

Chapter 2: Solar Radiation and the Seasons

Outline

- 1) Energy
 - i) Potential
 - ii) Kinetic

- 2) Energy Transfer
 - i) Conduction
 - ii) Convection
 - iii) Radiation

- 3) Radiation Characteristics
 - i) Electromagnetic
 - ii) Quantity and Quality
 - iii) Wavelengths and Bands
 - iv) Intensity and Emissivity
 - v) Solar Constant

- 4) Seasons
 - i) Earth Rotation and Revolution
 - ii) Solstices and Equinoxes
 - iii) Length of Daylight
 - iv) Angle of the Sun
 - v) Beam Spreading and Depletion
 - vi) Changes in Insolation

Chapter 2: Solar Radiation and the Seasons

Teaching Strategy

Student Learning Outcomes

- ▶ Identify the types of energy and how they can be transmitted.
- ▶ Describe the characteristics of solar radiation.
- ▶ Explain the influences of solar angle on solar radiation receipt at the surface.
- ▶ Describe how seasonal changes in solar energy vary with latitude.
- ▶ Explain the laws governing the amount and type of radiation emitted by objects.
- ▶ Recognize the characteristics of Earth's orbit around the Sun and how they create the seasons.

The important concepts for Chapter 2 deal with energy, radiation, and the peculiar characteristics of the Earth's tilt and resultant change in the sun's angle that produces the seasons. Using the two movies (January and July), you can point out the differences in the weather patterns as proof that the angle of the sun has a large effect. These are portions of the annual movie we used in Chapter 1.

Note the January temperatures (in colorized bands) changing on a daily basis, and how the storm systems are moving through North America in the mid-latitudes. Note also how the storm systems in the southern hemisphere in the westerlies are depressed southward. Compare that with the July movie, where the northern hemisphere temperatures are warmer, the storm systems are smaller and further north, and the southern hemisphere storms have migrated northward (their winter).

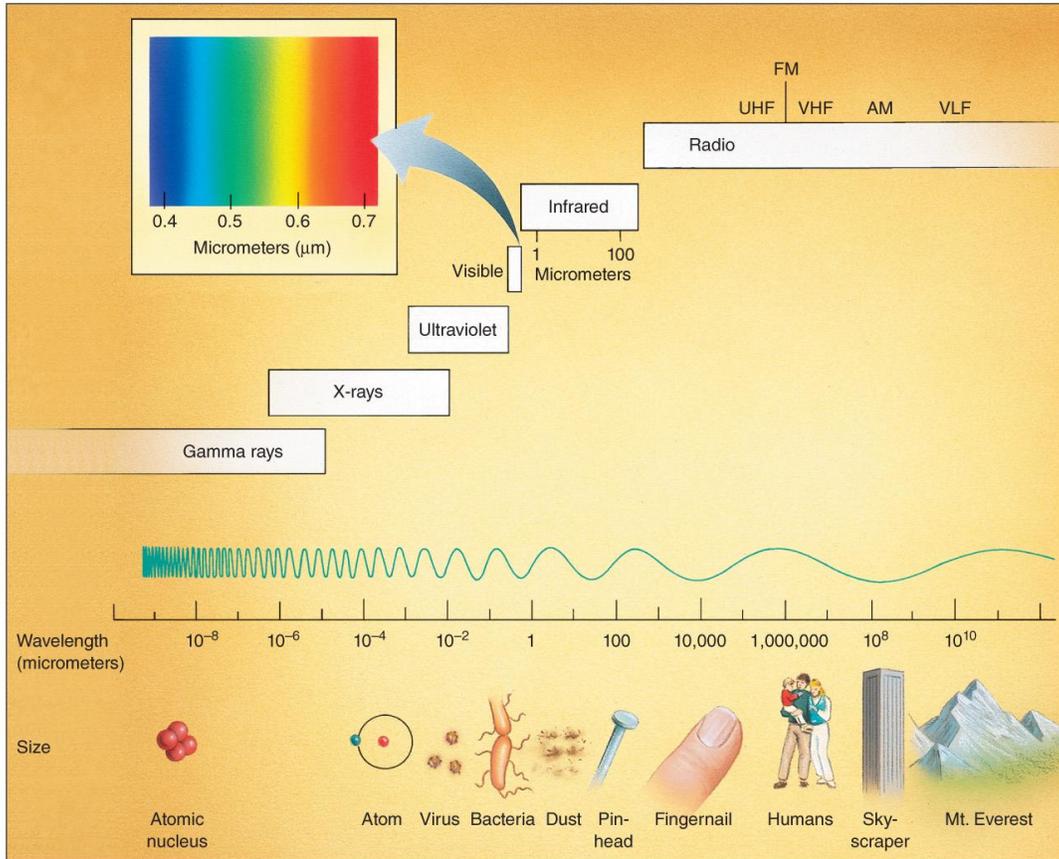
There are more detailed explanations of the features in the "Weather In Motion" transcripts.

With that background of the apparent movement of the sun now introduced, it is time for Energy.

Energy and Energy Transfer

It is important here to develop a sound foundation in the understanding of potential and kinetic energy, and the modes of energy transfer. Apply examples of each to the atmosphere (the raindrop as an example of potential energy when suspended in the cloud and kinetic energy when falling).

Introduce radiation in the same way. Concentrating on the different "bands" and their differing resultant energy.



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Figure 2.7

Mention that the gases in the atmosphere react differently to different wavelengths. This concept will be reinforced in later chapters.

Radiation

Using the radiation laws, show how the radiation from the sun occurs at a different wavelength than that of the Earth. Stress the fact that the Earth and sun have different temperatures, which drives the process. Reinforce again that the wavelengths from the Earth affect the molecules of the greenhouse gases in our atmosphere, but that the shorter-wave radiation from the sun does not.

Seasons

It is important to have a globe handy to explain the next concepts. If you use a globe to explain the difference in the sun's angle, make certain that you keep the axis of the globe aligned (keep the tilt the same) with respect to the classroom wall.

Note the difference between rotation (around the axis) and revolution (orbit around the sun).

Make certain that the students know the solstices and equinoxes and their importance not only as the markers for the start of the seasons, but also as the points at which the length of day is longest, shortest, or equal.

It is easy to slip into describing the March equinox as the “spring equinox” or the “vernal equinox.” However, as we become more globally aware, it is becoming more acceptable to refer to it as the March equinox. By the same token, the “summer” and “winter” solstice are different in the northern and southern hemisphere, so referring to them as the June and December solstices is better. The students should still know that the winter begins in December in the northern hemisphere, on the same day that summer begins in the southern hemisphere.

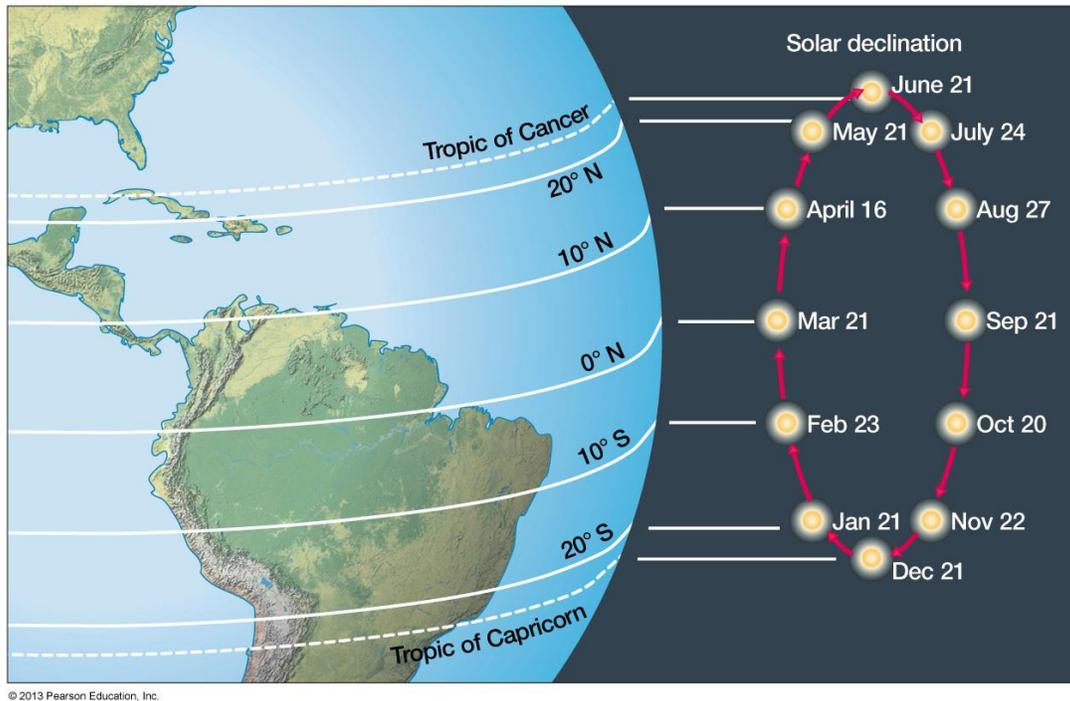


Figure 2.15

Using the above figure, you can point out the location of the sun on the important dates and explain the concept of solar declination at the same time.

To reinforce the concepts of perihelion and aphelion, mention the root of the word (helios) means the sun, and the prefix “a” means “away” (same letter). The prefix “per” is used in such words as “perilous,” meaning close by.

Finish the chapter with the eclipse movie, and then show the January and July movies again to review. Students should note many more features driven by the angle of the sun with this reprise.

Suggested Additional Activities and Exercises

1. A good exercise to stimulate discussion of the difference between potential and kinetic energy is to have the class begin to list them according to category. Quite a list can be compiled, and this also provides an opportunity for class participation. Break the class into teams or groups and see who can come up with the most examples of kinetic energy, potential energy, and both.
2. Explain "selective absorption" by using an example of a hot dog in a bun in a paper towel in a microwave. At the wavelength of the oven, the paper does not react, the bun heats up slightly (from moisture in the bread heating up) and the hot dog gets very hot and could, if left in too long, even explode. The same wavelength affects each item differently, just as atmospheric gases are affected differently by the same radiation from the Earth.
3. Using a flashlight and a globe, shine the beam directly at the equator, then at the pole. Notice the difference in how much area the light is spread over.
4. Access an infrared satellite image. Note that each image will have a scale indicating the relationship between the variations in the gray scale (or the colors) and temperature. Remote sensors on the satellite tell the temperature of the tops of the clouds by their infrared radiation. Processing of the image gives the different grays or colors. Note the temperature of a certain area of clouds. Knowing the temperature of the cloud top (from the scale), one can estimate its height by finding the height of that temperature on an upper-air chart or from an atmospheric sounding.
5. To help illustrate the differences in daylight around the world, find an Old Farmer's Almanac, in which you will find a table of the varying length of dawn and dusk. They vary with the time of year just as daylight does. Add the length of dawn to the beginning of the day and the dusk to the end to see the complete effect. Do not pay attention to the weather forecasts.

Chapter 2 Checkpoint Answers

p. 33

1. Potential energy is energy that is stored and is not yet in use.
2. A raindrop will contain potential energy as long as it is suspended in a cloud. As the raindrop begins to fall, gravity is responsible for turning the potential energy into kinetic energy.

p. 34

1. Energy is transferred by conduction when there is molecule-to-molecule contact without appreciable movement.
When a gas or liquid is heated (or cooled) and mixed, energy is transferred by convection (remember that the atmosphere is a gas, and acts like a very thin liquid). Transfer of energy by radiation requires no medium in between. Neither liquid nor solid is required.
2. As the fire burns, the potential energy stored in the wood is changed into heat energy that radiates upward to the cooking pot (radiation). The heat energy is absorbed by the cooking pot and transferred to both the soup and the cook's hand (conduction). The soup is then mixed by the heat from the bottom of the iron pot, and rises to the top. The cooler soup from the top then circulates downward (convection) and becomes warmed.

p. 36

1. Electromagnetic radiation is a type of energy which contains both electric and magnetic fields, oscillating in waves.
2. Depending on the frequency (the distance between waves), electromagnetic radiation will appear and behave differently. These differing "wavelengths" are categorized into bands ranging from short-wave to long-wave.

p. 39, column 1

1. An increase in temperature will bring a much larger increase in radiation. The Stefan-Boltzmann Law indicates that radiation will increase to a factor of four times more than the temperature increase.
2. An increase in temperature would result in four times more radiation from the Earth.

p. 39, column 2

1. The higher an object's temperature, the shorter the wavelength of its radiation.
2. In the infrared, cooler clouds will radiate at longer wavelengths than warmer clouds. By imaging these differences (by assigning different wavelengths to different shades of white and gray), we can tell where the clouds are both day and night. The cooler the cloud, the brighter it is in the image, and the higher it is in the atmosphere. Identifying the cloud's temperature and comparing it to an upper-air

observation can then tell us the height of the cloud. Thicker, lower clouds will radiate at longer wavelengths, and appear as a darker grey. Colors can be applied to the image for more precise analysis.

p. 49

1. Beam spreading occurs when the angle of the sun is lower in the sky. The same amount of solar radiation will cover a larger area, so the net radiation at any point under the beam will be less than when the beam is directly overhead.
2. As the sun appears to be higher or lower in the sky during the year, the point with the most intense midday heating will move as well. The latitude of this point varies during the year from the Tropic of Cancer ($23\frac{1}{2}^{\circ}$ north latitude) on the June solstice to the Equator (0° latitude) on the September equinox, to the Tropic of Capricorn ($23\frac{1}{2}^{\circ}$ south latitude) on the December solstice, and back to the Equator on the March equinox.

Chapter 2 Review Question Answers

1. Potential Energy (stored for use)

Water behind a dam, energy in a battery, pressure in a can or bottle or fire extinguisher, energy stored in firewood, food energy, fuels, and a can on a high shelf (potential energy from gravity), a race car or locomotive at rest, leaves on a tree, a raindrop or snowflake in a cloud

Kinetic Energy (in use)

Visible light, heat (radiation energy), a race car or locomotive in motion, electricity, falling leaves, falling rain or snow

2. Conduction is transfer of energy from molecule to molecule by touching. Convection is transfer of energy through the mixing of a liquid or gas.
3. "Electromagnetic" refers to the properties of a wave. One part is an electrical field, one part is a magnetic field. Differing lengths of waves (wavelengths) result in different characteristics of their radiation. The hotter an object's temperature is, the shorter the wavelength and the more energetic the radiation.
4. Some objects and gases have "selective absorption." This means that the same amount of radiation will produce different results. Most notably, atmospheric gases respond differently to short-wave (solar) and long-wave (Earth) radiation.
5. X-ray, Ultraviolet (UV), Visible, Infrared (IR), microwave
6. -40°
7. Fahrenheit and Celsius scales deal with the freezing and boiling points of water. The Kelvin scale allows us to compare temperatures from absolute zero to the surface of a star and everything in between.
8. As the temperature of an object increases, its radiation increases by a power of 4 (Stefan-Boltzmann's Law). Its emissivity depends on its temperature as well, but "selective emissivity" means that some gases behave differently than others.

9. 341.75 w/m²

10. The angle of the sun.

11. The latitude of the solar declination (the point where the sun is directly overhead at noon, or sub-solar point) reaches its northern maximum on the June solstice at 23 1/2° north latitude (the Tropic of Cancer), and moves to the Equator (0° latitude) on the September equinox, the south to 23 1/2° south latitude on the December solstice (Tropic of Capricorn) and then back to the Equator on the March equinox.

12. The Arctic and Antarctic Circles denote the lines poleward of which there is either no light or 24 hours of light at the solstices. For example, the area north of the Arctic Circle receives 24 hours of sun on the June solstice, when the area south of the Antarctic Circle is in complete darkness.

13. The Arctic and Antarctic Circles are computed by subtracting the tilt of the Earth from 90°. For today, they are at 66 1/2° north and south latitude (90-23 1/2°). If the Earth were tilted at 10°, the Arctic and Antarctic Circles would be at 80° north and south latitude (90-10°). The dates of solstices, equinoxes, perihelion, and aphelion would not change.

14. Example: December solstice (beginning of northern hemisphere winter)

North Pole: Sun is below the horizon, darkness is 24 hours

Tropic of Cancer: shortest daylight of the year

Equator: 12 hours of sunlight

Tropic of Capricorn: Longest daylight of the year

South Pole: Sun is above horizon for 24 hours

Example: June solstice (beginning of northern hemisphere summer)

North Pole: Sun is above horizon for 24 hours

Tropic of Cancer: Longest daylight of the year

Equator: 12 hours of sunlight

Tropic of Capricorn: Shortest daylight of the year

South Pole: Sun is below horizon for 24 hours

15. Although the sun appears to travel north and south of the Equator during the year, it is always visible above the Equator. This is the point on the curved surface of the Earth that receives 12 hours of light every day. Daylight increases and decreases north and south of the Equator depending on the season, except on the equinoxes, when the entire Earth receives 12 hours of light and dark.

16. As the angle of the sun decreases (the sun appears lower in the sky) the same amount of solar radiation becomes spread over a larger area (beam spreading). This results in a reduction of total incoming solar radiation.

17. In the northern hemisphere, the day with the least variation in solar radiation would be the June solstice. Because beam spreading would be at a minimum (compared to the southern hemisphere), the radiation received would vary the least. The length of day would vary from 12 hours at the Equator to 24 hours at the pole

18. Angle of noontime sun = (90-latitude) = declination

June solstice = (90°-44.5°)+23.5° (Sun over Tropic of Cancer)=45.5°+23.5°=67.5°

September and March equinox = (90°-44.5°)+0°(sun over Equator)=45.5°

December solstice = $(90^\circ - 44.5^\circ) - 23.5^\circ$ (negative because sun is over Tropic of Capricorn in southern hemisphere...below the Equator) = $44.5^\circ - 23.5^\circ = 22.0^\circ$