Chapter 10: Mars
A Near Miss for Life?

Outline

10.1 Orbital Properties
10.2 Physical Properties
10.3 Long-Distance Observations of Mars
10.4 The Surface of Mars
10.5 The Martian Atmosphere
10.6 Martian Internal Structure
10.7 The Moons of Mars

Summary

Of all the planets in the solar system, it is perhaps Mars that has garnered the most public attention. What began as a serious investigation into the possibility of intelligent life soon became a carnival of newspaper headlines and science fiction novels. However, the search for intelligent life ("anywhere," as the joke goes) does have a serious face, which will be discussed later in the text. Mars, on the other hand, serves as a perfect platform to discuss the possibility of life existing beyond Earth. Point out to the student, right away, that "life" does not necessarily entail intelligence. Today, Mars appears to be lifeless, but recent evidence suggests that conditions may have favored life long ago.

The connection to the issue of life past and present is strong among students today. It is a real hook to get them deeply involved with the material. Interestingly, this has almost always been the case for Mars, even when the observations did not support the conjectures about life. But now, "canals" have become runoff and outflow channels. The *Mars Global Surveyor* shows hints of recent water-eroded gullies. Layered terrain suggests numerous and complex changes in the Martian environment and the twin probes, *Spirit* and *Opportunity*, have all but confirmed the existence of standing pools of water, which have long been evaporated.

In addition to the search for life, this chapter on Mars also serves as a catalyst for discussing space probes and landers. There have been many successful unmanned missions to Mars (as well as many failed missions). Show plenty of images of the *Mars Global Surveyor*, the *Viking* Lander, *Pathfinder* and the highly successful, twin Mars Exploration Rovers (*Spirit* and *Opportunity*).

Major Concepts

- Orbital Properties
  - Superior orbit
  - Eccentric orbit
  - Low albedo
- Physical Properties
  - Size
  - Similar tilt and rotation period to Earth
- Observation
  - Polar caps
  - Varying surface feature visibility due to wind/dust storms

- Surface
  - Cratering
  - Volcanism
  - Olympus Mons, the Tharsis Bulge and Valles Marineris
  - Water (in the distant past)
- Atmosphere
  - Tenuous
  - Predominantly CO_2
  - Evolution
- Internal Structure
  - No magnetic field, so solid core
- Moons
  - Captured Asteroids
  - Small

Teaching Suggestions and Demonstrations

Section 10.1

Since Mars is the first planet to be encountered whose orbit lies outside of the Earth's orbit, this is a good opportunity to demonstrate how these planets are viewed from Earth. ➲ **DEMO** Set up the Sun (a light bulb) and two spheres for Earth and Mars. Remember that the Martian orbit is about 1.5 times the size of the Earth's orbit. Show how Mars appears in a full phase most of the time; this will be true for all the rest of the planets. Next demonstrate the arrangement for opposition. Although this is our closest approach to Mars, we are still farther away than we are from Venus at its closest approach (inferior conjunction). Ask the students which planet would be best or most easily viewed; Mars at opposition or Venus at inferior conjunction. Although Venus is closer and larger, it is also in seen in the glare of the Sun and appears as a thin crescent. Mars is seen full and will be the highest in the sky around midnight (because it is "opposite" the Sun). Astronomers usually try to observe most of the outer objects in the solar system during their respective oppositions.

The eccentricity of the Martian orbit is best demonstrated with respect to favorable oppositions. Using a scale of 1 m = 1 A.U., show that compared to the position of the Earth, Mars will be at 1.38 A.U. (favorable opposition occurring at perihelion) or 1.66 A.U. (unfavorable opposition occurring at aphelion). The difference of 28 cm in the position should be easily seen. Ask how a favorable opposition might depend on the orbit of the Earth and its eccentricity. Since this eccentricity is low, 0.017, the Earth will vary by only ±1.7 cm on this scale between its perihelion and aphelion. This effect produces a maximum of 12% variation in quality of the opposition, which is sufficiently large to be important.

Section 10.2

Overview the terrestrial planets and discuss similarities between each. Although Venus is similar in size and mass, any hopes of becoming a vacation destination were dashed by the realities of high pressure, intense heat and suspended acid droplets. Mercury fared no better. Mars, on the other hand, seems to be a relief from the two obviously uninhabitable worlds discussed so far. Mars has a period of rotation very similar to Earth's. The tilt of its axis is also very similar to Earth's, giving it seasonal variations somewhat like ours. These characteristics have made Mars a prime candidate for science fiction stories about colonizing another planet. Now, there have been recent confirmations of evidence for the existence of water long ago. You will definitely want to show Figures 10.11, 10.12 and 10.13. Have on hand images of Earth's river beds, river deltas and lakes for comparison.

Section 10.3

As noted in the text, Mars at opposition, appears about 25 arc seconds in diameter. Under the best viewing conditions on Earth, telescopes can view detail down to about half an arc second. Therefore, astronomers should be able to see objects on Mars down to a size of about 1/50th its size, or 135 km (rounded off to 100 km in the text). When Percival Lowell thought he saw canals on Mars, they would have had a minimum width of over 100 km to be seen! These are rather wide canals for such an arid planet! Often, simple arguments such as these can be used to recognize the fallacies of such reports.

Knowing the sizes of the polar ice caps or the volcano Olympus Mons, will these objects be visible from Earth? Will the caldera of Olympus Mons be visible, large craters, canyons, ancient rivers? For the most part, all these latter features cannot be resolved because of the limitations of the Earth's atmosphere.

Section 10.4

As measured at the Viking landing sites, set the thermometer high at 244 K (-20° F) during the summer and set the nighttime low at 187 K. Temperatures at the poles certainly reach 146 K, which is the freezing point of carbon dioxide. Note that soil temperatures can exceed the freezing point of water, 273 K, as it is warmed by the summer sun. Equatorial regions may also record higher temperatures than found at the Viking sites. Students are usually very interested to learn that the highest known temperatures on Mars are what we call "room temperature." However, it should be stressed that this would represent the hottest, tropical-like temperature and is not, by any stretch of the imagination, to be considered normal.

The large volcanoes of Mars are among some of the most interesting surface features of the planets. There is a common misconception that volcanoes are very steep-sided. Although some are, shield volcanoes have very gentle slopes. ➲ **DEMO** Model Olympus Mons using a meter stick for the base of the volcano. Attach a string slightly longer than a meter to both ends of the meter stick. Lift the string in the middle 3.5 cm above the meter stick and make a flat top 11 cm in length. This is a model of Olympus Mons. For comparison, Mauna Loa in Hawaii would be 17 cm at its base and 1.3 cm high. Note how Mauna Loa has a steeper rise to it than Olympus Mons. Instead of making these models, the same dimensions may be used in drawing a model on the chalkboard. Barring any demonstration, you could simply mention that Olympus Mons is roughly the size of Arizona and its height is about three times that of Mt. Everest.

Figure 10.5 is interesting and should be discussed. Point out the significant cratering in the southern hemisphere compared to the lack of cratering in the North. Engage again in comparative planetology. The southern hemisphere resembles Mercury and the Moon while the northern hemisphere shares more features with Venus (and Earth). Discuss old surface features and young surface features. Have the students conjecture as to why the two Martian hemispheres might be so different. Recall that one theory for the lack of atmosphere is that a large body impacted Mars. Can any parallels be drawn here that can account for the north-south features as well? Let the students explore this.

Concerning water on Mars, most students do not realize that the boiling point of water depends on temperature *and* atmospheric pressure. ➲ **DEMO** Use a vacuum pump and bell jar to demonstrate boiling water at room temperature. Fill a small beaker with tap water and have a student check the temperature by putting a finger in the water; no need to use hot water. Put the beaker under the bell jar and start the vacuum pump, making sure you have a good seal around the base of the bell jar. It should take no more than 2-3 minutes, depending on the quality of the pump, to start the water boiling. After the pump is turned off and air is released into the bell jar, have a student check the temperature of the water again to show that it has not changed and become hot. This is important because there is also an additional misconception that evacuating the air somehow raises the temperature and that the water boils for this reason. This demonstration is an excellent way of showing that liquid water cannot be present on the surface of Mars with its current atmosphere and that the atmosphere must have been much larger in the past in order to allow liquid water to exist.

Section 10.5

Remind the students that the atmosphere of Mars is composed predominantly of carbon dioxide, a greenhouse gas. Why is there no runaway greenhouse effect? Use the blanket analogy here. Although carbon dioxide can be thought of as goose down or some other good insulator, the thin atmosphere is like having a very thin layer as a blanket. In this case, the blanket is so thin that it really does not matter what it is made of. Contrast the very thin Martian atmosphere to that of Venus and Earth. The atmospheric pressure at the surface of Mars is equivalent to Earth's atmospheric pressure at an altitude of 35 km above the surface.

Model the atmosphere of Mars in the same way that was done for the Earth's and Venus's atmosphere using a meter stick (1 cm = 1 km). Contrast the differences between Earth and Mars using the table given for the Earth in Chapter 7.

Level	Mars
0 - 30 cm	Water-ice clouds and/or dust
25 cm	Top of Olympus Mons volcano
30 cm	Top of troposphere
50 cm	Carbon dioxide-ice clouds
30 - ~100 cm	Stratosphere, but no ozone

A good rule of thumb to help students remember the atmospheres of Earth, Venus, and Mars is to remind them that Venus has about 100 times more atmosphere than Earth and Mars about 100 times less; Mercury, of course, has no atmosphere. Also notice the differences in composition. It is useful, in reviewing the atmospheres of these planets, to ask: "What happened to the water? What happened to the carbon dioxide? What happened to the nitrogen? What is the composition of the clouds?"

Now ask "Which of these four planets has a 'normal' atmosphere?" The reason this is a good question is because we often think of Venus as having too much atmosphere and Mars too little. The same is often thought about their compositions. But possibly Venus is normal and Earth, for some reason, has less atmosphere than it should and Mars, even less. Which has the normal composition? See if your students can make some valid arguments for which is normal and which is not. Each of the four planets has a normal *amount* of atmosphere for their size and position in the solar system. With regard to *composition*, it is the Earth that is abnormal! It is the presence of life that has significantly changed the atmosphere of the Earth.

Section 10.6

Before discussing the internal structure of Mars, simply mention that Mars has no appreciable magnetic field. Since you presumably have already mentioned the relatively rapid rotation rate (compared to that of Venus), ask them to deduce the composition of the core based on their knowledge of the now-familiar dynamo effect. This is an example of inferring an un-measurable property through the application of theory and measurement of a related property. It is all part of the overall scientific process, which should be pointed out at every available opportunity.

From a lack of evidence supporting crustal motion, inferences can be drawn concerning other properties of the internal structure as well. In Section 10.4 above, you showed Figure 10.5. Show it again here and discuss the very old craters as well as the large volcanoes. Without too much coaching, ask the students if they can infer the internal structure of Mars from the surface features depicted. Both of these types of features show that there is no tectonic activity and, therefore, no molten or even semi-molten flow beneath the crust. In other words, Mars is "frozen" solid. This also goes in step with the fact that the planet is small, and therefore was able to cool relatively rapidly.

Section 10.7

Mars is believed to have captured rogue asteroids that remain in orbit as its moons. This fact will not require too much arm twisting for the students to agree. Show Figure 10.21 and compare to Figures 14.2 and 14.3 showing asteroids Gaspra, Ida and Mathilde.

Just as you demonstrated previously for Earth and the Moon, it is a good idea to demonstrate the relative sizes of Mars and its moons as well as the distance between them. ➲ **DEMO** If you have a Mars globe, then obviously that would be best for this, but a basketball would be sufficient. To represent Phobos, you would need to use a large grain of sand. Phobos is about 0.4% the size of Mars. On this scale, if you held Phobos a little less than ½ meter from Mars, then the orbital distance would be adequately demonstrated. Deimos would be half the size of Phobos and located slightly more than one meter away. Considering the sizes of these objects it is no wonder that the discovery of Mars's moons was not made until 1877.

Finally, since Phobos orbits Mars faster than Mars rotates, a Martian would see that moon rising in the West. Students often have a difficult time picturing this. ➲ **DEMO** You can demonstrate it fairly easily be using a rotatable globe (an Earth globe is fine). Start by moving a small marble representing Phobos around the globe in a West-to-East direction; this is the usual prograde revolution as described in the text. Do this first with no planetary rotation, so that the students understand that if the planet were not rotating, then the moon would appear to rise in the West and set in the East. Now, let the globe rotate slowly so that the moon still revolves quicker than the rotation rate. The moon will still appear to rise in the West and set in the East.

Student Writing Questions

1. We tend to think of Mercury, Venus, and Mars as having inhospitable environments for life. But there might also be some advantages to living on one of these planets. Choose one and make a "sales pitch" with regard to its advantages over the Earth or other planets. Think of yourself as a realtor with a big commission at stake.

2. Get a picture of a *Viking* image from the surface of Mars. What can be learned from this one image about Mars, its environment, its surface, and its atmosphere?

3. Bacterial forms of life are known to exist several kilometers deep in the Earth's crust. Is it possible that similar life might exist on one of the other terrestrial planets? Argue for and against this idea for Mercury, Venus, and Mars. Include consideration of the requirements for life such as water, appropriate temperature, protective environment and any others that occur to you.

4. From what you now know of orbital motion, plan a trip to Mars, from Earth, where Mars is at the aphelion of the trajectory and Earth is at the perihelion. How long will the trip take? How long would you want to have to explore Mars? How many people do you think such a trip should take? What sort of provisions would you have to take along? What would you miss most about the Earth and home?

5. Describe a landscape from Mars 3.5 billion years ago. Choose a location in the northern hemisphere near the edge of an ocean. There should still be an atmosphere. Speculate on what a panoramic view would show. Extrapolate from what is currently known of Mars at that time.

Answers to End of Chapter Exercises

Conceptual Self-Test

1. T
2. F
3. F
4. F
5. F
6. F
7. F
8. T
9. F
10. T
11. B
12. C
13. B
14. C
15. B
16. D
17. A
18. C
19. B
20. A

Problems

1. Use the formula for synodic period from *More Precisely 7–3*.

$$\frac{1}{S} = \frac{1}{365.26} - \frac{1}{686.9}$$

$$S = 780.0 \text{ days}$$

2. Use units of arc minutes in the equation from *More Precisely 1–4*. Minimum size will be from aphelion, 1.67 A.U. $d = 3438' (1.4\times10^6 / 1.67 \times 1.50\times10^8)$, $d = 19'$
Maximum size will be from perihelion, 1.38 A.U. $d = 3438' (1.4\times10^6 / 1.38 \times 1.50\times10^8)$, $d = 23'$.

3. This can be solved graphically or by using simple trigonometry. If θ is the angle of greatest elongation, then $sin(\theta) = 1/1.5$ and $\theta = 42°$.

4. The distance between Earth and Mars will be 0.37 A.U. Use units of arc seconds. 0.05" = 206,000" (d / 0.37 × 1.50×10^8), d = 13' km.

5. From *More Precisely 9–1*, R = 1.026 an P = 686.9, so D = 1.0275. Taking D - R = 0.0015 = 2.2 minutes.

6. Surface gravity is proportional to mass divided by the radius squared. In Earth units, the mass of Mars is 0.11 and the radius is 0.53, so 0.11 / $(0.53)^2$ = 0.39.

7. Surface gravity is 0.38 Earth's, so a 150 lb. person would weigh 57 lbs.

8. The circumference of Mars is $2\pi \times 3397$ = 21,340 km. At a speed of 150 km/h, it will take 21,340 / 150 = 142 h or almost 6 Earth days.

9. The mass of Earth's atmosphere is 5.0×10^{18} kg. For Mars, divide by 150 to get 3.3×10^{16}. Carbon dioxide is 95% of this; 0.95 of this mass is 3.2×10^{16} kg.

   The seasonal polar cap will have a volume of $\pi r^2 \times$thickness = $\pi(1{,}500{,}000 \text{ m})^2 \times 1$ m = 7.06×10^{12} m^3. Multiplying this volume by the density of 1600 kg/m^3 = 1.1×10^{16} kg. This is 2.9 times the atmospheric carbon dioxide. (Note that if the carbon dioxide ice cap is more like a snow or frost layer, then the density given may be much too high.)

10. Mass = $\pi(500{,}000 \text{ m})^2 \times 1{,}000 \text{ m} \times 1{,}000$ kg/m^3 = 7.85×10^{17} m^3. This is 71 times the seasonal cap.

11. Take the 1500 km as the radius. Mass = $\pi(1{,}500{,}000 \text{ m})^2 \times 6{,}000 \text{ m} \times 3{,}000$ kg/m^3 = 1.27×10^{20} kg. Mars's atmosphere is 3.2×10^{16} kg, which is 4,000 times less.

12. 10 million metric tons of water, with 1000 kg per metric ton, gives 10^{10} kg. The density of water is 1,000 km/m^3. Dividing the mass of water by its density will give its volume, or 10^7 m^3. This is the volume that flows each second.

    The cross-sectional area of the outflow channel is 10,000 m × 100 m = 10^6 m^2. Divide this into the volume flow rate: 10^7 m^3/s / 10^6 m^2 = 10 m/s. This is about 23 miles per hour.

13. Mass = $4\pi(3{,}394{,}000 \text{ m})^2 \times 2 \text{ m} \times 1{,}000$ kg/m^3 = 2.9×10^{17} kg. This is 4.5×10^{-7} of the total mass of Mars.

14. Phobos: its sidereal orbital period is 7 hours 39 minutes = 7.65 hours = 0.3188 solar days. The Martian day is 1.026 solar days. Computing S from *More Precisely 9–1* gives 0.4625 solar days or 11.1 hours.

    Deimos: its sidereal orbital period is 30 hours and 18 minutes or 1.2625 solar days. Computing S again gives 5.48 solar days.

15. Referring to *More Precisely 1-3*, we have the angular size of Phobos to be:

$$\text{angular diameter} = \frac{\text{true diameter} \times 57.3^\circ}{\text{distance}} = \frac{28 \text{ km} \times 57.3^\circ}{9378 \text{ km}} = 0.17^\circ = 10.3'$$

    For Deimos, we have:

$$\text{angular diameter} = \frac{\text{true diameter} \times 57.3^\circ}{\text{distance}} = \frac{16\ \text{km} \times 57.3^\circ}{23,459\ \text{km}} = 0.04^\circ = 2.3'$$

Since Mars is about 1.5 A.U. away from the Sun, the Sun will appear 1.5 times smaller. From Earth the Sun is about 30' in diameter; from Mars it will be 20' across. This is much bigger than the angular size of either moon.

Resource Information

Student CD Media

Movies/Animations
Rotation of Mars
Mars North Pole

Interactive Student Tutorials
None

Physlet Illustrations
None

Transparencies

T-85	Figure 10.1	Mars Orbit	p. 252
T-86	Figure 10.5	Mars Map	p. 257
T-87	Figure 10.7	Olympus Mons	p. 258
T-88	Figure 10.10	Valles Marineris	p. 260
T-89	Figure 10.12	Martian Outflow	p. 262
T-90	Figure 10.13	Martian River	p. 262
T-91	Figure 10.18	Spirit Panorama	p. 266
T-92	Figure 10.19	Martian Atmosphere	p. 266
T-93	Figure 10.20	Fog in the Canyons	p. 267
T-94	Figure 10.21	Martian Moons	p. 271

Materials

The video *Mars: Past, Present, Future* (Holiday Space and Science Series) is an excellent description of Mars, including how it has been viewed in the past and our current understanding of this planet.

1-World Globes (www.1worldglobes.com) sells two globes for Mars. The topography globe is particularly revealing.

Suggested Readings

Barile, S. "2002: A Martian Odyssey." *Mercury* (September/October 2002). p. 30. Discusses the various sensors on the Odyssey spacecraft. Many nice images along with discussions of what the sensors tell us.

Bell, J. "Red Rover's Rocky Road." *Mercury* (July/August 2003). p.14. Everything you always wanted to know about the twin rovers' mission to Mars including behind the scenes politics and many images of the rovers including a close-up with annotation for identifying the various sensors.

Burnham, R. "Envisioning Mars." *Astronomy* (April 2004). p. 38. Not much in the way of science, but lots of nice computer generated images of Mars based on actual data. Images are of Martian features today and as they might have appeared long ago.

Gibbs,W. Wayt. "Endangered: other explanations now appear more likely than Martian bacteria in ALH84001 meteorite." *Scientific American* (Apr 1998). p. 19. A short update on the controversy of the possible signs of fossil life in the Martian meteorite ALH84001.

Gibson, Everett K., Jr; McKay, David S.; Thomas-Keprta, Kathie; Romanek, Christopher S. "The case for relic life on Mars: meteorite ALH84001 offers evidence of past and current microbial life." *Scientific American* (Dec 1997). p. 58. Presents the hypothesis that the Martian meteorite ALH84001 contains fossilized bacteria.

Golombek, Matthew P. "A message from warmer times." *Science* (Mar 5 1999). p. 1470. Discusses evidence from the Mars *Pathfinder*, Mars *Global Surveyor* and the *Viking* lander missions in support of a warmer and wetter climate in Mars's past.

Golombek, Matthew P. "The Mars Pathfinder mission." *Scientific American* (July 1998). p. 40. A summary of the Mars Pathfinder mission.

Hartmann, William K. "Red planet renaissance." *Astronomy* (July 2000). p. 36. Traces the evolution of our thought about the age and geologic activity of Mars, including a discussion of the Martian meteorites and recent Mars Global Surveyor results.

Hartmann, William K. "Invading Martian territory." *Astronomy* (Apr 1999). p. 46. Discusses results from all the instruments on Mars Global Surveyor, including the spectrometer, the altimeter, the magnetometer, as well as the imaging camera.

Joyce, D. and Troiani, D. "Obsever's Delight." *Mercury* (July/August 2003). p. 24. Includes observation techniques for viewing Mars and a nice discussion of the opposition in August 2003.

Kerr, Richard A. "A wetter, younger Mars emerging." *Science* (Aug 4, 2000). p. 714. Reports on the evidence for geologically recent water seepage on Mars.

Krupp, E. C. "War stars." *Sky & Telescope* (July 1997). p. 80. Discusses the mythology associated with Mars.

Leovy, C. "Weather and Climate on Mars" *Nature* (12 July 2001) p. 245. In depth article of Martian climate and its evolution.

Lubick, N. "Goldilocks and the Three Planets." *Astronomy* (July 2003). p. 36. Outstanding and very useful (in the classroom) article comparing Venus, Earth and Mars. Excellent comparative planetology.

Malin, Michael C. "Visions of Mars." *Sky & Telescope* (Apr 1999). p. 42. A photo essay featuring the favorite images from the Mars Orbiter Camera by the camera's designer.

Moomaw, B. “Spirit Lands at Gusev.” *Astronomy* (April 2004). p. 32. Background of the mission as well as many nice images returned by the *Spirit* rover.

Naeye, Robert. “Back to Mars: three-dimensional photography.” *Astronomy* (Dec 2000). p. 38. Features three dimensional images from Mars *Pathfinder*.

Reichhardt, Tony. “NASA critics silenced as Mars loses face.” *Nature* (Apr 9 1998). p. 530. Details images of the alleged “face” on Mars taken by the Mars *Orbiter* Camera.

Schilling, G. “Mars on Earth.” *Astronomy* (January 2003). p. 46. Interesting article about a day in the life of a Mars Society member. This is a team researching daily concerns for a future Mars colony inhabitant.

Slater, T. “Inner Solar System Concepts.” *The Physics Teacher* (May 2000). p. 264. Discusses teaching comparative planetology on a conceptual level.

Tytell, David. “Martian mudflows.” *Sky & Telescope* (Sept 2000). p. 56. A short report on the observation of young water outflow features on Mars.

Zuber, Maria T. “Snapshots of an ancient cover-up.” *Nature* (Feb 18 1999). p. 560. An overview of four other articles in the same issue which summarize results from the Mars *Orbiter* Camera.

Notes and Ideas

*Class time spent on material: Estimated:*_______ *Actual:*______________

Demonstration and activity materials:

Notes for next time: