HEAT AND HEAT TRANSFER

Chapter 14

HEAT ENERGY

- We have determined that temperature is the mean kinetic energy of a substance, That means to increase temperature you must add energy to a system, to cool it you must remove energy.
- You can do this by doing work on your substance. Drilling into a rock, stirring a liquid, squeezing a ballon.
- More commonly you might bring your substance into contact with something hotter or colder than it, boiling water or an ice cube. Then heat energy will flow from the hotter substance to the colder one.

HEAT ENERGY

- The symbol Q is used for heat energy. This is because originally it was thought that he flowed like a fluid between substance and we still use some of that language.
- Now we understand that heat is just energy. The amount of heat one needs to change a substances temperature depends on the mass of the substance and what it is made of,

$$Q = mc\Delta T$$

- where c is called the specific heat and has different values for different materials.

EXAMPLE 14.1

- **Calculating the Required Heat: Heating Water in an Aluminum Pan:** A 0.500 kg aluminum pan on a stove is used to heat 0.250 liters of water from 20.0°C to 80.0°C. (a) How much heat is required? What percentage of the heat is used to raise the temperature of (b) the pan and (c) the water?

$$Q = mc\Delta T \qquad Q_{Al} = m_{Al}c_{Al}\Delta T \qquad Q_w = m_w c_w \Delta T$$

m_{Al} = 0.5 kg

V = 0.25 L

T_i = 20.0°C

T_f = 80.0°C

Q = ?

c_{Al} = 900 J/kg°C c_w = 4186 J/kg°C

$m_w = \rho_w V$ = (1kg /L) 0.25L = 0.25kg

$$Q_{Al} = (0.5kg)(900J/kg^\circ C(80^\circ C - 20^\circ C) = 27.0kJ$$

$$Q_w = (0.25kg)(4186J/kg^\circ C(80^\circ C - 20^\circ C) = 62.8kJ$$

$$Q = Q_w + Q_{Al} \quad = 62.8kJ + 27.0kJ = 89.8kJ$$

$$\frac{Q_{Al}}{Q} = \frac{27.0kJ}{89.8kJ} = 30.1\%$$

$$\frac{Q_w}{Q} = \frac{62.8kJ}{89.8kJ} = 69.9\%$$

EXAMPLE 14.2

- **Calculating the Temperature Increase from the Work Done on a Substance: Truck Brakes Overheat on Downhill Runs:** Truck brakes used to control speed on a downhill run do work, converting gravitational potential energy into increased internal energy (higher temperature) of the brake material. This conversion prevents the gravitational potential energy from being converted into kinetic energy of the truck. The problem is that the mass of the truck is large compared with that of the brake material absorbing the energy, and the temperature increase may occur too fast for sufficient heat to transfer from the brakes to the environment. Calculate the temperature increase of 100 kg of brake material with an average specific heat of 800 J(kg°C) if the material retains 10% of the energy from a 10,000-kg truck descending 75.0 m (in vertical displacement) at a constant speed.

m = 100 kg

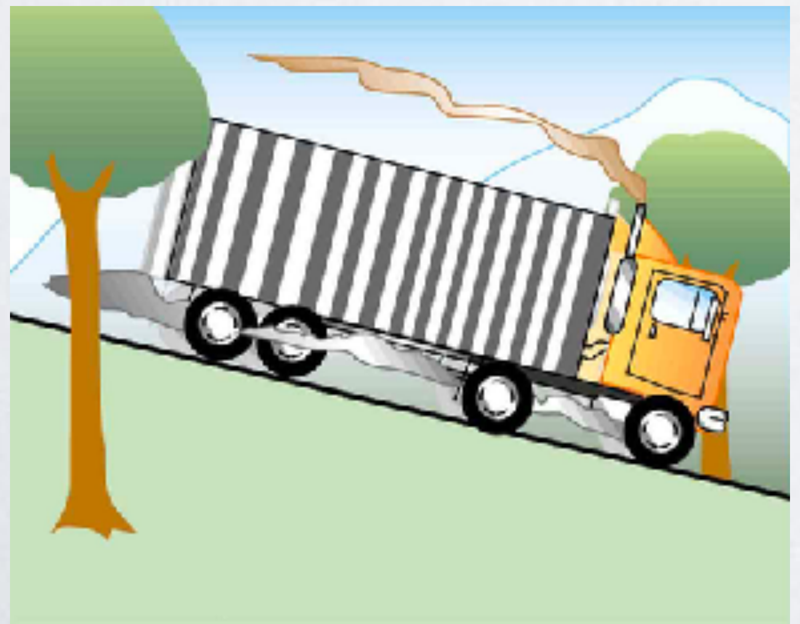
c = 800 J/(kg°C)

M = 10,000 kg

h = 75 m

ε = 10%

ΔT = ?



$$PE_g = Mgh$$

$$Q = \epsilon PE_g$$

$$Q = mc\Delta T$$

$$\Delta T = \frac{Q}{mc} = \frac{\epsilon Mgh}{mc}$$

$$= \frac{0.1(10,000kg)(9.8m/s^2)(75m)}{(100kg)(800J/(kg^\circ C))}$$

$$= 92^\circ C$$

LATENT HEAT

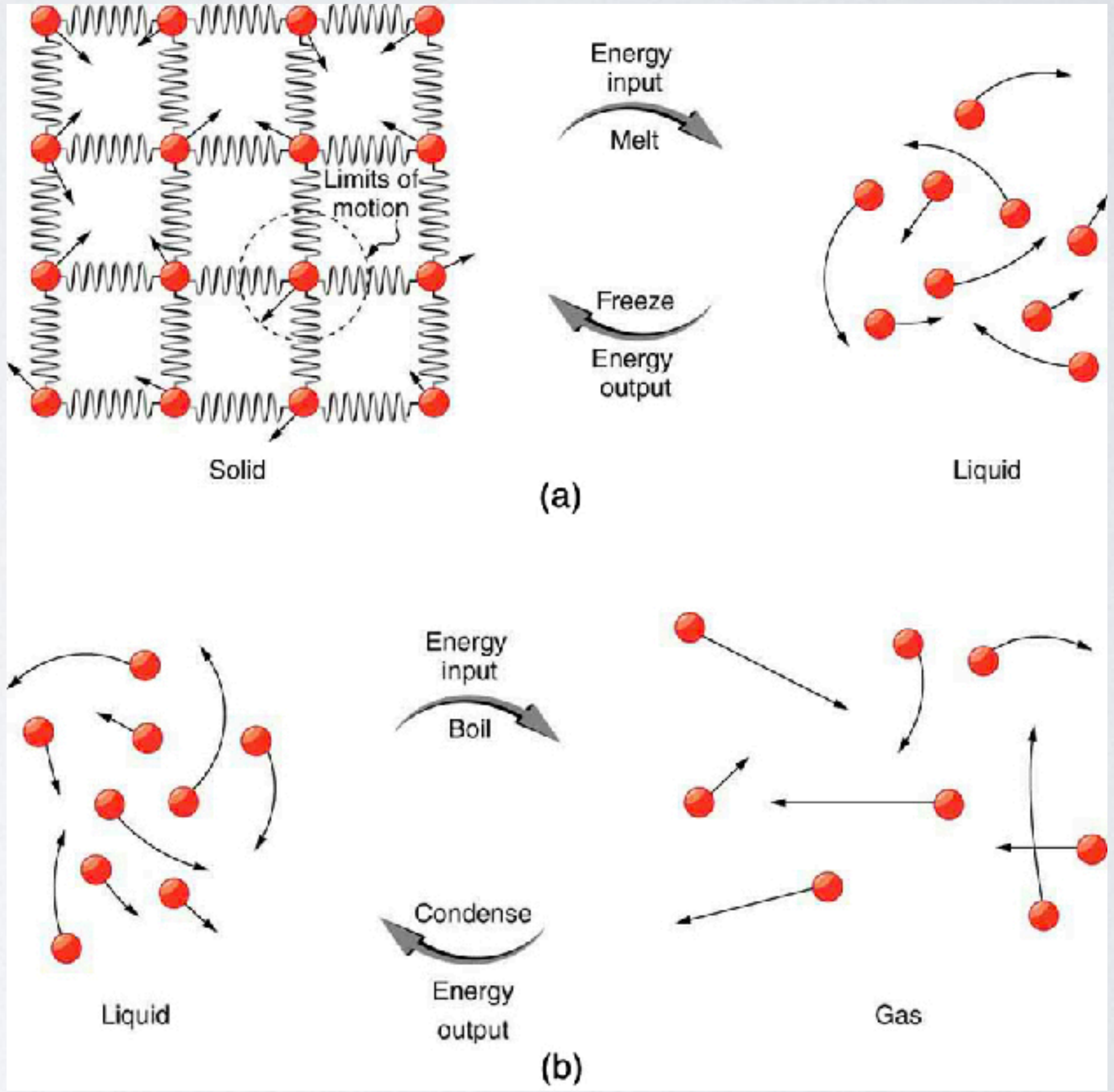
- When a substance reaches its melting or boiling point, more energy doesn't raise its temperature but instead changes its state.

- The energy added to the substance breaks the bonds that hold a solid together or a liquid in contact. This takes energy and is called latent heat.

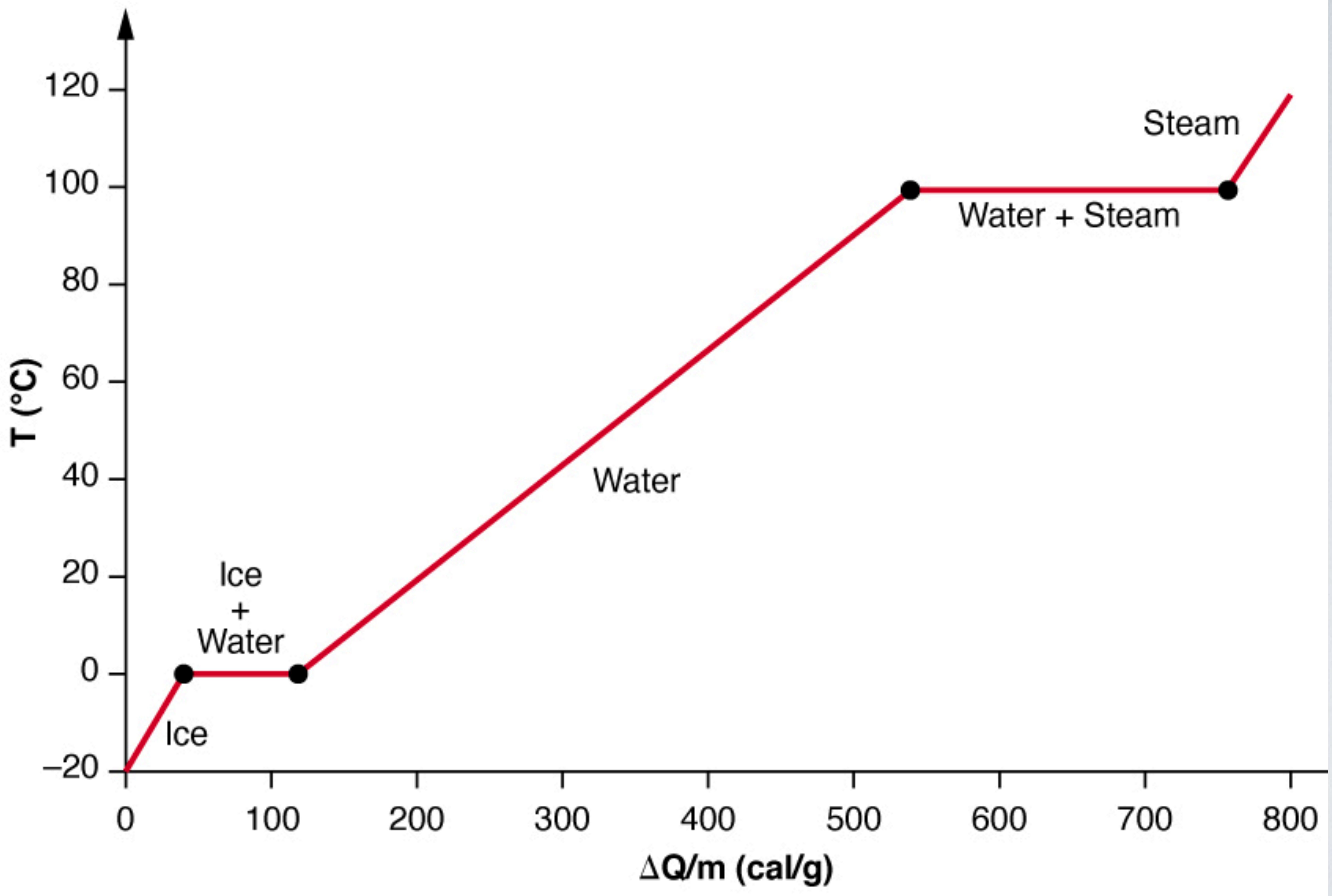
- We can calculate how much energy is required for a given mass by

$$Q = mL_f \quad \text{or} \quad Q = mL_v$$

- where L_f is called the latent heat of fusion and L_v the latent heat of vaporization and both depend on the substance.



- If one adds energy to solid water (ice) for example, first it will increase it's temperature.
- When you reach the melting point (0C) it will instead convert the ice to water.
- Once the ice is fully converted then added energy will heat the water until it reaches the boiling point, 100C.
- Added energy then will vaporize the water until you get all steam.
- Finally you will start heating the steam past 100C.



EXAMPLE 14.4

- **Calculate Final Temperature from Phase Change: Cooling Soda with Ice Cubes:** Three ice cubes are used to chill a soda at 20°C with mass, m_{soda} = 0.25 kg. The ice is at 0°C and each ice cube has a mass of 6.0 g. Assume that the soda is kept in a foam container so that heat loss can be ignored. Assume the soda has the same heat capacity as water. Find the final temperature when all ice has melted.

T_{soda} = 20°C
m_{soda} = 0.25kg
T_{ice} = 0°C
m_{ice} = 3×6g = 0.018kg

$$Q = mL \qquad Q = mc\Delta T$$

$$Q_{ice} = -Q_{soda}$$

$$m_{ice}L_{f,ice} + m_{ice}c_w(T_f - 0°C) = -m_{soda}c_w(T_f - 20°C)$$

$$m_{soda}c_wT_f + m_{ice}c_wT_f = m_{soda}c_w(20°C) - m_{ice}L_{f,ice}$$

$$T_f = \frac{m_{soda}c_w(20°C) - m_{ice}L_{f,ice}}{(m_{soda} + m_{ice})c_w} = \frac{(0.25kg)(4186J/(kg°C))(20°C) - (0.018kg)(334,000J/kg)}{(0.25kg + 0.018kg)4186J/(kg°C))} = 13°C$$

Return of the Jedi -Star Wars Episode VI

How much energy would it take to unfreeze Han Solo?

Let's assume Han Solo has a mass of 80kg.

Carbonite is apparently a form of frozen carbon dioxide which has a melting point of -56.6°C.

You can tell Han Solo is very cold from his shaking so he might not be all the way to 37°C; however, he must be very close. You get hypothermia at only 2°C lowering of your core temperature.

Human body temperature is 37°C so Han's body temperature has to be raised ΔT=(37 - -56.6) = 93.6°C.

Since the human body is mostly water we can just pretend a person is water, but at temperatures below 0°C water is frozen as ice. So to calculate the heat needed for this temperature change we need the specific heat of water, c_w = 4186 J/kg°C, the specific heat of ice, c_i = 2093 J/kg°C, and the latent heat of fusion for water, L_f = 333 kJ/kg. Given these facts we can write the heat energy as:

$$Q = m(c_i \Delta T_i + c_w \Delta T_w + L_f) =$$

$$180kg(2093J/(kgC)(56.6) + 4186J/(kgC)(37) + 333,000J/kg) = 606.3kJ$$

which is a whole lot of energy. In terms of kinetic energy it would be equivalent of changing Han Solo's velocity by about 82m/s.

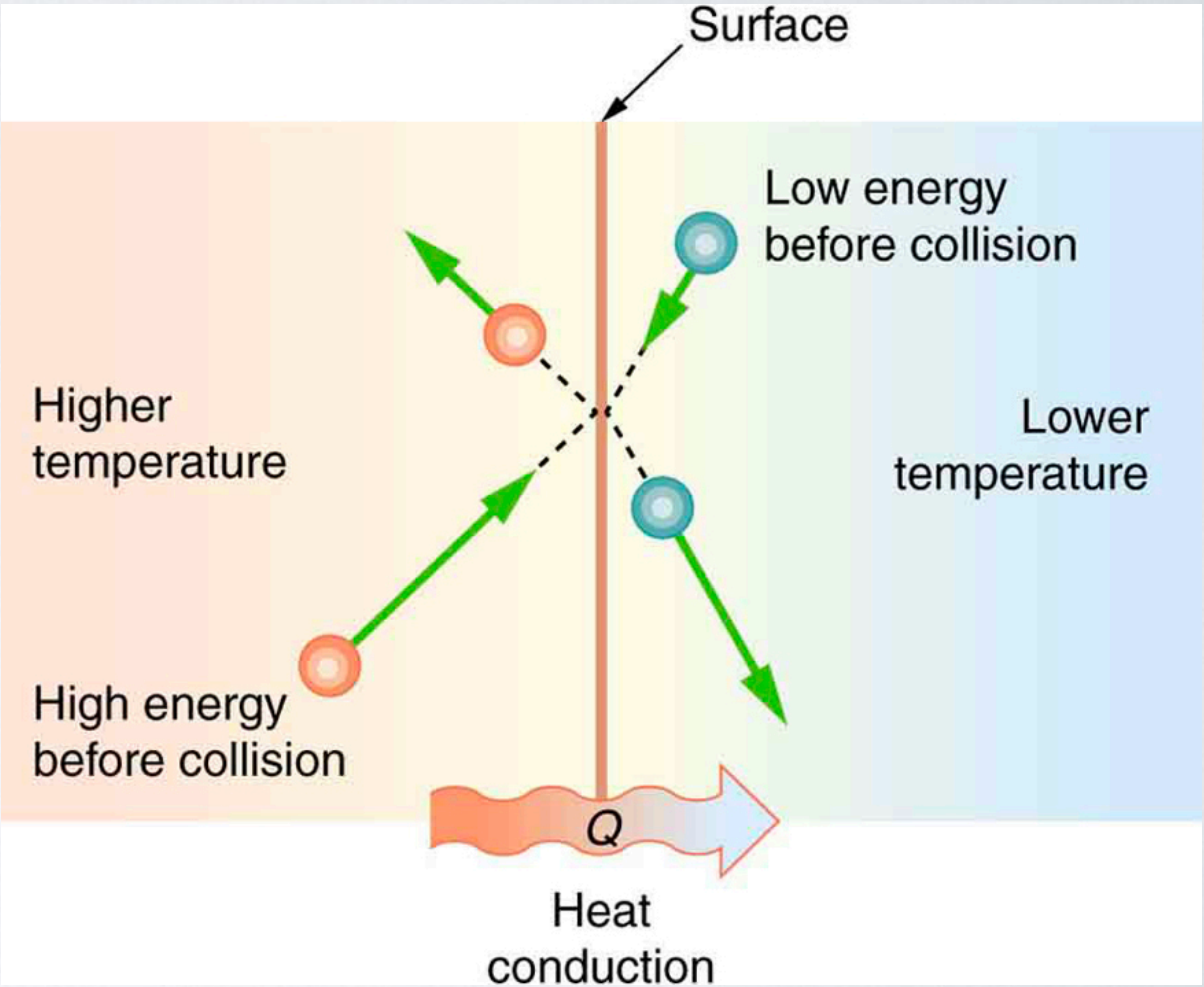
HEAT TRANSFER METHODS

- Heat is transferred by one of three ways:
  - Conduction - the bumping of molecules into other molecules that bump others all the way down transferring kinetic energy.
  - Convection - the movement of hot material to cold regions and cold material to hot regions.
  - Radiation - the carrying of heat by electromagnetic radiation

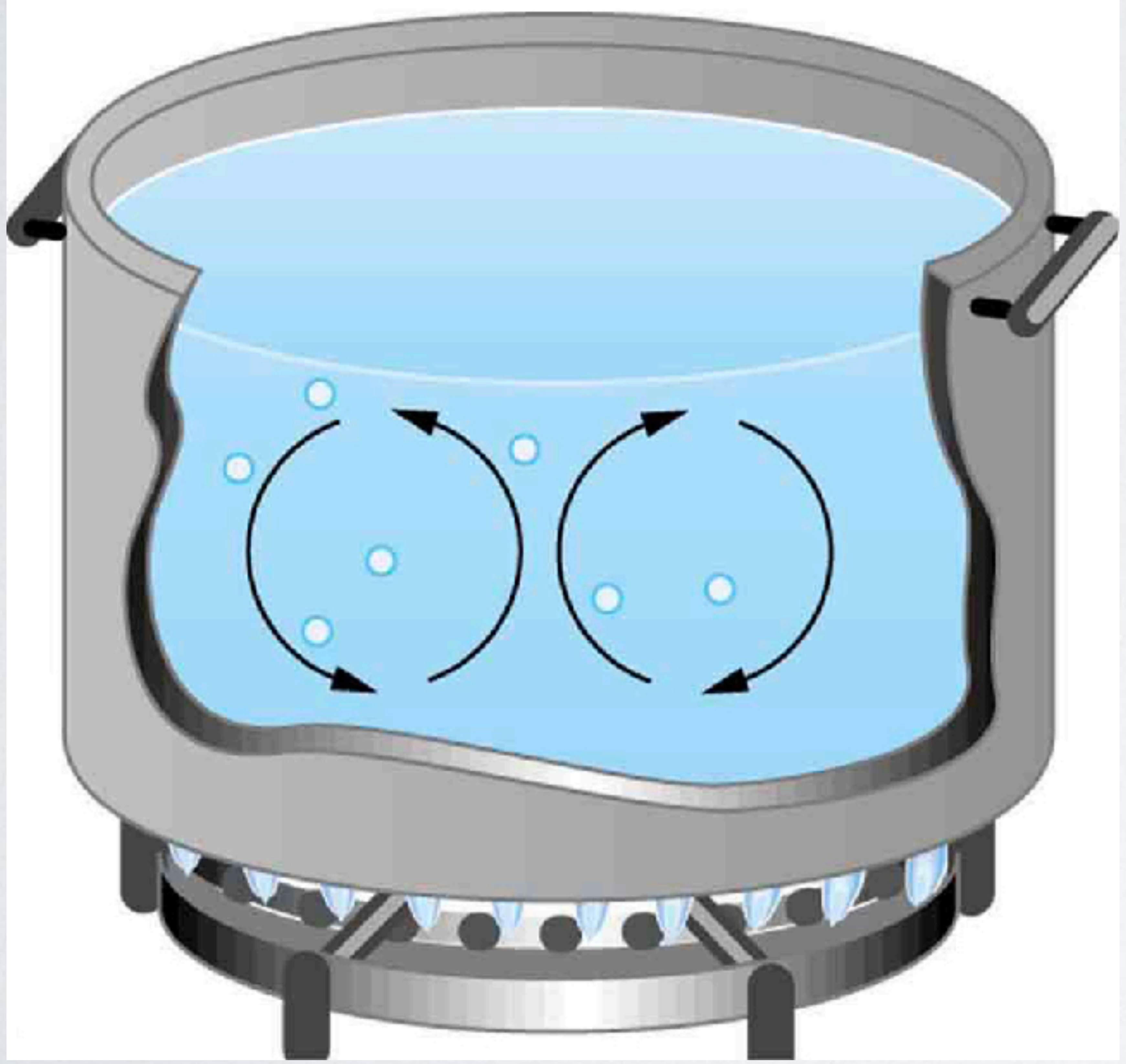
CONDUCTION

- Conduction is the most basic way that heat is transferred. When you touch something hot, its fast moving molecules bang into yours making them move faster.
- The thermal conductivity of a material, k, determines how quickly heat is transferred.
- We can calculate a rate from the formula:

$$\frac{Q}{t} = \frac{kA}{d}(T_2 - T_1)$$



CONVECTION



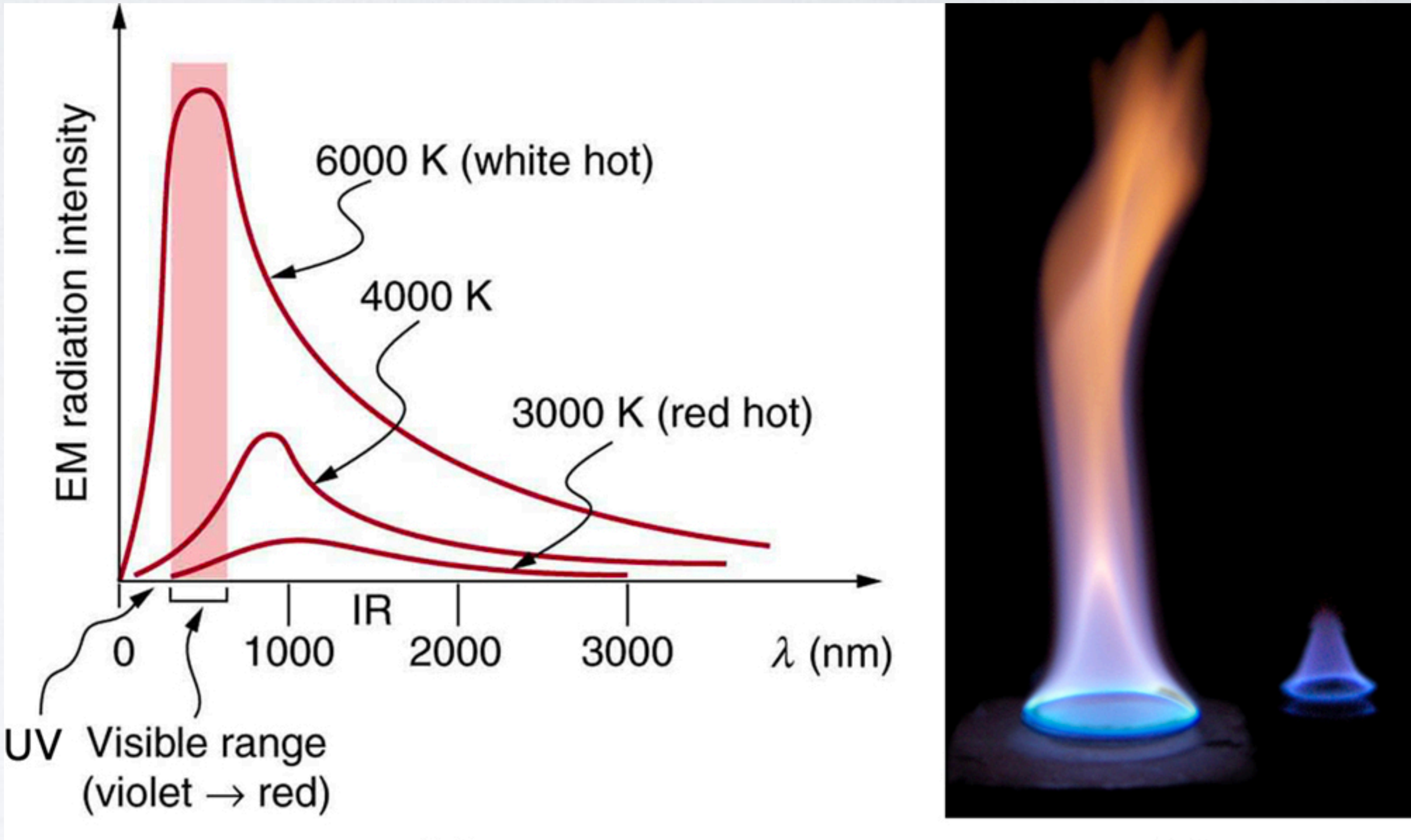
- Convection transfers heat by moving the hot material to a different location. This often occurs in fluids where the hotter material will have lower density and thus rise because of the buoyant force.

- This occurs in boiling water, the atmosphere, and the Earth's mantle.

RADIATION

- Finally heat is transmitted by electromagnetic radiation, also known as light.
- Sometimes you can see the light for objects that are very hot, but at normal Earth temperatures objects emit radiation in the infrared which we can not see by eye.
- The amount of energy emitted is a strong function of temperature, the formula being

$$\frac{Q}{t} = \sigma \epsilon A T^4$$



(a)

(b)

HOME WORK

- Chap 14 - 1, 6, 10, 13, 14, 16