Chapter 7: Earth
Our Home in Space

Outline

Summary

Chapter 7 introduces planet Earth from a science perspective. The structure of its atmosphere is discussed, followed by the interior layers and how they are modeled. The Earth generates a magnetic field which extends into the space surrounding the planet, thereby shielding us from the solar wind. This chapter discusses how this magnetic field is produced and how it periodically changes. The chapter concludes with a discussion of the tides and their cause.

Major Concepts

- Atmosphere of Earth
  - Composition
  - Layers
  - Convection
  - Ozone
  - Greenhouse effect
  - History/Evolution of the atmosphere
- Earth's Interior
  - Seismic waves and determining the interior structure
  - Layers
  - Differentiation
- Earth's surface
  - Plate tectonics and continental drift
  - Lithosphere and asthenosphere
  - Pangea
- Magnetosphere
  - Van Allen belts
  - Aurorae
- Tides and the tidal force
  - Spring and Neap tides

Teaching Suggestions and Demonstrations

Section 7.1

You may be surprised at how few students have actually studied a picture of the Earth, let alone a 3-dimensional globe. For this section of the text, you will find it extremely helpful to have both on hand. If you plan to show a globe with geographical relief, be sure to tell the students that the true surface feature heights, if they were to scale, would be un-noticeable. In fact, tell them that if the Earth were the size of a bowling ball, the surface would be as smooth as a bowling ball, even when considering the heights of the tallest mountains and the depths of the deepest ocean.

The transparency showing Figure 7.1 is useful in this section. As you discuss the interior layers, be prepared for the question "How do we know that the interior layers are structured as shown?" This is usually a perfect time to jump into the material from Section 7.3, the discussion of seismic waves, etc. You do not have to follow the chapter section sequence exactly, but rather seize on the curiosity which prompted the question. Once you present seismic wave propagation and seismographs as a tool for effectively "looking within" the Earth, you can return to the discussion of the actual interior layers. If the "How do we know…" question does not arise, you may want to pose it yourself.

Section 7.2

Earth's atmosphere is diagrammed in Figure 7.2. Show students a transparency of this figure and ask them why they think the layers are divided as they are. What, for instance, determines the line between the stratosphere and the mesosphere? The relationship of temperature to altitude is the main characteristic determining the different layers. For instance, in the troposphere, the temperature decreases with increasing altitude, but in the stratosphere it increases. For scale, use a meter stick to model the atmosphere (1 cm = 1 km). The Earth would be larger than a football field at this scale. ➲ **DEMO** Use the following to demonstrate the various levels.

5 cm	Half the atmosphere lies below this level
8 cm	The tallest mountain, Mt. Everest
9-12cm	Cruising altitude of jet airliners
10 cm	90% of the atmosphere is below this level
15cm	Top of the troposphere, most of the weather occurs below this level
24cm	Altitude record for a jet, set by SR-71
30cm	99% of the atmosphere is below this level
15-50cm	Stratosphere
20-50cm	Location of the ozone layer
50-90cm	Mesosphere
90-250cm	Thermosphere
200cm	Low Earth Orbit satellites and Space Shuttle

For many of the solar system objects to be studied, a range in surface temperatures (if there is a surface) is usually stated. This, of course, varies greatly throughout the solar system. ➲ **DEMO** Design a large picture of a thermometer that can show a range from 0°K to at least 700°K. Have two adjustable markers for HIGH and LOW to indicate the high and low temperatures at the surface. This can also be done by making a transparency of the thermometer and a second overlay transparency that shows the specific high and low for the object. Have this thermostat on hand as each object is discussed. This is a nice visual aid while presenting the reasons for the temperature range. For the Earth, set the high and low to 320 K and 210 K. Note that for a planet with an atmosphere, the temperature varies widely with elevation, so we generally use the temperature at the surface.

Be sure to include discussions of the greenhouse effect and global warming on Earth as they are widely debated topics and therefore relevant concepts for students to understand. Bring in current journal or newspaper articles to share with students or ask them to find and bring in articles of their own. This is one area in which their study of astronomy will have a direct impact on their understanding of current events. The greenhouse effect will come up again in the chapter discussing Venus.

Questions will invariable arise concerning the hole in the ozone layer. It is certainly worthwhile to spend part of a lecture discussing how the ozone layer is affected by man-made chemicals such as chlorofluorocarbons (CFCs). One of the advantages offered by CFCs is that they are inert. This fact, though helpful to many commercial products, is responsible for their ability to rise high into the atmosphere before being broken down by sunlight into constituents that are capable of destroying the naturally occurring ozone molecules.

Section 7.3

Is the Earth mostly made up of water? Obvious? Well, not to many students; actually this is a common misconception. If you have not yet demonstrated density, as suggested in Chapter 5, this is a good time to do so. Make sure you determine the density of two objects, one more dense and the other less dense than water.

Buoyancy is a concept related directly to density and of importance in the study of planetary structure. When the density of an object is greater than a fluid, that object will sink in that fluid. This concept is so familiar to students that a demonstration would be a waste of otherwise valuable time. ➲ **DEMO** However, if a demonstration is necessary, simply use the varying density items above and place them in a large beaker filled with water. The higher density object will of course sink while the lower density object will float. So, the varying density items have differentiated.

A common rock has a density in the range of 2000-3000 kg/m^3 and will sink in water, which has a density of 1000 kg/m^3. The continents, made up of this rock, cannot float on an interior of the Earth made of water; they would sink! The average density of the Earth (5500 kg/m^3) implies an interior with a higher density than the crust and, therefore, the crust actually "floats" on the higher density material of the mantle (which is semi-fluid). Since solid rock is rather difficult to move through, the question arises as to how the crust got to the top and the high-density rock to the core. The answer is differentiation. The Earth had to be molten when it was very young.

Now show again the transparency of Figure 7.1 and have the students see not only the structure of the Earth but how its layers depend upon density variation, from a high in the core of about 12000 kg/m^3 to about 5000 kg/m^3 in the mantle to about 3000 kg/m^3 in the crust. The oceans, with a density of 1000 kg/m^{3,} float on the crust and the atmosphere, with a density of 1 kg/m^3, floats above the continents and oceans.

Regarding how the interior structure is surmised using seismic waves, the analogies of light-waves traveling through a lens or sound waves traveling through walls are often helpful when discussing seismic waves traveling through the Earth.

Section 7.4

Plate tectonics is actively occurring on Earth. Ask students if they can figure out which characteristics of Earth are responsible for this fact. If you can find one, show a map of Earth with locations of earthquakes and volcanoes marked, but without the plate boundaries drawn in. Then compare to Figure 7.10 to show the alignment. Discuss areas where plates come together as well as where they spread apart. ➲ **DEMO** To demonstrate convection, which is responsible for driving the plates, add a couple of drops of food coloring to water in a clear beaker and set it on a hot plate. In the absence of a suitable demonstration, remind the students of what they see when watching soup boil.

Section 7.5

The magnetic, electric, and gravitational forces are very often confused and even referred to interchangeably by some people. There are many demonstrations of magnetic fields available to support physics classes and some of these can be quite useful here to remind astronomy students of a few basic properties of magnetic fields. The form of a dipole field and the effects of a magnetic field on moving charged particles are the two most important concepts to demonstrate. ➲ **DEMO** Get out the bar magnet and iron filings for the first demonstration. I particularly like to use the iron filings encased in plastic that fits nicely on an overhead projector. Place a bar magnet on it, shake a bit, and there it is, the outline of the field. Show how two magnetic fields interact and how there is no interaction between a magnet and a non-magnetic object.

➲ **DEMO** The second demonstration really depends on the equipment you have available. You need a source of moving electrons. This can be something as simple as a cathode ray tube or any plasma discharge tube. Bring a strong magnet near where the beam hits the screen and look for the beam to move. Change the pole of the magnet used and demonstrate again. Now ask your students why a magnet should affect moving charged particles. Since they just saw that magnetic fields only interact with other magnetic fields, they (hopefully) will conclude that the moving charged particles must have a magnetic field. This can be shown to be true by making a very simple electromagnet. ➲ **DEMO** Wind some copper wire around an iron nail and attach one end to a battery. When the other end is attached to the battery, an electromagnet is made, which you can easily demonstrate. Make this in front of the class so they can see how simple it is.

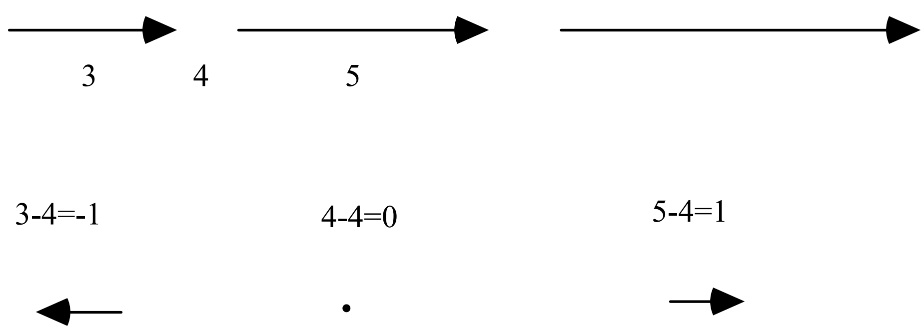
To show some of the very real effects from the magnetic fields surrounding our planet, show movies of the aurora borealis and/or aurora australis, which are spectacular light shows visible at higher latitudes. At a very minimum, project a transparency of Figure 7.20.

Section 7.6

The tides are unfamiliar to many students who do not live near coastal areas. Even for those students who regularly experience tides, they are usually at a loss to explain how there can be two high and two low tides each day. If the concept of the Moon pulling the tide on the Earth is known at all by students, it usually results in them saying there must be one high tide (pointing to the Moon) and one low tide (on the opposite side of the Earth). Various demonstrations, using rubber rings (dog toys) and small inflated inner tubes, have been used to show the effects of tides. The rings or tubes are pulled on one side and become elliptically shaped like the tidal pattern. But students often find these unconvincing because they want to know who or what is holding the other side of the Earth to stretch it into this shape! It is a good question. One simple answer would be to tell the students that just as the water on the Moon side of the Earth is effectively "pulled" away from the Earth's surface, so the Earth itself is effectively "pulled" away from the water on the side opposite the Moon.

A very important point to make to students regarding **tides** is that the significant quantity is the difference in gravitational force between the side of Earth facing the celestial body pulling on it and the opposite side, not just the amount of force itself. Ask students to guess which is greater, the gravitational force of the Moon on Earth or that of the Sun on Earth. Then do the calculation to show that the Sun's force is greater. (After all, we orbit the Sun, not the Moon!) Why then, ask students, are the high and low tides mainly determined by the Moon? The Moon is closer, and so the ratio of the forces it exerts on the two sides of Earth is greater than the corresponding ratio for the Sun.

The tidal force is simply a *differential* gravitational force, i.e., it results from differences in the gravitational pull of the Moon from one side of the Earth to the other *relative to the pull at the center of the Earth*. The following simplified example may help. The numbers represent the relative strength of the Moon's gravitational pull on the far side, middle, and near side of the Earth, respectively.



The tidal pull can easily be shown using a little calculus and Newton's law of gravity. With greater difficulty the same result can be obtained using algebra. Although mathematical explanations may not be as satisfying to some students, it is nonetheless another approach to helping them understand the reason for the two high and two low tides. If you have the time and the students have the background, you can use the calculus approach:

$$F = -\frac{GMm}{r^2}$$

$$\frac{dF}{dr} = \frac{2GMm}{r^3}$$

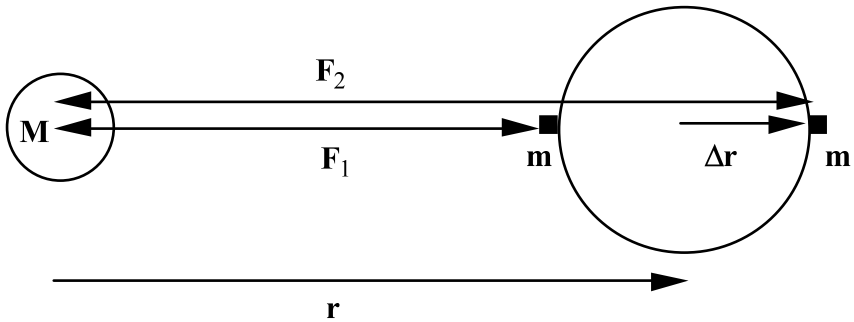
$$\frac{dF}{F} = -\frac{2dr}{r}$$

or

$$dF = \frac{2GMmdr}{r^3}$$

It is common to say that the tidal force, which is *dF*, falls off with the cube of the distance. Here, *dr* represents the distance across the object being tidally affected. For a system like the Earth-Moon, the only difference between the tidal pull on the Moon, produced by the Earth, and the tidal pull on the Earth, due to the Moon, is the term *dr*. Since the Earth is 4 times bigger than the Moon, the tidal pull on the Earth is actually 4 times bigger than it is on the Moon. This is not commonly understood. (However, the tidal distortion will also depend on the surface gravity of the body. Since the Moon's surface gravity is 6 times weaker than the Earth's, the net effect is greater on the Moon.)

The algebra approach takes a bit more work but will (must!) give the same basic result. Let mass M produce a tidal force on another mass with mass elements m on either side. F_1 and F_2 are the gravitational forces on these two mass elements, due to M.



$$F_1 = -\frac{GMm}{(r - \Delta r)^2}$$

$$F_2 = -\frac{GMm}{(r + \Delta r)^2}$$

Tidal force is the difference between these two forces.

$$F_1 - F_2 = -GMm\left(\frac{1}{(r-\Delta r)^2} - \frac{1}{(r+\Delta r)^2}\right)$$

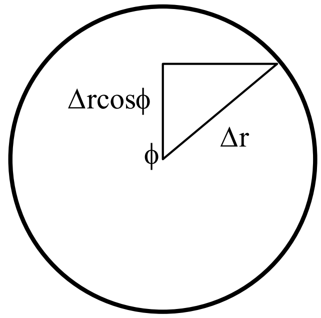
Simplifying and dropping small terms like Δr^2 gives:

$$\Delta F = F_1 - F_2 = -GMm\left(\frac{4\Delta r}{r^3}\right)$$

Comparison with the calculus-derived expression shows the same result, but here, Δr represents the radius, not the diameter, of the tidally distorted body. If Δr is the radius of the Earth and r is the Earth-Moon distance, then $\Delta r/r$ is about 0.017, which is << 1. Now a physical interpretation can be obtained from either of these expressions.

The Earth-Moon distance, r, is measured from the Moon to the center of the Earth. Δr is going to be ± radius of the Earth. Thus, the tidal force appears to be the same on both sides of the Earth (towards or away from the Moon). The size of the tidal force, $\Delta F/F$, is about 0.034 or 3% as stated in the text.

The above calculation seems to have a significant limitation in that it calculates the tidal force for only two points on the Earth. Deriving the force at other locations can be done approximately from these results.



As cosϕ varies from 0 to 90 degrees, the tidal force varies. At 90 degrees there is no force, i.e., low tide. The elliptical shape of the tidal bulge can thus be plotted out.

Student Writing Questions

1. What are some of the natural catastrophic events that occur on Earth that affect life? How often do these occur? Does life survive these events? What about specific species?

2. Some cartoons and science fiction stories have humans living among the dinosaurs. Although this did not occur, what would it have been like? How would daily life be changed? Could humans have developed their technology; might they have developed technology more quickly?

3. As of the year 2004, the Earth has a human population of about 6.4 billion. How much larger can this grow? Is there a limit? Human population has been doubling approximately every 50 years. How do you think this will affect you by the time you retire?

4. Identify and discuss at least six different features of the Earth that indicate the Earth is very old. Don't just include methods for actual age dating, find properties of the Earth that must have taken place over a long period of time. Giving more than six features will count as extra credit.

5. Describe what you might see if you were standing at your current location on Earth one million years ago and 100 million years ago. Describe your location one billion years ago.

Answers to End of Chapter Exercises

Review and Discussion

1. The density of water is 1000 kg/m^3 and the density of rock is typically 3000 kg/m^3. Since the average density of the Earth is 5500 kg/m^3, the interior of the Earth must be made up of high density material.

2. Rayleigh scattering is the effect by which particles selectively scatter waves, depending on the waves' wavelengths. Particles tend to scatter waves whose wavelengths are about equal

to or smaller than the particle size. Rayleigh scattering accounts for the blue sky of Earth and red sunrises and sunsets.

3. Without earthquakes to produce seismic waves and volcanos to bring material from the mantle to the surface, we would know almost nothing about the interior below a depth of a few kilometers.

4. Both P-waves and S-waves are seismic waves that move outward from the site of an earthquake. P-waves are the first to arrive; these pressure waves alternately expand and compress the material through which they move, just as sound waves do. They move through both liquids and solids. S-waves are shear waves and are like waves on the surface of water. They move more slowly than P-waves and move only through solids. These waves carry information about the earthquake that produces them and also about the material through which they have traveled.

5. The greenhouse effect is a process that adds extra heat to the Earth's surface. Sunlight passes through the atmosphere and is absorbed by the surface and turns to heat. But heat, actually infrared radiation, cannot pass through the atmosphere and back into space because it is absorbed by certain greenhouse gases. The heat gets trapped until the atmosphere can radiate it away. The Earth's surface is about 40 K° warmer than it would be without this effect.

6. Certain types of seismic waves cannot travel through liquid rock. It has been known for decades that these waves, produced by earthquakes, do not travel through certain parts of the Earth's interior. This region is now mapped out as being the outer core. The inner core appears to be solid.

7. The fact that the Earth is differentiated, structured in layers decreasing density towards the surface, suggests the Earth must have been molten in its past. If it was molten, then high-density material could slowly sink to the interior while lower density material would float to the surface. This is what is observed today.

8. Convection is the rising of hot material through cooler material. (a) In the Earth's atmosphere it transports heat from the surface into the atmosphere and is responsible for many of the weather patterns. (b) In the Earth's interior it helped for the crust, mantle, and core of the Earth. It currently is responsible for volcanism and plate tectonics.

9. A radioactive element breaks down into a non-radioactive element in a known amount of time; the half-life. By comparing the amount of the original to the one formed, the age of the rock can be determined. By looking for the oldest rocks of Earth, the Earth's age is measured.

10. Certain kinds of elements, such as uranium, are inherently unstable. The nuclei achieve greater stability by disintegrating into lighter nuclei. A half-life is the time required for half of the original nuclei to disintegrate. During this radioactive decay, subatomic particles are produced that move away very rapidly. When the particles collide with surrounding matter, their kinetic energy is converted into heat. Rock is such a good insulator that much of this heat remains in the interior of the Earth.

    Radioactive heating of the Earth still has not ended because there are still some radioactive elements remaining. But it is occurring at a much reduced rate than when the Earth was young.

11. Plate tectonics is the cause of mountains, trenches, and most other surface features of the Earth. Mountains are often caused by plates colliding with each other, pushing up parts of one plate into mountains. When plates pull apart, they form trenches that allow new crustal material to rise.

12. Quasars are so far away that they never show any measurable motion on the sky because of their own motion in space. Thus, any apparent change in their position can be interpreted as being due to the motion of the telescope or of the tectonic plate on which it is located.

13. A dynamo needs both liquid metal and reasonably rapid rotation. The dynamo in Earth's interior is believed to create the planet's magnetic field.

14. The magnetosphere is that region around a planet that is most influenced by the planet's magnetic field. The magnetic field can trap charged particles. Very early satellites detected fast moving particles that were trapped in our magnetic field. The regions in which the particles were found are called the Van Allen Belts.

15. The magnetosphere traps fast moving particles, mostly electrons and protons, that are given off by the Sun. Otherwise, these particles would slam into the surface of the Earth and harm life.

16. Hot mantle material, as it cools on the surface of the crust, freezes in the orientation of the magnetic field. Material of different ages show different orientations. Reversals of the Earth's magnetic field occur every 500,000 to one million years.

    Absence of the magnetosphere, during a reversal, would allow high-energy particles from space to reach the surface of the Earth. Although not fatal to life, it could induce evolutionary changes through reproductive mutations.

17. The Moon's gravity pulls more strongly on the side of the Earth facing the Moon than it does the center of the Earth. Likewise, the Moon's gravity pulls more weakly on the far side of the Earth, than it does the center of the Earth. The result is two high tides pulled by the Moon on these two sides of the Earth. The sides of the Earth perpendicular to the high tides experience low tides, as the water is pulled away from these sides.

18. The Moon would experience stronger tides than on Earth because of its weaker surface gravity; the tidal force is actually weaker due to the Moon's smaller size. Since the Moon rotates once during each orbit, the tidal bulges would not appear to move relative to the surface of the Moon.

19. Even without the Moon, the Earth would still experience tides from the Sun. The solar tides are half of the lunar tides or one third of the total tides experienced now. So even without the Moon we would know about the tides, albeit much smaller, weaker tides.

20. The greenhouse effect keeps the temperature of the Earth mostly above the freezing point of water and quite likely helps make life possible. In this sense it is quite helpful. An enhanced greenhouse effect could potentially raise the temperature of the Earth to the point of being detrimental to life. A higher temperature would melt the ice caps, flood most coastal regions, and significantly change the weather on Earth in, as yet, an unpredictable way.

Conceptual Self-Test

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

Problems

1. Perihelion and aphelion distances are given by $a(1\text{-}e)$ and $a(1+e)$. For $a = 1$ A.U. and $e = 0.017$ this gives 0.983 A.U. and 1.017 A.U.

   The mean orbital speed will be given by the circumference of the orbit (assuming a circular orbit) divided by the time, which is the year. Use units of kilometers and seconds.
   $v = 2\pi \times 1.496\times10^8$ km / 365.24 × 24 × 3600 s. $v = 29.79$ km/s.

   Surface gravity is the same as the acceleration due to gravity, $a = GM/r^2$. $a = 6.67\times10^{-11} \times 5.97\times10^{24} / (6.378\times10^6)^2$. $a = 9.79$ m/s^2.

   Escape speed is given in Chapter 2.

$$v_{escape} = \sqrt{\frac{2\times6.67\times10^{-11}\times5.97\times10^{24}}{6.378\times10^{6}}}$$

$$v_{escape} = 11{,}200 \text{ m/s} = 11.2 \text{ km/s}$$

2. Mass is equal to density times the volume.

$$M = 3000 \times 4/3 \times \pi \times (6.378\times10^6)^3$$

$$M = 3.3\times10^{24} \text{ kg}$$

   Using this value for the Earth's mass in Problem 1 for the surface gravity and escape velocity gives a = 5.4 m/s^2 and $v_{escape} = 8.3$ km/s

3. The volume of the atmosphere is the surface area of the Earth times the thickness of the atmosphere. $4\pi(6.378\times10^6\text{ m})^2 \times 7500\text{ m} = 3.8\times10^{18}\text{ m}^3$. This volume multiplied by the density will give the total mass of the atmosphere. $3.8\times10^{18}\text{ m}^3 \times 1.3\text{ kg/m}^3 = 5.0\times10^{18}$ kg. The mass of the Earth is 5.97×10^{24} kg; dividing this into the mass of the atmosphere gives 8×10^{-7} or about one millionth the mass of the Earth.

4. Since the luminosity in Stefan's law is proportional to T^4, compare the Earth at 250 K to Earth at 290 K. $(250 / 290)^4 = 0.55$. Subtracting this from 1 gives 0.45 or 45%.

5. Find the surface area of the Earth; Area $= 4\pi\times(6.378\times10^6)^2 = 5.1\times10^{14}\text{ m}^2$. Half of one-percent of this is $2.6\times10^{12}\text{ m}^2$. The volume of ice in the Antarctic will be this area times the depth, about 3 km or 3000 m. Volume $= 7.7\times10^{15}\text{ m}^3$.

   This volume spread over the oceans, 71% of the surface area of the Earth, or $3.6\times10^{14}\text{ m}^2$ would be 21 m deep. So, if the Antarctic icecaps were to melt, the oceans would increase in depth by 21 m.

6. The diameter of the Earth is 2 × 6378 km = 12,756 km. At 5 km/s the time it will take is 12,756 km/5 km/s = 2551 s or 42.4 minutes.

7. The volume of a spherical shell is $4/3\pi\,(r_2^3 - r_1^3)$ where r_1 and r_2 are the inner and outer radii. The volume of the Earth is $1.09\times10^{12}\text{ km}^3$. Each volume must be divided by this volume to obtain the fractional volume. The results are the following:

   inner core = 0.0085, outer core = 0.157, mantle (r_2 = 6348 km) = 0.821, crust (30 km thick) = 0.014

8. 6000 km = 6×10^8 cm. At a rate of 3 cm/yr, this will give 6×10^8 cm / 3 cm/yr = 2×10^8 yr or 200 million years.

9. Use the formula in *More Precisely 7–2*. $0.75 = (1/2)^{t/4.5}$. Solve this by taking the Log of each side: Log 0.75 = t/4.5Log(1/2). t = 1.9 billion years.

10. Doing the algebra, 3U = Pb and U + Pb = 1, where U and Pb are the fractions of Uranium 235 and Lead 206 in the sample. Solving, U = 1/4. For T = 713 million years, 0.25 = $(1/2)^{t/713}$. Solving for t as in the previous problem gives t = 1.426 billion years. Applying this time to the U-238 and lead-206 gives U = $(1/2)^{1.426/4.5}$ = 0.803. The lead must be 1 - 0.803 = 0.197. The ratio of these two numbers is 4.1.

11. For a low Earth orbit, the distance D can be assumed to be the Earth's radius without significant error. R = 1 m, M is the mass of the Earth, and m divides out of the tidal force ($F_t = ma$). $a = (2 \times 6.7\times 10^{-11} \times 6\times10^{24} \times 1) / (6.4\times10^6)^3 = 3.1\times10^{-6}\text{ m/s}^2$.

    Divided by 9.8, the acceleration at Earth's surface, gives 3.1×10^{-7} of surface acceleration.

12. Calculating the tidal acceleration due to the Moon gives $a_m = (2 \times 6.7\times 10^{-11} \times 7.4\times10^{22} \times 6.4\times10^6) / (3.8\times10^8)^3 = 1.1\times10^{-6}\text{ m/s}^2$. Dividing this by Earth's acceleration gives 1.1×10^{-7}.

13. The Sun is on the opposite side of the Earth but also pulling tidally like the Moon. It is known that the Moon pulls twice the tide that the Sun does. 0.5×1.1 = 0.5. 1.1 + 0.5 = 1.6, so the weight is reduced by 1.6×10^{-7}.

14. The tidal acceleration on Io is: $a = (2 \times 6.7\times 10^{-11} \times 1.9\times10^{27} \times 3.6\times10^{6}) / (4.2\times10^{8})^{3} =$ 0.012 m/s^2. Io's surface gravitational acceleration is $a = 6.7\times 10^{-11} \times 9.0\times10^{22} /(3.6\times10^{6})^{2}$, a = 0.46 m/s^2. Comparing these two gives 0.012 m/s^2 / 0.46 m/s^2 = 0.026 or 2.6%.

15. From the discussion above (Teaching Suggestions and Demonstrations Section 7.6), the tidal force, *dF*, is proportional to the mass of the body producing the tide and inversely proportional to the cube of its distance. It is easiest to answer this question by comparing Jupiter's tidal effect to that of the Moon. This allows lunar units to be used, i.e., Jupiter's mass in Moon masses and 4.2 A.U. in lunar distances. Jupiter's mass is 318 Earth masses and the Moon is about 80 Earth masses, so Jupiter is 25,400 Moon masses. The Moon's distance from the Earth is about 1/400 A.U. so 4.2 A.U. will be 1680 lunar distances. Jupiter's tidal effect is = $25{,}400 / (1680)^3 = 5.4\times10^{-6}$ or about 5 millionth that of the Moon's tidal effect on Earth.

Resource Information

Student CD Media

Movies/Animations
None

Interactive Student Tutorials
Greenhouse Effect
Atmospheric Lifetimes

Physlet Illustrations
Magnetic Field of Planet

Transparencies

T-59	Figure 7.1	Earth	p. 170
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T-61	Figure 7.5	Greenhouse Effect	p. 175
T-62	Figure 7.7	Seismic Waves	p. 177
T-63	Figure 7.10	Global Plates	p. 181
T-64	Figure 7.11	Earth's Upper Mantle	p. 184
T-65	Figure 7.14/16	Seafloor Spreading and Plate Drift	pp. 186/187
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Materials

The video *Aurora: Rivers of Light in the Sky*, produced by Skywater Films, Alaska, has some excellent footage of aurora as well as discussion of myth, tradition, and fact surrounding this phenomenon.

Simple supplies to demonstrate the connection between electricity and magnetism include a battery, a nail, and wire. To demonstrate magnetic fields, try the Fisher Science "Deluxe

Magnetic Field Apparatus" (item S43059-1.) It allows students to see iron filings align with the magnetic field in three dimensions.

Suggested Readings

Anderson, Robert. "Plates in motion: plate tectonics Internet sites." *Natural History* (Apr 1999). p. 24. Reviews web sites that feature information about plate tectonics.

Berger, R., Schmitt, M. "Estimating the Earth's Magnetic Field Strength with an Extension Cord." *The Physics Teacher* (May 2003). p. 295. A class demonstration of one way to determine the strength of the Earth's magnetic field. May be too advanced for some classes.

Bohen, R.; Vandegrift, G. "Temperature-Driven Convection." *The Physics Teacher* (February 2003). p. 76 Discusses easy-to-do demonstration of convection and its role in weather patterns on Earth.

Eicher, David. "Earth is a planet, too: three-dimensional photography." *Astronomy* (Dec 2000). p. 50. Presents topographic images of the Earth.

Hoffman, Paul F.; Schrag, Daniel P. "Snowball earth." *Scientific American* (Jan 2000). p. 68. Discusses the evidence of major climate reversals on Earth.

Jago, L. "The Making of an Aurora." *Astronomy* (January 2002). p. 73 An excerpt from the book *The Northern Lights* by Jago . Story about scientist named Kristian Birkeland. Includes fairly detailed description of his laboratory aurora simulator and aurora phenomena. Nice images as well.

King, Michael D.; Herring, David D. "Monitoring Earth's vital signs." *Scientific American* (Apr 2000). p. 92. Describes how information obtained by the Terra satellite is used to study the Earth.

Nguyen, J.; Holmes, N. "Melting of iron at the physical conditions of the Earth's core." *Nature* (22 January 2004), Volume 427 pp. 339-342. Good discussion of current work in seismology and the investigation of the Earth's Interior.

"Origins: special section on the origin and evolution of the Earth." *Earth* (Waukesha, Wis) (Feb 1998). p. 23. A special section devoted to articles about the origin and evolution of the Earth.

Taylor, S. Ross; McLennan, Scott M. "The evolution of continental crust." *Scientific American* (Jan 1996). p. 76. Discusses the conditions on Earth which allowed the development of our continental crust.

Wright, K. "Seeing the Light." *Discover* (July 2000). p.51. A very complete discussion of auroras, with great pictures.

Notes and Ideas

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

Demonstration and activity materials:

Notes for next time: