EXERCISE 21

# The Moon and Sun

The Moon and Sun are two of the nearest celestial objects to Earth, and each has inspired generations of observers to wonder about the nature of the cosmos (Figure 21.1). Many ancient civilizations revered these objects and devised methods for keeping track of their changing positions in the sky. Today, lunar and solar studies are providing astronomers with information that helps to answer questions about the evolution of the solar system and the source of energy of stars. This exercise investigates the motions and features of the Moon, as well as the structure and dynamic surface of our "nearest star," the Sun.

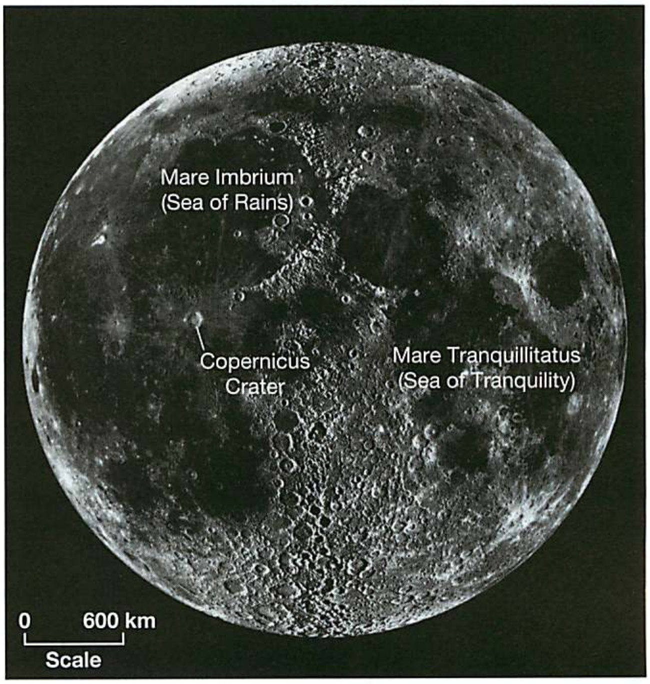



**Figure 21.1** Telescopic view of the lunar surface. (Image © UC Regents/Lick Observatory)

## Objectives

After you have completed this exercise, you should be able to:

1. Recognize and name each of the phases of the Moon.
2. Diagram the Earth, Moon, and Sun in their proper relation for each of the phases of the Moon.
3. Explain the difference between the synodic and sidereal cycles of the Moon.
4. Diagram the Earth, Moon, and Sun in their proper relation during a solar and lunar eclipse.
5. Discuss the difference between lunar terrae and maria and be able to recognize each on a lunar map or photograph.
6. Determine the relative ages of lunar features.
7. Recognize and name the different types of lunar craters.
8. Describe several of the features found on the solar surface.

## Materials

metric ruler, hand lens, calculator

*Materials Supplied by Your Instructor*

stereoscope, sandbox, meterstick, lunar globe (optional), sand, small balls (various masses)

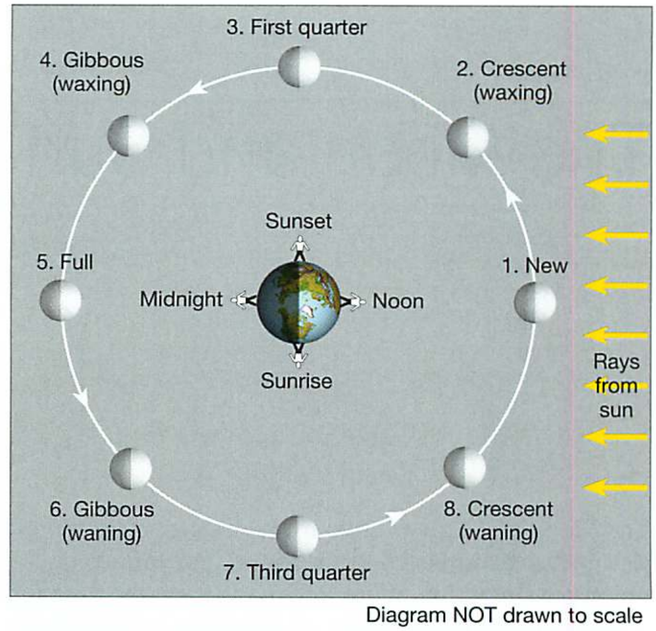
## Terms

synodic month
sidereal month
solar eclipse
lunar eclipse
terrae
maria
new Moon
crater
prominence
sunspot

# The Moon

At an average distance of 384,401 kilometers (238,329 miles), Earth's nearest celestial neighbor and only natural satellite is the Moon. The monthly counterclockwise revolution around Earth and associated Earth–Moon revolution about the Sun change the Moon's position relative to the Sun, producing the phases viewed by Earthbound observers. Furthermore, as the Moon moves in its orbit, its slow counterclockwise rotation results in the same side continuously facing Earthward.

The Moon has no atmosphere, and therefore no landforms produced by wind or water erosion. Instead, the vast majority of lunar surface features are the result of ancient volcanic eruptions and impact cratering by *meteoroids.* Many features that formed on the Moon's surface over 3 billion years ago are still discernible and have been only slightly modified by the continuous bombardment of tiny *micrometeorites.*



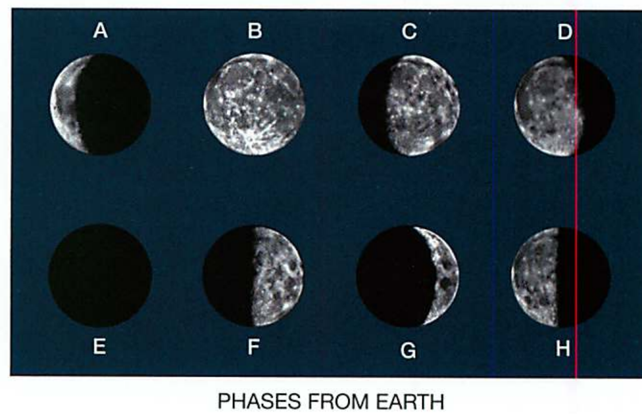




**Figure 21.2** The lunar cycle as viewed from above the Northern Hemisphere of Earth, including phases of the Moon as observed from Earth (A–H).

## Phases of the Moon

The changing phases of the Moon have been recorded throughout history and were among the first astronomical phenomena to be understood. The lunar phases observed from Earth are the result of the motion of the Moon and sunlight that is reflected from its surface. The half of the Moon facing directly toward the Sun is illuminated at all times. However, to an Earth-bound observer the percentage of the bright side that is visible depends on the location of the Moon with respect to the Sun and Earth. When the Moon lies between the Sun and Earth, none of the bright side can be seen by an Earthbound observer—a phase called *new-Moon* ("no-moon"). Conversely, when the Moon lies on the side of Earth opposite the Sun, all of its bright side is visible, producing the *full-Moon* phase. At any position between these extremes, only a fraction of the Moon's illuminated half is visible.

Figure 21.2 is a view of the Earth–Moon–Sun system from above the Northern Hemisphere of Earth. Eight positions of the Moon during its monthly journey around Earth are illustrated. Notice on the figure that the illuminated half of the Moon is always directly toward the Sun. However, the portion of the illuminated half visible from Earth changes during the lunar cycle. To help you understand the lunar phases, complete questions 1–13 using Figure 21.2.

1. For each of the eight numbered positions of the Moon, draw a line through the Moon that separates the half of the Moon that is *visible from Earth* (the half directly toward Earth) from the half which cannot be seen.
2. As the Moon journeys from position 1 to position 5, the proportion of its *illuminated side visible from Earth* is (increasing, decreasing). Circle your answer.
3. As the Moon journeys from position 5 to position 8, the proportion of its *illuminated side visible from Earth* is (increasing, decreasing). Circle your answer.
4. Complete the following by matching each of the eight drawings of the lunar phases as seen from Earth (A–H) with the Moon's appropriate position (1–8) on the figure.

| POSITION NUMBER | LETTER OF PHASE SEEN FROM EARTH | NAME OF PHASE |
|---|---|---|
| 1. | _____ | _______________ |
| 2. | _____ | _______________ |
| 3. | _____ | _______________ |
| 4. | _____ | _______________ |
| 5. | _____ | _______________ |
| 6. | _____ | _______________ |
| 7. | _____ | _______________ |
| 8. | _____ | _______________ |

Observe the time of day (noon, sunset, etc.) represented by the four positions of the Earth-bound observer on Figure 21.2. Note that an observer can see the Moon approximately 90° on either side of his or her location—that is, about $\frac{1}{4}$ of a circle in both directions. Using the eight positions of the Moon in its orbit and the times represented on Earth, answer questions 5–13.

5. The new Moon is highest in the sky to an Earth-bound observer at (noon, sunset, midnight, sunrise). Circle your answer.
6. The full Moon appears highest in the sky to an Earth-bound observer at (noon, sunset, midnight, sunrise). Circle your answer.
7. Throughout the lunar cycle, the Moon moves further (eastward, westward) in the sky each day. Therefore, to an Earth-bound observer, the time of day when the Moon is highest in the sky becomes progressively (earlier, later). Circle the correct responses.
8. Can a full Moon be observed from Earth by an observer positioned at noon? Explain the reason for your answer.

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9. A full Moon first becomes visible to an Earth-bound observer positioned at (noon, sunset, midnight, sunrise), and she or he must look (eastward, westward) to see the rising Moon. Circle the correct responses.
10. Can the first- and third-quarter lunar phases be observed during the daylight hours? Explain the reason for your answer.

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11. At approximately what times will the first-quarter Moon rise and set?

Rise: ________ Set: ________

12. At approximately what times will the third-quarter Moon rise and set?

Rise: ________ Set: ________

13. Assume a crescent-phase Moon is observed in the early evening in the western sky. During the next few days the Moon will be rising (earlier, later) and the visible, illuminated portion of the Moon will become progressively (larger, smaller). Circle your answers.

## Synodic and Sidereal Months

The time interval required for the Moon to complete a full cycle of phases is 29.5 days, a period of time called the **synodic month.** This complete cycle of the phases of the Moon (i.e., new-Moon to the next new-Moon) is the basis of the word "month" (or "moonth"). Although the cycle of phases requires 29.5 days, the true period of the Moon's 360° revolution around Earth takes only 27.3 days and is known as the **sidereal month**. The difference of approximately two days results from the fact that as the Moon revolves around Earth, the Earth–Moon system also is moving around the Sun.

Figure 21.3 illustrates an exaggerated month of motion of the Earth–Moon system around the Sun. Refer to the figure to answer questions 14–22.

14. On Month I of Figure 21.3, indicate the dark half of the Moon on each of the eight lunar positions by shading the appropriate area with a pencil.
15. Select from the eight lunar positions in Month I, and indicate which represents the following lunar phases.

| PHASE | LUNAR POSITION (MONTH I) |
|---|---|
| New-Moon | _____ |
| Third quarter | _____ |
| Full-Moon | _____ |
| First quarter | _____ |

16. On Month I, label the position of the new-Moon phase with the words "new Moon."
17. In Month II of Figure 21.3, lunar position number (1, 3, 5, 7) represents the new-Moon phase. Circle your answer and label the position of the new-Moon phase on Month II with the words "new Moon."

Begin with the position of the new-Moon phase in Month I, and imagine revolving the Moon 360° around Earth while at the same time moving it to Month II.

18. After a 360° revolution beginning at the new-Moon phase in Month I, the Moon is located at position (6, 7, 8) in Month II. Circle your answer.
19. A complete 360° revolution of the Moon around Earth is called a _________ month, which takes _________ days.
20. The position of the Moon you determined in question 18 occurs (before, after) the Moon completes a full cycle of phases from Month I to Month II. Circle your answer.
21. In Month II, when the Moon moves the additional distance in its orbit, from position 6 to 7, and again is at the new-Moon phase, it will have completed a _________ month, which takes _________ days.

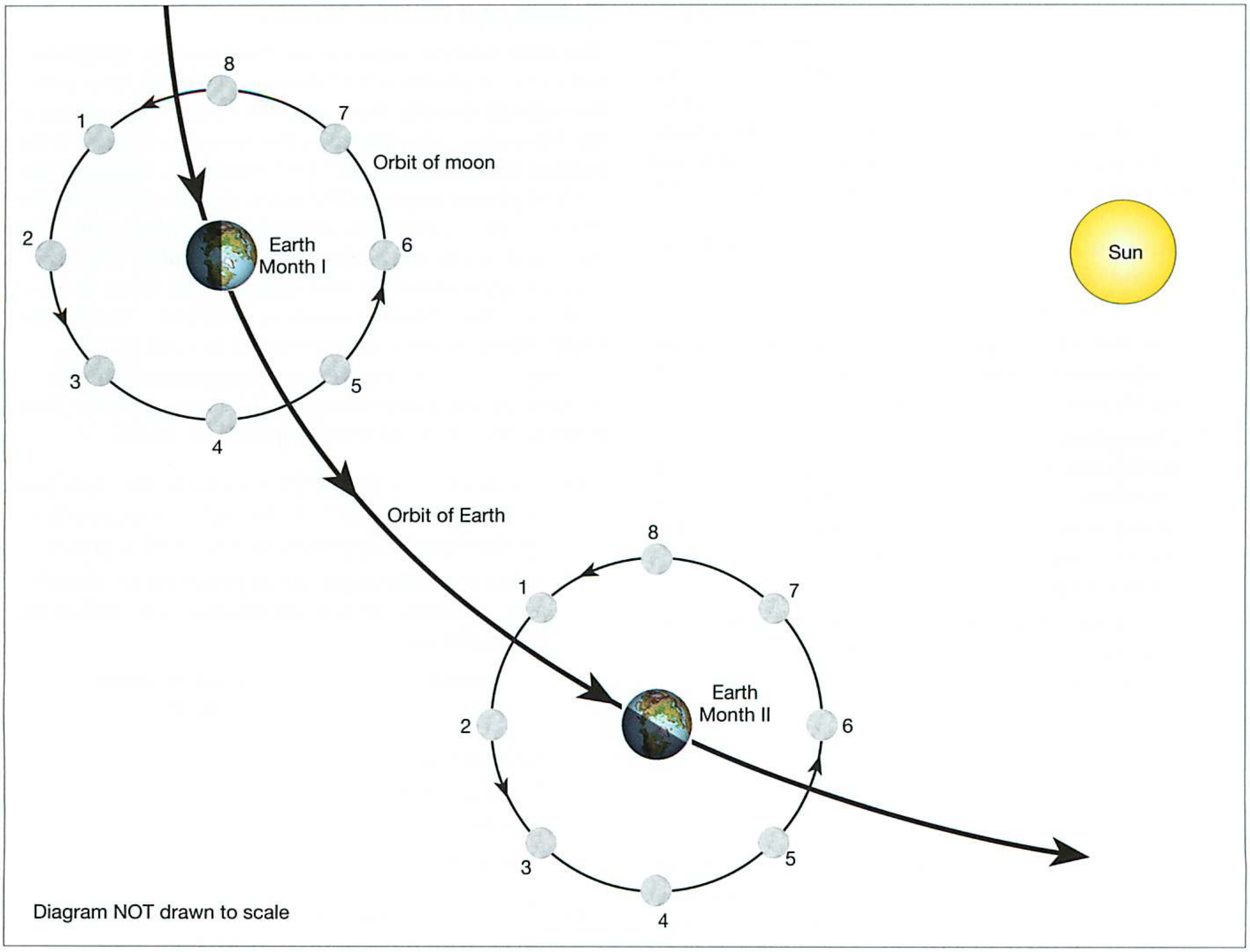


**Figure 21.3** Monthly motion of the Earth–Moon system around the Sun viewed from above the Northern Hemisphere.

22. In your own words, explain the difference between a sidereal and synodic month.

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## Eclipses

Eclipses occur when the Sun, Moon, and Earth are in a direct line. An eclipse can be either a **solar eclipse** (when the Moon moves in a line directly between Earth and the Sun) or a **lunar eclipse** (when the Moon moves within Earth's shadow).

23. Refer to Figure 21.4. Describe a solar eclipse and prepare a "side view" diagram showing the relation of the Sun, Earth, and Moon during the eclipse.

Description: ______________________________

______________________________________________

**Figure 21.4** Solar eclipse diagram.

24. A solar eclipse occurs during the (new-Moon, first-quarter, full-Moon) phase of the Moon. Circle your answer.

25. Refer to Figure 21.5. Describe a lunar eclipse and prepare a "side view" diagram showing the relation of the Sun, Earth, and Moon during the eclipse.

Description: ______________________________

______________________________________________

**Figure 21.5** Lunar eclipse diagram.

26. A lunar eclipse occurs during the (new-Moon, third quarter, full-Moon) phase of the Moon. Circle your answer.

27. Suggest a reason(s) why Earth does not experience a solar and lunar eclipse during each synodic month.

## The Lunar Surface

Since the Moon lacks an atmosphere, its landscape has been shaped primarily by meteoroid impacts and ancient volcanic processes. In general, the Moon's surface can be classified as one of two types. As illustrated in Figure 21.6, **terrae** (plural for *terra,* the Latin word for land) are lunar highlands, which are the bright areas of the Moon seen from Earth. The dark areas of the Moon, called **maria** (plural for *mare,* the Latin word for sea), are flat lowland regions. Together, the arrangement of terrae and maria on the lunar surface result in the well-known "face on the Moon."

The most obvious features on the lunar surface are **craters**. Many different types of craters exist (see Figure 21.6), with most of them produced when rapidly moving debris impacted the lunar surface.

Figure 21.7 is a near-side, enhanced photograph of the Moon with many of the major features labeled. Lunar latitude and longitude are indicated along the edges of the photo. A graphic scale for determining distances is also included. Use Figures 21.6 and 21.7 to answer questions 28–43.

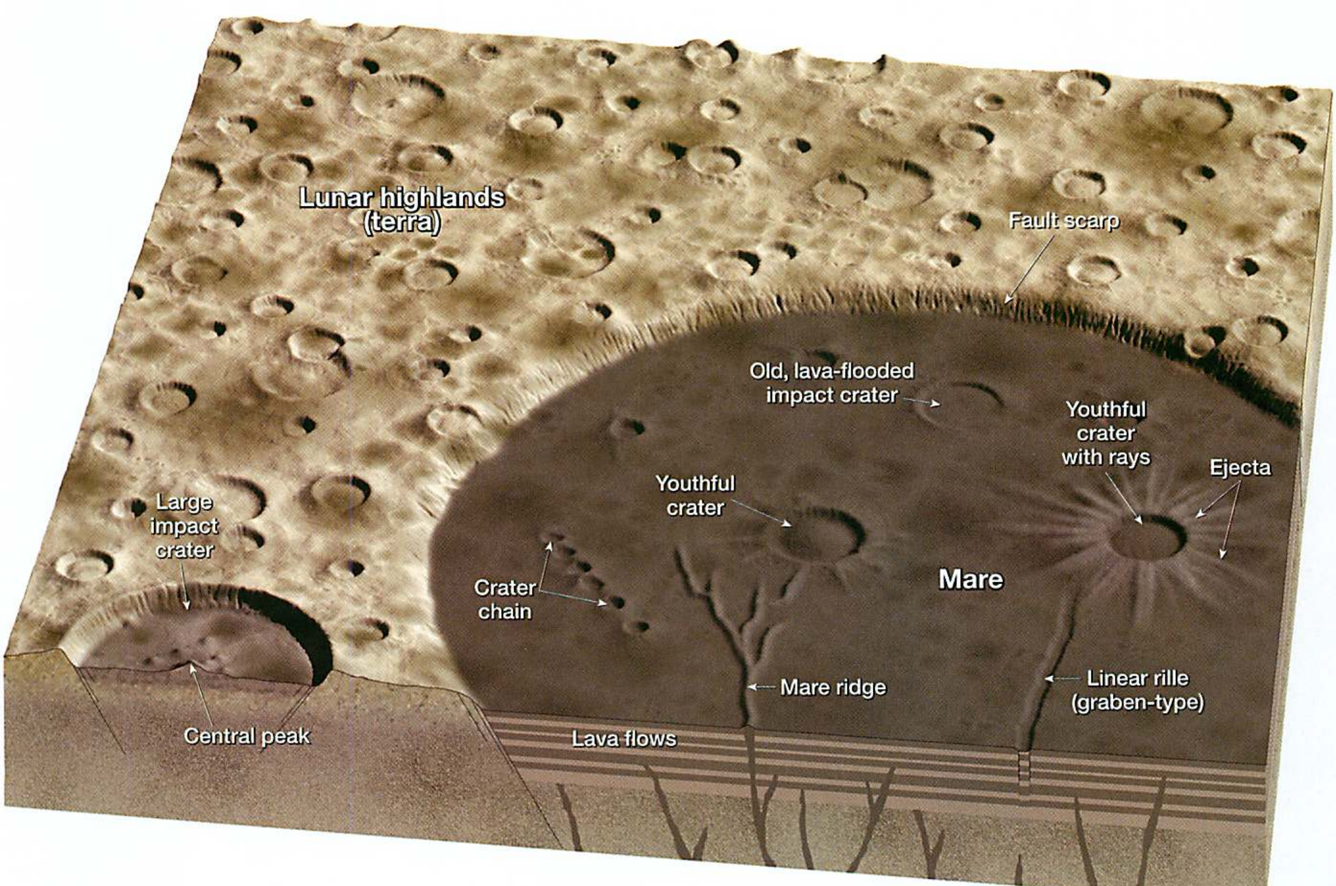


**Figure 21.6** Block diagram illustrating major lunar features.

**Figure 21.7** Near side image of the Moon. ((c) Mitchell Beazley Publishers, 1981, distributed in the U.S.A. by Rand McNally and Company. Used with permission)

0
100
200
300
400
500
600
700
800 km
± 50°
± 40°
± 30°
± 20°
± 10°
0°
EAST
10°
20°
30°
40°
50°
60°
70°
80°
90°
NORTH
SOUTH
Egede
Aristoteles
Mitchell
Baily
Hercules
Atlas
Mercurius
Zeno
Boss
Eudoxus
LACUS
Bürg
MORTIS
Plana
Mason
Williams
Chevallier
Oersted
Shuckburgh
Carrington
Schumacher
Vashakidze
Hooke
Cepheus
Cassini
MONTES CAUCASUS
LACUS
Grove
SOMNIORUM
Calippus
Messala
Franklin
Theaetetus
Maury
Rynin
Gauss
Berzelius
Geminus
Bernoulli
Daniell
Hall
G. Bond
Posidonius
Kirchhoff
Berosus
Vestine
Burckhardt
Hahn
Autolycus
MARE
Chacornac
Newcomb
MONTES
TAURUS
Römer
Linné
Cleomedes
Delmotte
Seneca
Liapunov
Joliot
SERENITATIS
Plutarch
Eimmart
Conon
Bessel
Littrow
Macrobius
Tisserand
Hubble
MARE
Cannon
Peirce
Sulpicius Gallus
Maraldi
PALUS
Al-Biruni
Vitruvius
Dawes
Menelaus
Plinius
Franz
Proclus
CRISIUM
Alhazen
Hansen
MARE
Goddard
Ibn Yunis
Ginzel
MARGINIS
Manilius
MONTES HAEMUS
Auwers
SOMNII
Yerkes
Picard
Lyell
Jansen
Lick
Condorcet
Ross
Maclear
Auzout
Boscovich
Julius Caesar
Sosigenes
Cauchy
Da Vinci
Neper
Jansky
Dreyer
RIMA HYGINUS
Rima Ariadaeus
MARE
Arago
Firmicus
Triesnecker
Taruntius
Apollonius
MARE
Dubiago
Agrippa
Tempel
TRANQUILLITATIS
SPUMANS
Babcock
Secchi
Godin
Maskelyne
Schubert
Rhaeticus
Censorinus
MARE
MARE
Lade
Webb
Maclaurin
Purkyne
Delambre
Saunder
Taylor
Hypatia
Torricelli
Messier
Gilbert
Hipparchus
Alfraganus
FECUNDITATIS
SMYTHII
Kästner
Hirayama
Zöllner
Isidorus
Capella
Gutenberg
Langrenus
Albategnius
Andel
Goclenius
La Pérouse
Brunner
Richey
Mädler
Theophilus
MARE
Parrot
Cyrillus
Lohse
Ansgarius
Vogel
Abulfeda
Lamé
Argelander
Tacitus
Colombo
Vendelinus
Behaim
Ritz
Airy
Almanon
NECTARIS
Cook
MONTES PYRENAEI
Gibbs
Geber
Catharina
Monge
Holden
Schorr
Delaunay
Donati
Abenezra
Balmer
Hecataeus
Faye
Azophi
RUPES
Fracastorius
Santbech
Lacaille
Playfair
Sacrobosco
Curie
Wrottesley
Blanchinus
Borda
Petavius
ALTAI
Phillips
Humboldt
Werner
Apianus
Weinek
Pontanus
Hase
Legendre
Snellius
Barnard
Piccolomini
Aliacensis
Reichenbach
Neander
Adams
Goodacre
Zagut
Lindenau
Stevinus
Abel
Gemma Frisius
Nonius
Rabbi Levi
Stiborius
Kaiser
Riccius
Furnerius
Fumerius
Büsching
Rheita
Wöhler
Buch
VALLIS
Marinus
Fraunhofer
Stöfler
Brenner
Gum
Faraday
Maurolycus
Metius
RHEITA
Young
Nicolai
Hamilton
Jenner
Fabricius
Oken
Barocius
Vega
Spallanzani
Janssen
Peirescius
Licetus
Clairaut
Breislak
Lockyer
Heraclitus
Ideler
Steinheil
Brisbane
Lyot

**28.** What is the origin of the lunar maria?

________________________________________

________________________________________

**29.** By examining Figure 21.7 (also see Figure 21.1), approximately (20, 40, 70) percent of the near-side of the Moon consists of lunar maria. Circle your answer.

**30.** What is the name and approximate width of the mare located at 16°N latitude and 59°E longitude?

Mare ________________, ________ km wide.

**31.** What is the lunar latitude and longitude of the crater named Copernicus, located near the center of the map?

Latitude: __________, longitude: __________

**32.** Locate the following lunar features on Figure 21.7 and give the lunar latitude and longitude of each. Also, use Figure 21.6 as a guide to indicate the type of feature represented by each.

| | LOCATION | TYPE OF FEATURE |
|---|---|---|
| Sinus Iridum: | __________ | ______________ |
| Humboldt: | __________ | ______________ |
| Mare Orientale: | __________ | ______________ |
| Rupes Altai: | __________ | ______________ |
| Kepler: | __________ | ______________ |

The number of impact craters within an area can be used to determine the age of a surface. In general, the more craters that are present, the longer the surface has been in existence.

**33.** Examine the frequency of craters on the lunar highlands compared to those on the maria. Lunar (terrae, maria) have formed most recently. Circle your answer.

**34.** Rocks brought back from the lunar maria during the manned Apollo landings are about 3.2–3.8 billion years old. Therefore, lunar highlands are (older, younger) than 3.2–3.8 billion years. Circle your answer.

**35.** Compare the crater frequency on the floor of Mare Smythii (2°S, 87°E) with that of Sinus Iridum (45°N, 31°W). Sinus Iridum appears to be (older, younger) than Mare Smythii.

**36.** Mare Smythii appears to be (older, younger) than Mare Crisium (16°N, 59°E).

When craters overlap, the rim of the most recent crater will cut through the rim of the older.

**37.** Using a stereoscope, examine the stereogram of the overlapping lunar craters shown in Figure 21.8

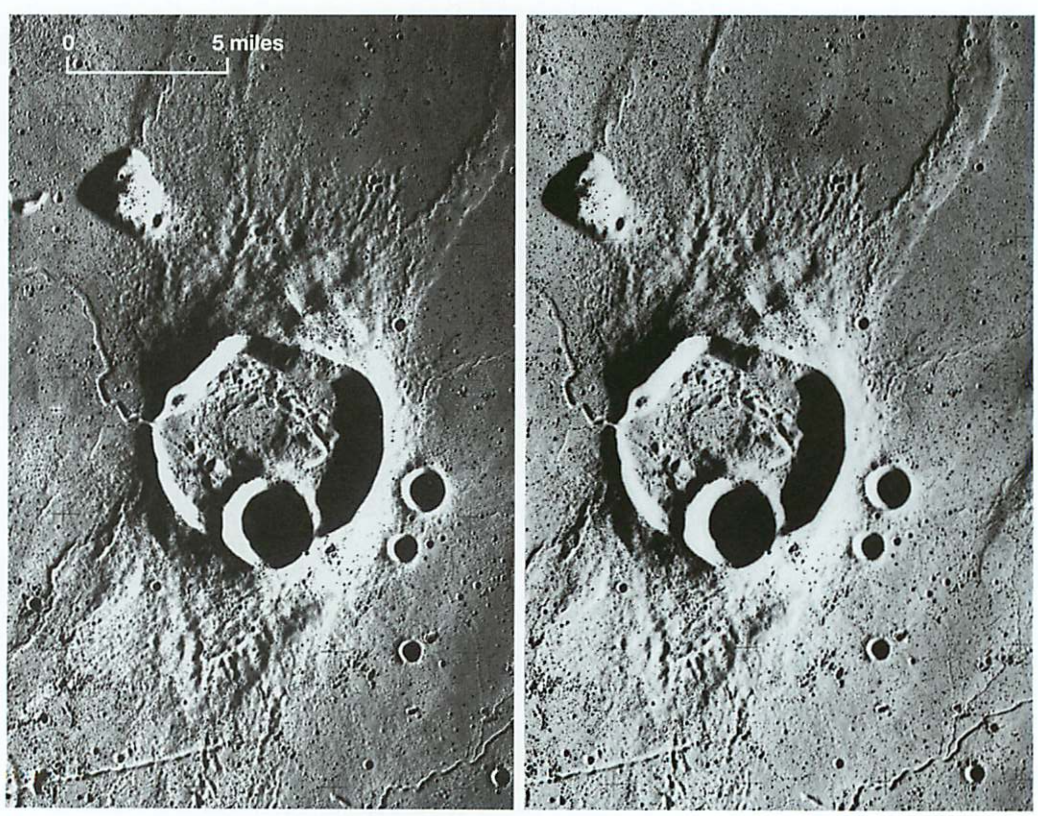


**Figure 21.8** Stereogram of lunar craters. (Photo courtesy of NASA)

and label the most recent crater with the word "youngest."

38. Observe the crater Gasserdi (17°S, 39°W) and its relation to Mare Humorum in Figure 21.7. Crater Gasserdi is (older, younger) than Mare Humorum.

39. Locate craters Mee, Hainzel, and the unnamed crater northwest of Hainzel at approximately latitude 42°S and longitude 35°W in Figure 21.7. List the craters in order, from youngest to oldest.

Youngest: ____________________

____________________

Oldest: ____________________

Most crater rims become rounded after long periods of bombardment by sand-size particles (micrometeorites). Therefore, the "sharpness" of a crater is an indication of its age.

40. Examine the crater Copernicus on the lunar map, Figure 21.7, and compare the "sharpness" of its rim to other lunar craters. What conclusion can you make about the age of Copernicus?

____________________

41. What conclusion can be made about the age of crater Mee compared to crater Tycho, directly east of Mee?

____________________

Examine the crater Copernicus and the area around it closely in Figure 21.7.

42. What type of crater is Copernicus? You may find Figure 21.6 useful.

____________________

43. What is the origin of the bright rays that radiate outward from Copernicus?

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44. It is likely that Earth was bombarded with meteoroids early in its history at least as frequently as the Moon. If so, why are there so few craters visible on Earth's surface today?

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## Impact Cratering

Impact cratering is one of the most common processes responsible for altering the surface of many planets and moons. To assist you in understanding the process and how the size and shape of an impact crater is related to the properties of the object that produce it, observe the equipment in the laboratory (Figure 21.9) and then conduct the following experiment by completing each of the indicated steps.

**Step 1:** Gather the equipment necessary to conduct the impact cratering experiment.

**Step 2:** Add sand to the sandbox. Flatten the surface of the sand with a wooden ruler.

**Step 3:** Write a hypothesis describing the suspected relation between an impact crater's diameter and the mass and velocity of the object that produces it.

____________________

____________________

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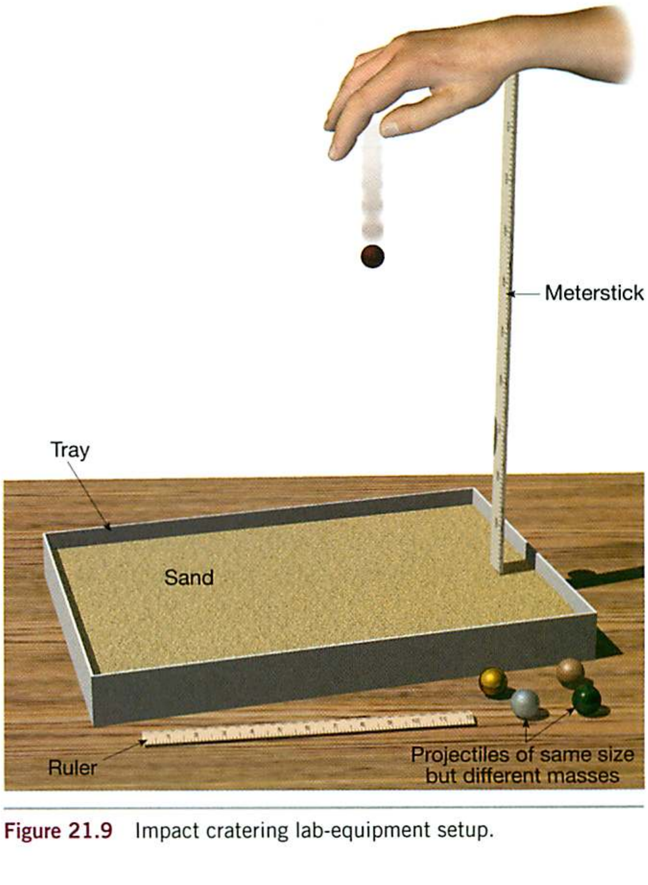


Figure 21.9 Impact cratering lab-equipment setup.

**Table 21.1 Impact Crater Data Sheet**

| Ball Type | | Crater Diameter | | |
|---|---|---|---|---|
| Description | Mass | 0.5 m Height<br>Crater Diameter (mm) | 1.0 m Height<br>Crater Diameter (mm) | 1.5 m Height<br>Crater Diameter (mm) |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

**Step 4:** One at a time, drop each of the balls from heights of 0.5 m, 1.0 m, and 1.5 m on the sand in the box and measure the diameter in millimeters of the crater produced in each drop. Make sure to flatten the surface of the sand between each drop. Repeat each drop several times, keeping all the variables constant. Record the average for each of the drops on the data sheet, Table 21.1.

**45.** Which of the variables is directly related to the velocity of the falling object(s)?

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**46.** Examine your data closely and state your conclusions concerning the general relationships between crater size and the (1) mass and (2) velocity of the object that produced the crater.

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**47.** Write a general statement that evaluates your impact-cratering hypothesis with reference to your conclusions.

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# The Sun

At an average distance of 150 million kilometers (93 million miles), the Sun is the nearest star to Earth. When compared to the other billions of stars in our galaxy, our Sun is considered only "average." However, it is not only important to us as our primary source of energy, but also to astronomers, since it is the only star whose surface can be observed in detail.

## Solar Features

As the Sun rotates, it does so differentially, taking fewer days to complete one rotation on its equator than near the poles. The unequal period of rotation causes variations in the Sun's magnetic field, which in turn influence many of its surface features.

Figure 21.10 illustrates several features of the active Sun when the solar disk is photographed in hy-

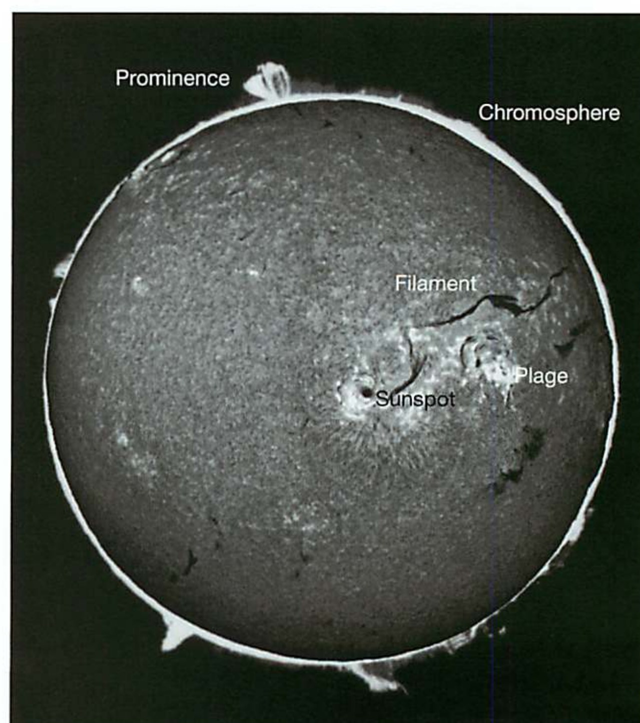


**Figure 21.10** The solar disk photographed in hydrogen alpha light. (This composite courtesy of Hale Observatories and National Solar Observatory, Sacramento Peak)

drogen alpha light. The actual diameter of the solar image in the figure is approximately 870,000 miles. Use Figure 21.10 to answer questions 48–54.

**48.** Using a metric ruler, measure the diameter of the solar image in millimeters. Then determine the scale of the photograph in miles per millimeter and write the scale on the photograph.

$$\text{Scale} = \frac{870{,}000 \text{ miles}}{\_\_\_\_\_\_\_\_ \text{mm}} = \_\_\_\_\_\_\_\_\_\_\_\_ \text{mi/mm}$$

**49.** The diameter of Earth is approximately 8,000 miles. Using the scale you calculated in question 48, draw a scale mile Earth on the surface of the Sun in Figure 21.10. Label your drawing "Earth." Approximately how many times larger than the Earth is the diameter of the Sun?

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Notice the "granulated" appearance of the solar image on the photograph.

**50.** What is the cause of the irregular, grainy appearance of the solar surface?

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Locate the large solar **prominence** near the top of the photograph.

**51.** Using the scale you prepared in question 48, approximately how many miles does the prominence extend above the surface of the Sun?

____________ miles

**52.** Describe the appearance and apparent cause of prominences.

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Examine the large **sunspot** (dark "blemish") near the center of the solar disk.

**53.** What is the approximate diameter of the sunspot?

____________ miles

**54.** Suggest a reason why sunspots appear as dark areas.

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## The Moon and Sun on the Internet

Continue your analyses of the topics presented in this exercise by completing the corresponding online activity on the *Applications & Investigations in Earth Science* website at http://prenhall.com/earthsciencelab

**Notes and Calculations.**

# The Moon and Sun

Date Due: ____________________

Name: ____________________

Date: ____________________

Class: ____________________

After you have finished Exercise 21, complete the following questions. You may have to refer to the exercise for assistance or to locate specific answers. Be prepared to submit this summary/report to your instructor at the designated time.

1. Write a brief paragraph explaining the reasons for the changes that occur in the phases of the Moon as observed from Earth during a full lunar cycle of 29.5 days.

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2. Each of the four photographs in Figure 21.11 was taken from Earth when the Moon was at its highest position in the sky. In the space provided below each photo, write the name of the phase represented and the time of day when the picture was taken.

3. Figure 21.12 (page 306) illustrates the Earth–Moon system viewed from above the Northern Hemisphere. If you have completed Exercise 17, "Astronomical Observations," draw a circle representing the Moon in the proper position in its orbit for each of the lunar phases you observed and recorded in the exercise. Indicate the dark half of the Moon by shading each circle. Label each position with the date and time of your observation. (If you have not completed Exercise 17, complete the diagram by illustrating the Moon at its proper position during full-Moon, new-Moon, first quarter, and third quarter. Label each position with the name of the phase.)

4. Explain the difference between a sidereal and synodic month.

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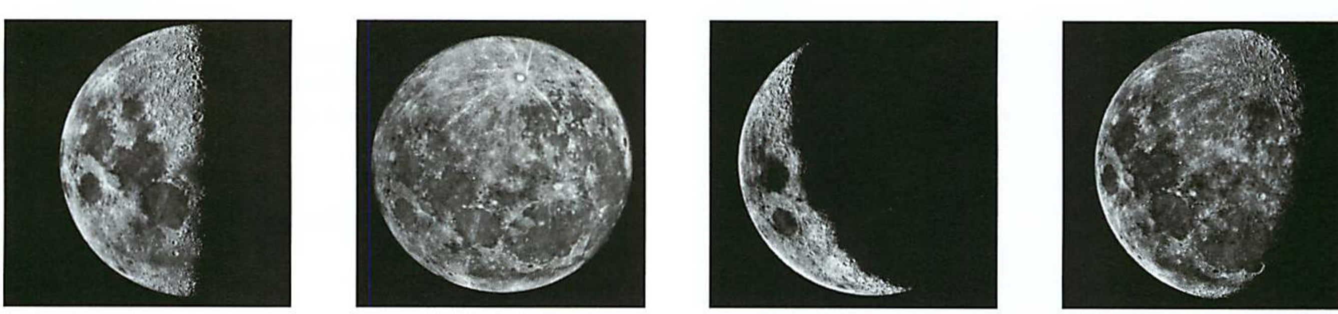

| | | | |
|---|---|---|---|
| Phase: ________ | Phase: ________ | Phase: ________ | Phase: ________ |
| Time: ________ | Time: ________ | Time: ________ | Time: ________ |

**Figure 21.11** Lunar photos. (Image © UC Regents/Lick Observatory)

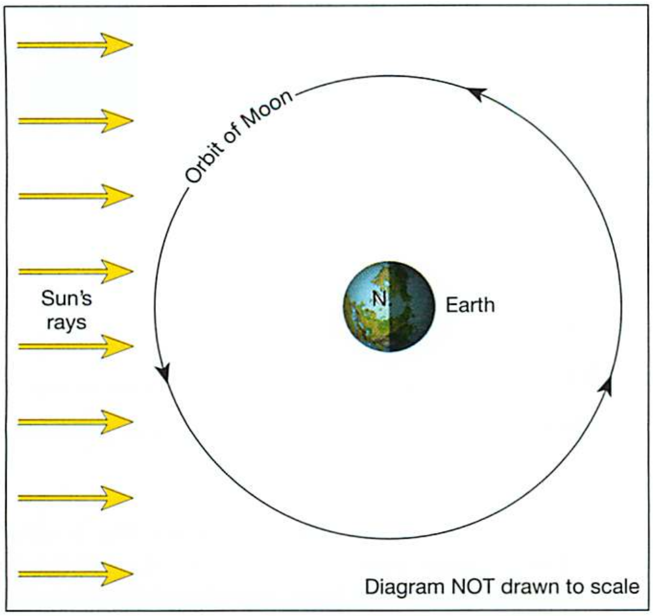


**Figure 21.12** Lunar phases diagram.

5. What are the most obvious differences in appearance between terrae and maria on a lunar photograph or map?

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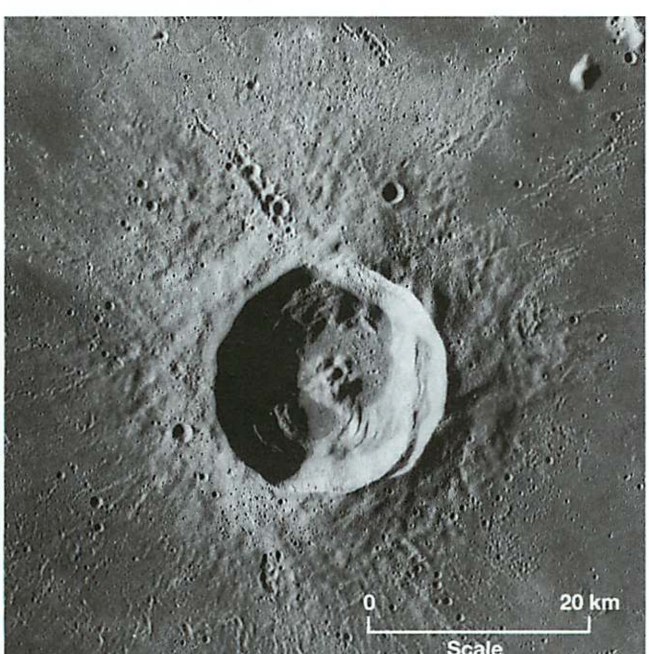


**Figure 21.13** A 20-km-wide lunar crater. (Photo courtesy of NASA)

6. Questions 6a–6d refer to Figure 21.13, a photograph of a 20-kilometer-wide lunar crater.

   a. The crater is located in a (terra, mare) region of the Moon. Circle your answer.

   b. What evidence suggests that the crater is of comparatively recent origin?

   _______________

   c. The large crater in the photograph is of what type?

   _______________

   d. What is the origin of the rays that extend from the crater rim?

   _______________

   _______________

7. When two craters overlap, how can you determine which is the most recent?

_______________

_______________

8. Define each of the following terms.

New-Moon: _______________

_______________

Solar eclipse: _______________

_______________

Sunspot: _______________

_______________

Lunar terrae: _______________

_______________

9. If there is a new moon on September 2, on what dates will the next first-quarter phase and following full-moon phase occur?

_______________

10. Briefly summarize the results of your impact-crater experiment.

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