Lecture 2

Solar Radiation and the Seasons

1.1 Energy

Energy is the ability to do work. It is an agent capable of setting an object in motion, warming a teapot, etc. The standard unit of energy in scientific applications is the joule (J).

1 Joule = 0.239 calories (calorie is also familiar to students)

Power: is the rate at which energy is released, tansferred or received and is measured in watt (W) which corresponds to 1 joule per second.

Even the simplest aactivity requires a transfer of energy from type to another type. In fact, while you read these words, an energy transfer is ocurring as the chemecal energy from food you are eating is converted into the kinetic energy (energy of motion) needed to move your eyes across line of type.

The same concept applies to our atmosphere. About one two billionth of the energy emitted by the Sun is transferred to Earth as electromagnetic radiation, some of which is directly absorbed by the atmosphere and surface. This radiation provides the energy for the movement of the atmosphere, the growth of plants, the eevaporation of water, and infinite variety of other activities.

1.2 Kinds of Energy

Energy can occur in a variety of forms such as radiant, electrical, nuclear, and chemical energy; but strictly speaking, all forms of energy fall into the general categories of kinetic energy and potential energy (See Table 2.1).

Table 2.1 Examples of kinetic and potential energy

Kinetic energy	Potential energy
Light and other forms of radiation	Battery
Motion of the water in a river	High pressure in fire extinguisher
Heat under food pot	Gasoline
Electrical power	Food

While kinetic energy can be viewed as energy in use and is often described as the energy of motion, potential energy is energy that has not yet been used. Another form of potential energy results from an object's position. Consider, for example, a cloud droplet that occupies some position above Earth's surface. The droplet is subject to the effect of gravity and the potential energy is converted to kinetic energy (P. E. = m g h). It is important to recognize that the droplet did not attain its height by magic, because energy was used to elevate its mass in the first place.

1.3 Energy Transfer Mechanisms

There are three processes of energy transfer:

A. **Conduction**: The transfer of heat from molecule to molecule within a substance is called conduction. Hold one end of a metal straight pin between your fingers and place a flaming candle under the other end. Because of the energy they absorb from the flame, the molecules in the end vibrate faster. The faster-vibrating molecules cause adjoining molecules to vibrate faster. These, in turn, pass vibrational energy on to their neighboring molecules, and so on, until the molecules at the finger-held end of the pin begin to vibrate rapidly. These fast-moving molecules eventually cause the molecules of your finger to vibrate more quickly. Heat is now being transferred from the far end to your finger. Heat transferred in this fashion always flows from warmer to colder regions. Materials are considered to be good conductors of heat. Air is an extremely poor conductor of heat, which is why most insulating materials have a large number of air spaces trapped within them. Air is such a poor heat conductor that, in calm weather, the hot ground only warms a shallow layer of air a few centimeters thick by conduction.

B. **Convection**: The transfer of heat by the mass movement of a fluid (such as water and air) is called convection. Convection happens naturally in the atmosphere. On a warm, sunny day certain areas of the Earth's surface absorb more heat from the Sun than others; as a result, the air near the Earth's surface is heated somewhat unevenly. Air molecules adjacent to these hot surfaces bounce against them, thereby gaining some extra energy by conduction. The heated air expands and becomes less dense than the surrounding cooler air. The expanded warm air is buoyed upward and rises. In this manner, large bubbles of warm air rise and transfer heat energy upward. Cooler, heavier air flows toward the surface to replace the rising air. This cooler air becomes heated in turn, rises, and the cycle is repeated. In meteorology, this vertical exchange of heat is called convection, and the rising air bubbles are known as thermals. The horizontally moving part of the circulation (called wind) carries properties of the air in that particular area with it. The transfer of these properties by horizontally moving air is called *advection*.

C. **Radiation**: The energy transferred from the Sun to the Earth is called radiant energy or radiation. It travels in the form of waves that release energy when they are absorbed by an object. Because these waves have magnetic and electrical properties, we call them electromagnetic waves. Electromagnetic waves do not need molecules to propagate them. In a vacuum, they travel at a constant speed of nearly 300,000 km per second. Notice that the wavelength (λ) is the distance measured along a wave from one crest to another. The average wavelength of visible light is about 0.5 μm (See Fig. 2.1 and Fig. 2.2). We can also see that the longer waves carry less energy than do the shorter waves. We can actually think of radiation as streams of particles, or photons that are discrete packets of energy. An ultraviolet (UV) photon carries more energy than a photon of visible light. In fact, certain ultraviolet photons have enough energy to produce sunburns and penetrate skin tissue, sometimes causing skin cancer.

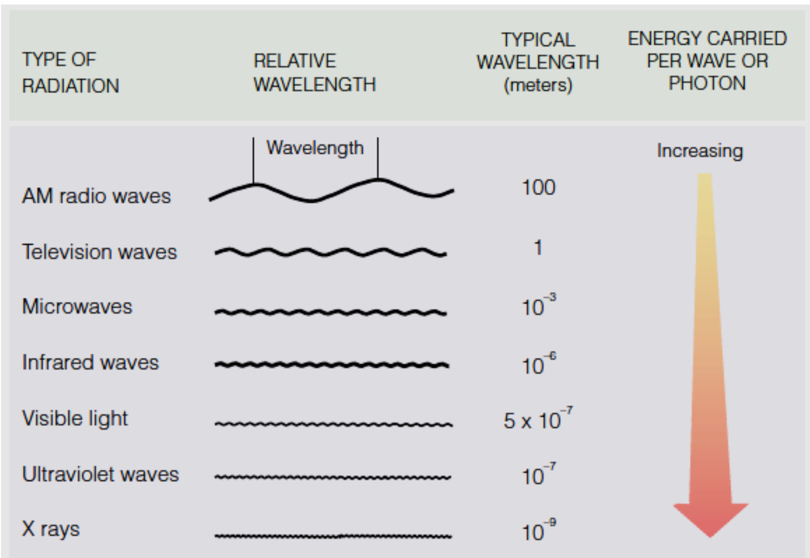

Fig. 2.1 As the wavelength decreases, the energy carried per wave increases

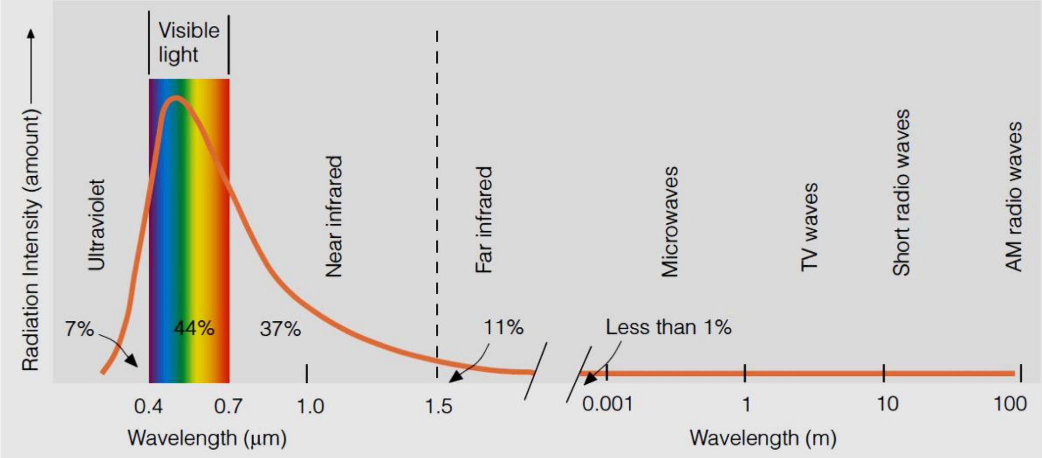

Fig. 2.2 The Sun's electromagnetic spectrum

To better understand the concept of radiation, here are a few important concepts and facts to remember:

1. All things (whose temperature is above absolute zero), no matter how big or small, emit radiation. The air, trees, the Earth, the stars are all radiating a wide range of electromagnetic waves.

2. 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 wavelengths of emitted radiation. This relationship between temperature and wavelength is called Wien's law ($\lambda_{max} = \frac{2898}{T}$).

3. Objects that have a high temperature emit radiation at a greater rate or intensity than objects with a lower temperature. Thus, as the temperature of an object increases, more total radiation (over a given surface area) is emitted each second. This relationship between temperature and emitted radiation is known as the Stefan-Boltzmann law ($E = \sigma T^4$); $\sigma = 5.67 \times 10^{-8}\ W\ s^{-1} K^{-4}$. We are able to see the page, however, because light waves from other sources are being reflected (bounced) off the paper. If this book were carried into a completely dark room, it would continue to radiate, but the pages would appear black because there are no visible light waves in the room to reflect off the page. The Sun emits radiation at almost all wavelengths, but because its surface is hot (6000 K), it radiates the majority of its energy at relatively short wavelengths (the maximum amount of radiation is at wavelengths near 0.5 µm) If we look at the amount of radiation given

off by the Sun at each wavelength, we obtain the Sun's electromagnetic spectrum. Since our eyes are sensitive to radiation between 0.4 and 0.7 µm, these waves reach the eye and stimulate the sensation of color (visible region). Whereas the hot sun emits only a part of its energy in the infrared portion of the spectrum, the relatively cool Earth emits almost all of its energy at infrared wavelengths. In fact, the Earth, with an average surface temperature near 288 K (15°C), radiates nearly all its energy between 5 and 25 µm, with a peak intensity in the infrared region near 10 µm (see Fig. 2.3). Since the Sun radiates the majority of its energy at much shorter wavelengths than does the Earth, solar radiation is often called shortwave radiation, whereas the Earth's radiation is referred to as longwave (or terrestrial) radiation.

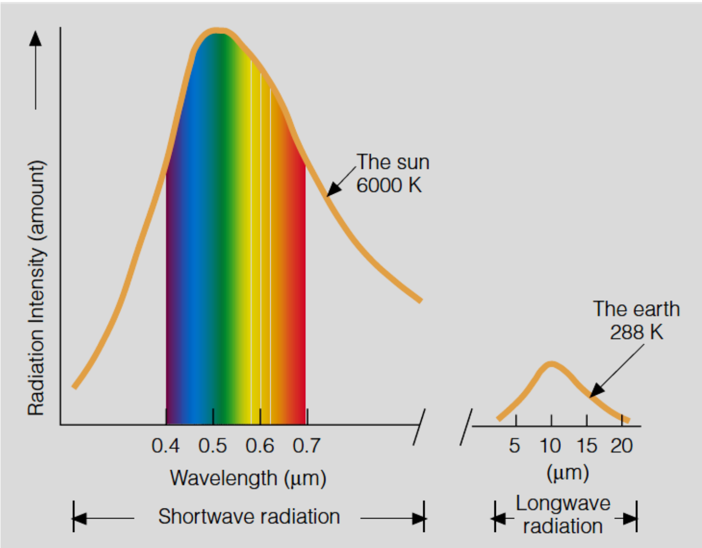

Fig. 2.3 The hotter Sun not only radiates more energy than that of the cooler Earth (the area under the curve), but it also radiates the majority of its energy at much shorter wavelengths.

1.4 The Solar Constant

The electromagnetic energy moving through space is not depleted as it moves from the Sun toward Earth. Radiation travelling through space carrying the same amount of energy and has the same wavelength as when it left the solar surface. However, at greater distances from the Sun, it is distributed over a greater area, which reduces its intensity. Hence, the Earth which is located at distance of 1.5×10^{11} m from the Sun receives an amount of solar energy (out of the atmosphere) equal to 1367 W/m^2 which is called the solar constant. This is just a small part of the total solar emission (3.865×10^{26} W):

$$\frac{3.865\times10^{26}W}{4\pi(1.5\times10^{11}m)^2} = 1367\frac{W}{m^2} \qquad (inverse\ square\ law)$$

1.5 The Causes of Earth's Seasons

The low latitudes such as tropics and subtropics receive more solar radiation per year at the top of the atmosphere than do regions at higher latitudes such as the Arctic and Antarctic. The rotation of Earth around the Sun makes the seasons as we will see in the next sections.

1.5.1 Earth's Revolution and Rotation

As we know, Earth orbits the Sun once every 365 1/4 days as if it were riding along a flat plane. We refer to this imaginary surface as the **ecliptic plane** and to Earth's annual trip about the plane as its **revolution**.

The orbit is an elliptical path, so that the distance between Earth and the Sun varies of the course of the year. Earth is nearest the Sun on January 3 and the Earth is farthest on July 3 (see Fig. 2.4).

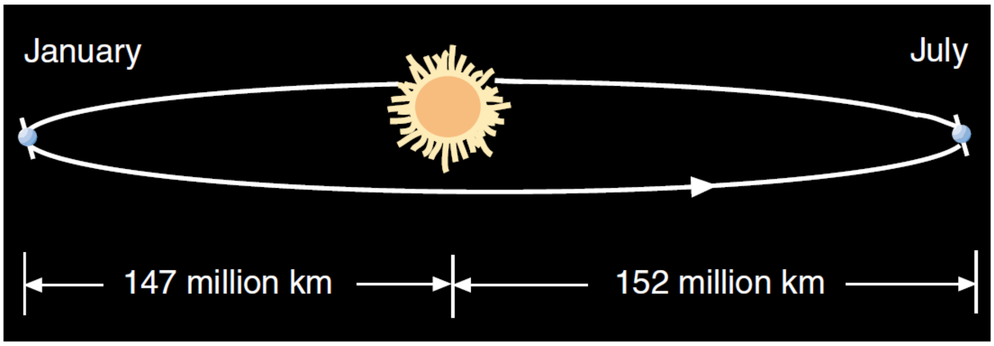

Fig.2.4 The elliptical path of the earth about the sun brings the Earth slightly closer to the Sun in January than in July.

In addition to its revolution, Earth also undergoes a spinning motion called **rotation**. Rotation occurs every 24 hours (23 hours and 56 min, to be exact) around an imaginary line, called *Earth's axis*. The axis is not perpendicular to the plane of the orbit of the Earth around the Sun but it is tilted 23.5^{o} from it, as shown in Fig. 2.5.

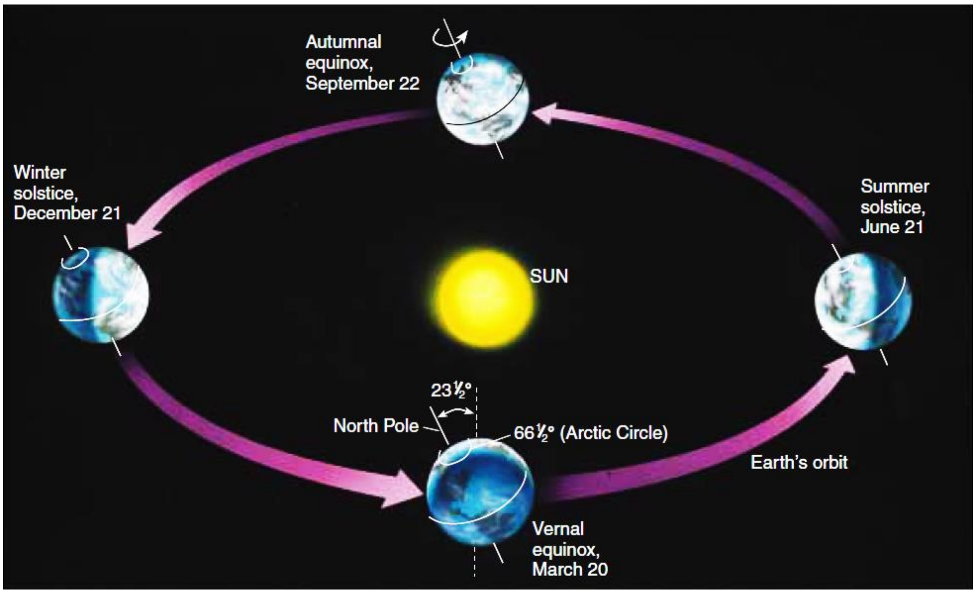

Fig.2.5 As the earth revolves about the Sun; it is tilted on its axis by an angle of 23 1/2°. The Earth's axis always points to the same area in space (as viewed from a distant star).

Moreover, no matter what time of the year it is, the axis is always tilted in the same direction and always points to a distant star called Polaris (The North Star). The constant direction of the tilt means that for half the year the Northern Hemisphere is oriented somewhat to the Sun, and for half the year it is directed away from the Sun. The changing orientation of the hemispheres with regard to the Sun is the true cause of the seasons-not the varying distance between Earth and the Sun.

During 6 months of the year, the Northern Hemisphere receives more sunlight than does the Sothern Hemisphere; during the other 6 months, the Sothern Hemisphere receives a greater amount of insulation. Subsolar point is the point on Earth where the Sun's rays meet the surface at a right angle and where the Sun appears overhead. The most northward latitude at which the subpolar point is located is 23.5^{o} N and is called the **Tropic of Cancer**. Likewise in on the December solstice, the Sun is directly overhead at 23.5^{o} S, the **Tropic of Capricorn** (See Fig. 1.6).

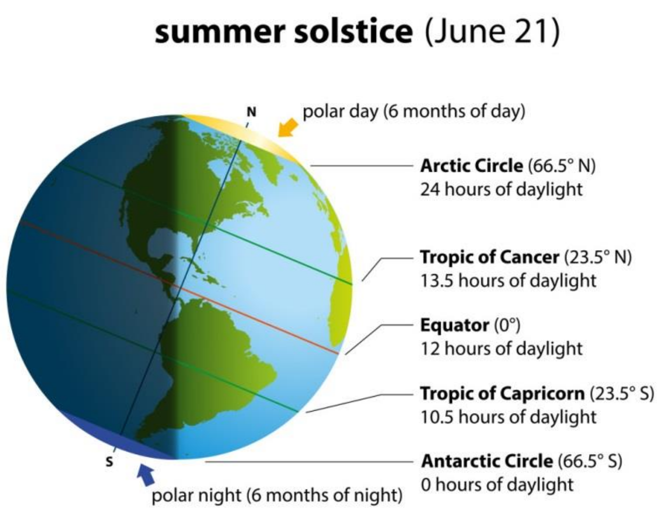

Fig. 1.6 Summer solstice

Homework:

1. Give several examples of kinetic and potential energy as they exist on Earth.
2. Conduction and convection are alike in that both transfer heat within a substance. What is the critical difference between them?
3. Describe how the wavelengths and total energy emitted change as the temperature of an object increases.
4. The solar constant is about 1367 W/m^2 of the Earth. Find the solar constant of Mars (2.25×10^{11} m from the Sun).
5. What is the most important factor responsible for seasons on Earth?
6. Do you think that the atmosphere would deplete the solar energy reaching the surface?
7. Why the radiation wavelengths of the Sun and the Earth are quite different?
8. Calculate the maximum wavelength and the emitted radiation at 40^{o} C.