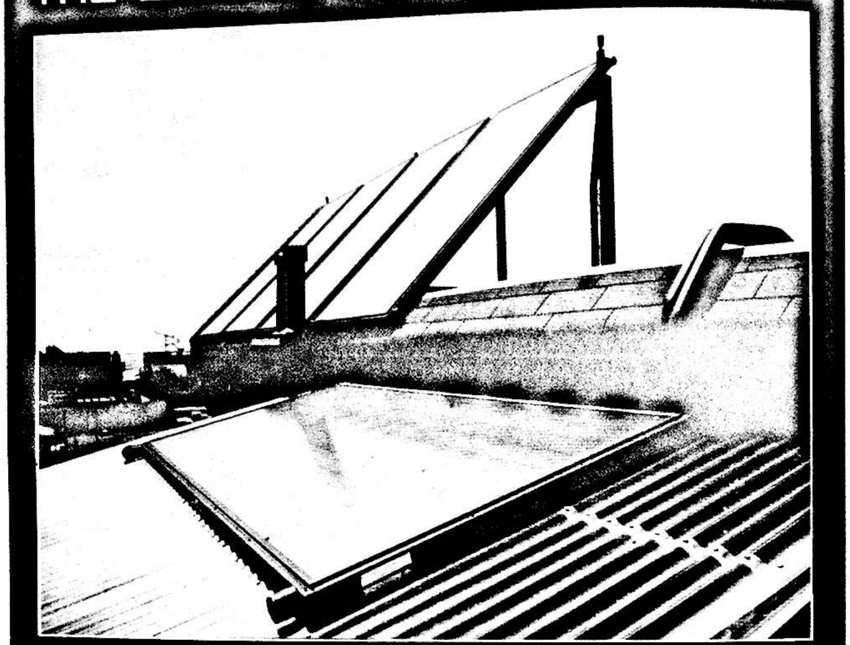
TOPIC VI
INSOLATION AND THE EARTH'S SURFACE



The more we learn about solar energy, the better we become at harnessing it for our everyday needs.

CHAPTER 9

You will know something about insolation and the earth if you can:

1. Describe the factors that affect the amount of solar energy reaching the earth.
2. Explain what happens to the solar energy that reaches the earth's surface.
3. Describe the effects of the atmosphere on radiant energy given off by the earth's surface.

In Chapter 8 you learned something about the ways in which energy can be transferred from one place to another, and transformed from one kind to another. In this chapter we are going to study the factors that affect the amount of the sun's energy that is transferred to the earth's surface at any particular time and place. We are also going to learn about the transformations of the energy that reaches the earth from the sun.

INSOLATION

The term *insolation* (from INcoming SOLar radiATION) refers to the portion of the sun's radiation that is received by the earth. It is our share of the sun's total energy output. However, we must remember that when radiation strikes matter, some of it may be reflected, some may be scattered, some may be absorbed, and some may be transmitted. All four of these things happen to the insolation that enters the atmosphere. So the amount and kind of insolation that gets through to the earth's surface is likely to be quite different from the insolation at the top of the atmosphere. We will be mainly interested in the insolation that actually reaches us down here on the ground.

Radiation and Temperature. You will recall from the last chapter that all bodies of matter radiate electromagnetic energy if their temperature is above absolute zero. As a body becomes hotter, it radiates a greater total amount of energy. A hotter body also radiates more of its energy at short wavelengths than a cooler body does.

We can see this happen if we heat an object, such as an iron bar, in a furnace or in a very hot flame. Remember that the longest wavelengths of visible light are at the red end of the spectrum. The shortest wavelengths are at the blue end. As the iron bar heats up, it begins to glow a dull red. This means that it has begun to radiate enough energy at red (long) wavelengths for the eye to detect it.

As the temperature of the bar rises further, its apparent color changes to orange, then to yellow. It is radiating more energy at these shorter wavelengths of visible light. It also appears brighter, because it is radiating more energy altogether.

If the bar becomes hot enough, it turns white hot. White light is a mixture of all the wavelengths of visible light. The iron bar is now radiating strongly enough throughout the visible spectrum to shine with a white light. If the temperature rises even further, the bar begins to radiate less strongly at the longer (red) wavelengths and more strongly at the short (blue) wavelengths. Its light now acquires a distinctly bluish color.

What we have just said about the wavelengths of radiation from a body applies only to radiation given off by the body because of its temperature. This has nothing to do with the color of objects that we see by the light they reflect, or the color of glowing gases in neon tubes and similar devices.

Intensity of Radiation. When we refer to "amount" of energy being radiated, we really mean the *rate* at which energy is given off—the amount given off in a certain time. *Intensity* is the term used to describe the rate at which energy is being transferred. It can be expressed in such units as calories per second. We can say, therefore, that the intensity of radiation from the iron bar increases as its temperature rises. We can also say that the intensity of its radiation at short wavelengths increases as its temperature rises.

Figure 9-1 shows the intensity of radiation at various wavelengths from the earth and from the sun. We see that the wavelengths of maximum in-

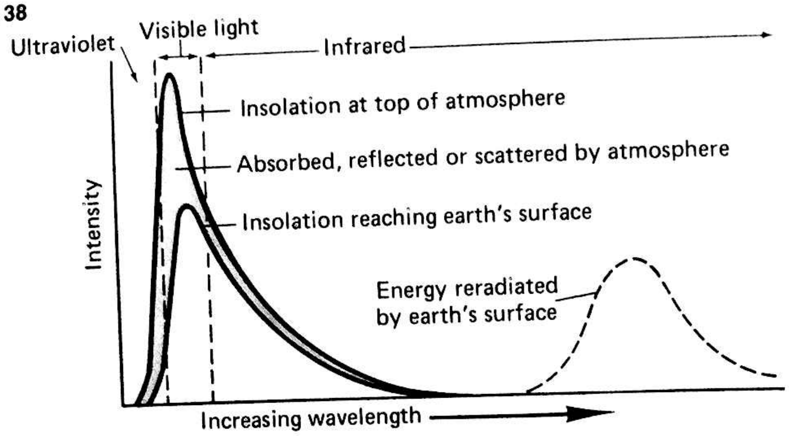


Figure 9-1. Intensity of insolation received and reradiated by the earth's surface. Total amount of energy is proportional to the area under the curves. About 50% of the insolation received at the surface is in the infrared range of wavelengths, but nearly 100% of the reradiated energy is in this range. (The reradiation curve is not drawn to the same scale as the insolation curves. If drawn to the same scale, it would be much flatter and would extend much farther to the right.)

tensity from the earth (a fairly cool body) are in the infrared (long) wavelength region of the electromagnetic spectrum. Maximum intensity of radiation from the sun (a quite hot body) occurs in the yellow region of the visible (short) wavelengths.

This does not mean that most of the sun's total energy is in the form of visible light. It still radiates much energy at other wavelengths, both longer and shorter than visible radiation. In fact, about half the energy of insolation that reaches the earth's surface is in the form of infrared radiation.

Intensity of Insolation. Just as we describe the intensity of radiation as the rate at which energy is radiated, we can apply the term "intensity" to the rate at which energy is *received*. The *intensity of insolation* is the rate at which energy of insolation reaches a given area.

Intensity of *radiation* can be expressed in calories per second. Intensity of *insolation* has to have an area factor in it—for example, calories per second *per square meter*. You can see why this is so. There is quite a difference between a rate of 1,000 calories per second per *square meter* and a rate of 1,000 calories per second per *square centimeter!* (Which do you think is more intense? Yes, the second rate is, by a factor of 10,000. If 1,000 calories reach a square centimeter of area in one second, 10,000,000 calories are falling on an area of one square meter. There are 100 × 100, or 10,000, square centimeters in a square meter, each receiving its own 1,000 calories.)

Once you have determined the intensity of insolation for a given area, you can also find the total insolation received by that area over a given period of time. You would find total insolation by multiplying the intensity of insolation by the time.

There are a number of different factors that affect the amount and type of energy received at the earth's surface. In the following section we're going to discuss each of them.

SUMMARY

1. Insolation is that portion of the sun's radiation that is received by the earth.
2. Intensity of radiation is the rate at which radiant energy is being transferred.
3. Intensity of radiation depends on the temperature of the radiating body. As the temperature increases, the total intensity increases, and the wavelengths of maximum intensity decrease.
4. Intensity of insolation is the rate at which insolation is received per unit area.

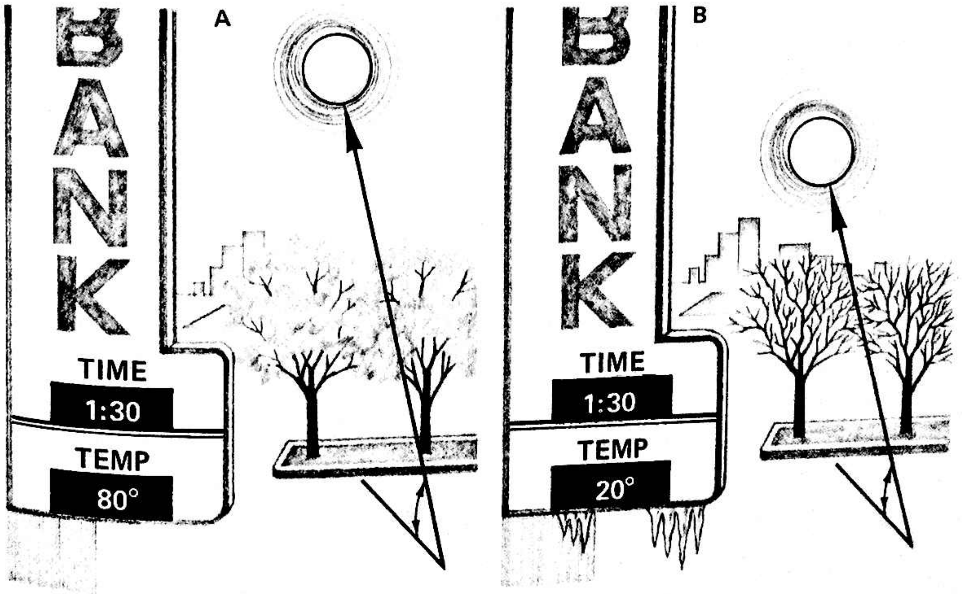
FACTORS AFFECTING INSOLATION

Figure 9-2 illustrates at least one factor that determines how insolation reaching the earth's surface is related to the seasons. Scene *A* appears to be summer-like, while scene *B* seems quite wintery. If you studied these pictures carefully, you probably noticed that the altitude of the sun, or its angle with horizon, is different in the two cases.

In scene *A* the sun is at a high altitude at noon, while in scene *B*, at the same hour, the sun is at a low altitude. Does the altitude of the sun affect the temperature? Are there other factors that influence seasonal changes? Let's find out.

Angle of Insolation. Intensity of insolation is determined by the angle at which the sun's rays strike the earth's

Figure 9-2. Season and the angle of insolation. These two scenes show the same view at the same time of day but at different seasons of the year. In scene *A*, which appears to be summer, the sun is almost directly overhead. In scene *B*, which appears to be winter, the sun is low in the sky.



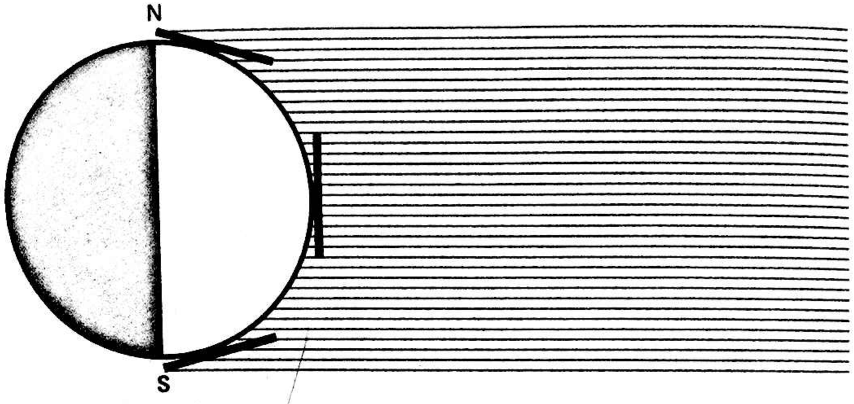


Figure 9-3. Shape of the earth and the angle of insolation. Note that the intensity of insolation is greatest where the rays are perpendicular to the surface.

surface. (This angle is called the *angle of insolation.*) The intensity of insolation is greatest when the angle of insolation is 90°. This is so because when the rays are perpendicular (make an angle of 90°), they are concentrated into the smallest possible area (see Figure 9-3).

As the angle of insolation decreases from 90° to 0°, the intensity also decreases to zero. When the sun's rays arrive parallel to the earth's surface, the intensity of insolation is zero. The intensity of insolation decreases with decreasing angle because as the angle becomes smaller, the same amount of radiant energy is spread over a larger and larger area.

There are several different factors that affect the angle of insolation.

1. *The shape of the earth.* The spherical shape of the earth is one of the factors that determine the angle of insolation. The sun is so distant from the earth that the rays of sunlight reaching the earth are practically parallel to one another. If the earth were flat and perpendicular to the sun's rays, all areas facing the sun would receive the same intensity of insolation. But since the earth is spherical, its surface is curved, and therefore there is only one place on the earth where the rays of the sun can be perpendicular at any given time (see Figure 9-3). At all other locations the angle of insolation will be less than 90°.

2. *Latitude.* From the previous section you can see that intensity of insolation varies with latitude because of the shape of the earth.

The rays of the sun that strike the earth at an angle of 90° are called *vertical,* or *direct,* rays. The only parts of the earth that ever receive vertical rays are those between latitudes 23½°N and 23½°S, depending on the time of year (see Figure 9-4). Therefore, the parts of the earth around the equator have, on the average, a greater intensity of insolation than any other latitudes.

If you look at Figure 9-4, you will see that at the time of the equinoxes, March 21 and September 23, only the equator receives vertical rays. At the time of the summer solstice, June 21, vertical rays strike at latitude 23½°N. At the time of the winter solstice, December 21, vertical rays strike at a latitude of 23½°S.

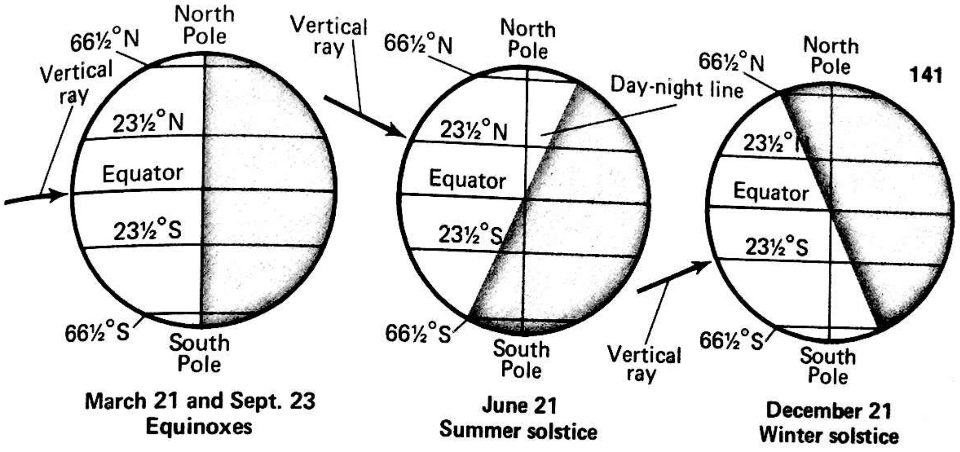


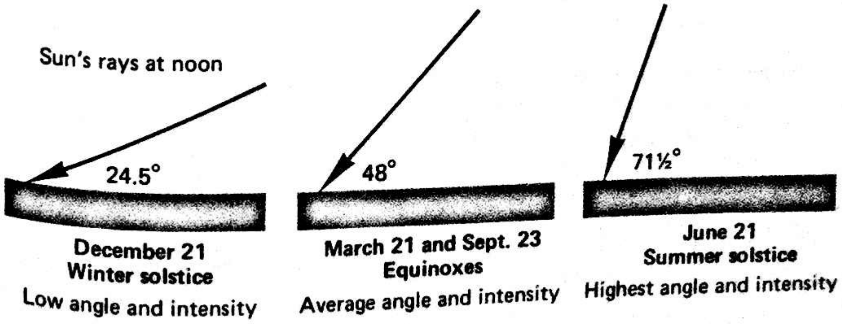
Figure 9-4. Intensity of insolation and latitude. At any given time, intensity of insolation is maximum at the latitude of the vertical rays, and is less at other latitudes.

3. *Season of the year.* From our discussion of insolation and latitude it should be clear that the season of the year affects the intensity of insolation at any given location.

At the summer solstice, June 21, the vertical rays of the sun strike at their northernmost point, 23½°N, and the noon sun reaches its highest angle everywhere north of 23½°N latitude. On this date the intensity of insolation is greatest in the Northern Hemisphere. This marks the beginning of summer in the Northern Hemisphere and the beginning of winter in the Southern Hemisphere. During the northern summer, locations at latitudes above 66½°N have 24 hours of daylight, while locations below 66½°S latitude have 24 hours of darkness. At the winter solstice, December 21, the conditions of the two hemispheres are reversed.

So, as the earth travels around the sun in the course of a year, the angle (and intensity) of insolation at a given location varies with the season. Figure 9-5 shows the maximum angle of insolation at noon at four different seasons for a location at 42°N latitude.

Figure 9-5. Maximum angle of insolation (at noon) at 42° north latitude at different seasons.



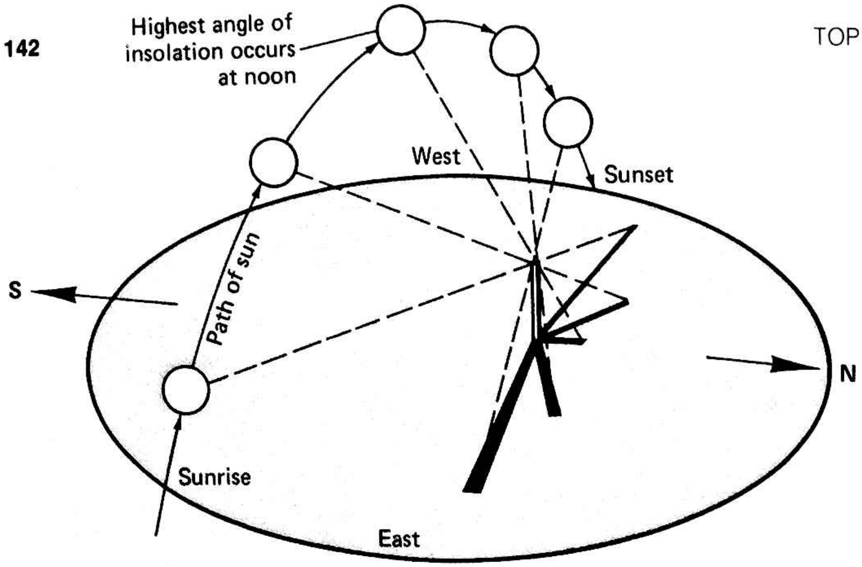


Figure 9-6. Changes in the angle of insolation in the course of one day. The shadow of a vertical post indicates how the angle of insolation varies during the day. The higher the angle of insolation, the shorter the shadow and the greater the intensity. Maximum angle and intensity occur at noon.

4. *Time of day*. Both the angle and the intensity of insolation change constantly during the course of a day. In the morning, when the sun is low in the sky, the insolation arrives at a very low angle, nearly parallel to the horizon (see Figure 9-6). As the day progresses, the sun rises higher and higher in the sky—its angle with the horizon increases—and insolation becomes more and more intense.

At noon the sun is at its highest point in the sky, and the intensity of the insolation is greatest. During the afternoon, the angle of insolation becomes smaller and smaller, and the intensity of insolation decreases accordingly.

Duration of Insolation. The duration of insolation is the number of hours of sunlight received by an area each day. You may remember from Chapter 6 (page 85) that the number of hours of daylight at a location is related to length of the arc, or path, that the sun makes across the sky. Since there is 1 hour of insolation for every 15° of arc, the longer the path, the more hours of daylight.

The duration of insolation depends on a combination of season of the year and latitude. This is illustrated by Table 9-1. In general, the duration of insolation in the Northern Hemisphere is greatest around the time of the summer solstice and least around the time of the winter solstice. However, the *difference* in duration between summer and winter is greatest at high latitudes and least at low latitudes. As we have already noted, the duration of daylight in the polar regions (above 66½° latitude) is 24 hours per day in summer and zero hours per day in winter. At a latitude of 42°N (average for the United States), the duration of insolation is about 15 hours in June and about 9 hours in December. At latitudes near the equator, however, the duration of insolation varies very little throughout the year.

Table 9-1. Angle and duration of insolation.

	SUMMER SOLSTICE June 21		EQUINOXES March 21 September 23		WINTER SOLSTICE December 21	
Latitude	Angle of insolation at 12 noon	Duration of insolation	Angle of insolation at 12 noon	Duration of insolation	Angle of insolation at 12 noon	Duration of insolation
90° N	23½°	24 Hours	0°	12 Hours	—	0 Hours
80° N	33½°	24	10°	12	—	0
70° N	43½°	24	20°	12	—	0
60° N	53½°	18½	30°	12	6½°	5½
50° N	63½°	16¼	40°	12	16½°	7¾
40° N	73½°	15	50°	12	26½°	9
30° N	83½°	14	60°	12	36½°	10
20° N	86½°	13¼	70°	12	46½°	10¾
10° N	76½°	12½	80°	12	56½°	11½
0°	66½°	12	90°	12	66½°	12
10° S	56½°	11½	80°	12	76½°	12½
20° S	46½°	10¾	70°	12	86½°	13¼
30° S	36½°	10	60°	12	83½°	14
40° S	26½°	9	50°	12	73½°	15
50° S	16½°	7¾	40°	12	63½°	16¼
60° S	6½°	5½	30°	12	53½°	18½
70° S	—	0	20°	12	43½°	24
80° S	—	0	10°	12	33½°	24
90° S	—	0	0°	12	23½°	24

SUMMARY

1. Intensity of insolation is determined by the angle at which the sun's rays strike the earth's surface.
2. Maximum intensity of insolation occurs when the sun's rays strike the earth at an angle of 90°. Intensity of insolation decreases as the angle of insolation decreases.
3. The angle of insolation depends upon latitude, time of day, and season.
4. Duration of insolation is the number of hours of insolation received by a given area each day.
5. Duration of insolation depends upon a combination of latitude and season.

TEMPERATURE AND INSOLATION

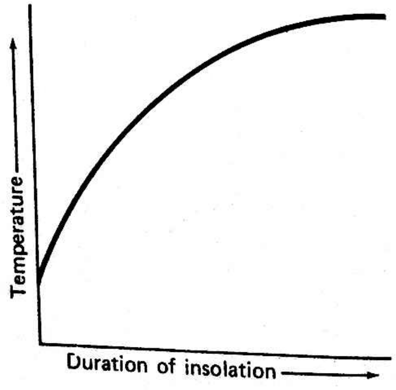
Why is it hotter in the summer than it is in the winter? The reasons for this difference are connected with two factors that you've probably observed for yourself—the days are longer during the summer and the sun feels stronger. In other words, the two factors that affect the temperature of a given area are duration and intensity of insolation.

You know that the intensity of insolation is the rate at which energy is received by a given area per unit time. The higher the rate (the greater the intensity), the more energy is received by an area in a given time. The more energy a surface receives, the more it absorbs. And as energy is absorbed, the temperature of the surface increases.

The change in air and ground temperature during the course of a day is a good example of this effect. In the morning, when the intensity of insolation is low, the sunlight is not very effective in heating either the ground or the air. As the sun rises higher in the sky and the angle of insolation increases, the temperature goes up. In the afternoon, as the sun sets, the intensity of insolation decreases, and the temperature drops. So there is a direct relationship between intensity of insolation and temperature at a given location. The greater the intensity, the higher the temperature.

There is also a direct relationship between duration of insolation and temperature. The longer the duration, the higher the temperature. This is true because the total amount of insolation reaching the area increases with increased duration. Figure 9-7 is a graphic model of the relationship between duration of insolation and temperature at a given location.

Figure 9-7. Duration of insolation and temperature.



Seasonal Temperature Changes. In the Northern Hemisphere, both the duration and intensity of insolation are greatest at about June 21, the summer solstice. On that day there are more hours of sunlight than on any other day of the year, and the noon sun is higher in the sky than on any other day of the year.

While duration and intensity of insolation are greatest around June 21, this is not usually the hottest period of the summer. In fact, the average temperature is often considerably higher in July and even August than it is in June (see Figure 9-8). Why does this happen?

To understand this "time lag," you must first remember that every object above absolute zero, such as the earth, continuously gives off electromagnetic radiation. The rate of this radiation depends only on the object's temperature. It is not affected by the rate at which it is *receiving* radiation from other bodies, such as the sun. When the earth's surface is cool, it radiates at a lower rate than when it is warm.

As the earth radiates energy, its temperature tends to drop. But this tendency is offset by whatever radiation it is receiving and absorbing. Therefore, what happens to the earth's temperature depends upon the balance between the rate at which energy is being absorbed and the rate at which it is being lost by radiation. At the winter solstice, the rate of incoming radiation is least. That is, the warming effect of insolation is at its lowest point. At this time the earth's surface is losing heat faster than it is coming in. So the temperature of the surface is dropping steadily, day by day, at around this time (December in the Northern Hemisphere).

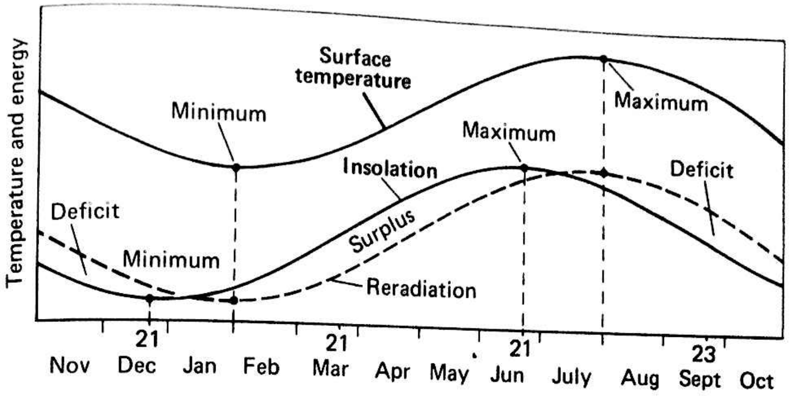


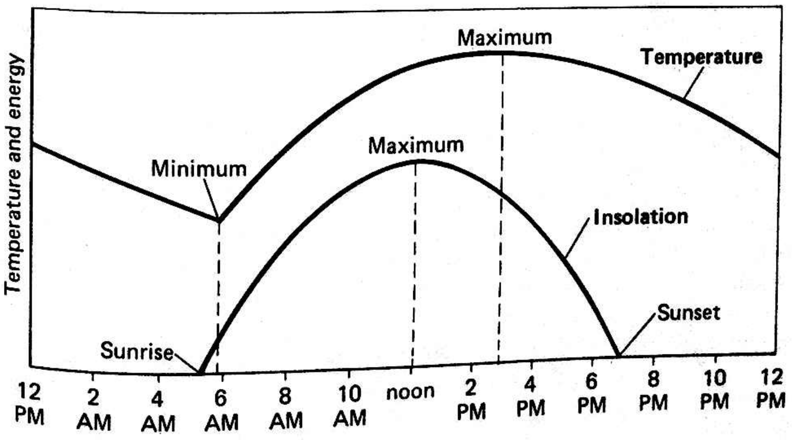
Figure 9-8. Average daily temperatures, insolation, and reradiation for mid-latitudes of the Northern Hemisphere during a year.

As soon as the winter solstice is passed, both the intensity and duration of insolation begin to increase. The rate of incoming energy begins to rise. At the same time, the rate of energy loss by radiation is actually dropping, because the earth's temperature is still dropping. At some time toward the end of January or beginning of February, the earth's temperature in northern latitudes has dropped low enough and the rate of insolation has risen high enough so that the two rates become equal. At this time, equilibrium is reached, and the earth's temperature stops falling. Then, as the rate of insolation continues to increase, there is an overall warming effect. The temperature begins to rise.

The same thing happens in reverse during the summer. The earth continues to warm up even after the point of maximum insolation on June 21. But once again a balance point is reached about 6 weeks later, at the time of peak summer temperatures. Thereafter the warm earth radiates energy more rapidly than it is receiving it, and temperatures begin to fall.

Daily Temperature Changes. There is a daily cycle of temperature change,

Figure 9-9. Typical variation in surface temperature and insolation in the course of one day.



just as there is a seasonal cycle. The earth gives off energy both day and night. But the temperature rises during the day because the earth is receiving more energy than it is giving off. The temperature falls at night because the earth is giving off energy, but is receiving almost none.

The coolest part of the day is usually just around sunrise (see Figure 9-9). This is so because the earth has been losing energy all night. Once the sun comes up, the earth begins to gain energy, and the temperature begins to rise.

The hottest part of the day is not generally at noon, when the intensity of insolation is greatest. Instead, it is in the midafternoon. The reason for this seeming delay in daily temperature change is the same as for the delay in seasonal temperature change. Although the intensity of insolation is greatest at noon, the earth is still receiving more energy than it is losing until some time in midafternoon. The point at which equilibrium is reached between incoming and outgoing radiation marks the hottest part of the day. After that brief and temporary balance, the earth begins to lose energy, and the temperature drops.

This discussion has described only a general tendency or average pattern of temperature changes over a period of time. It does not take into account the effects of weather—winds, clouds, movement of air masses, and precipitation. Because of changes in these conditions, the temperature changes during any particular day can be quite different from the pattern we have just outlined. The effects and causes of weather will be taken up in Chapters 10 and 11.

SUMMARY

1. The temperature at a given location varies directly with the intensity and duration of insolation.
2. Maximum insolation in the Northern Hemisphere occurs about June 21, the summer solstice. Maximum insolation in the Southern Hemisphere occurs about December 21, the winter solstice.
3. Maximum surface temperatures in the Northern Hemisphere occur some time after the summer solstice. Minimum temperatures occur some time after the winter solstice.
4. The highest temperature of the day occurs some time after noon, even though intensity of insolation is greatest at noon.

EFFECTS OF THE ATMOSPHERE ON INSOLATION

Before radiation from the sun can strike the surface of the earth, it must pass through the blanket of gases that surrounds the earth—the atmosphere. What happens as this energy begins to pass through the various layers of air above the surface? Remember that solar radiation is made up of radiant energy of many different wavelengths. The various wavelengths are affected differently as they pass through the atmosphere.

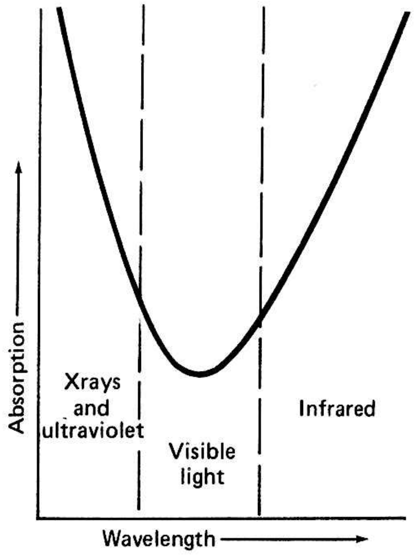


Figure 9-10. Absorption of radiation by the atmosphere.

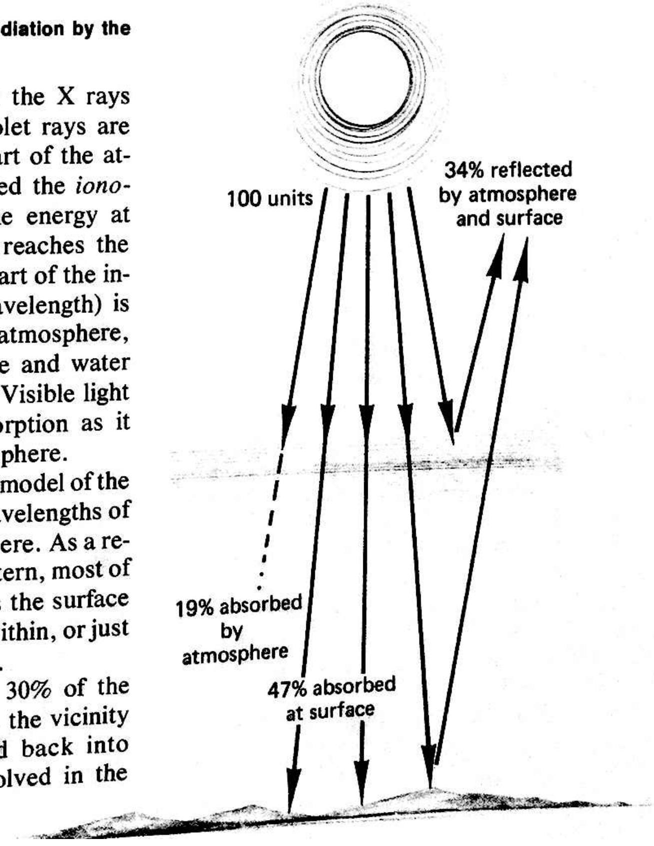
Absorption. Almost all the X rays and much of the ultraviolet rays are absorbed in the upper part of the atmosphere in a layer called the *ionosphere*. Very little of the energy at these short wavelengths reaches the earth's surface. A large part of the infrared radiation (long wavelength) is also absorbed by the atmosphere, mainly by carbon dioxide and water vapor at lower altitudes. Visible light is affected least by absorption as it passes through the atmosphere.

Figure 9-10 is a graphic model of the absorption of different wavelengths of insolation by the atmosphere. As a result of this absorption pattern, most of the radiation that reaches the surface consists of wavelengths within, or just outside, the visible range.

Reflection. More than 30% of the sun's energy that reaches the vicinity of the earth is reflected back into space without being involved in the earth's warming process. Most of this reflected energy (25% of the total insolation) is reflected by clouds. One of the most impressive sights from space is the bright light reflected off the clouds covering the earth.

Just as the angle of insolation is important in determining the intensity of insolation, it is also a basic factor in determining how much energy is reflected by a surface. The lower the angle of insolation, the more energy reflected. This is another reason why temperatures are generally lower in the higher latitudes—the angle of insolation is low, and more sunlight is

Figure 9-11. Effects of the atmosphere on insolation.



reflected than at lower latitudes. Since less energy reaches the earth's surface, it is not heated as much.

Scattering. In addition to the light reflected off clouds, some light is reflected by gas molecules and by *aerosols*—tiny particles of solid or liquid material in the atmosphere. When insolation strikes these molecules and aerosol particles, some of it is *scattered*—that is, reflected in all directions at random. Some of the scattered rays are turned back toward space, and some are reflected toward the surface of the earth. Figure 9-11 shows what happens to incoming solar radiation as it passes through the atmosphere and strikes the earth's surface.

As the concentration of aerosols in the atmosphere increases, the amount of insolation reaching the earth's surface decreases, and the average temperature in a given location drops. In areas where there is extensive volcanic activity and tons of material are spewed into the air, the amount of insolation reaching the surface is often greatly reduced, resulting in noticeably cooler weather.

SUMMARY

1. Most visible light passes through the atmosphere unchanged, but ultraviolet and infrared radiation are mostly absorbed by the atmosphere.
2. About 25% of insolation is reflected back into space by clouds.
3. The amount of insolation reflected depends on the angle of insolation.
4. Gas molecules and aerosols in the atmosphere cause scattering, or random reflection, of some insolation.
5. The amount of insolation reaching the earth's surface decreases as the amount of random reflection or scattering increases.

INSOLATION AND THE EARTH'S SURFACE

About 50% of the insolation that enters the top of the atmosphere actually reaches the surface of the earth. The rest has been either absorbed, reflected, or scattered by the atmosphere. Of the insolation striking the earth's surface, about 6% is reflected back into space. (Ice and snow reflect almost all the radiation that strikes them.) The rest is absorbed by the earth's surface. (These figures for absorption and reflection are for the earth as a whole, not for any one location.)

Because land surfaces are rougher, darker, and of lower specific heat than water, the surface temperature of land areas tends to rise more rapidly than the surface temperature of water. Also, water is nearly transparent, so insolation tends to pass through it to a greater depth. This, along with convection processes, tends to distribute the heat energy through a much larger volume of water than through land. The overall result is that land surfaces heat up more rapidly than water, even though the same amount of insolation strikes them both.

Reradiation of Insolation. The insolation that passes unchanged through the atmosphere is mostly in the visible wavelengths. Most of this insolation is absorbed by the earth's surface and thus tends to raise the surface temperature. The earth is constantly radiating electromagnetic energy. The temperature of the earth's surface is such that most of this energy is in the infrared range. This infrared radiation is absorbed by carbon dioxide and water vapor in the atmosphere, and tends to raise the temperature of the atmosphere. Thus, while the atmosphere is not warmed directly by the visible light passing through it, it is warmed indirectly by the reradiation from the earth's surface of energy at infrared wavelengths.

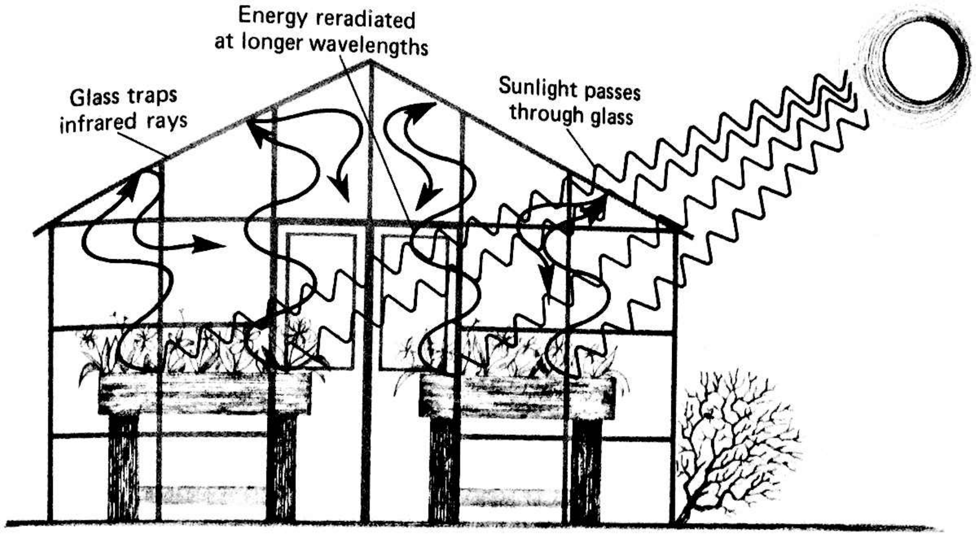


Figure 9-12. The greenhouse effect. Visible light, which is of short wavelengths, passes through the glass of the greenhouse and is absorbed by inner surfaces. This energy is reradiated as infrared radiation, which cannot pass through the glass walls. The energy remains inside the greenhouse and so raises its temperature.

The Greenhouse Effect. Have you ever been in a greenhouse in the winter? If you have, you probably found that it was comfortably warm even though it wasn't heated. Do you know why? The answer is the *greenhouse effect,* which we discussed in the section above, although we didn't give it a name.

Visible light can pass through glass, just as it passes through the atmosphere. Inside the greenhouse, the energy of the light is absorbed by the surfaces of the plants, soil, and other objects, and raises their temperature. This energy is then reradiated at infrared wavelengths. Very little of this infrared radiation passes outward through the glass. Most of its energy is transferred to the air inside the greenhouse by conduction, convection, and absorption. The glass effectively prevents the loss of heat, and the interior of the greenhouse becomes quite warm (see Figure 9-12).

You have probably observed the same effect when entering a car that was closed up and sitting in the sun. The interior of the car is much warmer than the outside air, because radiant energy that passes through the glass windows is trapped inside as heat that cannot escape.

In the section above we described the warming of the atmosphere by infrared radiation given off by the earth's surface. This is also called the greenhouse effect. But in this case, no glass walls are needed. The atmosphere itself absorbs the infrared energy being reradiated by the earth.

Other Methods of Energy Transfer. We have discussed some of the ways that energy is transferred between the earth's surface and the atmosphere, but there are two that we have not discussed.

The first involves latent heat and the evaporation and condensation of water. As water evaporates to form water vapor, it absorbs heat, which is stored as latent heat. So the evaporation of water from the surface of the earth removes heat energy from the earth, thus cooling it. When the water vapor in the atmosphere condenses, forming rain or snow, the latent heat is released, and this heat warms the atmosphere. Thus the evaporation of water removes heat from the surface of the earth, and the condensation of water vapor releases heat to the atmosphere. The net effect is a transfer of heat from the earth to the atmosphere.

The second method involves the direct transfer of heat by conduction between the earth's surface and the atmosphere. Where the land or water is warmer than the air, there is a transfer of heat from the surface to the air that is in contact with it. Circulatory motions of the atmosphere mix this heated air with the cooler air in upper layers. When the air is warmer than the surface of the earth, the flow of heat is in the opposite direction—from the air to the surface.

Radiative Balance. We have mentioned several times that the earth constantly gives off radiation. How does this loss of energy affect the earth? It is a cooling process—heat is being lost from the surface of the earth. But the earth's surface also gains energy during the hours of insolation, and it is warmed by this energy. In the course of a day the earth's surface cools off at night and warms up during daylight. During the cooling-off period the surface is losing more energy than it is gaining. During the warming-up period, it is gaining more energy than it is losing. In the course of a year the same type of cycle occurs. During the winter the earth is losing heat faster than it is gaining heat. During the summer, it is the other way around.

There may be periods during the daily cycle and during the seasonal cycle when the earth's temperature remains constant for a time. This means that the amount of heat being lost by radiation is equal to the amount being gained from insolation. This is called a condition of *radiative balance*.

As we have seen, any particular part of the earth's surface is usually not in radiative balance. Its temperature is usually rising or falling from hour to hour, from day to day, or from season to season. But can we say anything about the radiative balance of the earth as a whole? Does its overall average temperature change from one year to the next? Over periods of decades or centuries? Over longer periods of thousands or hundreds of thousands of years?

Worldwide temperature data seem to indicate that the earth's average temperature does change from year to year. In other words, the earth as a whole is not in radiative balance on a yearly basis. However, the year-to-year fluctuations seem to even out over periods of about a decade (10 years), so we can say the earth is in radiative balance over periods of that length.

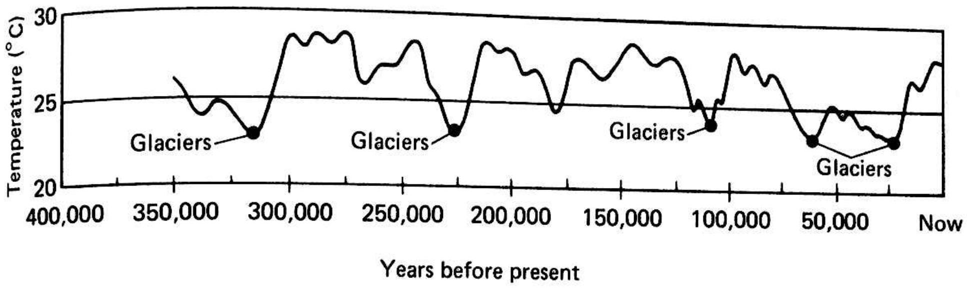


Figure 9-13. Estimated average temperatures of the earth for the past few hundred thousand years.

Geological records indicate that there have been many periods during the earth's history when the average temperature has dropped, resulting in "ice ages." During such intervals, glaciers spread down from the polar regions and covered large areas of land. The ice ages alternated with warmer periods, during which the glaciers retreated and the earth became warmer than average (see Figure 9-13).

These glacial and interglacial periods lasted for tens of thousands of years. So we can say that the earth is not in radiative balance over periods of that length. At the present time there is much debate among earth scientists as to whether we are in a long-term warming period or a cooling one. There is also disagreement over whether human activities are affecting the radiative balance of the earth, and if so, in which direction.

SUMMARY

1. Land surfaces heat up and cool off more quickly than water.
2. The greatest intensity of outgoing radiation from the surface of the earth is in the infrared range.
3. Visible light passes through the atmosphere unchanged. It is absorbed by the earth's surface and transformed into heat.
4. Infrared radiation from the earth's surface is absorbed by carbon dioxide and water vapor in the atmosphere and converted to heat, which warms the atmosphere. This is called the greenhouse effect.
5. The earth is not in radiative balance on a yearly basis.
6. Over the course of decades the earth does appear to be in radiative balance.
7. Over very long periods of time the earth is not in radiative balance.

RADIOACTIVITY

When an oven is turned on, the interior of the oven becomes quite hot, and its outer surfaces become warm. Heat is radiated from the oven, but it remains hot inside as long as energy is being supplied by burning fuel or an electric current. If the source of energy is turned off, the oven remains hot for a while, but gradually it cools down to room temperature.

Volcanic eruptions show that the interior of the earth is very hot. Even though the earth was probably very hot when it formed about 5 billion years ago, by now it should have cooled off. There must be an internal source of energy that is keeping the interior much hotter than most ovens. We believe that radioactivity is the source of this energy.

Radioactive Decay. In 1896 the French physicist Antoine Henri Becquerel made a discovery of great importance. He had placed a piece of the mineral pitchblende in a desk drawer on top of some unexposed photographic plates. When the plates were developed, Becquerel discovered that they had been partly exposed. He concluded that some form of energy had been emitted by the mineral and had affected the chemicals on the photographic plate. Becquerel found that the mineral constantly emitted radiation that was much like X rays, which had been discovered the previous year by Wilhelm Roentgen. This phenomenon was later named *radioactivity* by Marie Curie.

Pitchblende contains the element uranium. The radiation detected by Becquerel was caused by the uranium atoms, which emit energy as they break down, or decay, to form the more stable element lead. Radioactivity, or radioactive decay, is the natural and spontaneous breakdown of certain unstable elements to form more stable atoms of other elements. Energy is released by radioactive decay. This energy is given off at a rate that is constant for each particular radioactive element. The rate of energy release is not affected by temperature, pressure, or other environmental conditions.

We know that radioactive decay is going on in some of the rocks near the earth's surface. We therefore assume that it is also occurring deep within the crust and providing some of the energy for earth processes, such as mountain building and crustal movements.

SUMMARY

1. Radioactive decay is a process by which the breakdown of atoms releases energy.
2. The decay of radioactive matter is a source of energy for processes within the earth's crust.

REVIEW QUESTIONS

Group A

1. What is *insolation?*
2. What is meant by the *intensity of radiation?*
3. What factor does intensity of radiation depend on? Describe the relationship between temperature, intensity of radiation, and wavelength?
4. What is meant by *intensity of insolation?*
5. How is the intensity of insolation affected by the angle at which the sun's rays strike the earth's surface?
6. At what angle is intensity of insolation greatest?
7. What three factors affect the angle of insolation?
8. What is meant by *duration of insolation?*
9. What factors determine the duration of insolation?
10. What two factors affect temperature at a given location?
11. On what date does maximum insolation occur in the Northern Hemisphere? In the Southern Hemisphere?
12. At what time of year does maximum surface temperature occur in the Northern Hemisphere? Is this before, during, or after the period of maximum insolation?
13. At what time of day is the intensity of insolation greatest? When is the hottest part of the day?
14. Which type of radiation passes through the atmosphere for the most part unchanged?
15. What types of radiation are almost completely absorbed by the atmosphere?
16. What percentage of insolation is reflected back into space by clouds?
17. What determines the amount of insolation reflected?
18. How do gas molecules and aerosols in the atmosphere affect insolation?
19. How does random reflection affect the amount of insolation reaching the earth's surface?
20. Which heats up and cools off more quickly—water or land surfaces?
21. In what part of the electromagnetic spectrum is most of the outgoing radiation from the earth's surface?
22. What happens to visible light that strikes the earth's surface?
23. Explain the *greenhouse effect.*
24. Is the earth in radiative balance? Explain your answer.
25. What is *radioactive decay?*
26. Of what importance is radioactive decay in processes in the earth's crust?

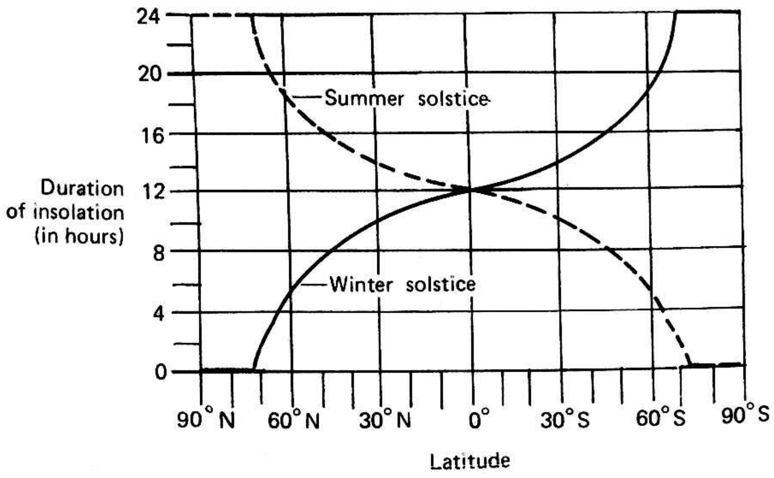
Group B

1. a. What factors affect the amount of solar energy falling each second on a one-square-meter area in the middle of your football field?
   b. Describe the effect that changes in season have upon the duration of insolation.
   c. Describe the effect that changes in latitude have upon the duration of insolation.

2. a. Explain why the highest temperature usually occurs later in the day than the time of maximum intensity of insolation.
   b. List and describe at least 3 effects that the atmosphere may have upon incoming solar radiation.
   c. Define the term radiative balance.
   d. Explain how it is possible for the earth to be in radiative balance over the course of decades, but not be in radiative balance on a yearly basis.
3. Name and describe the type of energy that earth scientists believe is responsible for heating the earth's interior.

REVIEW EXERCISES

1. The graph below shows how the duration of insolation varies with latitude at the time of the summer solstice (dashed line) and at the time of the winter solstice (solid line).

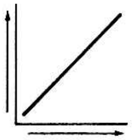
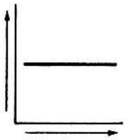
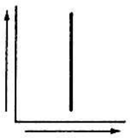
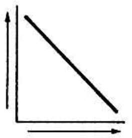


a. Describe the change in duration of insolation as one travels from the equator to each of the poles at the winter solstice.
b. From the graph, determine as accurately as possible the range in duration of insolation for 40° north latitude. Do the same for the latitude of your school.
c. What changes would there be in the graph if the inclination of the earth's axis were less than 23½° or more than 23½°?

2. The table below shows the average number of hours of daylight for the 15th of each month at a location in central New York State. This location is more than 100 km from the ocean. The table also shows the average monthly temperature for this location. Using this data, construct a graph plotting both hours of insolation and average monthly temperature on the vertical axis, using separate lines for each variable. The months of the year are shown on the horizontal axis. Base your answers to the following questions on the graph that you draw and on your knowledge of earth science.

	Hours of insolation	Temp. (°C)		Hours of insolation	Temp. (°C)
Jan.	9.5	−4.0	July	14.8	21.4
Feb.	10.7	−4.4	Aug.	13.8	20.2
Mar.	11.9	.8	Sept.	12.5	16.6
Apr.	13.2	7.4	Oct.	11.1	10.2
May	14.3	14.0	Nov.	10.0	3.6
June	15.0	18.9	Dec.	9.3	−2.0

a. Which of the following graphs represents the relationship between duration of insolation and surface temperature?

b. Explain why, although the duration of insolation was greatest in June, the average monthly temperature was greatest in July.
c. The location from which the insolation and temperature data was collected is inland. In what ways would the appearance of your graph be different if the data had been gathered from a location at the same latitude, but on an island in the middle of the Atlantic Ocean?

3. The following experiment was set up to show how the angle of
inclination affects surface temperature. Three thermometers were
placed at equal distances from a light source (see below). Light
from the source fell on the thermometers at angles of 30°, 60°, and
90°. Temperature readings from each thermometer were taken at
1-minute intervals for a period of 10 minutes. The results are shown
in the table below. Graph the data temperature for all three ther-
mometers on the same set of axes. Base your answers to the follow-
ing questions on the graph you draw and on your knowledge of
earth science.

a. As the angle at which the light strikes the thermometer in-
creases, the temperature ______ (increases, remains the same,
decreases). Make a simple graph showing the relationship be-
tween temperature and angle of insolation.

b. As latitude increases, the angle of insolation ______ (increases,
remains the same, decreases). Make a simple graph showing the
relationship between angle of insolation and latitude.

c. The angle of isolation is 0° at sunrise. From sunrise on, it in-
creases until noon, when it reaches its highest point; it then
decreases to 0° at sunset. Draw a simple graph showing the
relationship between angle of isolation and time of day (sunrise
to sunset).

		Time (in minutes)										
		0	1	2	3	4	5	6	7	8	9	10
Angle of inclination	30°	20.0	20.0	20.5	21.0	21.0	21.5	22.0	22.0	23.0	23.5	23.5
	60°	20.0	20.0	21.0	22.0	22.5	23.0	24.0	24.5	25.0	25.0	25.5
	90°	20.0	21.0	21.5	22.5	23.0	23.5	24.5	25.0	26.0	27.0	27.5