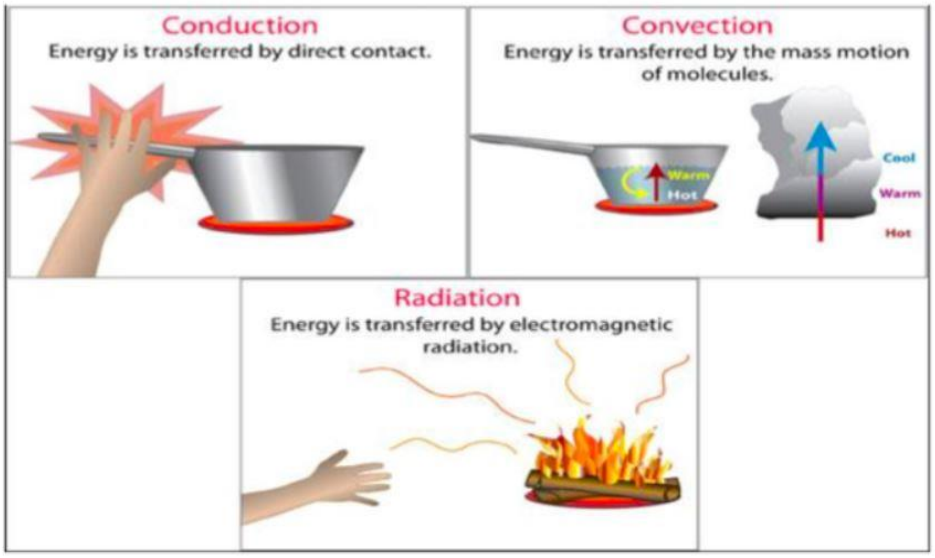
8.2 – Thermal energy transfer

Conduction, convection and thermal radiation

Conduction – energy is transferred by direct contact.
Convection – energy is transferred by the mass motion of molecules.
Radiation – energy is transferred by electromagnetic radiation.

Conduction and convection require a transmission medium, whereas radiation does not. Radiation can transfer through a vacuum (Eg. space).



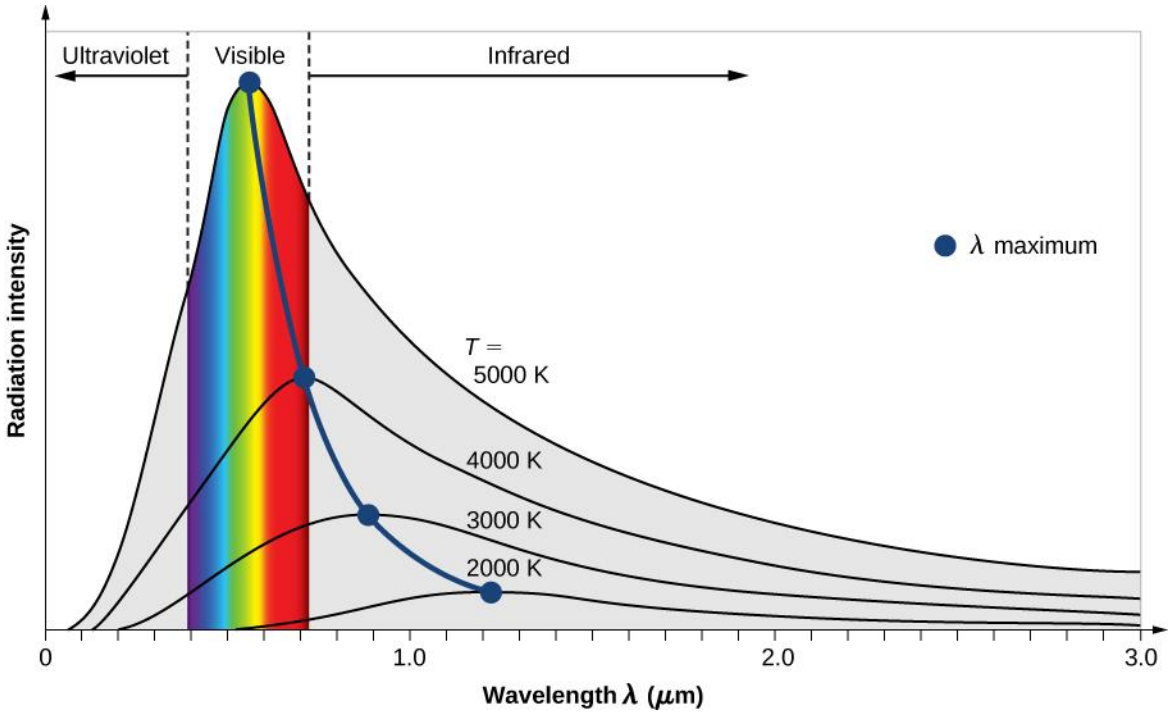
Black-body radiation

- A black body which absorbs all incident electromagnetic radiation is both a perfect absorber and a perfect emitter of radiation.
- The radiation emitted by such a body at constant temperature is called black-body radiation.
- The Stefan-Boltzmann law states that the power of radiation emitted by a black body per unit area is proportional to the fourth power of its temperature.

$$P = \sigma A e(T^4 - T_c^4)$$

P=radiated power; A radiating area; e=emissivity (=1 for ideal blackbody)
σ = Stefan's constant = 5.6703×10^{-8} W/m^{2}K^4
T = Temperature of radiator
T_c= Temperature of surroundings

Emission spectrum of a black body



Wien's Law

Objects of different temperature emit spectra that peak at different wavelengths. Hotter objects emit most of their radiation at shorter wavelengths; hence they will appear to be bluer. Cooler objects emit most of their radiation at longer wavelengths; hence they will appear to be redder.

$$\lambda_{peak} T = 2.898 \times 10^{-3}\ m \cdot K$$

λ_{peak} = wavelength (in m) at which maximum intensity radiation is emitted ;
T = temperature of the object (in Kelvin)

Albedo and emissivity

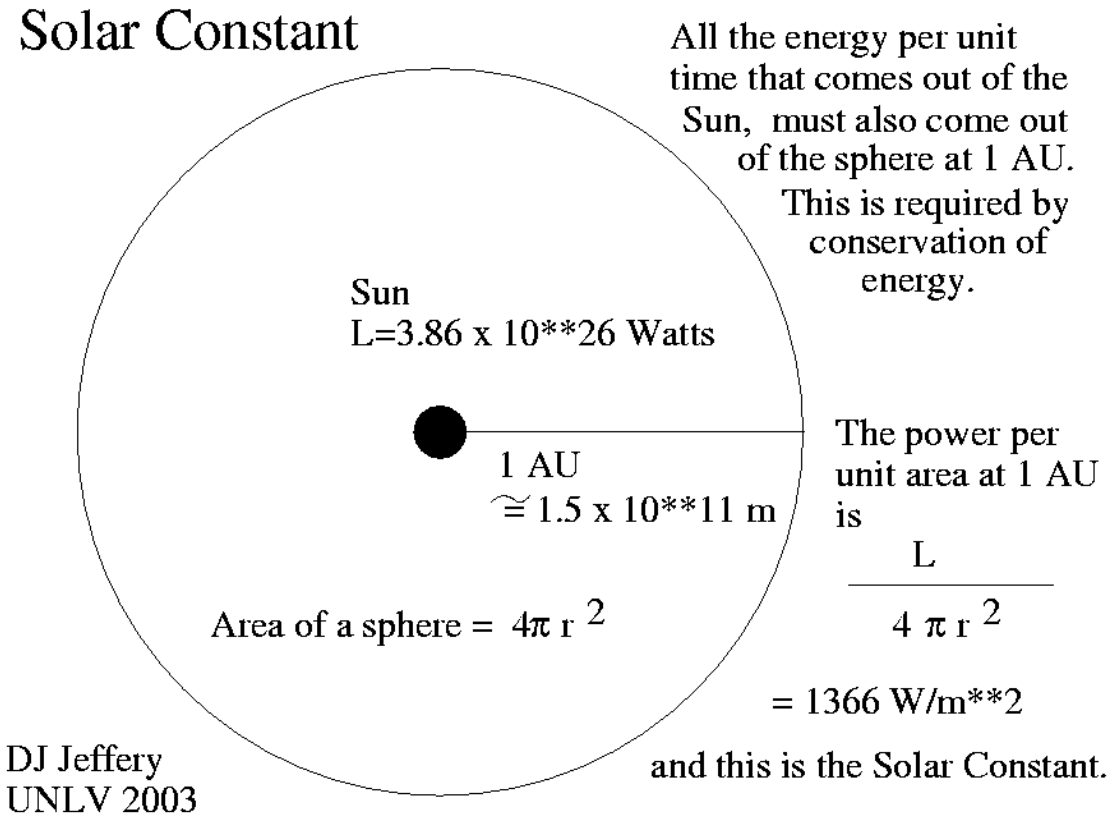
Albedo

- The Albedo (α) of a planet is defined as the ratio between the total scattered (reflected) radiation by the planet and the total incident radiation on that planet.
- Albedo = total scattered power / total incident power
- The albedo of a planet is affected by the following:
  - Season (cloud formations)
  - Latitude

- Terrain (ocean has low albedo because it mainly absorbs and snow has high albedo because it mainly reflects)
- The global annual mean albedo is about 0.3 (30%) on Earth.

Emissivity

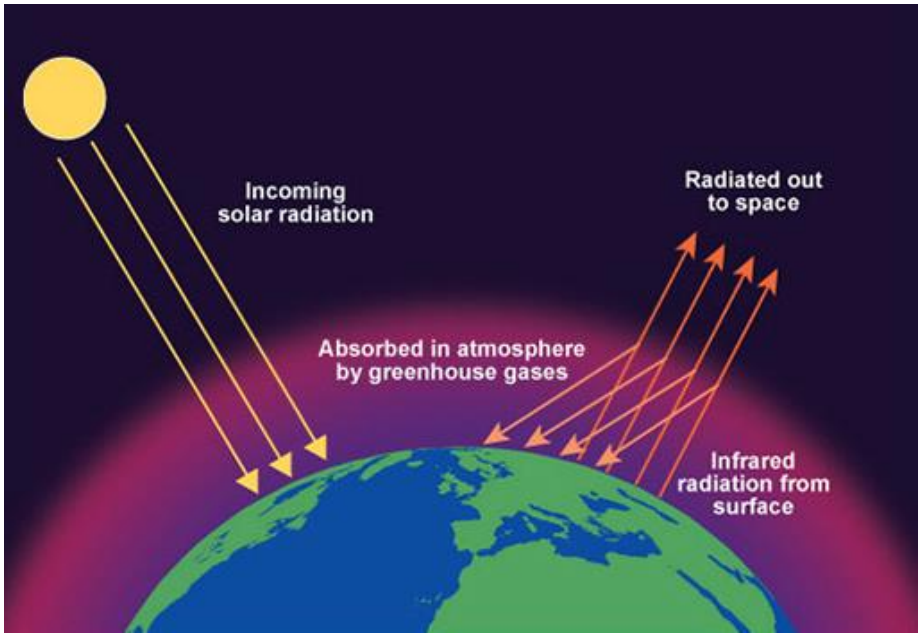
- Most objects are not black bodies. They radiate a fraction of the power per unit area compared to a black body at the same temperature. The value of this fraction depends on the object and is called the object's emissivity (e).
- Emissivity = power per unit area radiated by the object / power per unit area radiated by a black body at the same temperature.
- The equation for the power radiated by an object with emissivity e can be given by the diagram in the previous section (Black-body radiation).
- The solar constant
- The solar constant is the amount of energy that normally falls on a unit area (1m^2) of the Earth's atmosphere per second when the Earth is at its mean distance from the sun.
- The solar constant is approximately 1366 W/m^2.



The greenhouse effect

Greenhouse gases (CH_4, H_2O, CO_2 and N_2O) have both natural and man-made origins.

- Greenhouse gases absorb infrared radiation because their molecules have natural frequencies in the infrared region and readily absorb infrared radiation due to resonance.



Mechanism:

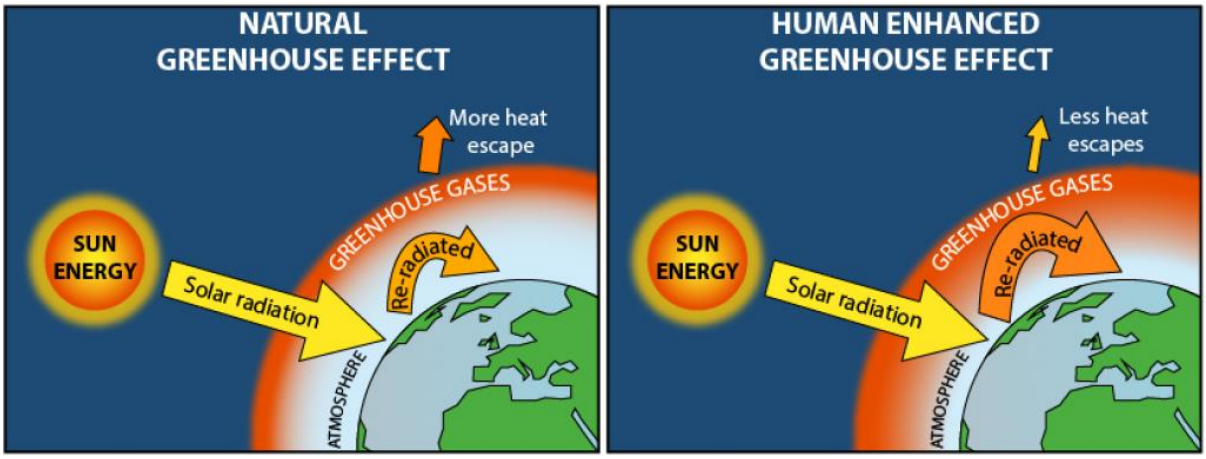
1. Incoming radiation from the sun takes the form of ultraviolet and visible radiation.
2. Some of this radiation is absorbed by the Earth's atmosphere and some of the radiation is reflected back into space by the Earth's surface (ground).
3. The radiation which is reflected back into space takes form of infrared radiation.
4. The greenhouse gases present in the atmosphere absorb infrared radiation and reflect it back towards the Earth's surface.
5. Thus, heat energy becomes trapped inside Earth's atmosphere and accumulates, leading to the greenhouse effect and an increase in average mean temperatures on Earth.

Global warming:

- Global warming reduces ice/snow cover. This causes a decrease in albedo and increases the rate of heat absorption by the Earth.
- The solubility of carbon dioxide in the sea decreases with increasing temperature, leading to an increase in the concentration of carbon dioxide (greenhouse gas) in the atmosphere.

Effects:

- Rise in mean sea level by the melting of ice on land.
- Extreme weather such as heat waves and heavy floods.



Energy balance in the Earth surface–atmosphere system

Earth's energy balance describes how the incoming energy from the sun is used and returned to space. If incoming and outgoing energy are in balance, the Earth's temperature remains constant.