Thermal Physics

Topic 3.2 Thermal Properties of Matter

Heat Capacity/Thermal Capacity

- When substances undergo the same temperature change they can store or release different amounts of energy
- They have different Heat Capacities
- Heat capacity = $\Delta Q / \Delta T$ in JK^{-1}
  - ΔQ = the change in thermal energy in joules
  - ΔT = the change in temperature in Kelvin
- Defined as the amount of energy to change the temperature of a body by unit temperature
- Applies to a specific BODY

Heat Capacity - 2

- A body with a high heat capacity will take in thermal energy at a slower rate than a substance with a low heat capacity because it needs more time to absorb a greater quantity of thermal energy

- They also cool more slowly because they give out thermal energy at a slower rate

Specific Heat Capacity

- Defined as the amount of thermal energy required to produce unit temperature rise in unit mass of the MATERIAL
- Unit mass is normally 1kg, and unit temperature rise is normally 1K
- Specific Heat Capacity = $\Delta Q / (m\Delta T)$
- in $J\ kg^{-1}\ K^{-1}$
  - where m is the mass of the material

- For an object made of 1specific material then
- Heat Capacity = m x Specific Heat Capacity

Specific Heat Capacity - 2

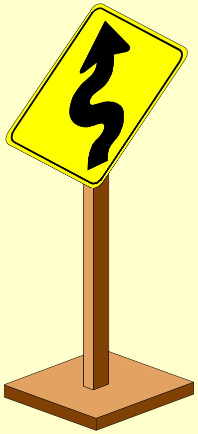
- Unit masses of different substances contain
  - different numbers of molecules
  - of different types
  - of different masses
- If the same amount of internal energy is added to each unit mass
  - it is distributed amongst the molecules

Specific Heat capacity - 3

- The average energy change of each molecule will be different for each substance
- Therefore the temperature changes will be different
- So the specific heat capacities will be different

Methods of finding the S.H.C

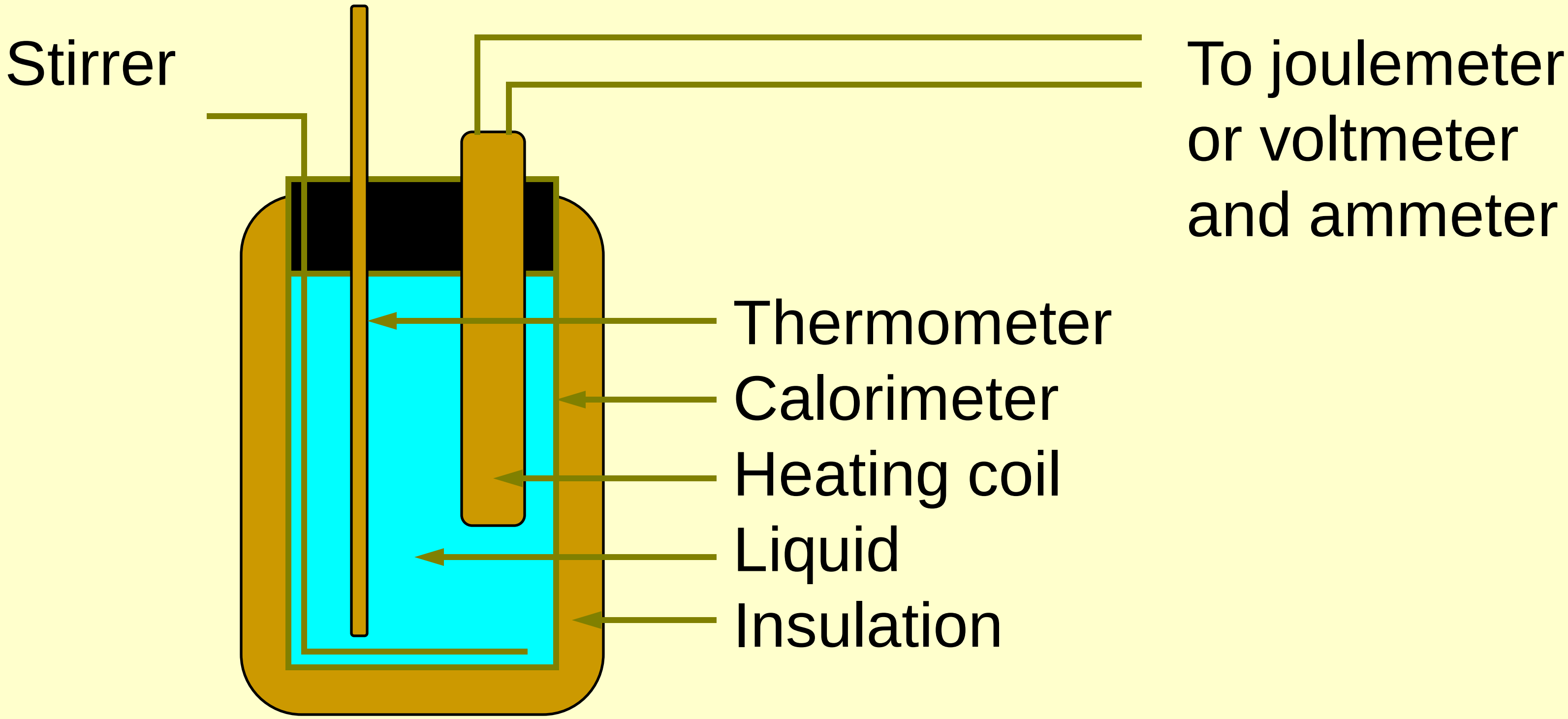
- Two methods
  - Direct
  - Indirect



Direct Method - Liquids

- Using a calorimeter of known Heat Capacity
- (or Specific Heat Capacity of the material and the mass of the calorimeter)
- Because
  Heat Capacity = Mass x Specific Heat Capacity

SHC of Liquids



Calculations - Liquids

- Electrical Energy input is equal to the thermal energy gained by the liquid and the calorimeter – this is the assumption that we are making

- Electrical energy = V x I x t
- Energy gained by liquid = m_l c_l ΔT_l
- Energy gained by calorimeter = m_c c_c ΔT_c

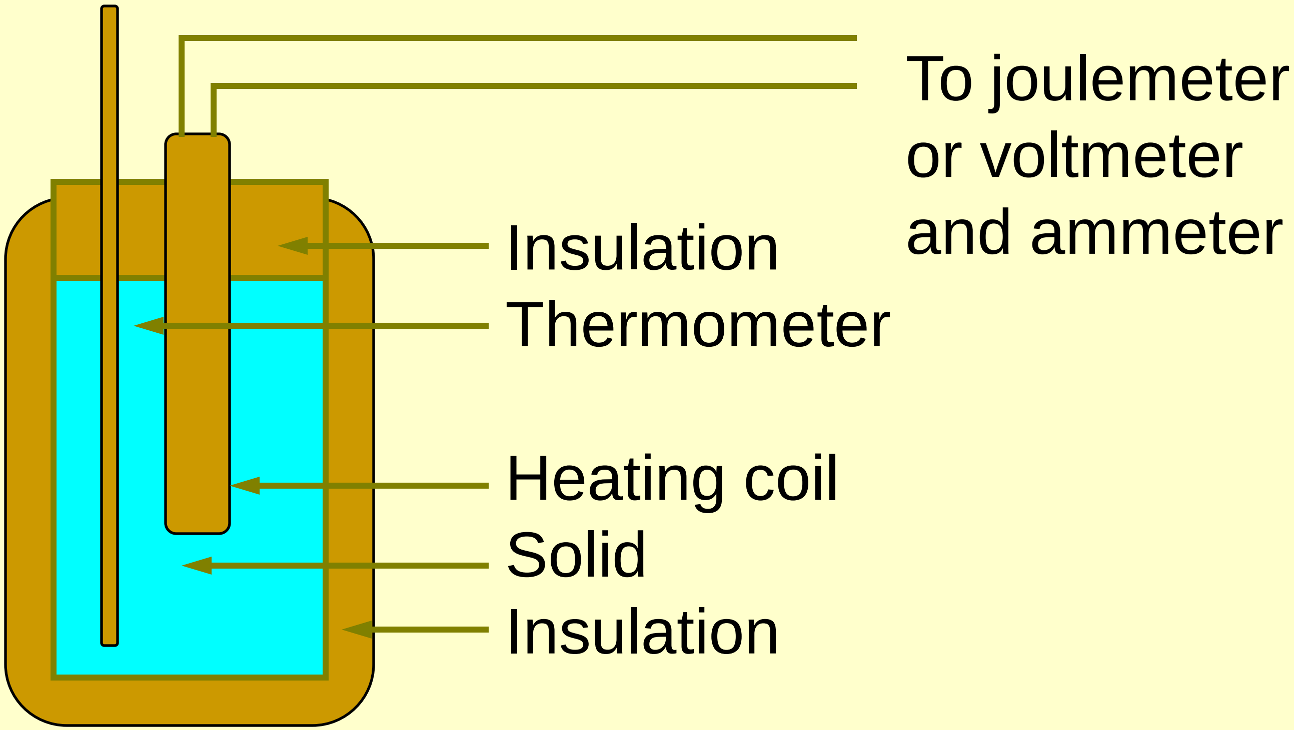
Calculations - Liquids -2

- Using conservation of energy
- Electrical energy in = thermal energy gained by liquid + thermal energy gained by calorimeter
- $V \times I \times t = m_l c_l \Delta T_l + m_c c_c \Delta T_c$
- The only unknown is the specific heat capacity of the liquid

Direct Method - Solids

- Using a specially prepared block of the material
- The block is cylindrical and has 2 holes drilled in it
  - one for the thermometer and one for the heater
  - Heater hole in the centre, so the heat spreads evenly through the block
  - Thermometer hole, ½ way between the heater and the outside of the block, so that it gets the averge temperature of the block

SHC of Solids



Calculations - Solids

- Again using the conservation of energy
- Electrical Energy input is equal to the thermal energy gained by the solid

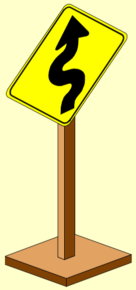
- Electrical energy = V x I x t

- Energy gained by solid = $m_s \, c_s \, \Delta T_s$

Calculations - Solids -2

- $V \times I \times t = m_s\ c_s\ \Delta T_s$
- The only unknown is the specific heat capacity of the solid

Indirect Method



- Sometimes called the **method of mixtures**
- In the case of solid, a known mass of solid is heated to a known temperature (usually by immersing in boiling water for a period of time)
- Then it is transferred to a known mass of liquid in a calorimeter of known mass

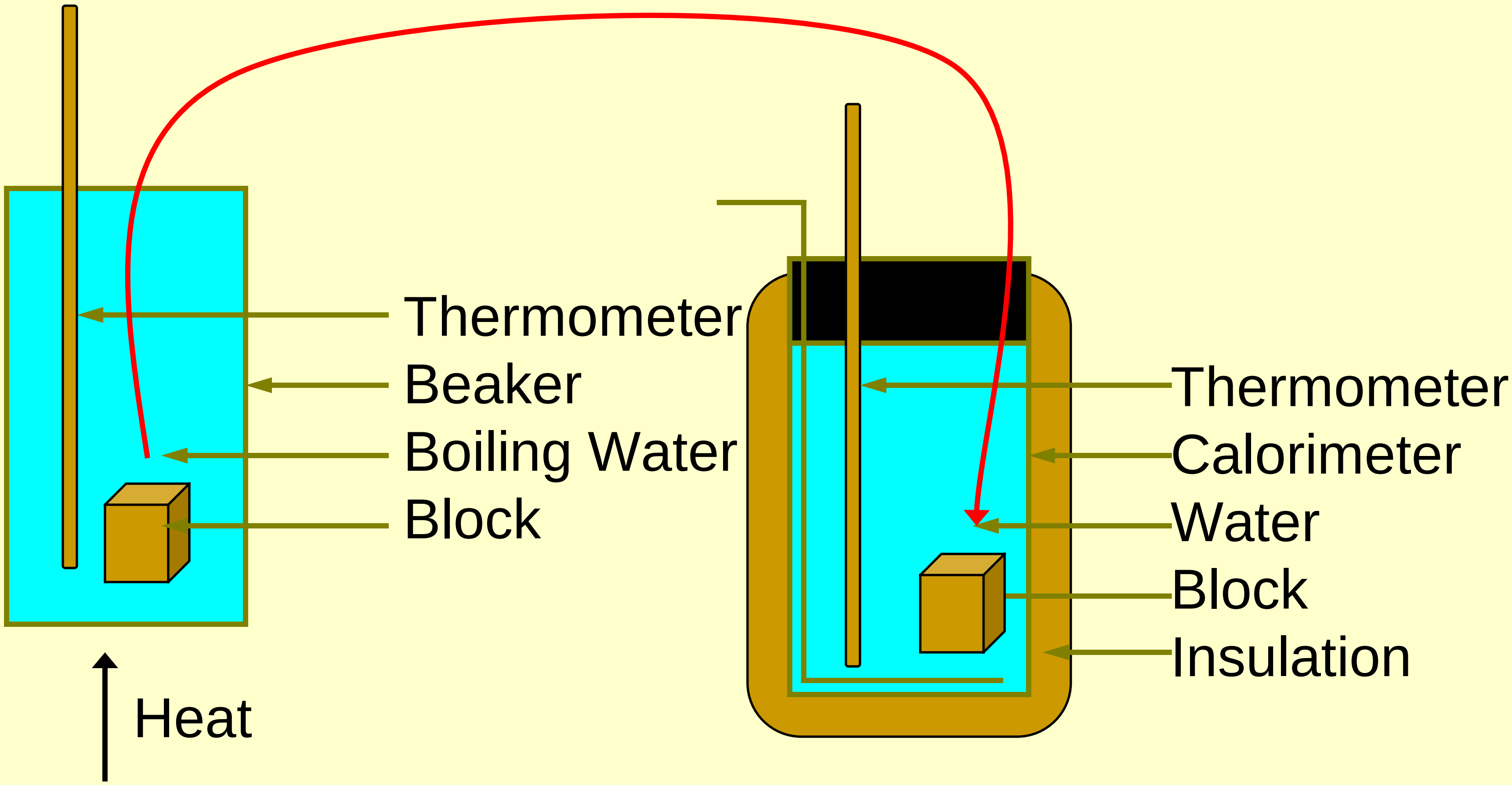
Indirect Method cont…..

- The change in temperature is recorded and from this the specific heat capacity of the solid can be found

- Energy lost by block = Energy gained by liquid and calorimeter

- $m_b \, c_b \, \Delta T_b = m_w \, c_w \, \Delta T_w + m_c \, c_c \, \Delta T_c$
  - the SHC of water and the calorimeter are needed

Apparatus



Thermometer
Beaker
Boiling Water
Block
Heat
Thermometer
Calorimeter
Water
Block
Insulation

Indirect Method – cont….

- In the case of a liquid

- A hot solid of known specific heat capacity is transferred to a liquid of unknown specific heat capacity

- A similar calculation then occurs

Phases (States) of Matter

- Matter is defined as anything that has mass and occupies space
- There are 4 states of matter
- Solids, Liquids, Gases and Plasmas
- Most of the matter on the Earth in the form of the first 3
- Most of the matter in the Universe is in the plasma state

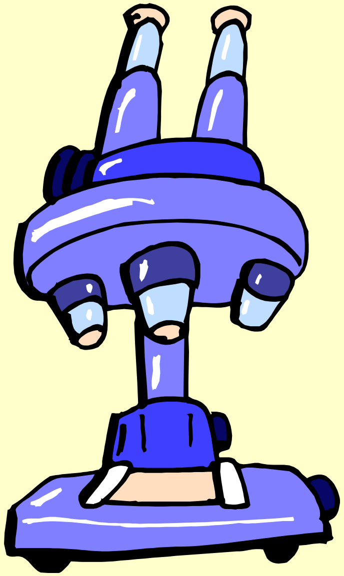
Macroscopic

- Macroscopic properties are all the observable behaviours of that material such as shape, volume, compressibility
- The many macroscopic or physical properties of a substance can provide evidence for the nature of that substance

Macroscopic Characteristics

Characteristics	Solid	Liquid	Gas
Shape	Definite	Variable	Variable
Volume	Definite	Definite	Variable
Compressibilty	Almost Incompressible	Very Slightly Compressible	Highly Compressible
Diffusion	Small	Slow	Fast
Comparative Density	High	High	Low

- These will help to explain what is happening at the atomic level, and this part of the model will be interpreted later



Microscopic Characteristics

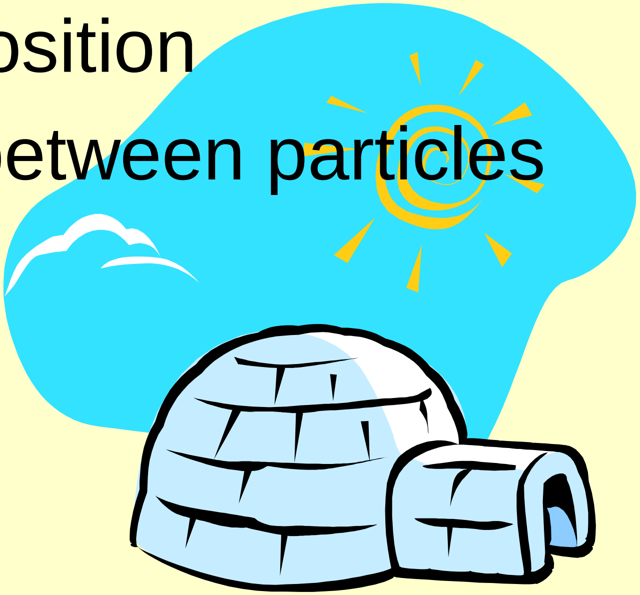
Characteristics	Solid	Liquid	Gas
KE	Vibrational	Vibrational Rotational Some Translational	Mostly Translational Higher Rotational Higher Vibrational
PE	High	Higher	Highest

Fluids

- Liquids
- Gases
- are both fluids
- Because they FLOW

Arrangement of Particles - 1

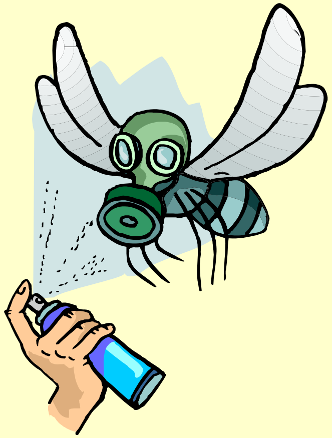
- Solids
  - Closely packed
  - Strongly bonded to neighbours
  - held rigidly in a fixed position
  - the force of attraction between particles gives them PE



Arrangement of Particles - 2

- Liquids
  - Still closely packed
  - Bonding is still quite strong
  - <u>Not</u> held rigidly in a fixed position and bonds can break and reform
  - PE of the particles is higher than a solid because the distance between the particles is higher

Arrangement of Particles - 3



- Gases
  - Widely spaced
  - Only interact significantly on closest approach or collision
  - Have a much higher PE than liquids because the particles are furthest apart

Changes of State

- A substance can undergo changes of state or phase changes at different temperatures

- Pure substances have definite melting and boiling points which are characteristic of the substance

Changes of State - 2

- The moving particle theory can be used to explain the microscopic behaviour of these phase changes
  - When the solid is heated the particles of the solid vibrate at an increasing rate as the temperature is increased
  - The vibrational KE of the particles increases

Changes of State -3

- At the melting point a temperature is reached at which the particles vibrate with sufficient thermal energy to break from their fixed positions and begin to slip over each other
- As the solid continues to melt more and more particles gain sufficient energy to overcome the forces between the particles and over time all the solid particles are changed to a liquid
- The PE of the system increases as the particles move apart

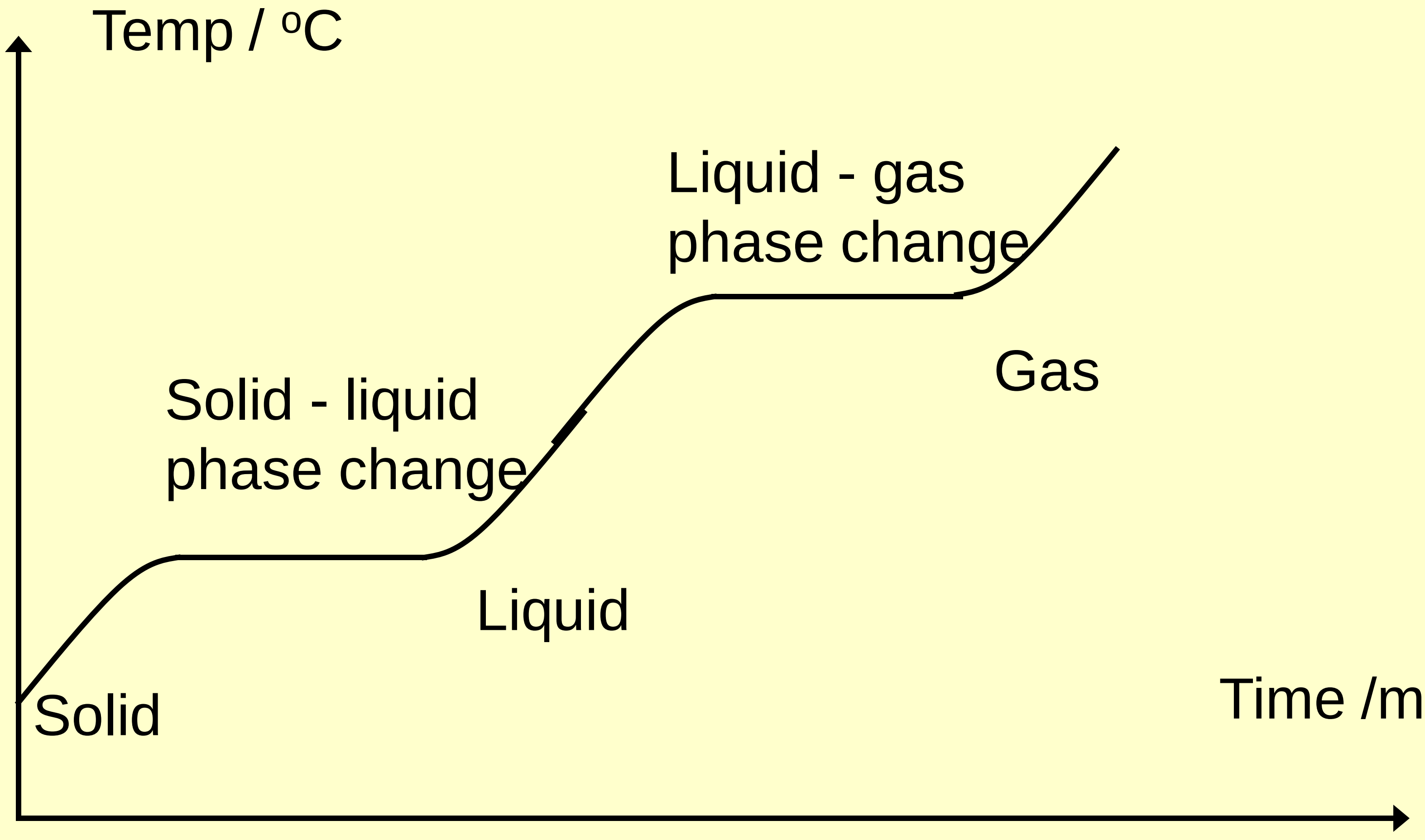
Changes in State - 4

- As the heating continues the temperature of the liquid rises due to an increase in the vibrational, rotational and translational energy of the particles

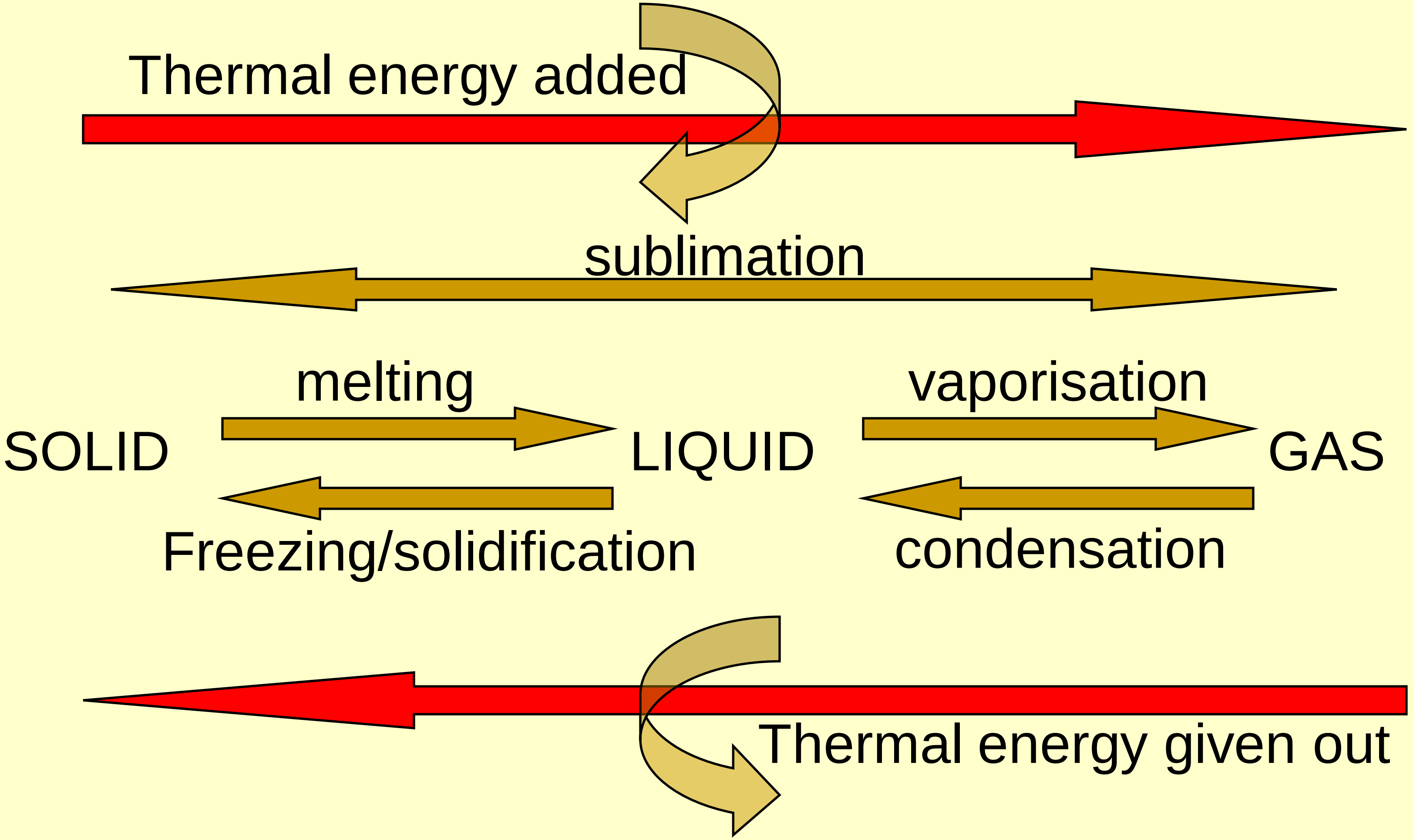
- At the boiling point a temperature is reached at which the particles gain sufficient energy to overcome the inter-particle forces and escape into the gaseous state. PE increases.

- Continued heating at the boiling point provides the energy for all the particles to change

Heating Curve



Changes of State



Evaporation

- The process of evaporation is a change from the liquid state to the gaseous state which occurs at a **temperature below the boiling point**
- The Moving Particle (Kinetic) theory can be applied to understand the evaporation process

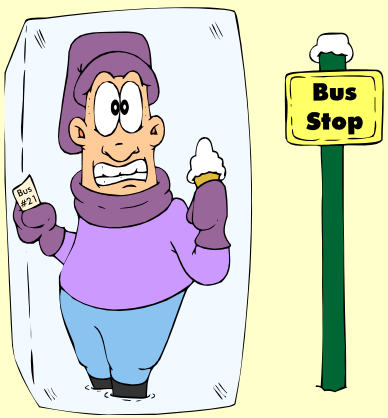
Explanation

- A substance at a particular temperature has a range of particle energies
- So in a liquid at any instant, a small fraction of the particles will have KE considerably greater than the average value

So

- If these particles are near the surface of the liquid, they will have enough KE to overcome the attractive forces of the neighbouring particles and escape from the liquid as a gas
- This energy is needed as gases have more PE than liquids.

Cooling



- Now that the more energetic particles have escaped
- The average KE of the remaining particles in the liquid will be lowered
- Since temperature is related to the average KE of the particles
- A lower KE infers a lower temperature

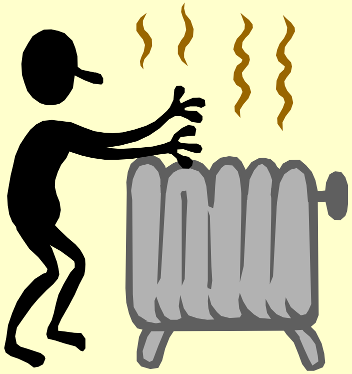
Cool

- This is why the temperature of the liquid falls as an evaporative cooling takes place
- A substance that cools rapidly is said to be a volatile liquid
- When overheating occurs in a human on hot days, the body starts to perspire
- Evaporation of the perspiration cools the body

Factors Affecting The Rate

- Evaporation can be increased by
  - Increasing temperature
  - (more particles have a higher KE)
  - Increasing surface area
  - (more particles closer to the surface)
  - Increasing air flow above the surface
  - (gives the particles somewhere to go to)

Latent Heat



- The thermal energy which a particle absorbs in melting, vaporising or sublimation or gives out in freezing, condensing or sublimating is called **Latent Heat** because it does not produce a change in temperature

Latent Heat cont….

- When thermal energy is absorbed/released by a body, the temperature may rise/fall, or it may remain constant
  - If the temperature remains constant then a phase change will occur as the thermal energy must either increase the PE of the particles as they move further apart
  - or decrease the PE of the particles as they move closer together

Definition

- The quantity of heat energy required to change one kilogram of a substance from one phase to another, without a change in temperature is called the **Specific Latent Heat of Transformation**

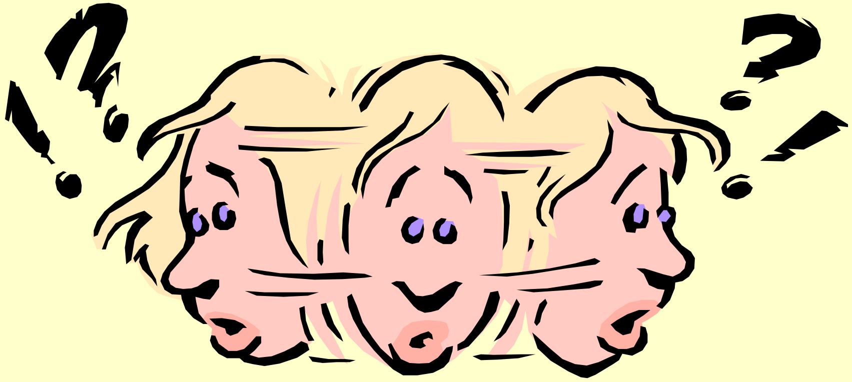
- Latent Heat = $\Delta Q / m$ in $J\ kg^{-1}$

Types of Latent Heat

- Fusion
- Vaporisation
- Sublimation

- The latent heat of fusion of a substance is less than the latent heat of vaporisation or the latent heat of sublimation

Questions

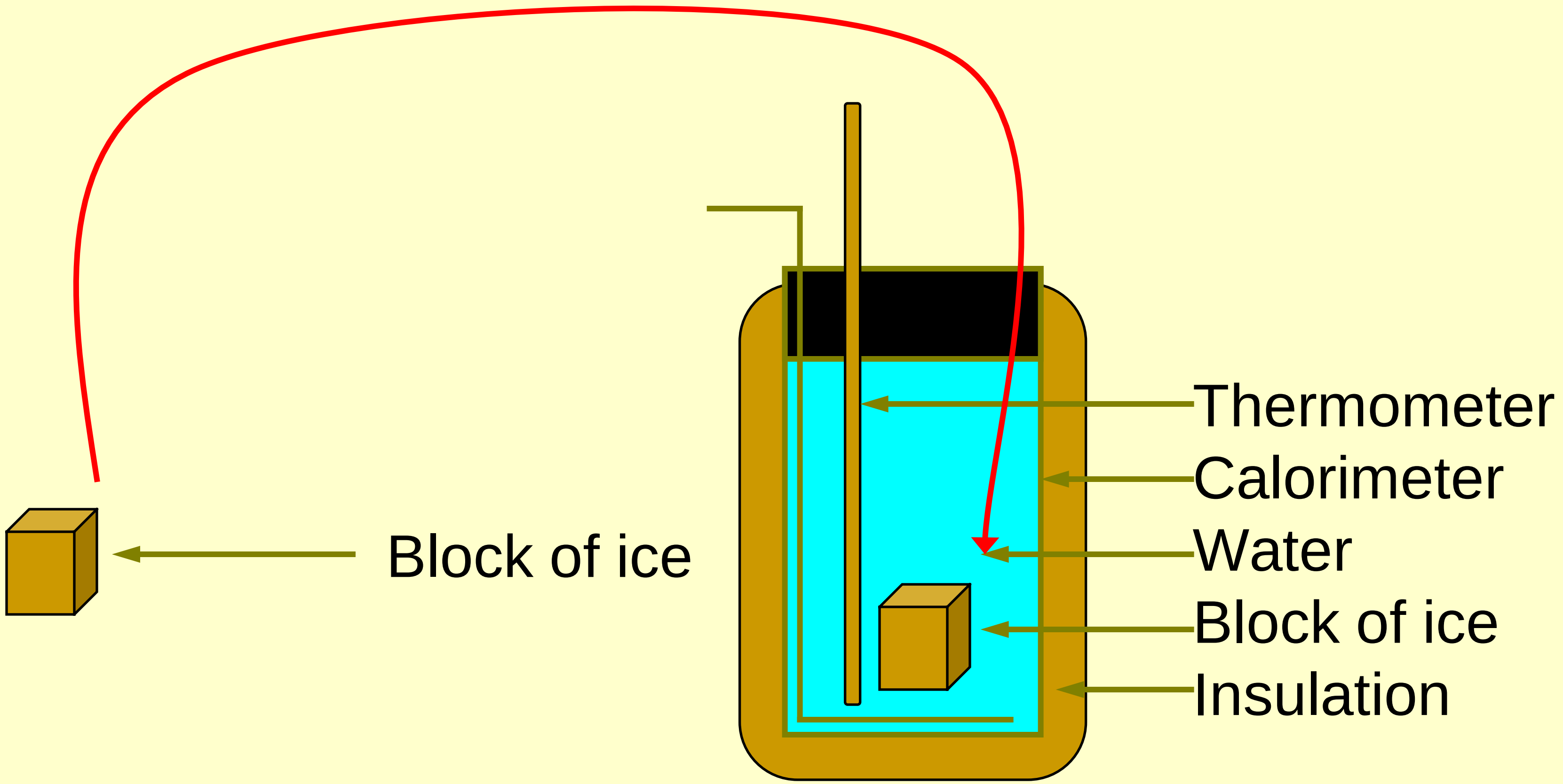


- When dealing with questions think about
  - where the heat is being given out
  - where the heat is being absorbed
  - try not to miss out any part

Methods of finding Latent Heat

- Using similar methods as for specific heat capacity
- The latent heat of fusion of ice can be found by adding ice to water in a calorimeter

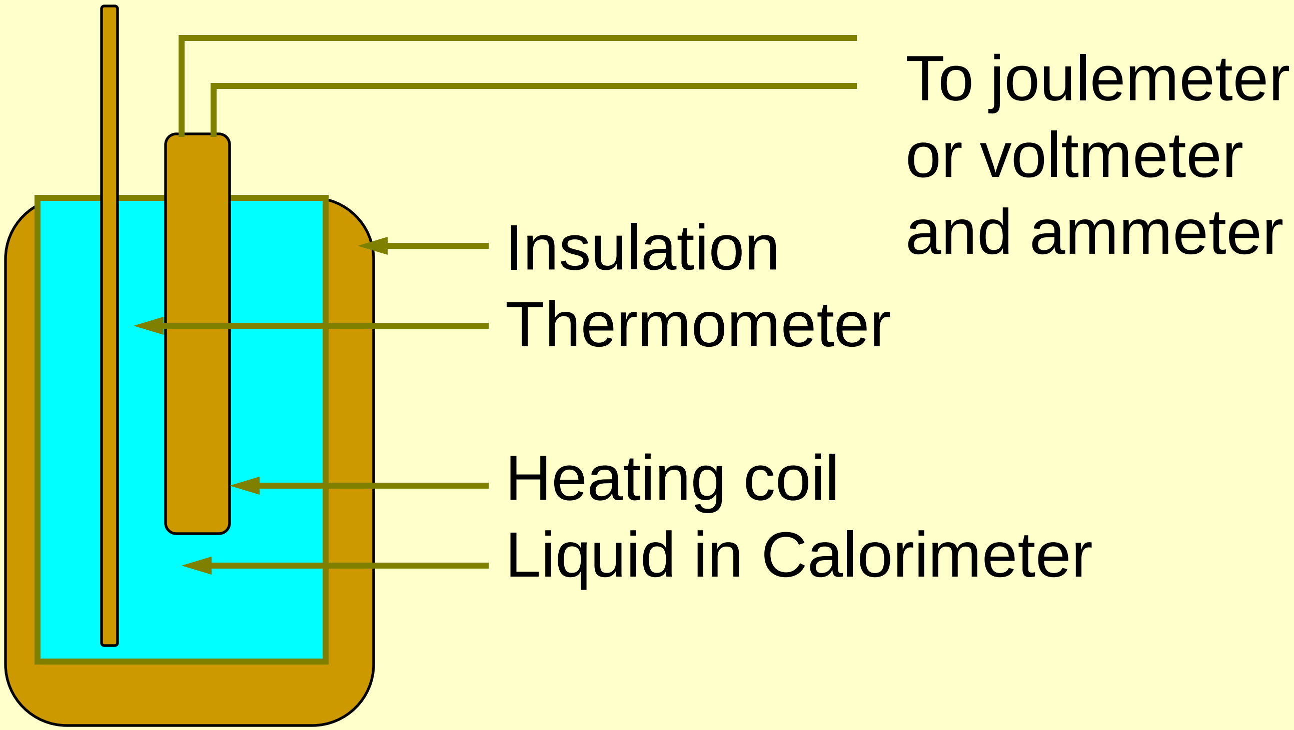
Apparatus


Block of ice
Thermometer
Calorimeter
Water
Block of ice
Insulation

- The change in temperature is recorded and from this the latent heat of fusion of the ice can be found
- Energy gained by block melting = Energy lost by liquid and calorimeter
- $m_b L_b = m_w c_w \Delta T_w + m_c c_c \Delta T_c$
- the SHC of water and the calorimeter are needed

- The latent heat of vaporisation of a liquid could be found by an electrical method

Latent Heat of Vaporisation



- The initial mass of the liquid is recorded
- The change in temperature is recorded for heating the liquid to boiling
- The liquid is kept boiling
- The new mass is recorded
- Energy supplied by heater = energy to raise temperature of liquid + energy use to vaporise some of the liquid
- (The calorimeter also needs to be taken in to account.
- $V\ I\ t = m_l\ c_l \Delta T_l + m_e\ L_e + m_c\ c_c \Delta T_c$

Pressure

- Pressure can be explained by the collisions with the sides of the container
- If the temperature increases, the average KE of the particles increases
- The increase in velocity of the particles leads to a greater rate of collisions and hence the pressure of the gas increases as the collisions with the side have increased
- Also the change in momentum is greater, therefore greater force

Pressure continued

- When a force is applied to a piston in a cylinder containing a volume of gas
- The particles take up a smaller volume
- Smaller area to collide with
- And hence collisions are more frequent with the sides leading to an increase in pressure

- Also, as the piston is being moved in
- It gives the particles colliding with it more velocity
- Therefore they have more KE
- Therefore the temperature of the gas rises.

Collisions

- Because the collisions are perfectly elastic
- There is no loss of KE as a result of the collisions

An Ideal Gas

- Is a theoretical gas that obeys the gas laws
- And thus fit the ideal gas equation exactly

Real Gases

- Real gases conform to the gas laws under certain limited conditions
- But they condense to liquids and then solidify if the temperature is lowered
- Furthermore, there are relatively small forces of attraction between particles of a real gas
- This is not the case for an ideal gas

The Kinetic Theory of Gases

- When the moving particle theory is applied to gases it is generally called the kinetic theory
- The kinetic theory relates the macroscopic behaviour of an ideal gas to the microscopic behaviour of its molecules or atoms

The Postulates

- Gases consist of tiny particles called atoms or molecules
- The total number of particles in a sample is very large
- The particles are in constant random motion
- The range of the intermolecular forces is small compared to the average separation

The Postulates continued

- The size of the particles is relatively small compared with the distance between them
- Collisions of a short duration occur between particles and the walls of the container
- Collisions are perfectly elastic

The Postulates continued

- No forces act between the particles except when they collide
- Between collisions the particles move in straight lines
- And obey Newton’s Laws of motion

Macroscopic Behaviour

- The large number of particles ensures that the number of particles moving in all directions is constant at any time