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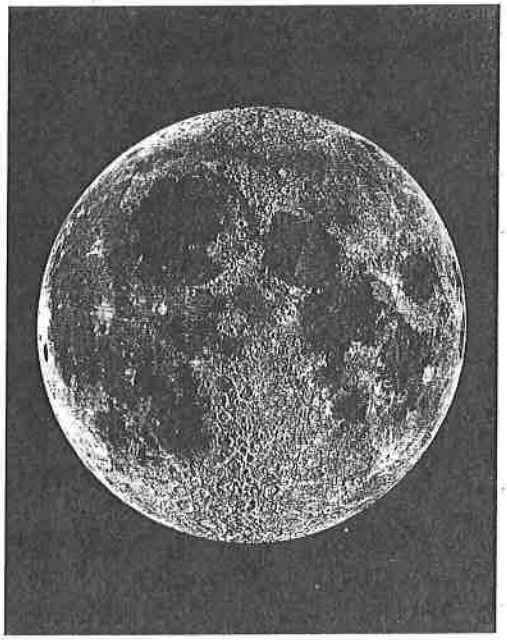
CHAPTER 3

The Moon: Our Nearest Neighbor

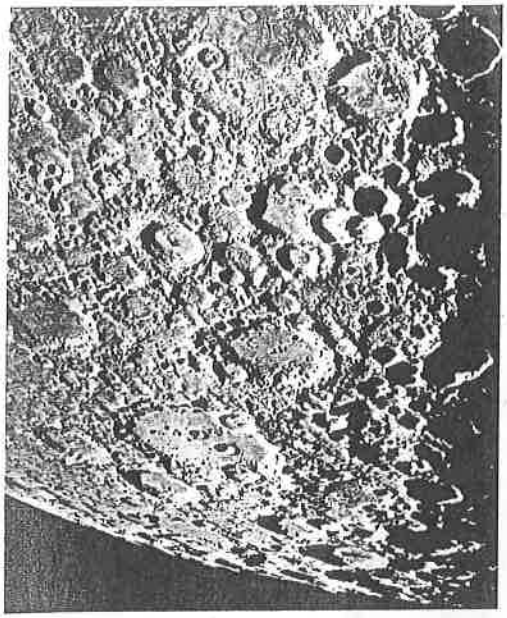
117 **The Moon, a small desolate world, is our nearest neighbor in space.** The Moon is 2,160 miles across, making it small enough to fit between the east and west coasts of the United States. It is an airless and waterless place (except for small amounts of ice near its south pole) where no life has ever existed. The average distance from the Earth to the Moon is about 238,000 miles.



The full Moon. Dark areas are the maria, or lunar lowlands. The bright areas mark mountain chains and the cratered regions of the lunar highlands. (UCO/Lick Observatory photo/image)

118 **During the day it gets very hot on the Moon, but at night things really chill off.** The denser a planet or satellite's atmosphere, the less difference there is between its daytime and nighttime temperatures. Since the Moon has no atmosphere, the local thermometer really gets a workout. At noon on the lunar equator, for example, temperatures hover around 210°F, while the same spot at midnight could come in with a bone-chilling reading of –250°F.

119 **The most common lunar features are *craters.*** There are millions of craters on the Moon, mostly created when asteroids, meteoroids, and comets crashed into the lunar surface. Most of these impacts occurred long ago. Others still happen today. The Moon has no atmosphere to protect it, so



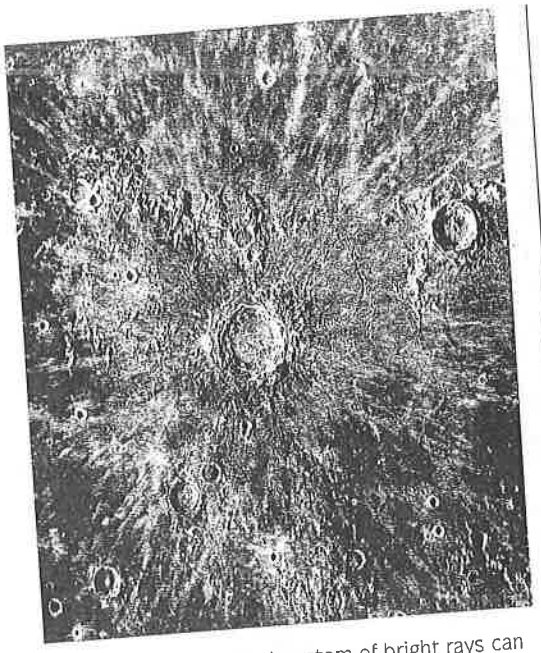
The rugged cratered terrain near the Moon's south pole. Old craters have younger craters within them. (UCO/Lick Observatory photo/image)

such objects plunge unimpeded into the lunar surface at tens of miles per second. Many lunar craters can be seen in even a small telescope. Craters range in size from microscopic pits to vast depressions over 100 miles across. Some craters have rim walls that are over 20,000 feet high.

120 **And little lunar craters have littler craters and so on . . . ad infinitum.** If we count up how many craters of different sizes there are on the Moon, we find that there are relatively few really big ones but progressively more smaller and smaller ones. One reason why is that there are far fewer large objects sailing around space that can crash into the Moon than small ones. (This is because, over time, many of the large objects have already collided with each other and fragmented.) Another reason for different numbers of different-sized craters deals with how craters are made. In short, it's not typically a one-step process. First comes the formation of what is called the *primary* crater when a meteoroid or other object from space strikes the Moon. As the impact occurs, smaller chunks of lunar rock are blasted out of the primary crater in all directions. These pieces of material, in turn, crash down onto the lunar surface and create surrounding *secondary* craters. Debris thrown skyward in the formation of secondary craters creates still smaller *tertiary* craters. And so on.

121 **Some lunar craters have bright systems of *rays*.** Lunar craters like Tycho and Copernicus display bright rays up to hundreds of miles long that look like the spokes of a wheel. The adornments are the result of the light-colored material that was blasted out of the crater when it formed. Ray craters are relatively young (perhaps only a few hundred million years old). As such craters age, their rays gradually fade from view as the extreme temperature differences between lunar day and night create minute surface expansions and contractions that eventually erode them away.

122 **Studying lunar features can help us to determine their relative ages.** Some craters have sharp, clearly defined rims. Others appear broken or crumbled. The former are newer, while the latter show signs of age from meteoroid bombardment or a type of lunar



The crater Copernicus. A system of bright rays can be seen radiating from the crater like the spokes of a wheel. (UCO/Lick Observatory photo/image)

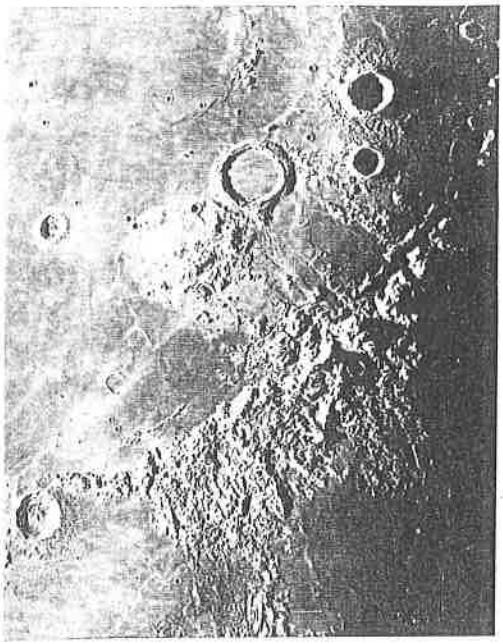
"erosion" that results from constant expansion and contraction of the lunar soil due to the big differences in day and night temperatures. Sometimes we see one crater superimposed on another. A crater that crosses another's rim or lies embedded within another crater is clearly the younger of the two.

123 **If you have 20/20 vision, you can actually make out a lunar crater with the naked eye.** The crater in question is, as you might imagine, one of the largest on the lunar surface. It is called Grimaldi and has a dark floor that helps it stand out from its lighter surroundings. If you think of the full Moon as the face of a clock, look for Grimaldi near the left-hand edge of the Moon at just about nine o'clock. It appears as a tiny dark oval, but it is over 100 miles across.

124 **The Earth has been struck by many more objects from space than the Moon, yet it has far fewer craters.** Because of its greater size and mass, the Earth has attracted far more meteoroids over its lifetime than the Moon. Yet the Moon looks like a truly cratered world, while the Earth does not. Our planet's weather and crustal movements perpetually wear it smooth, while the Moon's lack of such forces allows it to preserve its scars from earliest times.

125 **The Moon also has impressive mountain ranges.** The Moon has several mountain ranges. One of the most prominent is known as the Apennine Mountains. Some of its peaks are higher than Mount Everest. Unlike the Earth, the Moon does not have plate tectonics, nor does it have erosion due to wind and rain. Hence, once mountains form, except for crumbling due to impacts from objects in space, there is little wearing away as with mountain ranges on Earth.

126 **The Moon also has features known as "seas," cliffs, and rills.** The lunar "seas" are not actually bodies of water but rather vast relatively smooth plains of dark solidified lava hundreds of miles across. Elsewhere, we find *cliffs* that run for scores of



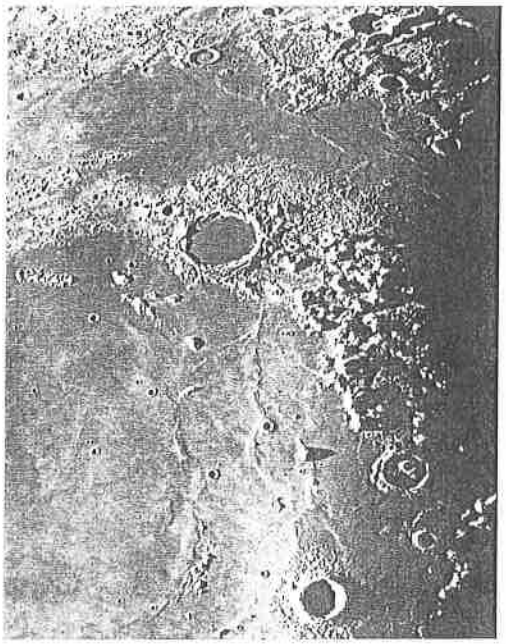
The mighty Apennine Mountains contain peaks as high as the Himalayas. (UCO/Lick Observatory photo/image)

miles and sinuous valleys called *rills* that may be places where subterranean tubes of lava collapsed just below the lunar surface.

127 **The Moon's face displays a variety of light areas.** Even a casual look at the Moon with binoculars or the naked eye reveals that its surface is not uniformly bright. Instead, the Moon has a somewhat mottled appearance. The lighter areas are generally regions of higher elevation known as the lunar *highlands.* Much of this is mountainous or heavily cratered terrain.

128 **The Moon also has dark areas.** The darker places on the Moon are roughly circular in shape and are known as the lunar *maria,* or "seas." The name dates back to earlier days when the smooth dark appearance of these areas led some astronomers to speculate that they might actually be bodies of water. Today, we realize that they are really large plains of solidified lava that welled up from deep inside the Moon during its early evolution and flooded lowland regions. The term "seas" is still applied, however, and many of these features still carry poetic names like the Sea of Serenity and the Sea of Clouds.

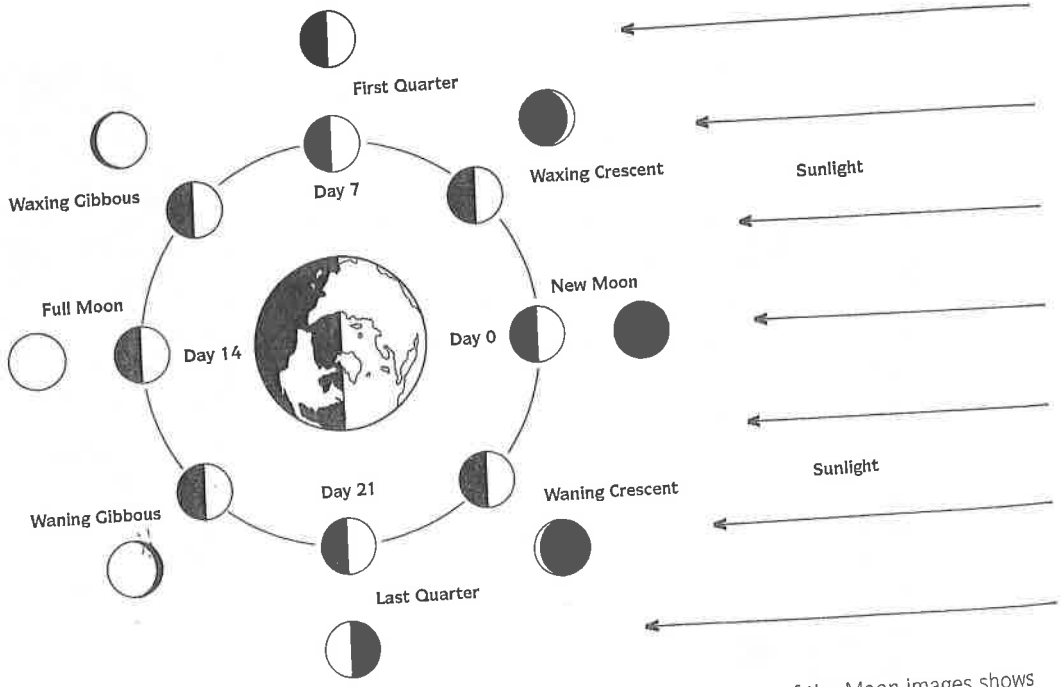
129 **What creates the illusion known as "the man in the Moon"?** The inter-



The large crater Plato has a smooth dark floor because it was flooded by lunar maria material after it was formed. (UCO/Lick Observatory photo/image)

play between the light highland regions and the darker lava plains, or "seas," creates what is commonly called "the man in the Moon." Two lunar plains, the Sea of Serenity and the Sea of Tranquillity (where astronauts first set foot on the Moon), make up the left eye, while the Sea of Rains is the right eye. A mountain range known as the Apennine Mountains forms the bridge of the man's nose and a conglomerate of other plains, including the Sea of Vapors, creates the man's puckered little mouth. Various other cultures interpreted these light and dark areas in other ways, seeing instead a "lady in the Moon," a "rabbit in the Moon," and even a "frog in the Moon"—all of which makes Moon gazing kind of a cosmic Rorschach test.

130 **The Moon goes through a regular cycle of phases.** The Moon goes through a regular cycle of phases that repeats every 29.53 days. The major "points" in this cycle are the new Moon, the waxing crescent, the first quarter, the waxing gibbous, the full Moon, the waning gibbous, the third or last quarter, and the waning crescent. The cycle begins with the new Moon.



As the Moon orbits the Earth, it goes through a cycle of phases. The inner circle of the Moon images shows the light and dark hemispheres of the Moon as the Moon orbits the Earth. The outer circle of the Moon images shows the resulting phases of the Moon as seen from the Earth.

131 **What's a *waxing* Moon vs. a *waning* Moon?** When the Moon is waxing, it is growing fuller from night to night. When the Moon is waning, it is growing less full from night to night. Between the new Moon and the full Moon, the Moon is waxing. Between the full Moon and the new Moon, it is waning.

132 **You can watch the cycle of lunar phases progress across the sky from night to night.** Except at times of a solar eclipse, we cannot see the *new Moon* because, during this phase, the Moon is located between the Earth and the Sun, so the Sun is illuminating the side of the Moon that is pointed away from the Earth.

Within a few days of the new Moon, we see a thin *waxing crescent* Moon appear low in the west after sunset. From night to night, this crescent grows thicker until, a little over a week after the new Moon, we see the *right* half of the Moon illuminated in the south at sunset. Ironically, this phase is called the *first quarter* because the Moon has now completed a quarter of its cycle of phases.

Over the coming nights, the Moon grows fuller and takes on the appearance of an egg. This is the *waxing gibbous* phase.

A little more than two weeks after the new Moon, the Moon is positioned opposite the Sun as seen from the Earth. Now the Sun illuminates the entire hemisphere of the Moon seen from the Earth and so we see a *full Moon.*

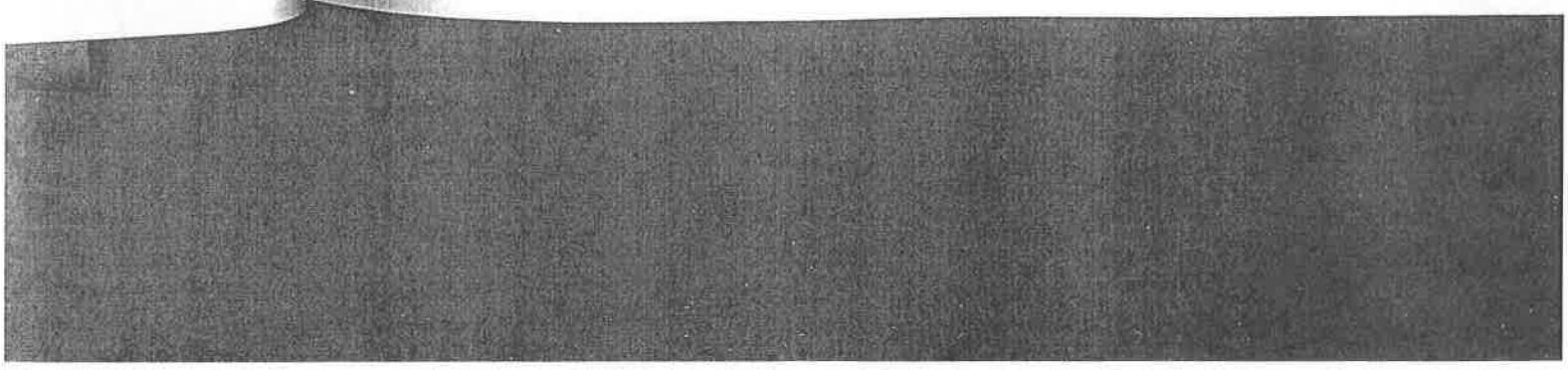
During the following two weeks, the Moon changes from being a *waxing* Moon, that is, one that grows a bit fuller from night to night, into a *waning* Moon. Now, from night to night, we see less of the hemisphere illuminated by the Sun as the Moon gradually becomes slimmer and slimmer.

First comes the *waning gibbous* Moon, which grows increasingly flatter on its left side. A little more than three weeks after the new Moon, we see the *left* half of the Moon lit up by the Sun. But because we are now three-quarters of the way through the lunar cycle of phases, we refer to this as the *third-quarter* or *last-quarter* Moon.

Finally, the Moon becomes a thinner and thinner *waning crescent* over the last days of its cycle in the predawn sky and ultimately rejoins the Sun in the sky as the next new Moon.

133 **You can understand how and why the Moon goes through phases by using a ball and a lamp.** Just how and why the Moon goes through its cycle of phases can be a pretty tricky thing to understand, but in a darkened room with a ball and a lamp you can demonstrate the whole thing to yourself in moments and you'll understand it for the rest of your life. All you need is a ball (any size will do) and a lamp without a shade, that is, one that casts good sharp shadows.

Turn the lamp on and place it on something that raises its lightbulb to about the same height from the floor as your shoulder. Turn off all the other lights in the room. Next stand several feet away from the lamp with the ball in your hand. The lamp represents the Sun, the ball is the Moon, and your head is the Earth. Now hold the ball straight out in front



of you at arm's length and at shoulder height. Slowly turn yourself around while continuing to hold the ball straight in front of you. As you turn, you will see the ball go through phases, just like the Moon. Indeed, the lamp, the ball, and your head will be in the same orientation as the Sun, Moon, and Earth for any particular lunar phase at any time.

As you bring the ball between your head and the lamp, you will see the ball cut off the light from the lamp and thus create an "eclipse of the Sun." As your head passes between the ball and the lamp at full Moon, the shadow of your head will fall on the ball and thus create an "eclipse of the Moon." You may want to try this little exercise with the shades drawn (so the neighbors don't start talking about you) . . . but do try it.

134 **The *terminator* marks the line along which sunrise or sunset is occurring on the Moon.** When the Moon is waxing, that is, growing fuller in the sky, the terminator marks the line along which sunrise is occurring along the lunar surface. From night to night in a telescope, you can see this line slowly advance to the west, just as it does hour after hour on Earth. When the Moon is waning, the terminator marks the line along which sunset is taking place. From night to night, the terminator progresses westward, engulfing more and more of the Moon's face in the shadow of night as the Moon grows slimmer and slimmer in our skies.

135 ***Earthshine* is a beautiful phenomenon to look for when the Moon is a slender crescent.** A few days before or after the Moon is new, it appears as a delicate crescent in the sky. But look carefully with a pair of binoculars and you will see the rest of the Moon faintly visible as well. This phenomenon, known as Earthshine, is the result of sunlight reflecting off the Earth and then spilling on the darkened portion of the Moon.

When applied to the waxing crescent seen in evening twilight, the phenomenon is sometimes poetically referred to as "the old Moon in the new Moon's arms."

136 **Quite often you can see the Moon in the daytime sky if you know where to look.** While the Moon is waxing, it rises before sunset and so can be seen at least during the afternoon hours. When the Moon is a waxing crescent, look for it in the southwestern sky during the late afternoon. At first quarter, the Moon can be spotted in the southeastern and southern sky during the afternoon, while the waxing gibbous is quite conspicuous in the east and southeast late in the day. After full, the Moon rises after the Sun sets but also sets after the Sun rises the following morning. So look for the waning gibbous Moon in the west early in the morning, the last-quarter Moon in the south early in the day, and the waning crescent to the right of the Sun all day long.

137 **We always see the same side of the Moon from Earth.** The Moon always keeps the same hemisphere pointed toward the Earth. This means that we always see the

same face of the Moon. Indeed, if you could shine a giant searchlight on the new Moon, you would see the same features that you see during a full Moon.

138 **There's no such thing as "the dark side of the Moon."** It's a great rock album but, for the record, there is no "dark side of the Moon." It's true that half of the Moon is in darkness at any particular time, but as the Moon orbits the Earth, the specific part of the Moon that's lit by the Sun constantly changes. The side of the Moon that is dark at the moment will be the brightly lit side in two weeks and vice versa.

139 **Over time, more than half of the Moon's surface is actually revealed to our eyes.** While the Moon always keeps one side turned toward the Earth, our satellite actually wobbles a bit on its axis. This motion, called *libration,* allows us to alternately peek around the Moon's eastern edge and then its western edge. Also, because the Moon's orbit is tilted a bit relative to the plane of the Earth's orbit around the Sun, we also periodically get to glimpse a bit over the top and bottom of the Moon as well. In all, this allows us to see a total of about 59 percent of the Moon's total surface instead of just half.

140 **The side of the Moon that faces the Earth looks quite different from the side that points the other way.** While the near side of the Moon displays both light and dark regions, the far side of the Moon has far fewer maria and instead more cratered and highland regions. No one really knows why, but the huge impacts that created the deep basins that ultimately filled with lava to form the lunar "seas" primarily occurred in only one hemisphere for some reason. It might be tempting to suggest that the Earth somehow exercised some influence on the situation, but the bombardment that led to these great lunar depressions likely occurred at a time before the Moon's rotation slowed to the point of keeping only one side of the Moon facing the Earth.

141 **The Moon typically looks larger when it is near the horizon than when it is higher in the sky.** Technically speaking, the Moon is actually about 4,000 miles farther away from us when it rises than when it is high overhead. But a rising full Moon can really look huge. The effect, referred to as the "Moon illusion," is psychological rather than physical. Various explanations for the "Moon illusion" have been put forth, the most notable of which is that the brain interprets the Moon as being closer when it is near the horizon because the human mind is somehow influenced by the presence of foreground objects. No explanation of this curious apparition is universally accepted, however. So the next time you see a big beautiful full Moon on the rise, revel in its romantic appearance, but remember . . . its size is just an illusion.

142 **The full Moon always rises in the east as the Sun sets in the west.** When full, the Moon always lies opposite

the Sun in our sky. (This positions the Moon in such a way that we see the full hemisphere lit up by the Sun.) For this reason, the full Moon always pops up above the eastern horizon as the Sun goes down behind the western horizon. As the full Moon sets in the west the next morning, the Sun rises again in the east.

143 **The full Moon may appear very bright, but . . .** The Moon can shine brightly in our skies, but it is actually a very dark object. Most of its rocks and soil are dark gray and, on average, the Moon only reflects about 7 percent of the light that falls on it from the Sun. Some of the moons of the outer planets reflect over 80 percent of the Sun's light because they are made largely of ice. Imagine how bright a moonlit night would be on Earth if we had such an "ice Moon" in orbit around us.

144 **In talking about the brightness of the Moon or other planets or their moons, astronomers frequently use the term *albedo*.** The albedo of an object is simply the fraction of sunlight that the object reflects or scatters back into space. Thus, we would say that the albedo of the Earth's Moon is about 7 percent, while that of some of the moons of the outer planets is over 80 percent.

145 **Different full Moons take very different paths across the sky.** Because the axis of the Earth is tilted to the plane of its orbit and the orbit of the Moon is also tilted relative to the Earth's orbit, the Moon can take very different paths across our sky. On a chilly winter night in midlatitudes, for example, the full Moon can climb almost to the top of the sky, while at the beginning of summer, the full Moon rides low across the southern sky. In some areas, this June Moon is seen through a lot of water vapor during what is a humid time of year. The humidity scatters the blues and violets out of the Moon's light, giving the Moon a yellow or orange cast. No wonder this Honey Moon occurs at a time of year traditionally associated with weddings.

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146 **Our word *month* is derived from the word *moon*.** Not surprisingly, since a cycle of lunar phases is just about a month long, it became a convenient way of measuring time and was used as such by many cultures.

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147 **Many Native American cultures traditionally give different names to the different full Moons of the year.** Among the more common names are:

January	Old Moon
February	Snow, Hunger, or Wolf Moon
March	Sap or Crow Moon
April	Grass or Egg Moon
May	Planting or Milk Moon
June	Rose, Flower, or Strawberry Moon
July	Thunder or Hay Moon
August	Green Corn or Hay Moon

September	Fruit or Harvest Moon
October	Hunter's Moon
November	Frosty or Beaver Moon
December	Long Night Moon

148 **Because of its location in the heavens, the Harvest Moon really did help farmers harvest their crops.** Because the Moon's orbit is tilted relative to the orbit of the Earth, the time of moonrise can vary considerably throughout the year. Around the first of spring, the nearly full Moon rises well over an hour later from one night to the next. Around the first of fall, however, the situation is reversed and the nearly full Moon rises at almost the same time for several nights in a row. This Harvest Moon thus provided farmers with a lingering source of light in the east after the Sun had set in the west at just the time of year when they needed to put in long hours to harvest their crops.

149 **The date of the Harvest Moon each year is determined by another celestial event.** The Harvest Moon is the full Moon that occurs closest to the *autumnal equinox* or, in other words, the full Moon that occurs closest to the first day of fall. Because the first day of fall occurs around September 22 or 23 and a full Moon can occur as much as about two weeks before or after this date, the Harvest Moon can take place anytime between about September 7 and October 7. Stevie Wonder's song *I Just Called to Say I Love You* has a lyric that goes "No Harvest Moon to light one tender August night." It's a great song and has sold millions of copies, but for the record, a Harvest Moon can never occur in August.

150 **Many cultures today still use a lunar calendar to fix the time of religious festivals or solemn occurrences.** The Chinese, Hindus, Jews, Muslims, and others still use a lunar calendar in this way. The Muslim holy month of Ramadan, for example, begins at the first sighting of a particular waxing crescent Moon and ends at the next, while the Jewish feast of Passover and even the modern date for Easter are also still determined by the Moon. The date for Easter, for example, floats from year to year but always occurs on the first Sunday after the first full Moon after the *vernal equinox* (the first day of spring). Since the date for Passover is set by the same full Moon, Easter and Passover usually take place around the same time each year.

151 **The worst time to look at the Moon through a telescope is when the Moon is full.** Full Moons can be very romantic, but they can be very disappointing when viewed through a telescope. When the Moon is full, the places at the center of the Moon's face are experiencing "noon" (when the shadows cast by the Sun are the shortest). With no lunar shadows to help topography stand out, the face of the Moon appears almost featureless. The best time to look at the Moon through a telescope is when the Moon is near first or last quarter. Then craters and mountains stand out in stark relief, especially along the Moon's flattened edge, and cast impressive long shadows.

152 **The notion that the Moon is up in the sky all night is true only about one night each month.** That night is the night of the full Moon. Most of the time the Moon is only visible for part of the night and for three or four days each month, around the time of the new Moon, there is essentially no Moon to be found in the sky at all. If you went out at random times on random nights, you would find the Moon in the sky about half the time.

153 **There are two kinds of "blue Moon."** The length of time between one full Moon and the next is 29.53 days. This means that, except during February, if a full Moon occurs at the very beginning of the month, a second full Moon will just sneak in before the month is over. This second full Moon in the same month is sometimes given the nickname the "blue Moon." On average, a "blue Moon" occurs every two and a half to three years. So if you have always wondered just how often something happens that happens only "once in a blue Moon," there's your answer. Of course, the "blue Moon" doesn't actually look blue; it just has that name. Can the Moon actually ever have a bluish cast? The answer is yes. Smoke from a fire or ash from a volcanic eruption can scatter the reds and oranges from the Moon's light and the Moon can take on a bluish color when seen through such a veil.

154 **The Moon's orbit around the Earth is not a perfect circle.** As with virtually all other astronomical bodies, the Moon's orbit is an *ellipse.* During the course of a month, its distance from Earth varies from about 221,460 to 252,700 miles. The nearest point to Earth (known as *perigee)* and the farthest point (called *apogee)* slowly move around the orbit, however, so no single phase always corresponds to a particular distance. Thus, at times, the Moon is closest when it's full and, at other times, the Moon is closest when it's new. A set of photographs carefully taken throughout a lunar cycle clearly shows the Moon's apparent change in size as its distance varies.

155 **What causes an *eclipse* of the Moon?** An eclipse of the Moon takes place when the Earth, Moon, and Sun line up in space with the Earth in the middle. When this happens, the Moon passes through the shadow that the Earth casts out into space and we see that shadow slowly crawl across the face of the Moon. Therefore, an eclipse of the Moon can only take place when the Moon is full. But a lunar eclipse does not take place every time the Moon is full. This is because the orbit of the Moon around the Earth is tilted a bit relative to the orbit of the Earth around the Sun. This results in the full Moon usually passing a little above or below the shadow of the Earth.

156 **An eclipse of the Moon clearly shows that the Earth is round (spherical).** People at different latitudes on the Earth can see the same lunar eclipse and can also see that the shadow that the Earth casts onto the

Moon is round. Yet people at different latitudes see the Moon at different places in the sky during the eclipse. These circumstances would only be possible if the Earth were round and not flat. Indeed, this argument was used as early as 350 B.C. by the Greek philosopher Aristotle as proof that our planet was a sphere. So much for the myth that everyone except Columbus in Columbus's time thought the Earth was flat.

157 **Eclipses of the Moon can be either *total, partial,* or *penumbral.*** The Earth's shadow consists of a dark inner region called the *umbra* and a fainter outer region that surrounds the umbra (like a doughnut) known as the *penumbra.* When the Moon passes completely through the umbral portion of the shadow, a total eclipse of the Moon takes place. If the Moon passes through only a portion of the umbra, we see a partial eclipse of the Moon. Should the Moon only pass through the Earth's penumbral shadow, a penumbral eclipse results. Because the penumbra is so faint, penumbral eclipses go by virtually unnoticed.

158 **When a lunar eclipse takes place, everyone on the same side of the Earth gets to see it.** Because half of the Earth is in darkness (nighttime) at any given time, the entire hemisphere that is facing the full Moon when it passes through the Earth's shadow is turned toward the eclipse. Thus, weather permitting, millions of people can witness the same lunar eclipse at the same time.

159 **You can easily get the impression that there are fewer eclipses than there +really are.** Unless you purposely globe-trot to the right place at the right time, you will see fewer lunar eclipses than actually take place. This is because you have to be on the nighttime side of the Earth during the time the Moon passes through the Earth's shadow to see the eclipse. So sometimes when an eclipse of the Moon occurs, we are on the right side of the Earth (the nighttime side) and sometimes we have the "cheap seats" on the daytime side, which means folks on the other side of the Earth are treated to the eclipse instead of us.

160 **Some lunar eclipses are very dark, while others are light or even quite colorful.** In some instances, a totally eclipsed Moon can be so dark that it seems to virtually disappear from the sky. At other times, the eclipsed Moon can remain very visible, even when passing through the very heart of the umbra, and can take on a reddish or coppery hue. The reason for these differences has nothing to do with the Moon but rather the state of the Earth's atmosphere at the time of the eclipse. Typically, some sunlight passes through the ring of atmosphere surrounding the Earth as seen from the Moon. The Earth's atmosphere scatters the blues and violets in the Sun's light but allows most of the reds and oranges to pass through. Some of these, in turn, spill into the Earth's shadow and onto the face of the Moon. Hence, the totally eclipsed Moon can take on the appearance of a softly glowing lantern. During times of large volcanic activity, however, large

amounts of ash and dust can be present in the Earth's atmosphere. These particles absorb all the colors of sunlight and so can leave the shadow and the eclipsed Moon very dark.

161 **A lunar eclipse can be a rather long affair.** When only a portion of the Moon skirts the umbra, the resulting eclipse can be quite short. But because the diameter of the Earth's umbral shadow at the distance of the Moon is more than twice the diameter of the Moon and because the penumbral shadow, in turn, surrounds that, a total eclipse of the Moon from beginning to end can last about five hours (with the total phase almost two hours long). I refer to short and long lunar eclipses as "one and two six-pack eclipses," respectively.

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162 **Lunar eclipses are perfectly safe to look at.** Unlike an eclipse of the Sun, a lunar eclipse will not harm your eyes in any way. After all, the full Moon itself is safe to look at and, indeed, has been gazed at by lovers from time immemorial. During an eclipse, the Moon is passing through the Earth's shadow, so less light, rather than more, is falling on your eyes. Binoculars and telescopes enhance the view of the eclipsed Moon and help to bring out sometimes subtle colors in the Earth's shadow.

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163 **The tides are caused by both the Moon and the Sun.** It is a common notion that the Moon causes the tides, but actually the Sun also plays a role, albeit a smaller one. Although the Sun is farther from the Earth than the Moon is, the Sun is so much more massive that it still exerts a significant gravitational influence.

164 **Two tides occur each day.** Two tides typically occur at the same spot on Earth every day. This is because the Moon raises two bulges of water on the Earth—one that faces the Moon and another on the side of the Earth that lies opposite the Moon. The Earth then rotates under these tidal bulges, creating two high tides per rotation. Midway between these "watery mountains" or regions of high tide are two corresponding troughs or areas of low tide. Thus, two low tides, midway between the high tides, also occur each day. The times of high and low tide change a bit each day because the Moon is constantly advancing in its orbit around the Earth, so the time when the Moon is high in the sky advances a bit from day to day.

165 **The tidal bulge in the direction of the Moon is pretty easy to understand, but the bulge on the side of the Earth that points away from the Moon is a bit harder for most folks to fathom.** The secret to understanding the second bulge lies in understanding what really causes the tides. Most people think the Moon's gravity causes the tides, but this isn't exactly correct. It isn't the Moon's gravity per se but rather the *difference* in the *amount* of *gravitational pull* the Moon exerts on the *near* side of the Earth vs. the *far* side of the

Earth. The amount of gravitational force exerted by the Moon on the Earth depends on the *distance* between the Earth and the Moon. But the side of the Earth facing the Moon is almost 8,000 miles closer to the Moon than the opposite side. This means the Moon pulls with more force on the side of the Earth closest to it, less force on the side of the Earth farthest away, and an intermediate amount of force on the center of the Earth. The Moon pulls the water on the near side of the Earth away from the rocky core of the Earth, thereby creating the tidal bulge facing the Moon. But—and here's the tricky part—the Moon pulls *harder* on the Earth's *core* than on the *opposite side* of the Earth. Thus, the core of the Earth is *pulled away from* the water on the *far* side of the Earth in the direction of the Moon. This creates the second tidal bulge.

166 ***Spring* tides and *neap* tides are signs of a cosmic tug-of-war.** When the Earth, Moon, and Sun all line up in space (at the times of a full and new Moon), the Moon and Sun pull on the Earth along the same line. This produces enhanced tides known as spring tides. (The name, however, is misleading, for these tides occur every few weeks throughout the year and not just in the spring.) In contrast, when the Moon and the Sun are positioned at right angles to each other as seen from the Earth (when the Moon is in its first- and third-quarter phases), they pull at cross-purposes, so the resulting tides are minimized. These are known as neap (rhymes with *pep*) tides.

167 **Although the Moon is the major influence on the tides, it is erroneous to think of the Moon generating tides in human beings and, in so doing, influencing human behavior.** The key to understanding this frequently misunderstood notion is to again remember that tides are the result of how much *harder* the Moon pulls on *one* side of the Earth than the *other.* In the case of the Earth, this *difference* in gravitational pull can be substantial because the Earth is nearly 8,000 *miles* across. Thus, one side of the Earth is always nearly 8,000 miles *closer* to the Moon than the other. Human beings, on average, however, are less than 6 *feet* tall and only about 1 foot thick. Thus, the difference between the Moon's gravitational pull on your head and your feet or your front side and your back side is millions of times less than across the diameter of the Earth. The capillary forces within the body are millions of times greater. Thus, the human body is neither aware of nor influenced by the Moon.

168 **But isn't there proof of the Moon's influence in the close correlation between the length of time from one full Moon to the next and the human menstrual cycle?** Coincidence, yes. Influence, no. After all, of the many species that exhibit menstrual cycles, only some come reasonably close in length to the cycle of the Moon's phases. And the length and regularity of menstrual cycles within the human species varies significantly. Furthermore, the start of each woman's menstrual cycle is different

from most other women, so if a few females seem synchronized to a particular phase of the Moon, the vast majority are not.

169 **Yet many nurses and doctors who work in maternity wards claim that the frequency of births and multiple births goes up significantly around the time of the full Moon.** This is an interesting point but one that can easily be tested. In a study some years ago, Dr. George Abell, an astronomer at UCLA, decided to find out. He simply looked at the birth records and the phases of the Moon for the past several years. The result? No correlation whatsoever. The human mind can be a funny thing.

170 **Some suggest that a higher incidence of violent crimes or other abnormal behavior occurs around the time of the full Moon.** Again, most scientific studies of such situations, when large enough data samples are used, show little or no correlation. In this case, however, we must differentiate between the actual influence of the Moon and the influence a person is willing to believe the Moon has over them. In short, if a person believes strongly enough that the full Moon will influence his or her behavior, then his or her behavior is indeed more likely to show some variation. It is clearly important, however, to differentiate between the power of the Moon and the power of the human mind. To paraphrase the great philosopher Pogo: "We have met the phenomenon and it is us."

171 **The Moon was probably formed when the Earth was struck by a huge object from space.** Before we knew about *plate tectonics* (that is, the movement of large sections of the Earth's crust), some people noticed that the Moon was about the size of the Pacific Ocean and suggested that it somehow spun off this part of the Earth. Others have suggested that the Moon was formed elsewhere in the early solar system and, upon passing close by, was captured by the Earth. The most commonly held theory today, however, suggests that the Moon formed early in our solar system's history when an object about the size of Mars underwent a grazing collision with the Earth. The matter that was dislodged initially formed a ring around the Earth but ultimately coalesced to form the Moon. However, the Earth was probably still molten at the time.

172 **The Moon has had a violent past.** The history of the Moon (and most other objects in our solar system, for that matter) is a violent one. The Moon formed out of a cloud of gas and dust about 4.6 billion years ago. Smaller pieces of space debris continued to be swept up by the Moon as it solidified. Between 4.2 and 3.9 billion years ago, this great period of bombardment created many of the lunar craters that we see today.

By 3.8 billion years ago, the radioactive decay of materials at the Moon's center caused the interior to heat up, become molten, and trigger *volcanism* on the lunar

surface. Lava flowed onto the surface, flooding low-lying basins and creating the lunar maria, or "seas."

By 3.1 billion years ago, the period of volcanism was over, the maria solidified and, except for occasional meteorite impacts, the Moon took on the general appearance it has today.

173 **The interior of the Moon is lumpy.** When spacecraft were first sent into orbit around the Moon, scientists noticed that they unexpectedly slowed down and speeded up at various points along the way. In time, scientists surmised that the changes in speed were due to the presence of large dense meteoroids that had collided with the Moon shortly after it formed and sunk below the molten lunar surface. The denser lumps created stronger gravity in their vicinity, which increased the speed of the spacecraft. Thus, the careful measurement of the motion of lunar probes allowed scientists to map the invisible distribution of material inside the Moon.

174 **The interior of the Moon also can be studied via seismographs that were left behind by the Apollo astronauts.** Almost 10,000 moonquakes have been recorded by this equipment. Some were due to objects striking the Moon at high velocity, but the vast majority were the result of stresses inside the Moon induced by tidal forces exerted by the Earth. Most moonquakes seem to occur in a zone that ranges from about 400 to 750 miles below the lunar surface. Below this lies the Moon's core, which many scientists think is still molten. Above the zone of moonquakes lies the Moon's mantle and its surface crust. The crust, on average, is only about 45 miles thick.

175 **A total of twelve astronauts have walked on the surface of the Moon.** Only a dozen human beings have left footprints on another world. They are the six teams of two astronauts each that rode the lunar lander to the Moon's surface in Apollo missions 11 through 17. Originally, there were several more lunar landing flights planned, but they were canceled due to NASA cutbacks. The ill-fated *Apollo 13* orbited the Moon without being able to land, as

Apollo astronaut Gene Cernan, one of only 12 men who ever walked on the Moon, stands next to the lunar rover. (NASA)

portrayed in the famous movie of the same name. According to detailed plans that were kept secret during the Cold War, the Soviets also attempted to at least send men around the Moon, but all attempts were aborted before takeoff.

176 **In all, the astronauts brought back 381 kilograms (840 pounds) of material from the Moon.** The material ranged in size from rocks the size of your head to fine grains of dust and came from a wide range of locations, including the vast lunar plains and the mountainous highlands. The youngest rocks brought back were about 3.1 billion years old, while the oldest were about 4.42 billion years old—almost as old as the solar system itself.

177 **Lunar rocks are generally much older than terrestrial rocks.** The Moon became geologically inactive 3.1 billion years ago and many places there have been geologically dead for far longer. By comparison, the Earth remains active with volcanism and plate tectonic movements till this day. As a result, most rocks on Earth are far younger than 3 billion years old, while most lunar rocks date back 4 billion years or more. Thus, the study of Moon rocks gives us clues about the early history of our solar system that we cannot obtain by studying rocks on Earth.

178 **There are similarities and differences between Earth rocks and those brought back from the Moon.** The rocks brought back from the Moon were all types that are familiar to geologists. In the maria and highland regions explored by the Apollo astronauts, some of the rocks are *breccias,* that is, rocks that are a mixture of different types of rock that have been "welded" together under pressure. In the maria, however, most of the rocks are *basalts,* which are fine-grained rocks containing metals and silicates.

The lunar rocks showed that the Earth and Moon appear to be similar chemically, at least near the surface, although the Moon rocks recovered contain no traces of water and some elements that are rare on Earth, including uranium and thorium, are found in greater abundance on the Moon. Perhaps someday mining the Moon will be financially feasible.

179 **The Moon has only about one-sixth the gravity of the Earth.** Because of its much smaller mass, the Moon has significantly less gravitational pull than the Earth. A person weighing 100 pounds on Earth would weigh less than 17 pounds on the Moon because the Moon pulls down on the person with only one-sixth the force that the Earth does. Astronauts quickly developed a kind of combination "saunter and hop" maneuver that allowed them to get around quite well on the lunar surface. If it weren't for their cumbersome space suits, however, they would have been able to jump six times higher and farther than they can on Earth. Given more flexible suits, the first Lunar Olympics someday will be one for the record books.

180 **If you drop a hammer and a feather at the same time on the Moon, they hit the ground at the same time.** Try this little experiment in your backyard and the hammer clearly hits the ground first. This is because the feather has a lot more surface area for its weight than the hammer and so is buoyed up by more air resistance as it falls. On the Moon, there is no air, so there's no air resistance. The Moon pulls down on the hammer with more force than the feather, but the hammer, because of its *inertia,* requires more force to fall as fast as the feather. The *inertia* of an object depends on its mass and is a measure of how easy or difficult it is to get the object moving or stop it once it is moving. A Cadillac, for example, has more mass than a hockey puck and so has more inertia. It takes a lot more force to get a Cadillac going from 0 to 60 than a hockey puck, but a Cadillac is also a lot harder to stop once it's going that fast. So the Moon pulls harder on the hammer than the feather but in so doing, it only causes the hammer to achieve the same acceleration, thus causing both it and the feather to hit the ground at the same instant.

181 **As seen from the Moon, the Earth goes through phases.** For the same reason the Moon goes through phases as seen from Earth, the Earth goes through phases as seen from the Moon. These phases, however, are always the exact complement of each other. In other words, when we see a full Moon on Earth, astronauts on the Moon would experience a new Earth. When a first-quarter Moon is seen in Earth's skies, a third-quarter Earth hangs over the lunar landscape. Also, since it's almost four times larger, the Earth looks almost four times bigger in the Moon's sky than the Moon looks to us on Earth.

182 **The Moon is gradually moving away from the Earth.** The Moon is gradually spiraling away from the Earth. Each year it is about an inch farther away than it was the year before.