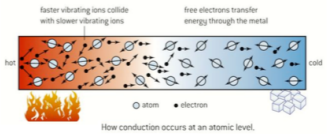
Thermal Energy Transfer

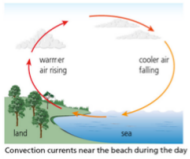
Principal Methods of Thermal Energy Transfer

I. Thermal Conduction:
In conduction processes, energy flows through the bulk of the material without any large-scale relative movement of the particles (atoms/molecules) that make up the object. Faster moving particles collide with slower moving ones and transfer energy during the collisions. Conduction is primarily of importance in solids and less so in liquids and gases where the particles are further apart.



How conduction occurs at an atomic level.

II. Convection:
Convection is the bulk movement of groups of particles within fluids (liquids and gases) due to variations in density. Hotter less-dense fluid rises and cooler more-dense fluid falls to take its place. This is known as a convection current (cycle).



Convection currents near the beach during the day

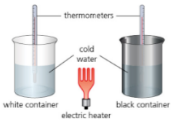
	Solids	Liquids	Gases
Conduction	X		
Convection		X	X

III. Radiation:
Thermal radiation is the transfer of energy by means of electromagnetic radiation. It has its origins in the thermal motion of the charged particles of the object that emit photons as they move and are accelerated. Radiation from the Sun reaches Earth across the vacuum of space.

Dark/black objects are better **absorbers** of radiation than light/white and shiny objects.

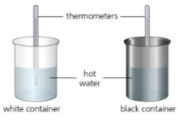
Dark/black objects are better **emitters** of radiation than light/white and shiny objects.

Absorption of Radiation



Comparing thermal radiation gains

Emission of Radiation



Comparing thermal radiation losses

1. In the two experiments pictured above, which thermometer changes the fastest?

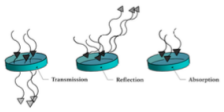
   Thermometer in the black container in both cases

2. When incoming light (radiation) strikes an object, it will undergo . .

   a) transmission

   b) reflection

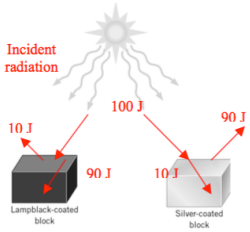
   c) absorption



3. Notice that . . .

   a) Light-colored or silvery objects: absorb little energy, reflect most energy

   b) Dark objects: absorb most energy, reflect little energy



4. An object will also . . .radiate energy (= EM radiation)

5. a) If the rate of absorption > rate of radiation then . . .

   object heats up

   b) If the rate of absorption = rate of radiation then . . .

   Thermal equilibrium

   c) If the rate of absorption < rate of radiation then . . .

   Object cools down

6. An idealized physical body that absorbs all incident electromagnetic radiation, regardless of frequency or angle of incidence, is called a . . . black body

7. An object that is a good absorber of radiation is also a good emitter of radiation. Therefore, the radiation emitter by a "perfect" emitter is known as . . . black body radiation.

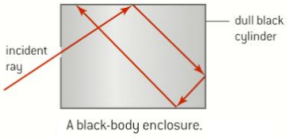
   NOTE: A "black-body" will not appear black if it is hot enough to emit visible light.

   Examples of black-bodies:

   a) the Sun

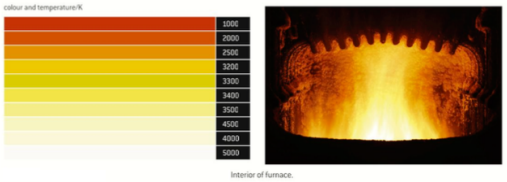
   b) a furnace

   c) a pottery kiln

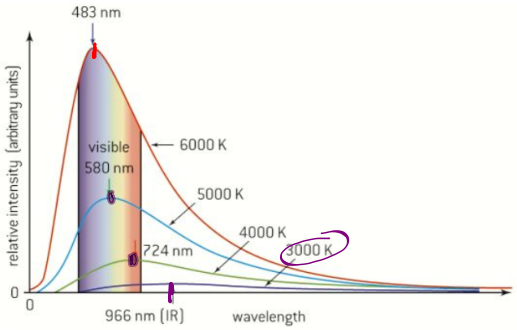


A black-body enclosure.

8. The colors of the radiation emitted by a hot object can tell us about its . . .temperature



Although there is a predominant color to the radiation emitter by a black-body radiator, the entire EM spectrum is emitted in differing amounts (intensities). A graph of the relative intensity of the radiation versus wavelength does not depend on the material or shape of the object and is shown below.



Intensity against wavelength for black bodies at four temperatures.

a) Not all wavelengths of light will be emitted with equal intensity.

b) Emitted wavelength with highest intensity (λ_{max}) is related to . . . temperature.

c) Area under curve is proportional to . . . total power radiated by body

d) As body heats up, λ_{max} . . . decreases and total power . . . increases

Wien's Displacement Law:
The wavelength at which the maximum power is emitted by a black-body is inversely proportional to its absolute temperature.

Formula: $\lambda_{max} \alpha \frac{1}{T}$

$$\lambda_{max} = \frac{2.90x10^{-3}\,K \cdot m}{T}$$

9. Determine the frequency of radiation that is emitted by the Sun with the highest intensity. Assume the Sun to be a black-body with a temperature of 5778 K.

$\lambda_{max} = \frac{2.9 \times 10^{-3}\ K\,m}{5778\ K} \approx 500\ nm$

	Definition	Formula	Units
Power	energy per unit time	P = E/t	W = J/s
Intensity	power per unit area	I = P/A	W/m^2

The Stefan-Boltzmann Law of Radiation:
The total power radiated by a black-body per unit area is proportional to the fourth power of the absolute temperature of the body.

Formula: $\frac{P_{BB}}{A} \alpha T^4$

$P_{BB} = \sigma A T^4$

where σ=Stefan-boltzmann constant

$\sigma = 5.67 \times 10^{-8}\ \frac{W}{m^2 K^4}$

Emissivity (e): the ratio of the power emitted by an object to the power emitted by a black-body of the same dimensions at the same temperature

Material	Emissivity
water	0.6–0.7
snow	0.9
ice	0.98
soil	0.4–0.95
coal	0.95

Formula $P = e P_{BB}$

$P = e \sigma A T^4$

10. What is the emissivity of a perfect black-body?

11. The supergiant star Betelgeuse has a surface temperature of about 2900 K and a radius of 3×10^{11} m.

a) Determine how much energy Betelgeuse radiates each second if it is assumed to be a black-body.

$P = e\sigma AT^4$

$(1)\ 5.67\times10^{-8}\ \frac{W}{m^2K^4}\ 4\pi(3\times10^{11}m)^2(2900K)^4$

$\approx 4.5\times10^{30}\ J/s$

b) How will the power radiated by Betelgeuse change if its temperature doubles?

$P \propto T^4 \rightarrow 16\times$

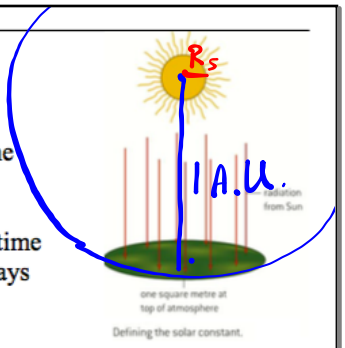
c) Calculate the intensity of the energy radiated by Betelgeuse at its surface.

$I = \frac{P}{A} = \frac{4.5\times10^{30}\ J/s}{4\pi r^2} = 4\times10^6\ W/m^2$

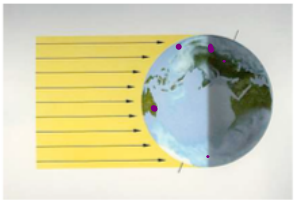
Solar constant $I = \frac{P_{sun}}{A} = \frac{e\sigma 4\pi R_s^2 T^4}{4\pi(1.5\times10^{11}m)^2}$

Meaning: The amount of energy from the Sun that arrives at the top of the atmosphere

Definition: The total radiation energy received from the Sun per unit of time per unit of area on a theoretical surface perpendicular to the Sun's rays and at Earth's mean distance from the Sun.



Defining the solar constant.

Value of solar constant: 1360 W/m^2

Average value over entire surface of Earth: 340 W/m^2