Purpose of this Guide

The purpose of this guide is to explain, in hopefully easy-to-understand terms, how to photograph Earth's closest celestial neighbor, the moon, or Luna. It covers the equipment you need and how to properly choose exposure settings. It does *not* explain how to photograph phenomena such as Earthshine or eclipses, but that may be added by request or at some later date. This also does not cover any "photogenic" considerations when photographing, nor the finer points of post-processing … just the mechanics of getting a properly exposed moon.

If you have any questions, comments, criticisms, compliments, or additional material requests, please feel free to e-mail me at `stuart@sjrdesign.net`. **If you obtained this document from any source other than `http://photos.sjrdesign.net`, please e-mail me as this is NOT to be hosted elsewhere.**

Some Terms Explained

Photography/Camera Terms

Aperture: Aperture is the opening through which light enters at the front of the camera lens. Modern lenses have generally a 5-8 blade system that is used to shrink or expand the aperture within the limits of the physical size of the lens itself. An "open" aperture has a low *f*/number and lets in the most light. A "stopped down" or "closed" aperture has a high *f*/number and decreases the amount of light. Every change in 3 *f*/numbers is "1 stop."

Focus: Focus is when an object is not "fuzzy" but sharp and crisp. Almost all camera lenses (Zeiss being a notable exception) have auto-focus capabilities, but they require a reasonable amount of contrast in the scene to find the proper focus. For the moon, many camera systems cannot automatically focus, and so manual focus is necessary.

ISO: This is the digital equivalent of film "speed." It is a digital gain which will increase or decrease the intensity of the image recorded on a CCD or CMOS detector. ISO does *not* actually increase nor decrease the amount of light that the detector receives, just how much it is multiplied by in the final image. Because of this, any increased ISO will increase the brightness in the final image, but it will also increase the amount of noise, since noise is amplified along with the signal.

Shutter Speed: This is the length of time that the shutter is open and lets light in through the camera to be recorded. This is generally synonymous with exposure length.

Moon Terms

Full Moon: This is a lunar phase when Earth is between the Sun and Moon and we see the completely lit side. This is the only time when a lunar eclipse can happen.

New Moon: This is a lunar phase when the moon is between the Sun and Earth and we see the unlit side. This is the only time when a solar eclipse can happen.

Phase: The amount of "fullness" that the moon appears to have as seen from Earth. A crescent phase is less than half full, a gibbous is when it is more than half full. A waxing moon is when it is getting more full, and a waning moon is when it is getting less full. A first quarter moon is when it is a waxing half moon, and a third quarter moon is when it is a waning half moon.

EQUIPMENT NEEDED/RECOMMENDED TO PHOTOGRAPH THE MOON

1. Camera with Manual Settings

At the very least, you will need a camera with which you can *manually* set the exposure length, aperture, focus, and ISO.

Manual focus is a must because, unless you are using a long telephoto lens (300 mm equivalent or longer, probably), your camera will likely not be able to automatically focus on the Moon. It will focus in and out and never find where the proper focus point really is. In addition, if you simply focus at "infinity" or "∞" as marked on the lens, it still will not be at the proper focus point because there is some degree of play built into the lens to compensate for changes in temperature, focal distance, and other variable factors. Often, you will need to manually find the proper focus point and you will not be able to rely upon your camera's auto-focus nor even the markings on an SLR camera's lens.

Manual exposure length (AKA shutter speed) and aperture go hand-in-hand for my purposes in this guide because they both control how much light will be recorded by the camera's detector. A longer exposure length or a wider aperture (lower *f*/number) will give you the same effect - more light. A shorter exposure length or a smaller aperture (higher *f*/number) will give you the same effect as well - less light. You need to be able to set these manually because your camera will otherwise likely over-expose any image of the moon (unless you rely upon spot-metering, which is not addressed in this guide).

A camera determines the exposure and aperture by taking a reading of how much light is in the field of view - an *average* over the *entire* field (again, unless you're spot-metering). If the image in the camera's field of view is of a mostly dark sky with a small circle of white (the Moon), then the *average* of the entire field is fairly dark. The camera will then interpret this average dark scene as needing a long exposure so that the *average* light recorded will be a neutral 50% intensity. In actuality, you want the night sky to be nearly black and the Moon to be properly exposed, requiring a shorter exposure than your camera thinks is necessary.

If you only set the camera to manually select either the shutter *or* aperture, it will try to compensate by setting the other automatically and still over-expose the moon. I recommend choosing a wide aperture, perhaps ⅔ to 1⅔ *f*/stops (2 to 5 "changes") smaller than your maximum (that is where the lens is usually sharpest), and then only adjust the exposure length. A good website to check for *your* lens' sharpest aperture is `http://www.photozone.de/all-tests`.

An alternate way to think about shutter speed and aperture is to think about it in terms of EV, or "Exposure Value." EV is defined as:

$$\mathrm{EV} = \log_2\left(\mathrm{aperture}^2 / \mathrm{shutter\ speed}\right)$$

EV is useful because it is ISO-independent, and it combines aperture and shutter speed into one term to easily show how much light reaches the camera sensor. Also, objects can be defined as having a certain EV of brightness. For example, the "sunny 16 rule" is defined as an aperture of *f*/16 and a shutter speed of $1/100^{\mathrm{th}}$ second for an ISO 100 to properly expose a sun-lit scene which has an EV15. In a cloudy scene, the highlights may have an exposure of either *f*/11 at $1/100^{\mathrm{th}}$ of a second, or *f*/16 at $1/50^{\mathrm{th}}$ of a second, which corresponds with EV14. If you increase the ISO by one stop (such as from ISO 200 to ISO 100), you must make a corresponding 1 EV decrease to compensate.

The full moon is approximately EV15 according to Wikipedia; however, I have found it - on average - to be closer to EV12-EV13 (why this is the case is addressed in the "How to Photograph the Moon" section). Thus, if your sharpest aperture is *f*/8, then your shutter speed should be 1/120-sec (if EV13). (Note that this is covered again and in more depth in the "How to Photograph the Moon" section.)

Besides aperture and shutter speed, manual ISO is also important, again for the reason mentioned above: Your camera may try to compensate with your manual exposure by increasing the ISO to give a brighter picture. You do not want this. The lower the ISO, the less noisy the end image will be, so you should try to set this to the lowest ISO you can and work from there. In terms of EV, you need to divide your shutter speed by any change in ISO (so if you go from ISO 100 to ISO 200, that is a factor of 2 or a 1 stop change, so divide your shutter speed by 2 to increase the exposure value by 1 stop get the same amount of light).

Remember, though: ISO does *NOT* change how much light the sensor receives, only how much it amplifies the signal of the light when recording the image. Due to this being a strictly electronic process (or chemical in the case of film), any *noise will also be magnified*.

Finally, if your camera has RAW capability then you should be photographing in RAW mode. JPEG adds compression which negatively affects image quality, starting with the blue channel and dark areas of the picture (not something you want in a dark image!).

2. Telephoto Lens

Although any length lens can photograph the moon, the longer the lens, the more detail you will be able to capture simply because it will appear larger in the picture. Note that, if you are using a non-SLR, I recommend *not* using the "digital zoom" as this has nothing to do with optics and gives you the same (but often worse) image you would get when manually resizing in Photoshop or other image editing software.

Ideally for imaging, you want your subject to fill the entire field of view of the lens to give you the maximum final resolution. The Moon averages ~30' (or ½°). A lens that gives this field of view vertically is approximately a 2700 mm equivalent (divide by any crop factor your camera body may introduce, such as 1.6x on the Canon Digital Rebel series, so a 1700 mm lens would work in that case). As stated above, though, this is the theoretical *maximum* length you would ever want to use for a single-image shot, and it does not mean you cannot use a shorter lens, such as a 1000 mm, 500 mm, 300 mm, 200 mm, 100 mm, or even 50 mm. This will simply give you a smaller moon with less detail in the final image.

3. Tripod

Though a tripod is not necessary, it does eliminate one extra thing you have to worry about when photographing the Moon -- holding your camera. It is also useful because (1) you do not have to manually re-locate the Moon between photos, and (2) it will allow you to take longer exposures without any concern of camera shake; depending upon how steady your hands are, this may actually be a necessary piece of equipment. Invest in a tripod and you will be thankful! Another piece of equipment that will be helpful is a wireless remote/trigger or cable release so the camera does not shake when you press the shutter release to take the photo.

4. Mount that Tracks the Sky

The moon moves from East to West, just like the Sun and stars appear to move, though its rate is ever-so-slightly less than other objects'. This motion is not significant when photographing a full Moon as you can take relatively short exposures and so will not capture its movement. However, the longer your lens and the slower your exposure, the more this motion plays a role.

When I use an 800 mm lens (~1300 mm equivalent) to photograph the Moon, I can see motion within 1 second. With a 300 mm lens (~500 mm equivalent), I see motion within 5-10 seconds. This is, therefore, really a non-issue when just photographing the moon normally, and only becomes important when photographing earthshine or eclipses (which are not addressed in this Guide). It is also fairly easy to calculate how fast the moon will move across your camera's sensor, but that is more advanced than what this Guide intends.

HOW TO PHOTOGRAPH THE MOON

Basic Camera Settings

The steps to do this are (1) set up your equipment, (2) make sure it is working right, (3) determine your basic exposure settings, and (4) focus properly. So go ahead and do 1-2.

Steps 3 and 4 are somewhat iterative - you will need to determine your exposure so that you can focus. Then go back and make sure your exposure is still correct, and then if you have changed it, you will want to verify your focus is still correct.

When determining your exposure settings, remember that the three main things that determine how much light is recorded are (1) shutter speed / exposure length, (2) aperture, and (3) ISO (remember that shutter speed and aperture can be collectively referred to in the EV measurement).

1. **Set your ISO to its *lowest* setting** (this will probably be 100 or 200).
2. Set your aperture to its *largest* setting, which is the *lowest f*/number. Then increase the *f*/number by about 1-2 stops (remember, this is based upon a "sweet spot" of sharpness in most lenses). This will **usually be about *f*/8**.
3. Experiment with shutter speed until the moon is exposed properly. Use your *f*/number and an EV13 for the full Moon *as a starting point*. The following table should help:

f/number	1.4	2.0	2.8	4.0	4.5	5.0	5.6	8.0	14.0
Shutter Speed	1/4000	1/2000	1/1000	1/500	1/400	1/320	1/250	1/120	1/40

The above table should only be used *as a guide*, especially because the moon's brightness will vary depending upon its position in the sky, its phase, atmospheric turbulence, and particles and pollution in the air. If the moon is *not* full, you will need to *increase* the exposure length because there will be less light from it. I have found that thin crescent phases are approximately 10% the brightness of the full moon (so at *f*/8, you may need 1/10th - 1/15th sec. exposure).

An example: With an *f*/14 aperture on a 900 mm (1440 mm equivalent) lens, an exposure of around 1/120-sec properly exposed the full moon for me. That corresponds to EV14.5, and this was when the moon was near its highest point in the sky.

Another example: When using a 480 mm equivalent lens at *f*/5.6, an exposure of around 1/250- to 1/320-sec properly exposed the full moon a few months earlier.

Note that in these examples, the focal length has nothing to do with the exposure length, I just mention it for completeness' sake.

Take a Test Photo

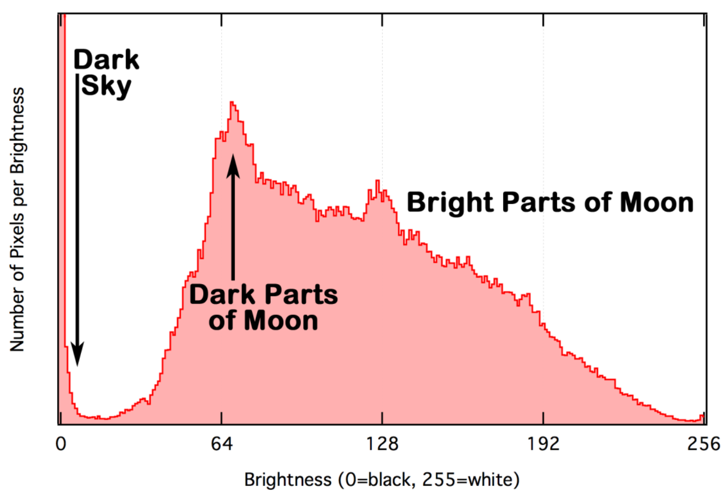
If the Moon appears too black/dark with your shutter speed, decrease the speed to allow more light in. If the Moon appears all white/bright with your shutter speed, increase the speed to allow in less light.

This is where using the Histogram feature on your camera helps. The Histogram is a graph telling you where most of the recorded light falls. If the Histogram peaks towards the left side, this means that most of the pixels in the image are dark. If the Histogram peaks towards the right side, then the opposite is true. Ideally, you want it to peak in the middle. But, unless the Moon fills the entire field of view of the image, this will not happen because the night sky will dominate the scene.

Therefore, most of the pixels will be fairly dark, up against the left side of the Histogram. However, there should be a peak in the brighter part of the Histogram (the right side) - this is the Moon. You want that peak to be somewhere in the middle of the Histogram. You do not ever want it to truncate prematurely against either side.

Further explanation of Histograms is not the purpose of this guide. For more information, many people recommend this webpage: `http://www.luminous-landscape.com/tutorials/understanding-series/understanding-histograms.shtml` .

The image below shows an example full moon and its annotated histogram next to it.



If you are finding that you need very slow shutter speeds at this point (such as 1/30-sec or longer *if* the moon is *more than* half full), then double-check your aperture and make sure that it is mostly open (you are using a small *f*/number). If you are finding you need really fast shutter speeds (such as 1/300-sec or faster), then double-check the ISO to make sure it is not too high.

Now, Focus, and Shoot the Moon!

To focus, set the manual focus at infinity, or if you have an SLR, then set it as far "past" infinity as you can. Take a picture. Either look at it on the camera's LCD screen (zoomed in), or at the image on a computer. It will probably be out of focus. Now - just a little at a time - change the focus in the other direction, and take another picture. Continue this process until the picture you take is in focus (or in focus enough for your purposes).

For me, this used to be the longest part of setting up and it can be a pain. But it is a very necessary step … you would not want to spend 5 hours out in the cold photographing the moon and come back and look at out-of-focus blobs. If you are photographing for a long time, you should also check the images periodically throughout the night to ensure the focus has not changed due to temperature, focus creep, or accidentally bumping the lens.

An alternative method that can be used on newer cameras involves the "Live View" feature - something that has been on Point & Shoot cameras for much longer than dSLRs. This is where you can view the field on the camera's LCD screen as opposed to through the viewfinder. On many of these, you can even zoom in to see finer details. Using the Live View, you can refine your focus much more easily and much more quickly -- it usually takes me about 10 seconds as opposed to several minutes. You may find it easier to refine your focus by looking at a bright star as opposed to the moon, getting the star to be a point instead of a big ball or doughnut.

Now that the lens is in focus, double-check the exposure Histogram to make sure your exposure settings are still alright, and adjust accordingly if they are not.

Now for the most important part: *Write down your settings!* These are your baseline settings and you can use them as a starting point for all other lunar photography. I usually make a detailed log of all my settings along with details of the night (how clear the sky was, any significant light pollution, etc.) and also any processing details in order to use as reference for future photography.

STUART'S PET PEEVES -- AKA, THINGS TO AVOID!

Claiming to Use the "Sunny 16" or "Looney 11" Rule

Don't!

Okay, now that that's out of the way … the "Sunny 16" rule for photography is a rule-of-thumb approach on how to set your exposure settings (shutter, aperture, ISO) for a bright, sun-lit scene, and properly expose it. The claim goes, "The moon is brightly lit by the sun, so you should follow the 'Sunny 16' rule!"

This is true, the moon is lit by the sun (and a bit by Earth, but that's a different issue). However, the reflectivity of the lunar surface is around 8-10% … the reflectivity of Earth is generally 30-90%, with asphalt being the closest lunar analogue with a reflectivity of around 5-10%. Consequently, if you use the "Sunny 16" rule, you will under-expose the moon, or at the very least not take advantage of the full dynamic range of your camera.

There is similar reasoning with the "Looney 11" rule, though it states, "Well, the 'Sunny 16' rule will under-expose the moon 'cause the moon's dark, so let's increase the aperture size and just modify the 'Sunny 16' to make it the 'Looney 11,' so you set your aperture to *f*/11."

While this modification will get you a decent exposure, it completely ignores where your lens is sharpest. Most lenses are sharpest around *f*/8, and the sharpness dramatically decreases for larger apertures. Since the moon is relatively small and the atmosphere can be very blurry, you want to take maximum advantage of your optics and *choose the aperture that's sharpest, not one that has a whimsical catch-phrase!*

Going for Super-High-Resolution When the Sky Won't Allow It

I'll be among the first to admit that I've been guilty of this: Claiming that I have a lunar image that's 7200 pixels across that's super-high-resolution. While this may be practically true - I may have an image of the moon that's 7200 pixels across, it completely ignores the practicalities of photographing through Earth's atmosphere.

Earth's atmosphere is turbulent. It moves around, and it moves in different directions at different elevations within the atmosphere. This is what makes stars "twinkle." The ability to resolve - see fine details - objects through Earth's atmosphere is defined by the term "seeing."

From the ground, the average site on Earth will have a seeing of about 1 arcsecond. There are 60 arcseconds in 1 arcminute, and there are 60 arcminutes in 1 degree. In other words, the moon, being about ½° across, is about 1800 arcseconds across ($0.5 \cdot 60 \cdot 60 = 1800$). This means that from an average location on Earth, even if the image that comes off your camera has the moon being 4000 pixels across, you do not have 4000 pixel's-worth of detail. So, you should decrease the resolution in your photo-editing software of choice.

There are of course exceptions. The best astronomical viewing sites are in deserts on top of mountains (Arizona, Hawai'i, Chili, etc.). At these sites, the best seeing is around 0.1 arcseconds, so you could theoretically get up to 18,000 pixels across of detail. Average seeing at these sites is more like 0.3-0.5 arcseconds, 3600-6000 pixels. And then on the other side, there are really bad locations. Here in Boulder, where we get turbulent air coming off the Rocky Mountains, seeing averages 2-3 arcseconds, limiting the usable resolution to 600-900 pixels across.

Note that there are ways to figure out the seeing in your location on a given night by photographing a bright star, but that is beyond the scope of this guide. Additionally, there are techniques to help mitigate the atmospheric distortion (image stacking), but that is also beyond the scope of this guide.

The take-home message here is that all because your camera may spit out an image at very high resolution, that does not mean that it is usable. Actually look at the image to see how many pixels across a feature appears, and then down-sample (reduce the image size) until that is closer to 1-2 pixels.

Using an Über-High ISO and Über-Fast Shutter Speed

I got into an argument with a guy once on a certain photography forum. He claimed that if you can get decent results with ISO 1600 and a shutter speed of around 1/2,000th sec, then why not use it? He was recommending this to a beginner who was trying to figure out how to photograph the moon and no one had yet recommended this guide (until I posted).

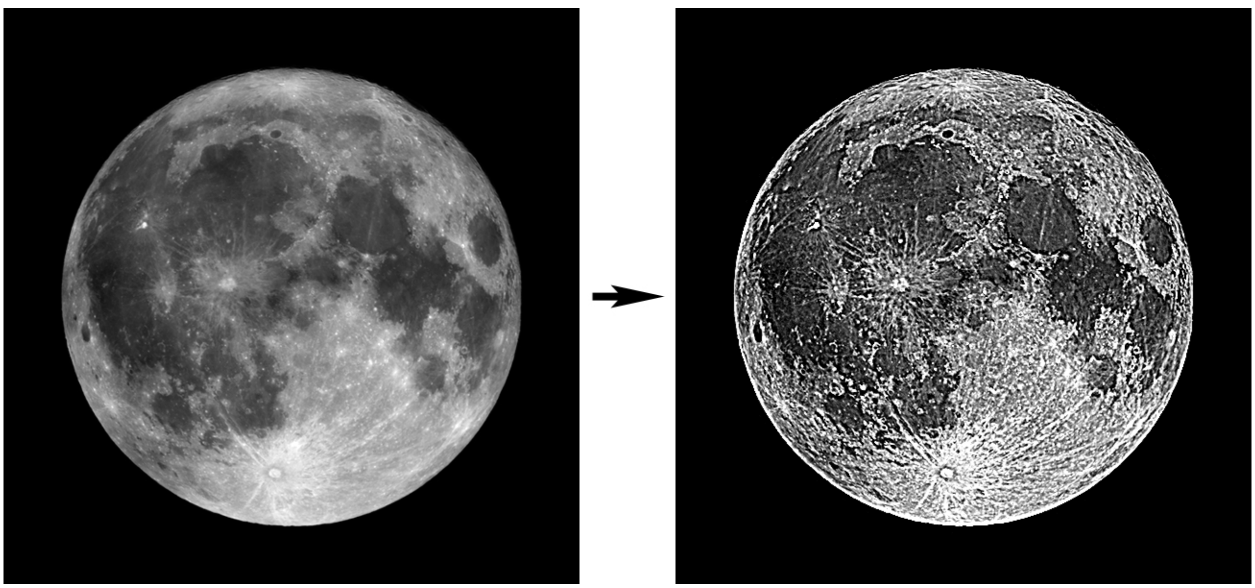
I explained to the poster that there was absolutely no good reason to be using such a large ISO. The difference in shutter speeds of 1/2000 versus 1/100 in terms of camera shake or the motion of the moon is completely negligible. And I really don't care what camera you're using - as of 2010, pushing any camera to ISO 1600 is going to introduce noticeable noise. The other guy argued that you can always lower it later on.

So I pointed out two reasons. First, if the guy is trying to take his first decent photograph of the moon, then he should start out with "good form" and use a low ISO. Second, I argued that if he got a good exposure with such a high ISO, the image would still not look as good as it could have if he had used a lower ISO. It would look grainy and have significant color noise.

Sharpening

Do not over-sharpen. I cannot emphasize this enough. Over-sharpening an image will result in a blob-like moon that looks like it was painted in oil or water colors. If you feel you must sharpen, then please pay close attention to what you are doing. Do not choose too large of a pixel radius over which to sharpen. Do it sparingly.

Below is an example of an over-sharpened moon, taken from the image I used above. The one on the left was sharpened with the Unsharp Mask filter. And this is not a Straw Man argument - I have seen people do this.



Summary -- Print This Page to Use in the Field

When choosing your equipment, the following is recommended:

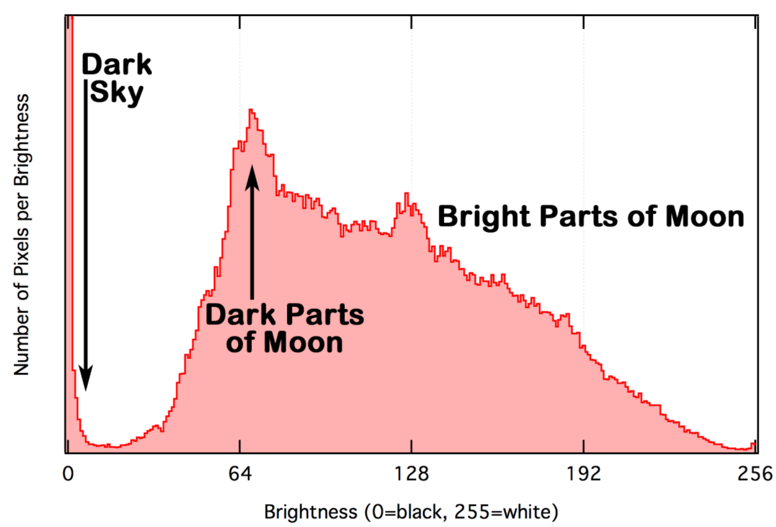
1. Camera with manual exposure settings (shutter speed, aperture, and ISO) as well as manual focus.
2. Reasonably long (200mm or longer) telephoto lens.
3. Tripod.

When determining exposure, remember the following, in order:

1. **Set your ISO to the lowest value possible** (usually 100, but it may be 50 or 200).
2. Set your aperture to its most open (lowest *f*/number) and then increase the *f*/number about 3 times ("1 stop"). **Usually this will be about *f*/8**.
3. Use the table included in this guide *as a starting point* to determine the proper shutter speed for that aperture. (Table is copied below.)

f/number	1.4	2.0	2.8	4.0	4.5	5.0	5.6	8.0	14.0
Shutter Speed	1/4000	1/2000	1/1000	1/500	1/400	1/320	1/250	1/120	1/40

When determining if you have your exposure correct, look at the histogram - it should have a peak somewhere in the middle, like the image below:



If you're good at math, go ahead and use the "Looney 11" rule but for an aperture of about *f*/8 instead of *f*/11 -- refer to Step 2 above for aperture.

When processing your photos, avoid the impetus to over-sharpen.