Chapter 2
Energy that Drives the Storms

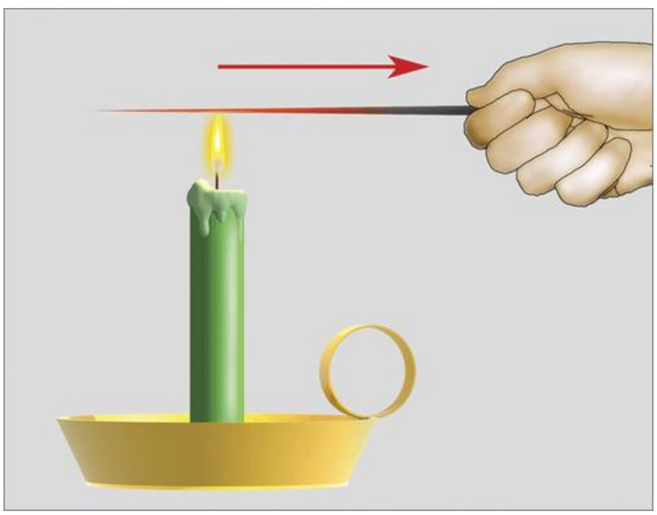
Summary

The atmosphere has the amazing capability of concentrating very large amounts of energy in relatively small areas. To understand how this works, one naturally must first learn the basics of energy and energy transfer. After presenting fundamental definitions of energy and heat transfer, the different types of energy relevant to atmospheric phenomena are described: latent heat, conduction, and convection. Radiation is given a more lengthy treatment, with emphases on the selective absorption and the atmospheric greenhouse effect. These concepts are blended together in sections on energy balance and seasons.

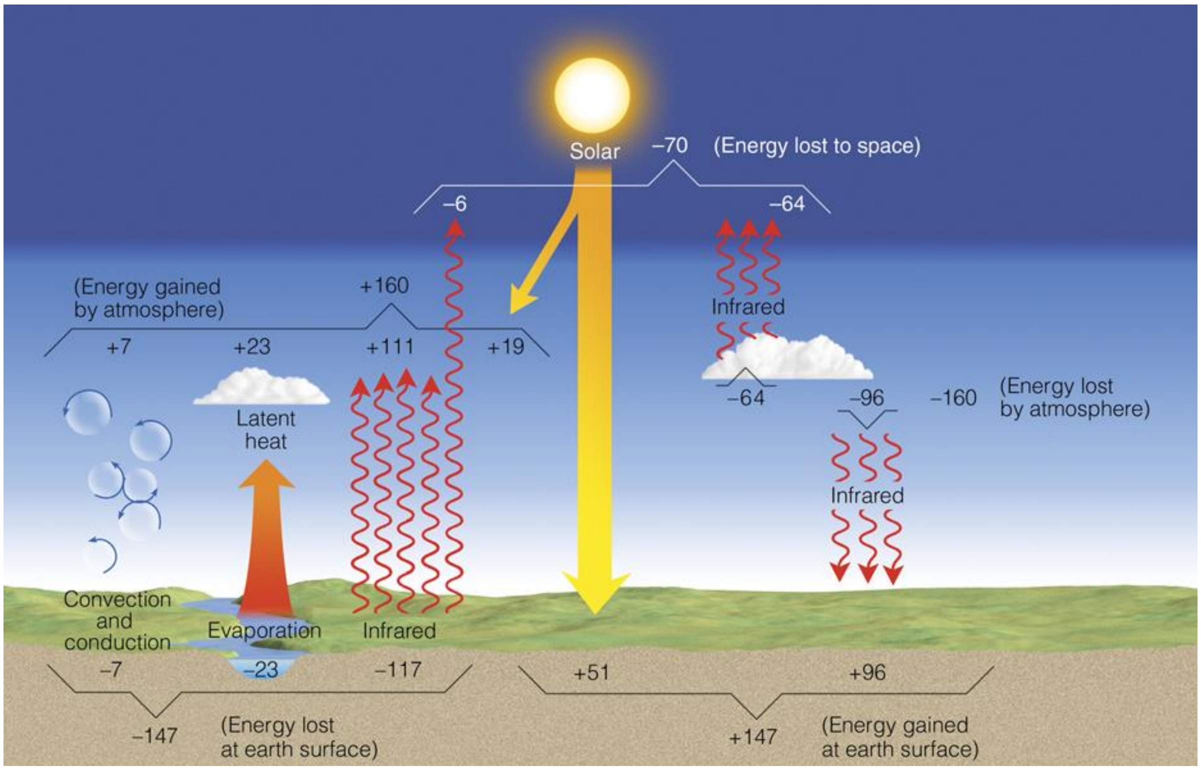
Several focus sections are included in the chapter: *Comparing Energy in Storms*, *Is Tanning Healthy?*, *Space Weather*, and *Year Without a Summer*.

Teaching Suggestions

1. Refer to Figure 2.4 and conduct the following experiment to demonstrate various types of heat transfer. Heat the end of a thin iron bar in a flame (from a Bunsen burner or a propane torch). Begin by holding the bar fairly close to the heated end of the bar. Students will see that heat is quickly conducted through the metal when the instructor is forced to move his or her grip down the bar. Ask the students what they would do to quickly cool a hot object. Many will suggest blowing on it, an example of forced convection. Someone might suggest plunging the hot object into water. Evaporating water can be seen and heard when the hot iron bar is put into the water. The speed with which the rod is cooled is proof of the large amount of latent heat energy associated with changes of phase. Repeat the demonstration with a piece of glass tubing or glass rod. Glass is a poor conductor and the instructor will be able to comfortably hold the glass just 2 or 3 inches from the heated tip. Ask the students if they believe energy is being transported away from the hot glass and, if so, how? Without heat loss by conduction, the glass will get hotter than the iron bar and the tip should begin to glow red – a good demonstration of energy transport by radiation. (The heated glass tube will shatter if submerged in water.)

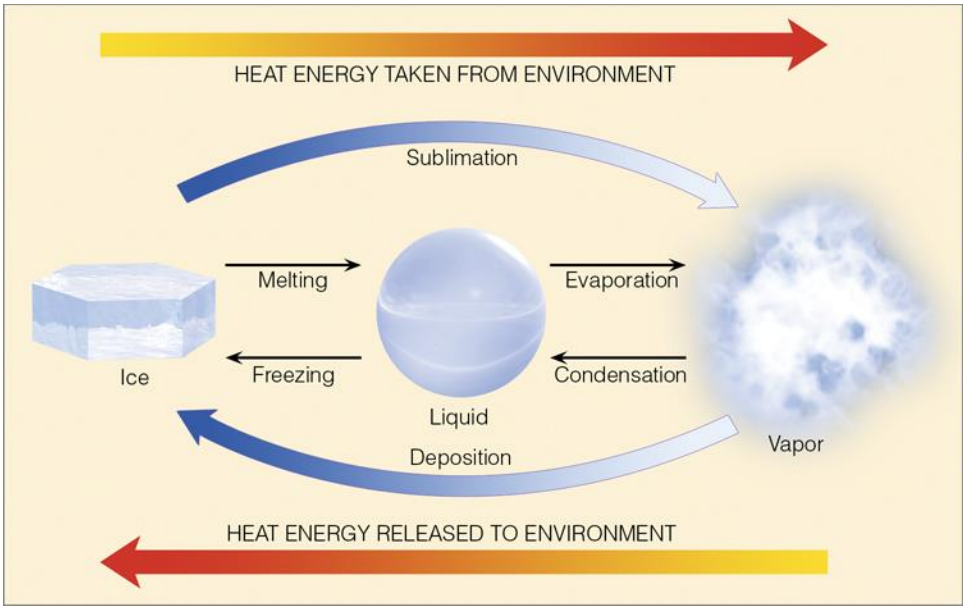


2. Ask the students whether they believe water could be brought to a boil most rapidly in a covered or an uncovered pot. The question can be answered experimentally by filling two beakers with equal amounts of water and placing them on a single hot plate (to ensure that energy is supplied to both at equal rates). It is a good idea to place boiling stones in the beakers to ensure gentle boiling. Cover one of the beakers with a piece of foil. The covered pot will boil first. Explanation: a portion of the energy added to uncovered pot is used to evaporate water, not to increase the water's temperature. Relate the fate of the energy supplied to the hot plate to the fate of solar energy as shown in Figure 2.14.



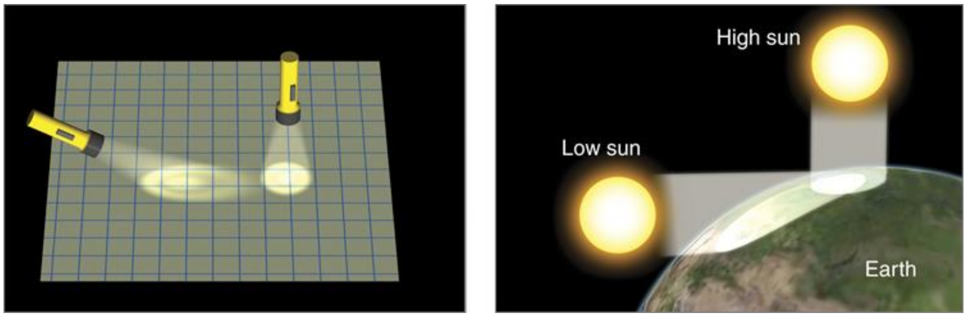
3. The concept of equilibria is sometimes difficult for students to grasp. Place a glass of water on a table top and ask the students whether they think the temperature of the water in the glass is warmer, cooler, or the same as the surroundings. Many will say it is the same. Ask the students whether they think there is any energy flowing into or out of the glass. With some encouragement, they will recognize that the water is slowly evaporating and that this represents energy flow out of the glass. Energy flowing out of the glass will cause the water's temperature to decrease. Will the water just continue to get colder and colder until it freezes? No – as soon as the water's temperature drops below the temperature of the surroundings, heat will begin to flow into the water. The rate at which heat flows into the glass will depend on the temperature difference between the glass and the surroundings. The water temperature will decrease until energy flowing into the glass balances the loss due to evaporation.

4. Conduct a thought experiment to illustrate the magnitude of latent heat of evaporation/condensation (refer to Figure 2.2). Ask students to think about taking a hot shower. Their body temperature is ~ 100ºF; the water temperature is > 100ºF; the air temperature in the room is ~75ºF. Why, then, do you feel cold when you step, dripping wet, out of the shower?



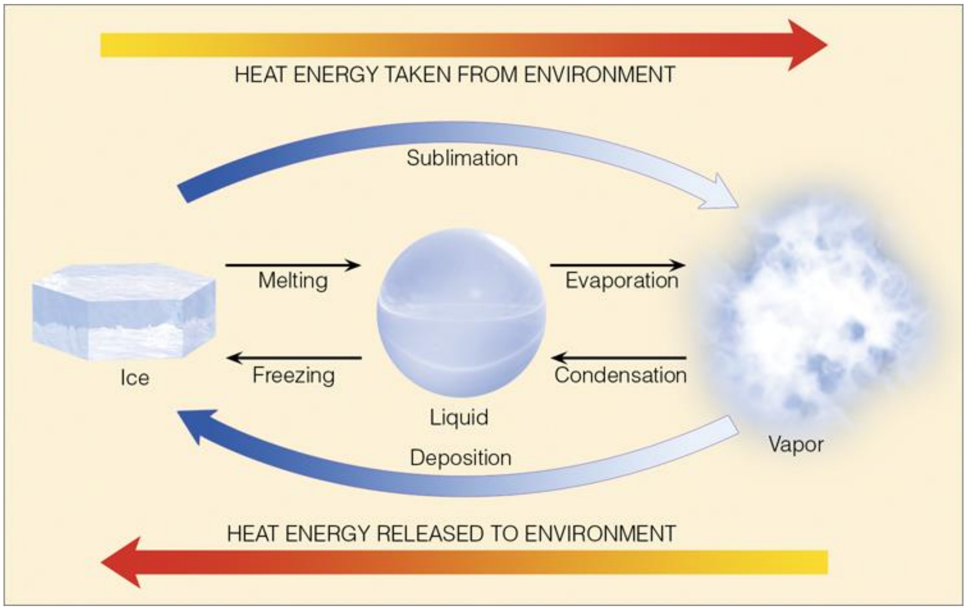
5. Draw an ellipse on the blackboard with the sun positioned much closer to one end of the ellipse. On the other end of the ellipse, closest to the sun, make a dot for the earth and label it, "January and winter." Then label the other end "July and summer." Act confused and ask, "Wait a minute, is that correct?" Hopefully this will start an interesting discussion on what causes the seasons.

6. Ask the students: if the Arctic Ocean receives 24 hours of sunlight for half the year, why do the temperatures remain cold? Refer to Figure 2.17 to invoke the concepts of sun angle and albedo.



Student Projects/Activities

1. Have students list at least two weather phenomena that correspond to each of the six arrows in the Figure 2.2 phase change diagram.



2. Using appropriate heat transfer concepts, have students explain why heat vents for forced-air heating systems are typically located closer to the floor than to the ceiling.

3. Have students explain why it is that on a hot summer day, a sandy beach is warmer than the adjacent water.

4. Have students explain why a florist's greenhouse stays warm despite cold outdoor temperatures. Compare and contrast this with the processes contributing to the atmospheric greenhouse effect.

5. Have students consider the mid-latitude location of Milwaukee, Wisconsin and the tropical location of Cancun, Mexico. During summer at each place, compare the: noontime sun altitude, noontime solar intensity, noontime length of your shadow, and length of day.

Answers to Review Questions

1. Heat is energy in the process of being transferred from one object to another because of the temperature difference between them.

2. The kinetic energy (KE) of an object is equal to half its mass multiplied by its velocity squared. The faster something moves, the greater its kinetic energy.

3. Conduction: the transfer of heat from molecule to molecule within a substance. Convection: the transfer of heat by the mass movement of a fluid such as water and air. Radiation: 1. Energy that travels in the form of waves that release energy when they are absorbed by an object.

4. Convection refers to the transfer of the air's properties by rising or sinking motions. Advection describes the transfer of properties by horizontal motions.

5. The wavelengths of radiation that an object emits depend primarily on the object's temperature. The higher the object's temperature, the shorter are the wavelength of emitted radiation. Also, objects that have a high temperature emit radiation at a greater rate or intensity than objects with a lower temperature.

6. Objects that have a high temperature emit radiation at a greater rate or intensity than objects with a lower temperature. Thus, the sun emits a much larger intensity of radiation than the earth.

7. The sun emits radiation at almost all wavelengths, but because its surface is hot—6,000 K (10,500°F)—it radiates the majority of its energy at relatively short wavelengths. The relatively cool earth emits almost all of its energy at longer, infrared wavelengths.

8. When the rate of absorption of solar radiation equals the rate of emission of infrared earth radiation, a state of radiative equilibrium is achieved.

9. The earth's surface is constantly absorbing radiation emitted by the sun.

10. Water vapor, carbon dioxide, nitrous oxide, methane, and ozone.

11. Water vapor and CO2 (and nitrous oxide, methane, and ozone) selectively emit radiation at infrared wavelengths. This radiation travels away from these gases in all directions. A portion of this energy is radiated toward the earth's surface and absorbed, thus heating the ground. The earth, in turn, radiates infrared energy upward, where it is absorbed by these gases, warming the lower atmosphere. In this way, the selectively-absorbing greenhouse gases absorb and radiate infrared energy and act as an insulating layer around the earth, keeping part of the earth's infrared radiation from escaping rapidly into space. Consequently, the earth's surface and the lower atmosphere are much warmer than they would be if these selectively absorbing gases were not present.

12. Water vapor, carbon dioxide, nitrous oxide, methane, and CFCs.

13. The outpouring of solar energy constantly bathes the earth with radiation while the earth, in turn, constantly emits infrared radiation. If we assume that there is no other method of transferring heat then, when the rate of absorption of solar radiation equals the rate of emission of infrared earth radiation, a state of radiative equilibrium is achieved. The average temperature at which this occurs is called the radiative equilibrium temperature. At this temperature, the earth (behaving as a blackbody) is absorbing solar radiation and emitting infrared radiation at equal rates, and its average temperature does not change. As the earth is about 150 million km (93 million mi) from the sun, the earth's radiative equilibrium temperature is about 255 K (0°F, –18°C).

14. The selectively-absorbing greenhouse gases absorb and radiate infrared energy and act as an insulating layer around the earth, keeping part of the earth's infrared radiation from escaping rapidly into space.

15. On average, the albedo of clouds is near 60 percent. When solar energy strikes a surface covered with snow, up to 95 percent of the sunlight may be reflected. Water surfaces, on the other hand, reflect only a small amount of solar energy. Averaged for an entire year, the earth and its atmosphere (including its clouds), will redirect about 30 percent of the sun's incoming radiation back to space.

16. The outpouring of solar energy constantly bathes the earth with radiation while the earth, in turn, constantly emits infrared radiation.

17. Our seasons are regulated by the amount of solar energy received at the earth's surface. This amount is determined primarily by the angle at which sunlight strikes the surface, and by how long the sun shines on any latitude (daylight hours). The second important factor determining how warm the earth's surface becomes is the length of time the sun shines each day. Longer daylight hours, of course, mean that more energy is available from sunlight.

18. Our spinning planet is inclined on its axis (tilted) as it revolves around the sun. The angle of tilt is 23½° from the perpendicular drawn to the plane of the earth's orbit. The earth's axis points to the same direction in space all year long; thus, the Northern Hemisphere is tilted toward the sun in summer (June), and away from the sun in winter (December).

19. Summer and January.

20. Even though in the far north the sun is above the horizon for many hours during the summer, the surface air there is not warmer than the air farther south where days are appreciably shorter. When incoming solar radiation (called insolation) enters the atmosphere, fine dust, air molecules, and clouds reflect and scatter it, and some of it is absorbed by atmospheric gases. Generally, the greater the thickness of atmosphere that sunlight must penetrate, the greater are the chance that it will be either reflected or absorbed by the atmosphere. During the summer in far northern latitudes, the sun is never very high above the horizon, so its radiant energy must pass through a thick portion of atmosphere before it reaches the earth's surface. Some of the solar energy that does reach the surface melts frozen soil or is reflected by snow or ice, and that which is absorbed is spread over a large area. So, even though northern cities may experience long hours of sunlight, they are not warmer than cities farther south.

21. This situation, called the lag in seasonal temperature, arises because although incoming energy from the sun is greatest in June, it still exceeds outgoing energy from the earth for a period of at least several weeks. When incoming solar energy and outgoing earth energy are in balance, the highest average temperature is attained.

22. Nearly 81 percent of the Southern Hemisphere surface is water compared to 61 percent in the Northern Hemisphere. The added solar energy due to the closeness of the sun is absorbed by large bodies of water, becoming well mixed and circulated within them. This process keeps the average summer (January) temperatures in the Southern Hemisphere cooler than the average summer (July) temperatures in the Northern Hemisphere. The water's large heat capacity also tends to keep winters in the Southern Hemisphere warmer than we might expect.

Multiple Choice Exam Questions

1. Energy of motion is also known as:
   a. dynamic energy.
   b. kinetic energy.
   c. sensible heat energy.
   d. static energy.
   e. latent heat energy.

ANSWER: b

2. Heat is energy in the process of being transferred from:
   a. hot objects to cold objects.
   b. low pressure to high pressure.
   c. cold objects to hot objects.
   d. high pressure to low pressure.
   e. regions of low density toward regions of high density.

ANSWER: a

3. The heat energy released when water vapor changes to a liquid is called:
   a. latent heat of evaporation.
   b. latent heat of fusion.
   c. latent heat of fission.
   d. latent heat of condensation.

ANSWER: d

4. This is released as sensible heat during the formation of clouds:
   a. potential energy
   b. longwave radiation
   c. latent heat
   d. shortwave radiation
   e. kinetic energy

ANSWER: c

5. The cold feeling that you experience after leaving a swimming pool on a hot, dry, summer day represents heat transport by:
   a. conduction.
   b. convection.
   c. radiation.
   d. latent heat.

ANSWER: d

6. The processes of condensation and freezing:
   a. both release sensible heat into the environment.
   b. both absorb sensible heat from the environment.
   c. do not affect the temperature of their surroundings.
   d. do not involve energy transport.

ANSWER: a

7. The transfer of heat by molecule-to-molecule contact is:
   a. conduction.
   b. convection.
   c. radiation.
   d. ultrasonic.

ANSWER: a

8. A heat transfer process in the atmosphere that depends upon the movement of air is:
   a. conduction.
   b. absorption.
   c. reflection.
   d. convection.
   e. radiation.

ANSWER: d

9. Snow will usually <u>melt</u> on the roof of a home that is a:
   a. good radiator of heat.
   b. good conductor of heat.
   c. poor radiator of heat.
   d. poor conductor of heat.

ANSWER: b

10. The temperature of a rising air parcel:
   a. always cools due to expansion.
   b. always warms due to expansion.
   c. always cools due to compression.
   d. always warms due to compression.
   e. remains constant.

ANSWER: a

11. The proper order from shortest to longest wavelength is:
   a. visible, infrared, ultraviolet.
   b. infrared, visible, ultraviolet.
   c. ultraviolet, visible, infrared.
   d. visible, ultraviolet, infrared.
   e. ultraviolet, infrared, visible.

ANSWER: c

12. If the average temperature of the sun increased, the wavelength of peak solar emission would:
    a. shift to a shorter wavelength.
    b. shift to a longer wavelength.
    c. remain the same.
    d. impossible to tell from given information

ANSWER: a

13. Which of the following determine(s) the kind (wavelength) and amount of radiation that an object emits?
    a. temperature
    b. thermal conductivity
    c. density
    d. latent heat

ANSWER: a

14. Often before sunrise on a clear, calm, cold morning, ice (frost) can be seen on the tops of parked cars, even when the air temperature is above freezing. This condition happens because the tops of the cars are cooling by:
    a. conduction.
    b. convection.
    c. latent heat.
    d. radiation.

ANSWER: d

15. Evaporation is a __________ process.
    a. cooling
    b. heating
    c. can't tell – it depends on the temperature
    d. both a and c

ANSWER: a

16. If you want to keep an object cool while exposed to direct sunlight, you should:
    a. put it inside a brown paper bag.
    b. wrap it in black paper.
    c. wrap it in aluminum foil with the shiny side facing inward.
    d. wrap it in aluminum foil with the shiny side facing outward.

ANSWER: d

17. The sun emits its greatest intensity of radiation in:
    a. the visible portion of the spectrum.
    b. the infrared portion of the spectrum.
    c. the ultraviolet portion of the spectrum.
    d. the x-ray portion of the spectrum.

ANSWER: a

18. Air that rises always:
    a. contracts and warms.
    b. contracts and cools.
    c. expands and cools.
    d. expands and warms.

ANSWER: c

19. If the earth's average surface temperature were to increase, the amount of radiation emitted from the earth's surface would __________ and the wavelength of peak emission would shift toward __________ wavelengths.
    a. increase, shorter
    b. increase, longer
    c. decrease, shorter
    d. decrease, longer

ANSWER: a

20. Without the atmospheric greenhouse effect, the average surface temperature would be:
    a. higher than at present.
    b. lower than at present.
    c. the same as it is now.
    d. much more variable than it is now.

ANSWER: b

21. Which of the following gases are mainly responsible for the atmospheric greenhouse effect in the earth's atmosphere?
    a. oxygen and nitrogen
    b. nitrogen and carbon dioxide
    c. ozone and oxygen
    d. water vapor and carbon dioxide

ANSWER: d

22. The combined albedo of the earth and the atmosphere is approximately:
    a. 4%.
    b. 10%.
    c. 30%.
    d. 50%.
    e. 90%.

ANSWER: c

23. The albedo of the moon is 7%. This means that:
    a. 7% of the sunlight striking the moon is reflected.
    b. 7% of the sunlight striking the moon is absorbed.
    c. the moon emits only 7% as much energy as it absorbs from the sun.
    d. 93% of the sunlight striking the moon is reflected.

ANSWER: a

24. On the average, about what percentage of the solar energy that strikes the outer atmosphere eventually reaches the earth's surface?
    a. 5%
    b. 15%
    c. 30%
    d. 50%
    e. 70%

ANSWER: d

25. If the amount of energy lost by the earth to space each year were not approximately equal to that received,
    a. the atmosphere's average temperature would change.
    b. the length of the year would change.
    c. the sun's output would change.
    d. the mass of the atmosphere would change.

ANSWER: a

26. The earth's radiative equilibrium temperature is:
    a. the temperature at which the earth is absorbing solar radiation and emitting infrared radiation at equal rates.
    b. the temperature at which the earth is radiating energy at maximum intensity.
    c. the average temperature the earth must maintain to prevent the oceans from freezing solid.
    d. the temperature at which rates of evaporation and condensation on the earth are in balance.

ANSWER: a

27. Suppose you are outside in very cold temperatures, wearing a winter coat that is quite effective at keeping you warm. Which of the following is true?
a. The coat is the source of the heat that keeps you warm.
b. Your body generates the heat that keeps you warm.
c. The coat prevents your body's heat from escaping to the surrounding air.
d. both (a) and (c) are true.
e. both (b) and (c) are true.

ANSWER: e

28. During the winter in the Northern Hemisphere, the "land of the midnight sun" would be found:
a. at high latitudes.
b. at middle latitudes.
c. near the equator.
d. in the desert southwest.
e. on the West Coast.

ANSWER: a

29. In the Northern Hemisphere, this day has the fewest hours of daylight:
a. summer solstice
b. winter solstice
c. vernal equinox
d. autumnal equinox

ANSWER: b

True/False Exam Questions

1. During an equinox, the days and nights are of equal length except at the poles.

ANSWER: true

2. On December 22, the equator (0^{o} latitude) would experience fewer hours of daylight than the latitude 60^{o} N.

ANSWER: false

3. Considering each hemisphere as a whole, seasonal temperature variations in the Southern Hemisphere are greater than those in the Northern Hemisphere.

ANSWER: false

4. The fact that solar energy is spread over a larger area in northern latitudes helps to explain why even though these latitudes experience 24 hours of sunlight on June 22, they are not warmer than latitudes further south.

ANSWER: true

5. When it is January and winter in the Northern Hemisphere, it is July and summer in the Southern Hemisphere.

ANSWER: false

6. The most important reason why summers in the Southern Hemisphere are not warmer than summers in the Northern Hemisphere is that over 80% of the Southern Hemisphere is covered with water.

ANSWER: true

7. The changing distance between the earth and the sun over the course of the year is the main cause of the seasons.

ANSWER: false

8. Although the polar regions radiate away more heat energy than they receive by insolation in the course of a year, the insulating properties of snow prevents them from becoming progressively colder each year.

ANSWER: false

9. The latitude 90 ^{o}N is closer to the earth's axis than the latitude 40 ^{o}N.

ANSWER: true

10. More solar radiation is received at the top of the atmosphere than at the earth's surface.

ANSWER: true

Essay/Critical Thinking Exam Questions

1. The earth radiates energy constantly. What prevents the earth from getting colder and colder?

2. Will a rising parcel of air always expand? Why? How does this expansion affect the air temperature? Why?

3. Explain how energy in the form of sunlight absorbed at the ground could be transferred upward in the atmosphere in the form of latent heat. How or when is the latent heat energy released in the air above the ground?

4. Describe the atmospheric greenhouse effect. Is there any difference between the way the atmospheric greenhouse effect works on a clear night and on a cloudy night?

5. How could clouds increase the surface temperature? How could clouds decrease the surface temperature?

6. When you remove a cold beverage from a refrigerator in a humid room, water vapor will condense on the sides of the container. Would this act to warm or cool the beverage, or would the condensation have no effect on the beverage's temperature?

7. Many people will blow on a bowl of hot soup to try to cool it. What are the two most important heat transport processes being used to cool the soup?

8. When you place an ice cube in your hand, the ice cube melts and your hand cools. List all the heat transport processes that are taking place.

9. Which wavelengths of radiation does your body radiate most: ultraviolet, visible or infrared? Why?

10. Describe why noontime shadows are longer in New York City than they are in Cancun, Mexico.