Chapter 16

Heat Transfer

Mechanisms of Heat Transfer

- Conduction:

  This is the primary heat transfer mechanism in a solid. Thermal energy is transferred by molecular and electron collision within the material.

- Convection:

  This is the primary heat transfer mechanism in fluids (liquids and gases). Thermal energy is transferred by the motion of a fluid molecular and electron collision within the material.

- Radiation:

  Thermal energy is transmits through empty space by means of electromagnetic waves.

Examples of Heat Transfer

- Conduction:

  A long metal rod with one end placed in boiling water will eventually get too hot on the other end to touch.

- Convection:

  A warm air parcel near the Earth's surface expands becomes less dense and rises only to be replaced by cooler denser air. Circulation of the air (winds) occur.

- Radiation:

  The warmth that the Earth receives from the Sun.

Radiation

All atoms and molecules vibrate as a result of their temperature. At higher temperatures the atoms and molecules with higher vibrational frequency due to their higher average kinetic energy per molecule.

The peak frequency of vibration is directly proportional to the temperature of the substance. The vibrating charged particles produce these electromagnetic waves.

Electromagnetic waves include:

Radio waves, Microwaves, Infrared radiation, Visible light, Ultraviolet radiation, X-rays, and Gamma rays.

Substances at "room temperature" vibrate in the infrared. A hot glowing ember from a campfire is radiation in the visible range. The surface of a neutron star is so hot that its peak radiation is emitted in the x-ray part of the spectrum.

Newton’s Law of Cooling

Hot object placed in cooler surroundings will eventually cool to the temperature of the surroundings. Sinilarly, a cold object placed in warm surroundings will eventually warm to the temperature of the surrounding.

However, the *rate of cooling* (or warming) directly proportional the difference in temperature between the object and its surroundings. That is,

$$\text{Rate of cooling (or warming)} \propto \Delta T$$

Rate of Cooling Example

An object is removed from boiling water (T_i = 100 ^{o}C) and placed in a room having temperature of 20 ^{o}C. Suppose that the object cools 1.0 C^o (from 100 ^{o}C to 99 ^{o}C) in 10 s.

Note that the ΔT between the object and room is 80 ^{o}C and the rate of cooling = 0.1 C ^{o}/s.

Questions: What is the rate at which the object cool when its temperature is 60 ^{o}C. How long will it take the object to cool by 1 C ^{o} (from 60 C ^{o} to 59 C ^{o})?

Answers: When T_{object} = 60 ^{o}C, the ΔT between the object and the room is 40 C ^{o}. This is half the ΔT at the beginning, so the rate of cooling will be half. Rate = 0.5 C ^{o}/s. Now, half the rate means twice the time. Therefore, the time to cool 1 C^o will be 2x(original rate) = 2x(0.1 C^o/s). So t = 20 s.

The Greenhouse Effect

Because the surface of the Sun is “hot” (surface temperature about 5500 ^{o}C), the frequency of most intense emitted electromagnetic waves are the “shorter” visible light waves.

A greenhouse is made of glass and is transparent to these waves. This allows the energy from the Sun pass through. The interior of the greenhouse is much cooler and emits lower frequency electromagnetic wave that are “longer” infrared waves. Glass is opaque to the infrared and prevents this energy from escaping back out. The trapped energy warms the interior of the greenhouse.

Certain gases in the Earth’s atmosphere acts much like a greenhouse. Greater amounts of these gases (such as carbon dioxide) allow solar radiation to pass through but trap the terrestrial radiation trying to escape, thus warming the Earth.

Unless serious effort is made to control the amount of these “greenhouse gases” being pumped in the atmosphere, the increased warming is likely to have a detrimental effect on Earth’s climate (melting of polar ice, stronger storms, droughts, etc.)

Solar Power

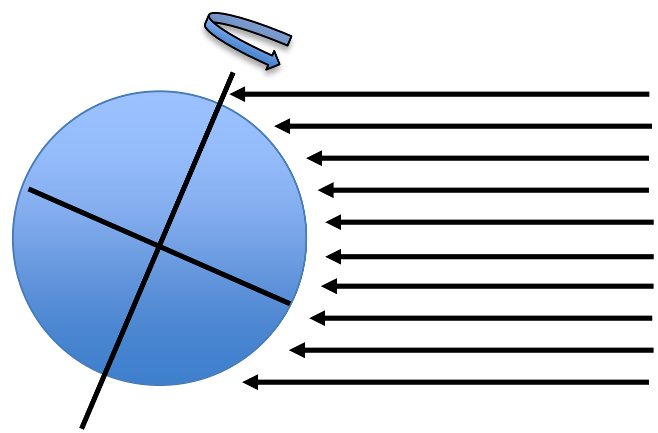
Why is it hotter in the summer?

It is NOT because the Earth is closer to the Sun!

(The Earth is closest to the Sun on January 2nd.)

The reason is that the axis of the Earth is tilted relative to its orbital plane around the Sun.

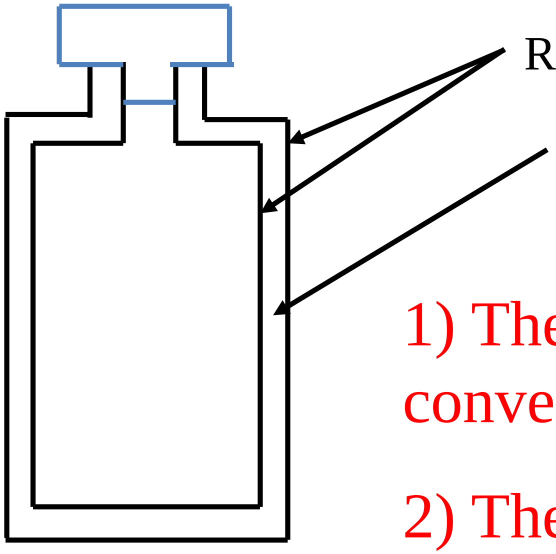
As a result, the hemisphere that receives the light perpendicular to the surface has greater energy concentrated on a given area.



In this figure, the Northern Hemisphere experiences summer while the Southern Hemisphere experience winter. Six months later, the Southern Hemisphere receives direct (perpendicular) sunlight and has its summer, while the Northern Hemisphere has its winter.

Controlling Heat Transfer

How does a Thermos™ bottle work?



Reflective coating on inner and outer surfaces.

Vacuum between inner and outer can.

1) The vacuum prevents conduction and convection between the walls of the container.

2) The lid prevents convection directly with the outside.

3) The reflective coating minimizes the heat transfer by radiation.