Basic Photography

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Introduction

This started as a series of emails that I sent to someone who had just bought a digital single-lens reflex camera (DSLR) who asked for advice on how to take good pictures with it. It's a collection of things learned reading and discussing photography with my friends and family (mainly my dad and my sister Alisa). It's meant to be short enough that someone would read it even if the last book they read voluntarily was Skinnybones in the 5th grade. (Just kidding, Griff. But I don't think I'm too far off the mark.)

While keeping it short, I've tried to go into the technical details that are most important if you want to understand what the devil all the settings do on an SLR if you just decided to leave the world of point-and-shoot cameras with their abysmal response times. This isn't to say that I think point-and-shoot users can't benefit from reading this, but with some cameras it's hard to change the settings I talk about here and with some you just can't change them. Forgive me for getting wordy where I talk about digital sensors. The main reason I spend so much time there is because I've seen that it takes some convincing to get people to use their camera's raw format instead using of jpegs. I think once you understand how digital sensors work, it's almost painful to use jpegs knowing what you're throwing away, especially with memory so cheap these days.

One more thing: just because I love SLRs doesn't mean that I don't like point-and-shoot cameras. I had a Canon point-and-shoot that I loved until I started trying to take pictures of my son. Frankly, I think they just don't cut the photographic mustard for kids since it's hard to tell a kid, "Hold that pose for a second while the camera gets ready to take the picture." Child photography with a point-and-shoot is more hunter-gatherer than agricultural. I found myself taking hundreds of pictures and keeping maybe ten or twenty. There is one more main reason I've never regretted upgrading to an SLR. The more controls you have and learn to use, the more creative possibilities there are. And being creative is what makes photography fun.

I should also thank Jo White here, who gave me feedback on what to change and add when I went from the emails into this compilation.

Feel free to distribute this. If I succeed in making just one photographer somewhere in the world just a little bit better, I feel like I will have failed miserably.

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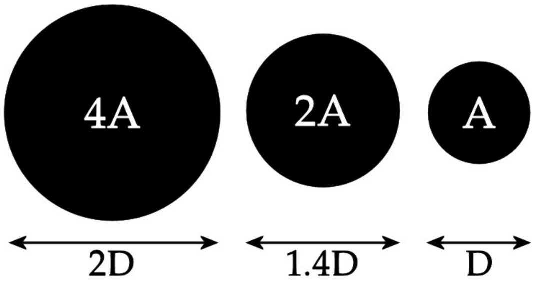
Lesson 1: Exposure

Exposure is how much light gets to the sensor inside a camera. The two settings that you can change to adjust exposure are the shutter speed and the aperture. If you let more light in by opening up the aperture, you can have your shutter open for less time and still get the same amount of light. On the other hand, if you use a smaller aperture you need to leave the shutter open for longer to get enough light to the sensor.

Aperture (or f/number)

The aperture is the size of the hole that lets light into a camera. The aperture diameter is given as a fraction of the focal length of the lens. For example, if you're taking a picture at a focal length of 50mm and you have an aperture of f/4, your aperture has a diameter of 50mm / 4 = 12.5mm. To make things easy, they used to have the aperture get bigger in steps (called stops) that would give you 2x as much light per stop. But since the amount of light gathered depends on area and not diameter, you only need an aperture that is 1.41 (the square root of 2) times as wide to get twice as much light, shown in the diagram below.



Doubling the diameter of the aperture actually gives you four times the area.

So this is how the f-stop series goes, starting at 1: f/1, f/1.4, f/2, 2.8, 4, 5.6, 8, 11, 16, 22, etc. Since you're making your aperture bigger, you get double the light when you move to the left one value in this list, and half the light moving one value to the right in the list since dividing by a bigger number makes the aperture smaller. Cameras nowadays split up the f/numbers even further, into steps that are 1/3 or 1/2 of a stop, so you've got intermediate values between those that I listed.

Those wicked huge lenses that you see at sports venues are so big because they'll be something like 400mm lenses with f/2.8 as their widest aperture. That means that wide open the aperture is about 400mm/2.8 = 150mm = 15 cm = 6 in! That's a lot of perfectly ground glass, and you pay for it (a 400mm f/2.8 will run in the $8000 range). But the reason it's worth it to them is they can then have very fast shutter speeds. In fact, sometimes people will talk about a "fast" lens, and what they really mean is the lens has a wide maximum aperture (small f/number) so that your shutter speed can be fast compared to using other lenses.

An $8,500.00 thing of beauty

Besides changing how much light comes in, the aperture also controls how much of your field of view is in focus: the smaller the aperture, the greater the range of distances that will be in focus. This is easy for people with bad eyes to understand because when they need to see something without glasses they squint, making the aperture of their eye smaller (now it's not the pupil, it's the little space between their eyelids or eyelashes that's letting light in). In fact, if the aperture is small enough, everything will be in focus (but then you deal with fuzziness from diffraction, which is, as they say, a "whole nother story"). Try it with your thumbs and pointer fingers—make a tiny hole and look through it and you'll see that everything is in focus. This is the idea behind pinhole cameras, which don't even need a lens.

Even things that are in focus won’t be perfectly sharp since the lens won’t be shaped perfectly. Lenses are shaped best close to the center, so using a smaller aperture will usually give you better sharpness. One more thing to note is that there are differences in lenses. You can generally get a sharper image from a wide-aperture lens stopped down to f/4 than you can from one that has a maximum aperture of f/4 since the center of the wide one is more likely to be shaped right.

To every aperture there is a season (and a time to every shutter speed under heaven): a time for small apertures (large f/numbers)—generally landscapes and group shots—and a time for large apertures—portraits for aesthetics, and indoor or action shots where you need to collect all the light you can.

Shutter speed

Photographers talk about "stopping motion," and what they mean is that if you leave the shutter open for too long, then something moving in your frame will leave a streak in your pictures or at least make the moving thing look blurred. To have something look sharp you want to just capture one instant, and how long the instant will be is your shutter speed. Shutter speed is usually given in fractions of a second (since it's rare for anyone except astronomers to take pictures longer than 1 second): so a shutter speed of 60 means the shutter is open for 1/60 of a second. You can also talk about stops in shutter speed, but it's simpler than with f/numbers since doubling the time your shutter is open just doubles the amount of light you let through, so to change the shutter speed by one stop you double it (or halve it). Your camera will use the same increment for shutter speeds you can choose as for apertures you can set (usually 1/3- or 1/2-stop increments).

For most action shots you want a shutter speed of 400 or higher, but sometimes you want a longer shutter speed. The pictures of waterfalls that look like the water is actually flowing are taken with long shutter speeds (about 1 second). To have the picture still look good with the shutter open for that long, you need to hold the camera very still so you need to use a tripod or at least set the camera down on something.

Leave the shutter open for a while, and moving things get blurry whether you like it or not.

Actually, that brings us to another important thing: it's not just subject motion that you want to stop—there's also camera motion. If you've ever shot a gun, you know that it's impossible to hold something completely steady. If you've shot a gun with a scope, which essentially magnifies your gun sights, you know that as you zoom in your body's shakiness is even more apparent. You can improve things by resting your gun on something steady or even changing your posture. One of the worst positions is both hands out in front of you holding, say, a handgun. With cameras, it's the same. No matter how steady you try to be, your body is always making minute twitches that will ruin pictures with a long enough shutter speed. How long is "long enough?" That depends on how steady you are and your position (holding a point and shoot out in front of you like a handgun is, like with guns, one of the worst positions—even holding the camera against your head helps). A conservative rule of thumb for most of the smaller-frame digital SLRs (ones with sensors called APS-C) is to always have a shutter speed that is 1/2f or faster (if you can afford a full-frame SLR, use 1/f instead). For example, if you're taking a shot at 50mm you want a shutter speed of at longest 1/100. This is conservative, though, so you have to experiment to see what fraction of pictures turn out for you at slower speeds and then you can decide how close to the edge you want to live.

The best way to reduce camera shake is to put the camera on a good tripod, but lots of new cameras and lenses also have other ways to reduce it. There are two main types of image stabilization: optical and sensor-based. Canon and Nikon favor optical image stabilization (their sytems are called IS and VR, respectively) and most of the other companies favor sensor-based stabilization. With optical image stabilization, there is a little accelerometer in the lens (like the motion sensor in a Wii remote) that monitors the way the lens is shaking. That information is used to actually move one of the lenses inside the lens to keep the image on the same spot of the sensor while the shutter is open. The sensor-based IS is similar, but instead of moving a lens, the sensor itself is moved around to counteract the shake. The most important thing to remember about any image stabilization system (including tripods) is that even though you can reduce camera motion, it doesn't do anything about subject motion. This is why pros will still buy really fast lenses: if you need fast shutter speeds, IS can still be useful but the bottom line is you need a wide aperture (or fast film, and that's the next thing I'll write about).

Lesson 2: Sensors and File Formats

There are really two kinds of sensors that you can use for photography: electronic (digital cameras) and chemical (film cameras). Both depend on the fact that light has energy that can be released when the light is absorbed.

Film

I don't know very much about film. It never made too much sense to learn about it since I got into photography after digital photography was pretty mature, but I'm sure they have a really nice Wikipedia article about film if you want to learn more than I say here.

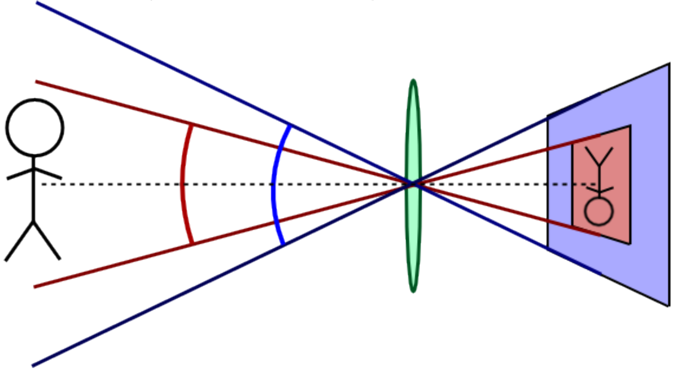
Basically, when light hits certain molecules in the film, it changes them so that after you put the film through various chemical baths during development, light of certain colors can or can't pass through the film. So the number of the light-sensitive molecules that change in a certain area during exposure leaves a record of how much light was absorbed by that area. Then after developing the film, that information can be extracted by shining light through the film again.

The standard size film for single-lens reflex cameras is 36mm x 24mm (35mm film).

Digital sensors

Digital sensors will usually be referenced to standard 35mm film by a crop factor, which is (aptly) the factor that they crop each dimension of the sensor relative to full frame. Full frame digital sensors are the same size, so their crop factor would be 1 (you get the same field of view as with a 35mm film SLR). Full frame sensors are still very expensive to make, so they're only on high-end SLRs, and a big part of the price difference is from that alone. Most SLRs' sensors have a crop factor of about 1.5, which means that full frame sensors are half again as big on each side. This might not sound like much but it means that a full frame sensor has a little more than twice the area of one with a crop factor of 1.5.

Changing the size of the sensor also changes the field of view—how much of the outside world your sensor can see at a given focal length. Imagine looking outside a window and the window shrinks. Now you see less of the outside world. Shrinking the sensor size is basically the same thing.



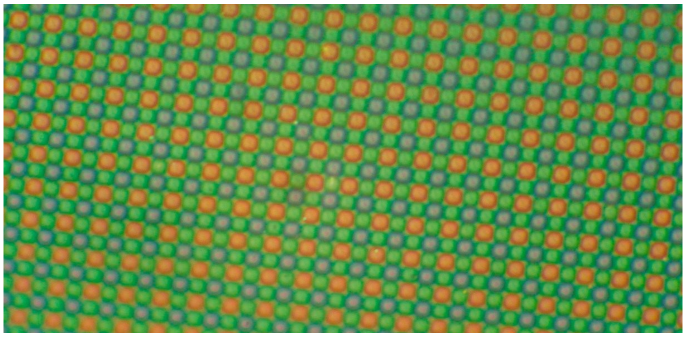
A bigger sensor (blue) gives you a bigger angle of view for a given lens focal length than a smaller one (red).

So what actually happens when light hits the sensor? The sensor is an array of tiny photodiodes (diodes only let electrical current go one way) with the cute name of pixels (short for picture elements, which sounds much too formal). When light energy gets absorbed in the sensitive area of a photodiode, the energy is converted into making mobile electrons (current), which then flow to one side of the diode. You count up the number of electrons that got freed during exposure and that tells you how much light got absorbed at that pixel.

If only it were that simple. You've now got three major issues:
(1) How do you count the electrons?
(2) How do you get color information if light of every color can create electrons at the pixel?
(3) How do you change the list of counted electrons at each pixel into something that makes sense to our eyes?

To solve (1) you have to add little wires and electrical circuits to the photo diodes. That can be done, but all of it uses precious real estate that you could be using to collect light. Your sensor is less and less sensitive the more extra stuff you put on. To try to minimize that problem, they actually put microlenses over each pixel to concentrate incoming light onto the sensitive photo diode and not onto the dead zone with the wires and amplifiers. This is one of the major advantages large sensors have over small ones: the bigger the area of each pixel, the more light-gathering each pixel can do. I would usually take a 6 megapixel picture from a large DSLR sensor over a 14 megapixel picture from a point-and-shoot camera with a small sensor any day.

For (2) they do some tricky things. Most sensors filter the light coming into each pixel so that only light of one color gets to the photo diode for that pixel (the only counterexample I can think of is the Foveon sensor, which has layered photodiodes that get different amounts of light of each color based on their depth in the sensor. It has its own set of problems, though). The standard pattern of color filters over the pixels is called the Bayer pattern.



This is the pattern that lets the camera record color at different places on the sensor.

Since our eyes are most sensitive to green light, there are twice as many green pixels as red or blue. Let’s discuss one pixel where the filter above it only lets in green light as an example. If that particular pixel is only counting electrons made by green light, how do you get all the other colors that should be in the photo at that pixel?

It turns out that you can make almost all the colors our eyes can see by mixing different combinations of red, green, and blue light. Each pixel in a monitor or TV has three tiny spots, and you get different colors by changing the relative intensity of those three spots. So if you know how much red, green, and blue light should be mixed in, you know which color the pixel should be in the photo. Sometimes you'll hear people talk about the red, green, and/or blue channels, and those values for each color are what they mean. To get the red and blue values for the green pixel in our example, a computer chip in the camera will interpolate: it just averages the closest blue pixels and the closest red pixels to get the complete RGB (red, green, blue) value for that pixel.

That's not the whole story, though, and we finally come to (3). When our eyes look at something that gives off twice as much light as something else, we see it brighter, but not twice as bright. You'll see this if you sit by a window and check what your camera's automatic exposure does looking out the window and compare it to what it does looking in. (Since most people aren't interested in actually doing things like this, I'll do it for you.) I pointed my camera inside and then, without changing the aperture, I pointed it outside the door. The shutter speed for proper exposure changed from 1/100 to 1/2500, so right now my camera is telling me there is 25 times more light outside than in, but it looks like maybe 3 times brighter to me. So who's right? We both are. To describe this, you would say that eyes have a nonlinear response to light—all that means is that the response doesn't follow a line: doubling light intensity does not double the perceived intensity. Digital sensors are almost completely linear: twice the light means twice the electrons that get counted. So to make the pictures look right to us, the values the sensor records have to be stretched. This is also done by a computer in the camera. Or, you can save exactly what the sensor sees and have the stretching done by your own computer (it’s called a raw format and I'll get to it in a minute).

ISO Speed

So besides controlling the exposure of your sensor, there is another setting on your camera that lets you decide how sensitive the sensor is to light. They call it the ISO sensitivity, and it's a throwback to the days of film, when people would classify films based on how much exposure they needed to be properly exposed. The higher the ISO speed of the film, the more sensitive it is to light, and the numbering is conveniently chosen so that ISO 200 is one stop more sensitive than ISO 100 (it needs half the light ISO 100 needs), ISO 400 is two stops more sensitive than ISO 100 (it needs 1/4 the light ISO 100 needs), and so on. In digital cameras, what you actually change is how much you amplify the number of charges made during exposure before reading it out.

So set your camera to the highest ISO and then you don't need fast lenses or long exposure times, right? Well, it's not a free lunch. The more you amplify the signal, the more you amplify the noise from each pixel. It's about the law of large numbers: each photo diode doesn't even come close to absorbing every photon (light particle) that goes through it (it's a 25% kind of thing), and if you give it enough photons to get a good feel for how much light there is, you get about the same number of electrons for a given amount of light every time. But if there are only a few photons to catch, the value from one photo to the next (or from one pixel to the next) will probably be wildly different. Amplify those differences and...well...yuck.

The general rule is to use higher ISO only when you have to, and use the smallest possible ISO in every situation.

File formats

I mentioned before that you don't always need to have your camera convert the raw data from the sensor's electron counting into something reasonable. Some cameras support a raw format where you just store the red, green, or blue value (but not all three) from each pixel, as captured. I'll talk more about raw files in a minute, but for now I'll mention the other types of files so we can compare them.

JPEG or JPG

Jpeg files are by far the most common these days. They are a compressed format, which means they don't actually store the RGB values for each pixel, but through some complex math, it stores the way to get pretty close to each pixel's RGB value when you reverse the process. Jpegs are 8-bit, which actually means that the red, green, and blue channels are each broken down into 256 levels (or 2^8, hence 8-bit) before the compression. Somewhere black on your image might have RGB values of [12, 7, 11] and a pixel in the sky might be [50, 85, 220]. The major advantage with jpegs is that they make files so much smaller.

TIFF or TIF

Tiff files can be either 8-bit or 16-bit (256 levels per channel or 65536 levels per channel). There are compression schemes for tiff files, but they don't compress files nearly as much as jpeg compression does. Tiffs store an RGB value for every pixel, so tiff files get huge: 16 bits is two bytes, and with three channels, that's 6 bytes per pixel. A 10-megapixel 16-bit tiff with no compression, then, will set you back about 60 megabytes, and an 8-bit version will be half that. Yikes. You can see why tiffs are usually used in commercial settings where even the slight loss of quality you get with jpegs is unacceptable.

RAW (CR2, NEF, DNG, etc.)

Finally, back to my favorite file type and the one that makes the most sense to me for backups: raw. Even if your camera's sensor reads 12 bits (4096 levels) for each pixel, you can have a raw file that is smaller than an 8-bit tiff because you only keep one channel per pixel—the file is stored before the interpolation of the reds, greens, and blues. For example, that same 10-megapixel picture in uncompressed raw format will have 1.5 bytes per pixel, and you get a 15 megabyte raw file. That seems like a lot, but you don't throw away any of the information the sensor records, which can come in handy if you need to change your pictures later (and let's face it, we often do). My personal opinion is that if you have a camera that supports raw capture, you should always use it so information that might be useful someday isn't thrown away. It can't work miracles on really bad pictures, but it can help and it's only slightly more work to process raw, anyway.

For the still-curious

A white paper on how you go from linear capture from a digital sensor to something logarithmic like your eye would see. [http://www.adobe.com/digitalimag/pdfs/linear_gamma.pdf]

A really good article on shooting raw. [http://www.bythom.com/qadraw.htm]

Lesson 3: Focus and Metering

Sometimes people see me with my camera and ask me, "So what's the big deal with a camera like that? What can it do that my point and shoot can't do?" The simplest answer is almost nothing. But everything that they do, a single lens reflex does better and/or faster than a point and shoot, and in my opinion the price difference (twice as much, more or less) is worth it if you're really interested in photography. For example, SLRs have bigger sensors, better available lenses, more artificial lighting options (flashes), more sophisticated metering, and quicker and more accurate autofocus. All of these things add up to more consistently good images, even if the extra controls on the SLR can be a bit daunting if you're used to a point and shoot camera. This lesson will discuss a couple of those differences, specifically focus and light metering systems. The next lesson, which will be on light and color, will cover flashes as part of that.

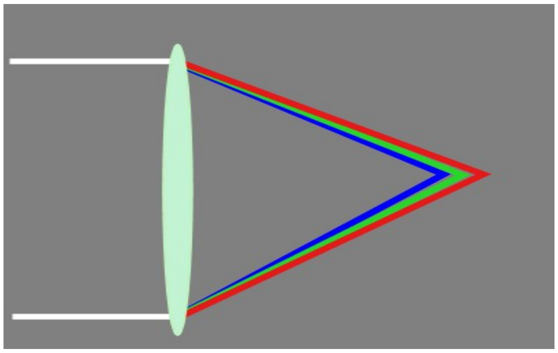
Focus

I think the best way to start a discussion of focus is with a bit of physics (an admittedly biased view). Lenses change the direction of light that passes through them. So how do you change the direction? There are two ways to do it: refraction and reflection. Reflecting lenses (ones based on mirrors) are rarely used in general photography because of the way that out-of-focus objects look, but since astronomers are almost always looking at things that are basically infinitely far away, they make sense for them and are used almost exclusively mostly because they have no chromatic aberration (see below), but also because they offer size, weight, and cost benefits.

Refraction is just the bending of light as it crosses the boundary between two areas where its speed is different. What?, you say (or maybe not). The speed of light isn't constant? What about relativity and Einstein and all that? It turns out that the speed of light in vacuum is constant but when it goes through something like air, glass, or water, its interactions with the matter slow it down. But why would changing speeds have anything to do with changing directions? I'll use my favorite analogy to explain it. Let's say you're driving a dune-buggy through a parking lot that is surrounded by sand. To make things simple, let's assume that it's only front-wheel drive. If you drive straight toward the pavement-sand boundary (perpendicular to it), when you get to the boundary your buggy keeps going in the same direction, only slower because now your wheels are going through sand. Your dune buggy is like the light; the pavement could be air, where light goes fast; and the sand could be glass, where light travels more slowly. Well, driving straight at the boundary isn't the most enlightening situation, so let's say next time you drive toward the boundary at an angle. This time, one of your wheels hits the sand first, and that side of your buggy slows down while the other side keeps going fast, so your buggy turns toward the side that hit first. It's just the opposite for the reverse direction: come toward the pavement from the sand at an angle and the wheel that hits the pavement first will pull that side of the buggy forward, turning the buggy away from that wheel.

If you know how much a material (like glass) bends light, you can get a lens to focus light that's coming from one side onto the sensor in the camera by making the lens the right shape so that it bends it just how you want it. By moving the lens closer or further away from the sensor, you can bring one plane (it's mostly a plane, anyway) of your vision into focus, and the further things are from that plane, the more blurry they'll be. How fast things get blurry as you move away from the focal plane is controlled by the aperture (with smaller apertures, a bigger range of things is in focus—see lesson 1), and the range where things are reasonably in focus is called your depth of field.

Nature throws us a curve, though, and makes it not quite as simple as just shaping a lens right. Light of different colors has different speeds in any medium except vacuum, so generally red light will get bent less than blue light because red light will go faster than the blue. It's the phenomenon behind splitting white light into colors with a prism and also the one behind rainbows, where the water droplets act like reflecting prisms. It's pretty, but it makes trouble for lens design because a lens will have a different focal length for each color (see the picture). They call this chromatic aberration (color mistakes). Have you ever wondered why you would need to have something like 5, 10 or maybe even 20 elements (lenses) just to make one lens? A big part of the answer is to correct for this chromatic aberration, and they use all kinds of exotic materials and different lens elements to try to control it.



Since light of different colors gets bent different amounts by a lens, a single lens would have very bad chromatic aberration (color mistakes).

Autofocus is a pretty recent thing (30 years or so old). There are two types of autofocus systems that are generally used now: contrast detection systems and phase detection systems.

Contrast detection is what most point and shoot cameras use. When you push the shutter button, the camera will actually move the lens back and forth and find where the contrast is best in the area where you want it to focus—it just looks for the sharpest edges in that area. The main disadvantage with this is that you have to sit and wait while the lens gets moved to find the best focus, and that can take a while (meanwhile, your child has stopped smiling and started picking his nose or has closed his eyes).

Phase detection I don't really understand (you've got to have something to learn about, right?), but the main idea is that you split light from opposite sides of the lens, and based on how it lands on the autofocus sensor the camera (usually) knows both how far out of focus the lens is and in what direction you need to move the lens to bring it in focus. The bottom line is that it's much faster than contrast detection.

Metering
If you get the exposure wrong in either direction, you've got problems on your hands. If you underexpose and then try to increase the brightness of the picture, at best your shadows will have extra noise and at worst your whole image will have extra noise. If you overexpose, you can saturate your photodiode at pixels in highlight areas (the analog to digital converter has a maximum, and if it gets a value higher than its max, it still just reads the maximum value). That means that highlights lost are lost forever. Before you go taking darker pictures, though, know that there are times when you don't care so much about blown highlights and times when you do (one that comes to mind is detail on a bride's dress—it's really better to keep that information if possible).

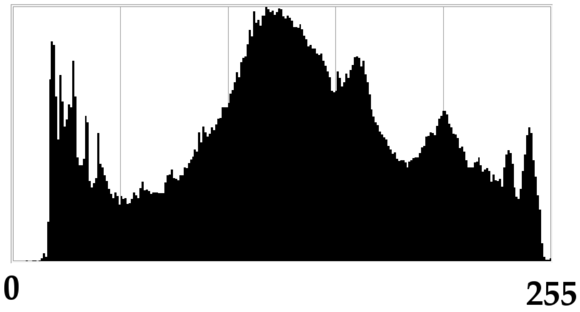
Since our eyes are so good at adjusting to different lighting conditions to give reasonable results almost anywhere we would need to see, you really need an objective witness to help decide how much to expose your sensor. Back in the day, this meant either being able to put a light meter where your subject was and then choosing your exposure based on how much light it would reflect or pointing a directional light meter at your subject and setting exposure based on the actual light coming off the subject.

Pros still set flash output with light meters, but really most metering has gone into the camera. With a point and shoot, they use the sensor itself as a meter, but SLRs have them up in the viewfinder housing. With most cameras you choose how you want your camera to meter: usually the choices are a spot (called, aptly, spot metering), a bigger spot (center-weighted average), or a "smart mode" where the camera guesses what kind of scene it's looking at and sets exposure based on what it thinks is important (matrix or multi-zone metering). My opinion on them is that if I shoot raw, matrix metering gets me a usable exposure 97% of the time, but there are times when I prefer the other options because they're easier to predict—specifically when I want to hold detail in a subject that is either very dark or very light. What if (heaven forbid!) you want to hold detail in both highlight and shadow (think black tux and white wedding dress—incidentally, I'd favor keeping highlight detail here)? This is one time when I would say if it's possible don't shoot jpeg whatever you do because they are so unforgiving. Even if you can only shoot jpeg, the beautiful thing about digital is the instant feedback. If you were doing a wedding with wrong technique with film (say you blew the highlights of the wedding dress in every picture), you'd never know until it was all developed so that could be a huge problem. With digital, you might shoot five before you checked if your metering was right and adjusted for the mistake.

Histograms and Exposure Compensation
There are some situations where the camera won’t choose the right exposure no matter what metering mode it’s in. The camera’s metering system tries to keep things not too bright and not too dark. This means that if you’re taking a picture of a scene with a lot of dark things or a lot of bright things, you have to tell the camera or it will get the exposure wrong.

You tell the camera to adjust its metering with a setting called exposure compensation. It's given in exposure value (EV) steps which are exactly equal to the stops I talked about in the first lesson. A setting of +1 EV is one stop brighter than usual, so the camera will get twice the light it normally would, either by keeping the shutter open twice as long, or making the aperture 1.4 times bigger. To make white snow white, tell the camera to overexpose (with a positive exposure compensation). To keep things dark in a dark scene, tell the camera to underexpose (with a negative exposure compensation)

So do you believe the unfeeling (but well-programmed) camera got the exposure right? You can get a feel whether it's close by looking at the image in the LCD after you take it, but there has to be a way to take out the guesswork. Besides, in bright sunlight your LCD monitor can be so overpowered by the ambient light that it's hard to see the image let alone check the exposure, or a picture that looks great in the dark on your LCD screen might be underexposed without you noticing. It turns out that there's something called the histogram that lets you check exposure objectively, no matter the ambient conditions. What the camera does to build the histogram is count the number of pixels at each brightness level, and plot the number at each level from darkest to brightest. It takes some learning, but once you get the hang of it, using the histogram can save you in tricky exposure situations. Keep in mind that there's not one "good" histogram. If you're taking a picture of a scene with huge dark areas, you'll have a lot of low-brightness pixels and that will show as a spike on the left of the histogram. A picture of someone skiing might have a huge lump on the right of the histogram caused by all the snow pixels. Using it for a while will give you a feel for how much exposure compensation you have to use in different situations for future pictures.



The histogram of a safely exposed picture. Note that at both highlight and shadow ends, the pixel count falls to zero before the edge.

There's another reason to use the histogram, though. To reduce noise in the shadows, you want to get as much light as you can from those areas without completely filling up the pixels that are getting light from bright areas of your image. The histogram lets you "expose to the right." You flirt with disaster (disaster here is blowing out highlights) by getting the bright pixels as close to the right edge of the histogram without going off of it. That might mean the dark pixels are bunched up around halfway, but that's okay since you can always bring the exposure down when you process the images. If you underexpose and then bring the exposure up in processing it's like you shot the picture with a higher ISO sensitivity, and that's not a good thing since you'll see more noise.

If you think the exposure of a scene is tricky and don't want to spend a long time making sure you get it right, some cameras have a way to bracket exposure: it takes a sequence of shots spread around what it thinks is the right exposure separated by steps that you set.

Shooting Modes

M is manual mode. Here you set both aperture and shutter speed, and the camera still meters to tell you how your exposure is.
A is aperture priority mode. You set the aperture, and the camera adjusts shutter speed to get exposure right.
S or T is shutter priority mode (T for reasons unknown to me). You set shutter speed, the camera sets aperture.
P is programmed auto mode. The camera sets both settings. Be careful with this one because it sometimes does some silly things. For example, my camera won't ever open the aperture past f/3.5 or so in programmed auto, so you can't even use some lenses at their best with it.

Lesson 4: Light and Color

It probably shouldn’t be surprising that every one of these lessons so far has talked about light to some extent. These are photography lessons, and photography means "light writing." Photography is about using the energy from light to create something permanent. There are different ways to do this, and each person can decide what they think is the best way (or ways) to interpret a given situation: what to emphasize and how to emphasize it. Lots of elements go into photography: composition, perspective, exposure, and focus to name a few. Some I’ve discussed (focus and exposure, for example). Some I don’t feel qualified to talk much about (specifically composition). For almost every element of photography, though, a little knowledge about light goes a long way to help improve control. This lesson will be about the basics of light and color (one of its characteristics).

(Visible) Light and Color

So what exactly is light? Ask a physicist and they'll tell you it's an electromagnetic wave and that it comes in small packets of energy called photons. They would also tell you a photon of light will have more or less energy depending on what the frequency of the wave is (higher frequency = higher energy). But this general description isn't terribly helpful for photography, so we should get one thing straight early on: the light we're almost always talking about in photography is light you can see—what's called the visible spectrum.

If you've ever seen a rainbow, you've seen the visible spectrum. The lowest-energy photons that we can see are red, and the energy gets higher and higher as you go through the rainbow into yellow, green, blue, and then all the way to violet, which has the highest-energy photons our eyes can see. The molecules in our eyes that are designed to respond to light don't respond to photons with more energy than a violet photon or with less energy than a red photon. So why would we only talk about light in the visible spectrum? Because not many people want to make photographs of things they can't see, but there are some exceptions. To name a couple, infrared photography uses light that has a bit less energy than those low-energy red photons (infra means below), and astronomers look at things in space using the entire light spectrum from very low-energy radio frequency light to very high energy x-rays, gamma rays, and cosmic rays.

R*ainbows have all the visible colors.*

Talking about the color of light, then, is actually the very same thing as talking about the energy of light. Change the energy, and you get a different color. But you may be thinking we've left out some important colors if all we talk about is the colors of the rainbow. What about things like black, white, and gray? It turns out you can get any of these by using a combination of the light from the colors of the rainbow. White is all the colors combined, black is none of the colors, and gray is white in disguise (it's all the colors with less intensity than something you interpret as white).

How do you take light of all different colors (energies) coming from different parts of your image and record that as something recognizable? You just record how much of each color comes to each point of your sensor, then tell the display medium (photo paper or a monitor, for example) how much of each color to display at each point on the image. It sounds easy enough, but as with many other things, nature throws us a curve.

Sources of Light and White balance

For better or worse, not all light is created equally. The band of colors that something emits is called its spectrum, and the spectra for different light sources can be very different indeed. Take as one extreme example light from a laser, which is only at one very specific color. You'll see only red if you use a red laser to light your subject. For the other extreme, let's take the light from the sun. It's a complex spectrum, with most of the energy it emits in the green energy range, and smaller parts in both the red (lower energy) and blue (higher energy). The main point is that it emits all visible colors, unlike the laser which emits at just one.

Sunlight is one example of a whole class of light sources called black body emitters. The idea is that if you get something hot enough, even if it normally absorbs visible light (hence, black body) it will start to emit light by radiation to get rid of some of its extra energy. You've probably seen this on an electrical stove's heating elements. If you crank up the heat as high as it will go with nothing on the stove, as it heats up you'll see the element glow a dim red, then brighter red, and finally almost orange. Not surprisingly, the hotter something is, the more high-energy photons it gives off. Take the other classic example of a black-body emitter: an incandescent light bulb. When you flip the light switch on to send current through the light bulb, the filament gets so hot that it actually looks white because it's hot enough to emit the higher-energy green and (hardly any) blue. If you hear someone talking about the color "temperature" of a light source, they're talking about the temperature in Kelvin that you would have to heat something to in order to get it to give off light with that color balance (Kelvin are almost the same as degrees celsius in this case). For example, direct sunlight has a color temperature of about 5500K. The visible surface of the sun, aptly called the photosphere, is at a temperature of 5800K (5500 degrees C or 10000 degrees F). For comparison, light bulbs that use tungsten filaments can't get hotter than 3700K since that's where tungsten melts, so they give off more red and less green and blue compared with the sun.

I mention these examples to show the fact that you can't always control the balance of colors in the light that you're recording in a photograph. It's the most literal application of wysiwyg (what you see is what you get). There are times when you can help things out by adding light of colors that are missing, but other times the best you can do is to tell your camera (or computer) which colors to boost to get more realistic colors. This is what's called white balance. You tip the scales toward one color or another until whites look white. In the days of film, you had to do this as you shot the images by putting a colored filter in front of your lens. For example, if you were shooting in incandescent light (again, this is mostly red), to lower reds while keeping blues and greens mostly constant you would put on some kind of aqua-colored filter that lets through blues and greens, giving them a boost relative to reds. Now, you just increase one color or another by telling your camera or the software you're using to process your pictures what kind of light you're using, and it boosts the channels that need help to get a good balance. It's good to remember what you're doing here, though. If you have a picture with almost no blue light to begin with, boosting the blues is going to make noise in the blue channel more visible. White balance control is one more advantage to shooting raw when you can. If you shoot raw, you don't need to worry too much about white balance because you'll do that on your computer before you convert the pictures to jpegs. Shooting jpegs, you run the risk of forgetting to set the on-camera white balance for the situation you're in, and it's sometimes so bad you can't fix it.

Confusingly, people talk about photos with more red and yellow tints being "warm" and photos with blue tints being "cool," but just remember that's backward from the black body temperature of the light source. Higher temperatures have more high-energy blue photons in the mix. What makes it even more confusing is that setting a higher white balance temperature on whatever is interpreting the sensor's data actually boosts reds, but that's because a higher temperature source would have extra blue, so it will boost reds to correct for it. That's enough of that!

Something else you sometimes have control over is the direction of light, and it can vary from directional (coming from a single point) to diffuse (coming from many angles). Directional light gives hard shadows and diffuse light will fill in cracks and wrinkles, so diffuse light is used more often in portrait photography, but you can use directional to get different effects. For a light source of a certain size, the closer the subject is to the source the more diffuse the light will be. This might make more sense when you think about how the light source will look bigger to your subject if it's closer, and the light will come in from a bigger range of angles.

One more useful light source in photography is flash. Flashes are based on gas discharge. What you do is shoot electrons through a gas (xenon in this case) with enough speed that they can rip electrons off of the gas atoms. When the knocked-off electrons find their way back to the atoms, they give up the extra energy by emitting light. This all happens very fast—faster than a millisecond (1/1000 s), so if flash is your main light source and you have a longer shutter speed like 1/60, your flash duration is effectively your shutter speed. This can really help for stopping motion.

There are a couple of disadvantages to on-camera flash. For one thing, we're not used to seeing faces and things lit by a light that's coming from right next to our eyes, so everything looks flat since the only shadows you see are behind what you're looking at. The other issue is called red eye, and that's from red light that gets reflected by the retina at the back of people's eyes. Annoying preflashes to make people's pupils smaller can help, but a better plan is to take the light as far from the lens as possible. If you've seen someone with a flash that mounts to the top of the camera, maybe you've seen them point it up at the ceiling (assuming the ceiling is a fairly neutral color so that you don't get some bizarre color cast). That's called bounce flash, and since the light from the flash reflects from the ceiling it gives a nice, diffuse, off-camera patch of light that is your light source instead of the point-like, on-axis light from the on-camera flash.

Flash shot directly from camera (left), bounced off the off-white colored ceiling (center), and shot through a diffuser—basically a piece of white tent fabric (right).

Another use flash is fill flash. Flash is white balanced to daylight so that you can fill in shadows in normal daylight. A good starting point is to get about a 3:1 ratio of the light on the bright side of someone's face to light in the shadows (true or not, someone told me this is the ratio Rembrandt tried to use in his paintings). To use the flash for this the output is set to 1 stop less than the incident light (so the flash gives half as much light as the sun where the subject is). That means you get 3/2 incident light on the bright side and 1/2 incident light in the shadows, for a ratio of 3:1. With flash output at the same level as the incident light, you get a 2:1 ratio. You can experiment to see what looks good to you. How can you know how much incident light you have? You can buy a light/flash meter, or some camera systems have a flash you can buy that will let you do the metering through the lens. The camera meters the ambient light and fires a metering flash to check the flash level, then fires the fill flash at the level you ask it to. For fill flash, don't bounce the light. Point it right at the subject because you may need all the power you can get from the flash.

Now I'll list some of the most common light sources with a few of their properties.

Direct sunlight.
Color content: ~5500K black body spectrum. The color temperature depends on how much of the earth's atmosphere the light has to go through to get to the subject. The more it goes through, the more blues get scattered out, making the light look yellower (this scattering is why the sky is blue). Noonish, it just goes through the thickness of the atmosphere, so it's only slightly shifted—from 5800K to 5500K. In the morning and evening, the light goes through the atmosphere at an angle so more blue gets scattered out and depending on how many particles are in the air (dust, smoke, etc.) the light can be anywhere from yellow to red. Since sunlight is directional (coming from only one direction), shadows can be harsh. It's a good idea to fill the shadows with some flash or a reflector if you have one.

Light from clouds.
Color content: usually about like direct sunlight (it depends on the amount of cloud cover), but now the blue from the sky is more

important if the sun is covered by clouds, so you may have to kill some blues.

Clouds act like diffusers, bouncing the light in from many angles. This fills in shadows more than direct sunlight, but even overcast can be pretty directional. Watch for this and use fill flash when you need to (bright clouds can provide the fill light if you're lucky).

Shade and window light.

Color content: often has lots of blue, since it's usually coming from the sky.

Close to the shade/sunlight boundary, shade is very diffuse since light comes in from almost everywhere. Porch light can be very flattering for portraits if you get the white balance right. If you're using trees for shade, watch out for spots of direct light filtering down through the leaves. Your eye might not notice them very much, but your camera will (they might be a few stops brighter than the rest).

Window light is like shade, but it only comes from a small area (the window). For window lighting, you need to remember that the light falls off really quickly (if you double the subject-window distance, you get about 1/4 the light you had before). Shade is the same way, but not quite as extreme. It's surprisingly dark inside a forest or even deep in the shade of a building, so look for somewhere on the edge of shadows if possible. Be aware that light reflecting off of big, colored objects can change your white balance—a big yellow building will add yellow, etc.

Incandescent lighting.

Color content: ~3500K black body spectrum (very red with some green, very little blue, so it ends up looking yellow)

With the right white balance settings, incandescent light by itself can actually render color very well, though you'll have extra noise in the blue channel. The main issue is that if you have mixed incandescent/window lighting, you'll know which is which really easily because of the difference in color content.

Fluorescent lighting.

Color content: complicated

Fluorescent lights are based on mercury gas discharge, which emits mostly in the ultraviolet range. They're coated with phosphorescent materials that convert the UV light into visible light, but only at certain colors—usually three different colors or sometimes four. What the camera sees depends on the mix of phosphors painted on the tube and on the red, green, and blue filters painted on the sensor, so it's harder to set white balance consistently. Another thing to remember is that fluorescent lights aren't continuous—they flash 120 times per second, so remember that when you choose your shutter speed.

Solid State Lighting (SSL).

Color content: like fluorescents

These aren't so common now, but you've probably seen white LED flashlights and headlamps, and soon LEDs will be used more in light fixtures in homes, etc. White LEDs use a blue LED coated in phosphors that convert some of the blue light to red and yellow to get a natural white balance, but again it's only at a few distinct colors, so white balancing is tricky.

Rules of thumb

Now that I've gone over most of the important technical aspects of photography, I'll include a list of some practical statements based on what we've discussed in these lessons.

Exposure

- To double the exposure to light while changing the aperture, divide the f/number by a factor of 1.4 (the square root of 2).
- Smaller apertures (bigger f/number) make a bigger range of distances in focus.
- To double the exposure while changing shutter speed, make it twice as long.
- For hand held photos, a conservative shutter speed to stop camera motion is 1/(2*focal length) for cameras with APS sensors (almost all digital SLRs) or 1/(focal length) for cameras with full frame sensors.
- Optical image stabilization can help stop camera motion, but doesn't do anything about subject motion.

Sensors and File Formats

- Just because your eyes say two things have almost equal brightness doesn't mean they do.
- To double the camera's sensitivity to light, double the ISO sensitivity.
- Use the lowest ISO possible when you can (meaning the camera's base ISO), since raising the sensitivity amplifies the noise in the picture.
- Shooting JPEG is less forgiving than shooting raw, but you don't have to do any processing later.
- When shooting JPEG, make sure not to overexpose highlight detail that you want to keep. You'll never see it again.
- When shooting raw, expose to the right (err on the side of having bright pictures by about 1 stop, maybe a bit less), and then bring the exposure down in post processing. This helps with shadow noise.

Focus and Metering

- For smaller apertures, chromatic abberation and image sharpness (and I don't mean depth of field) are better since you're using the central sweet spot of the lens.
- To have the camera's metering system adjust the exposure, change the exposure compensation. Setting +1EV of exposure compensation will tell the camera to let in twice as much light as at 0EV.
- Use the histogram unless it scares you. Even if you don't want to expose to the right, make sure your highlights are highlights or you'll regret it when you see the noise on boosting the exposure later on.
- Try to avoid the programmed auto shooting mode (P), since the camera makes silly decisions sometimes. If you want the camera to make most of the decisions, it's better to choose aperture priority auto (A) or shutter priority auto (S or T) and have the camera just set one.

Light and Color

- Correcting for the different mix of colors from different light sources is called white balance.
- Shooting raw, don't worry too much about white balance since you can always

change it later.

- If you're using flash as your primary light source, try to bounce it off of the ceiling so that it's more diffuse and natural-looking.
- You can use flash to fill in the shadows when the light on your subject is very directional.
- To make light more diffuse, get the subject closer to it if possible.