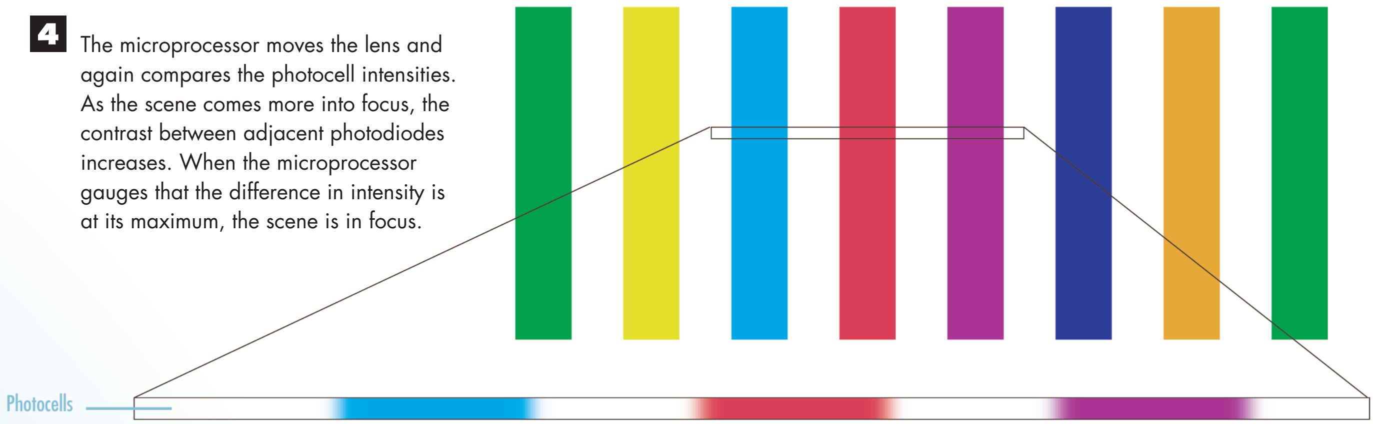
1 Light passing through the lens of a camera is diverted from the image sensor at the back of the camera by a mirror, or prism.

2 The light falls on a strip of 100–200 photocells, called **linear sensors**, which are similar to those that make up the imaging sensor. The strip is positioned so that the distance the light travels to it is equal to the distance to the imaging sensor.



3 The camera's processor compares the intensity of the light falling on each photocell to the intensities of the adjacent cells. If the image is out of focus, adjacent pixels have similar intensities; there is little contrast among them.

4 The microprocessor moves the lens and again compares the photocell intensities. As the scene comes more into focus, the contrast between adjacent photodiodes increases. When the microprocessor gauges that the difference in intensity is at its maximum, the scene is in focus.



Autofocus Limitations

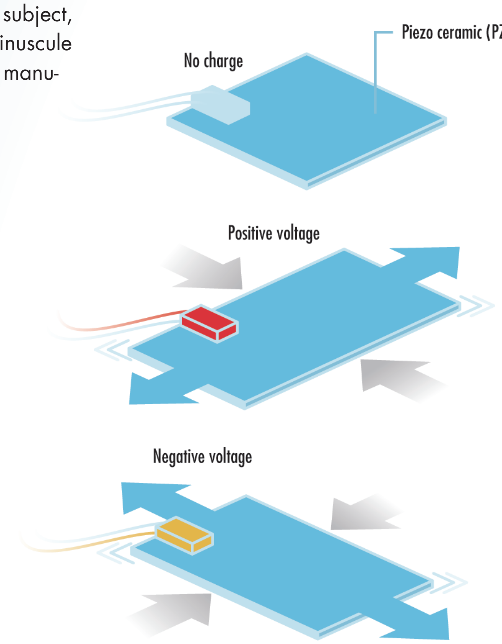
Both passive and active autofocus have advantages and disadvantages. Active focusing works at night and in dim lighting, but the infrared light can bounce off glass or mirrors, confusing the camera's processor. Using passive focusing, you aim through windows and there are no distance limitations beyond which it cannot work. But a blank wall or a scene devoid of straight edges, particularly vertical lines, throws some passive autofocus for a loop.

To minimize the effects of shooting through glass, the photographer can put the lens directly on the glass. The infrared light passes through the glass. Any light that bounces back makes the trip too quickly for the camera to use its timing information.

With passive autofocus, turning the camera 90° can give the camera the perpendicular lines it needs. Higher-end cameras take readings on both vertical and horizontal lines to avoid having to turn the camera. In scenes with little contrast, try focusing on an object elsewhere about the same distance away as your subject. Then keep the shutter button pressed down about halfway as you turn to frame your real subject. On some cameras, holding the button locks the focus until you press the button all the way to shoot your photo or until you release it.

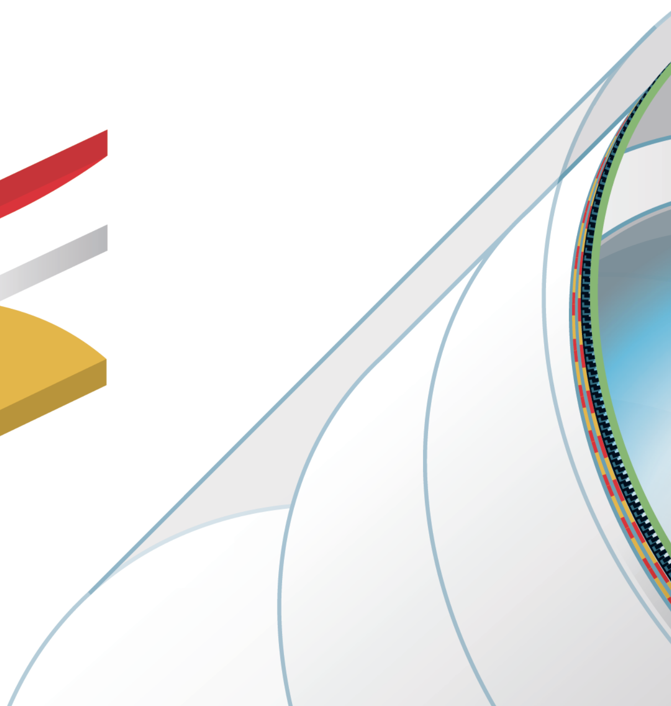
How a High-Tech Motor Moves the Lens

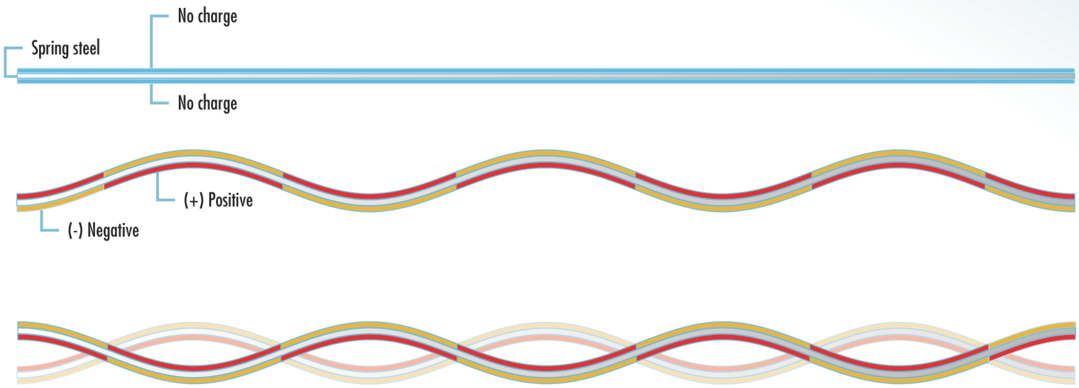
Any automatic focusing camera must have a motor to move the lens elements to bring the subject into focus. That's not a simple task when you consider how much speed and precision the camera requires and how little space the lens provides to hide a motor. As with the autofocus mechanisms devised to measure the distance from camera to subject, camera makers have come up with several ingenious ways to slip motors into minuscule spaces. We'll look here at a motor designed by Canon that many other camera manufacturers have adapted: the **ultrasonic motor (USM)**.



1 The ultrasonic motor is built on a phenomenon called the **piezoelectric effect**. The effect turns up in certain substances, such as the ceramic lead **zirconium titanate** (**PZT**). When an electrical voltage is applied to a strip of PZT, the ceramic expands in one direction and compresses in the other. If the voltage's **polarity**—the plus or minus charge—is reversed, the ceramic now compresses in the first direction and expands in the second.

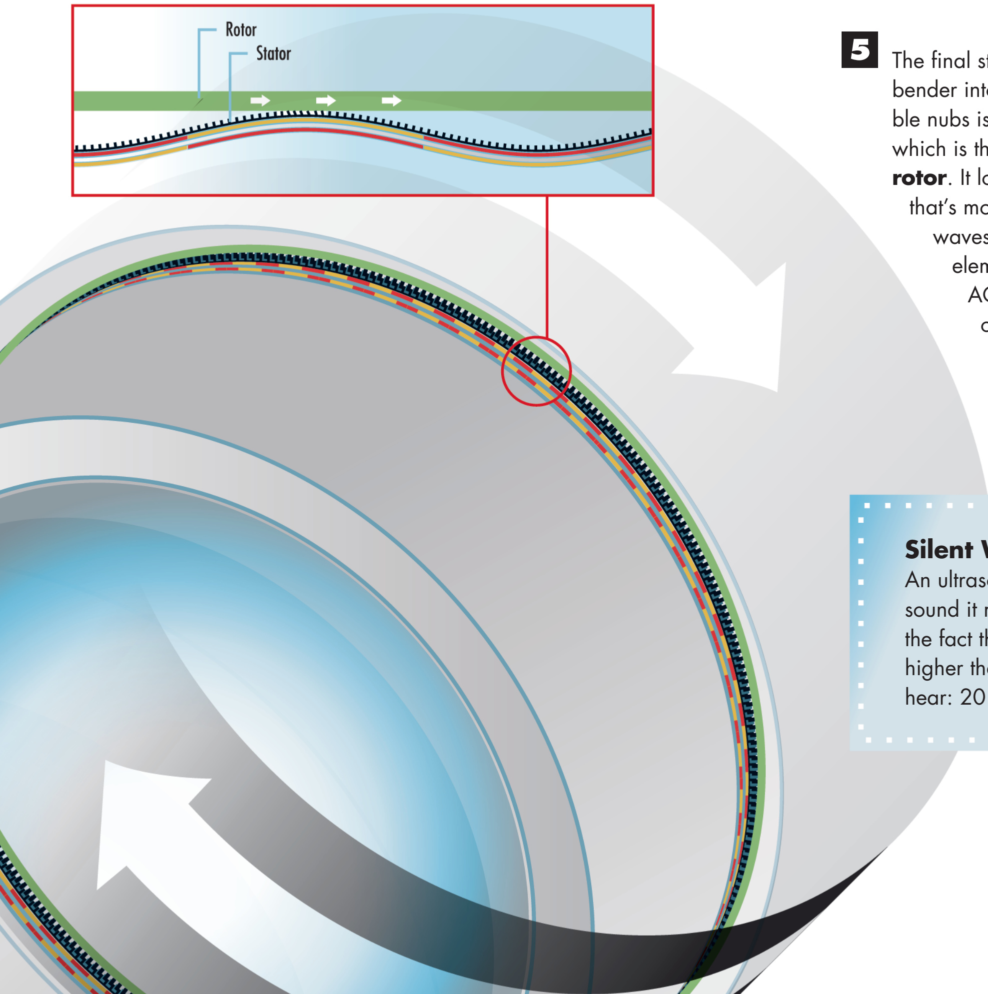
2 To create a **piezo bender**, or **bimorph**, PZT is bonded to both sides of a thin strip of steel spring metal. A positive charge is applied to one side and a negative charge is applied to the other side. Now the only way the ceramic can expand or contract is to bend the metal strip. The negatively charged side bends out, and the other, positively charged side bends inward. If the charges are reversed, the bimorph bends the opposite way.





3 The next step in creating a piezo motor, or **actuator**, is to send opposite charges to alternating sections of the bender. The charge on one section makes the bender bow out at the same time the opposite charges going to the sections on either side make them curve inward.

4 By using an alternating current that switches its polarity several times a second, the bender seems to ripple as the adjacent sections bend first one way and then the other, looking like waves that have up-and-down motion but no lateral movement. The amplitude of the combined waves is only about 0.001mm, but it's enough movement to power adjustments on even a weighty telephoto lens.



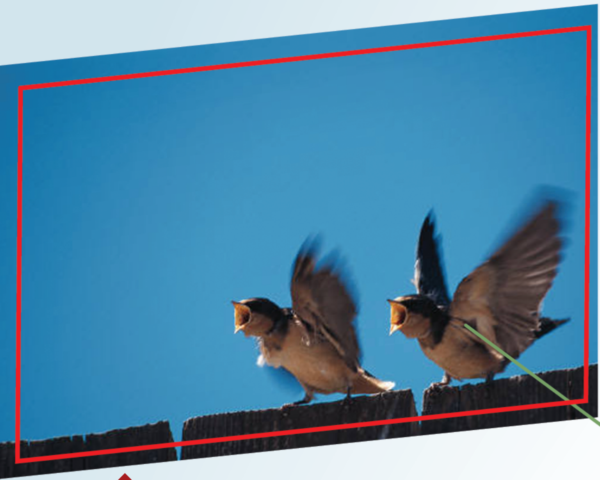
5 The final step in creating an ultrasonic motor is to mold the bender into a circle. An elastic material studded with flexible nubs is bonded to the circle's rim, creating a **stator**, which is the stationary part of a machine that moves a **rotor**. It looks like an endless caterpillar, a resemblance that's more than superficial. As the piezo strip makes waves, the feet press against the rotor, turning the lens elements. Each of the two layers of PZT has its own AC voltage that is slightly out of sync with the other. This allows the autofocus control to determine which way the rotor turns. When both springs are turned off, the friction between the stator and rotor holds the focus steady.

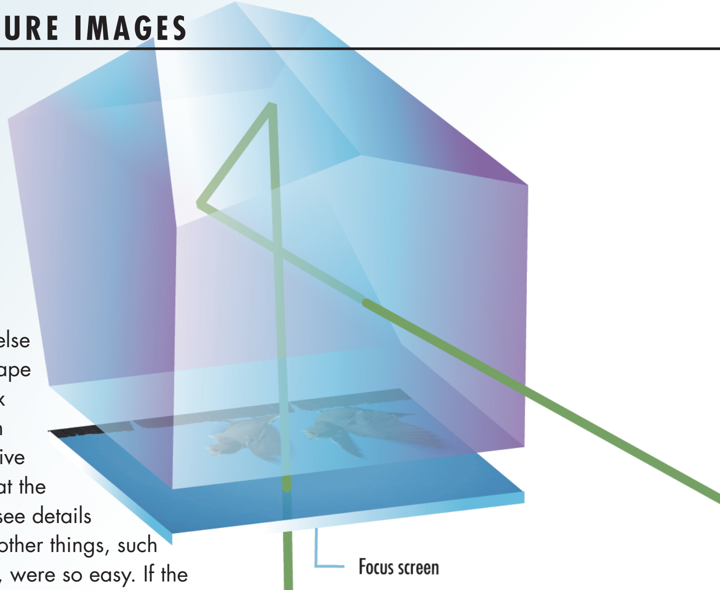
Silent Waves

An ultrasonic motor is not called that because of the sound it makes. It is virtually silent. Ultrasonic refers to the fact that the vibrations of the piezo waves are higher than the frequency of sound waves humans can hear: 20 kilohertz, or 20,000 vibrations a second.

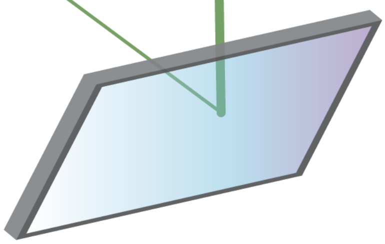
How the Eye Controls Autofocus

Few things are as easy as simply looking. You turn your eye, and everything else happens automatically. Muscles tug on the cornea to pull it into the proper shape to bring into focus whatever you're looking at. Other muscles contract or relax their holds on the iris so that the pupil shrinks in bright light or expands in dim light so the light-sensitive cells lining the retina at the back of your eyeball see details without strain. If only other things, such as focusing a camera, were so easy. If the true object of your photo isn't dead-center in your viewfinder, most cameras—digital or film—require you to do a sleight of hand with the shutter button, aiming at where you want it focused and then pressing the button halfway while you frame the picture for real. But some cameras, pioneered in the film days by Canon, have found a way to make focusing, literally, as simple as looking.

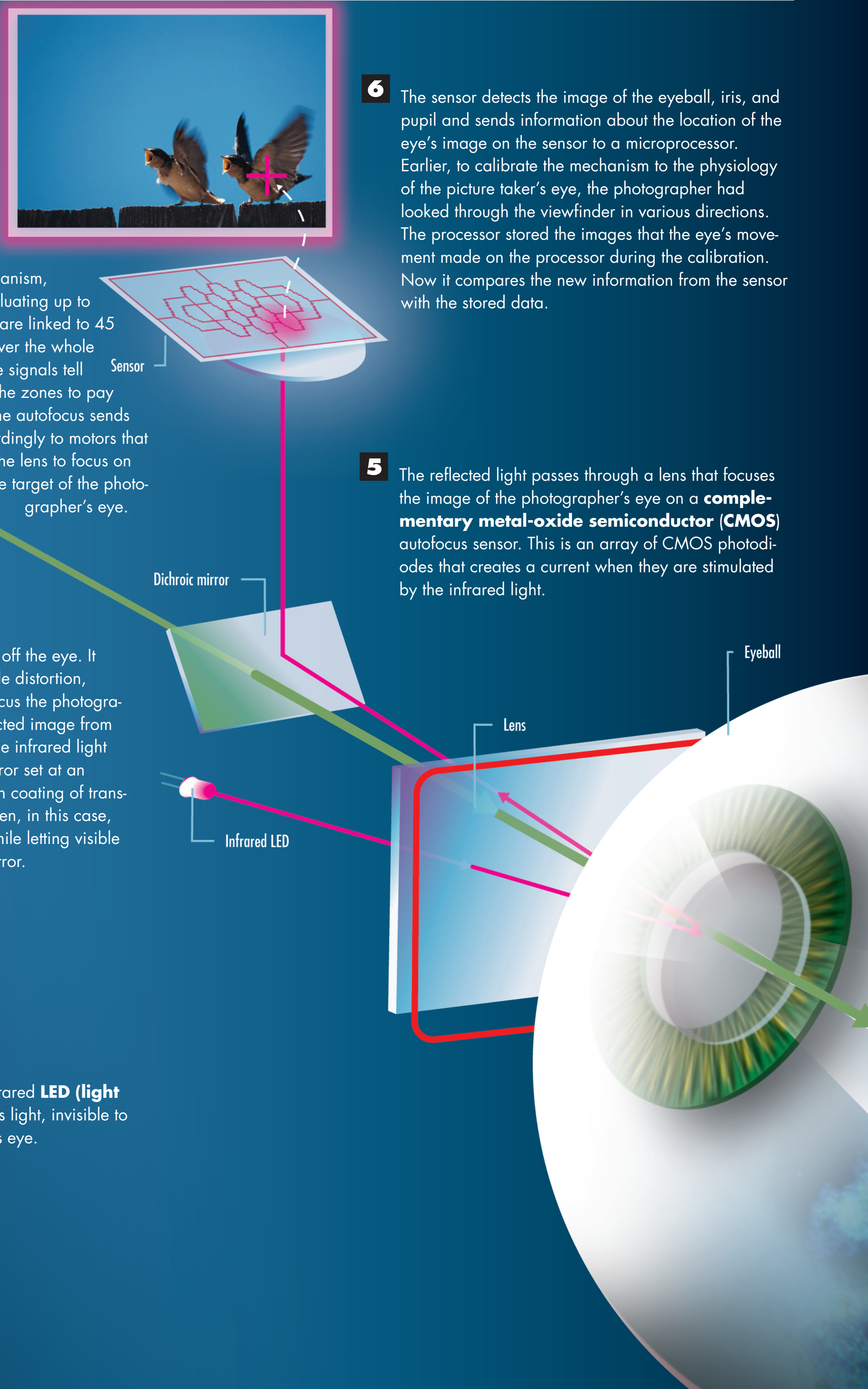




1 When the photographer puts his eye to the viewfinder, he sees an image that has come through the camera lens and been reflected up to a focusing screen, a plate of glass that has been ground to have a rough surface on one side. The rough surface catches the light so it can be seen, like the image on a rear-screen projection TV.



2 The photographer sees the image on the screen after it has been reflected up by a mirror and passed through a prism, which flips the reversed image from the screen 180° so the photographer sees the image in its proper orientation. A smaller mirror behind the main mirror sends the image to the autofocus sensor in the base of the camera.



3 At the same time, an infrared **LED (light emitting diode)** shines light, invisible to the photographer, on his eye.

4 The infrared light reflects off the eye. It passes, with no noticeable distortion, through a lens used to focus the photographer's vision on the reflected image from the ground glass. Then the infrared light reflects off a dichroic mirror set at an angle. A mirror has a thin coating of transparent metal oxides chosen, in this case, to reflect infrared light while letting visible light pass through the mirror.

5 The reflected light passes through a lens that focuses the image of the photographer's eye on a **complementary metal-oxide semiconductor** (**CMOS**) autofocus sensor. This is an array of CMOS photodiodes that creates a current when they are stimulated by the infrared light.

6 The sensor detects the image of the eyeball, iris, and pupil and sends information about the location of the eye's image on the sensor to a microprocessor. Earlier, to calibrate the mechanism to the physiology of the picture taker's eye, the photographer had looked through the viewfinder in various directions. The processor stored the images that the eye's movement made on the processor during the calibration. Now it compares the new information from the sensor with the stored data.

7 From that comparison, the microprocessor quickly determines what part of the image the photographer is looking at. It conveys that information to the camera's focusing mechanism, which is capable of evaluating up to 21 metering zones that are linked to 45 autofocus points that cover the whole frame of the picture. The signals tell the autofocus which of the zones to pay attention to, and the autofocus sends signals accordingly to motors that adjust the lens to focus on the target of the photographer's eye.