Topic
19b

The infra-red image of a head shows the distribution of heat. Different colours indicate different temperatures. Which do you think are the warmest regions?

Thermal Properties of Matter

contents

internal energy

Energy contained inside a substance is called the internal energy.

- exists in the form of kinetic energy (due to motion) and potential energy (due to intermolecular forces which depends on spacing between molecules)
- Internal energy = k.e. + p.e. of molecules

internal energy

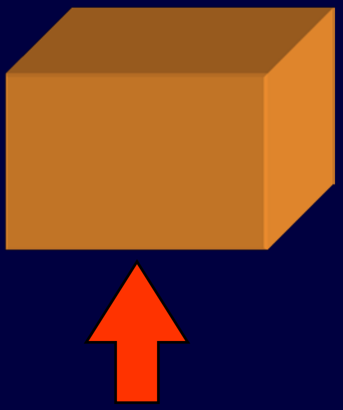
1. when <u>temperature</u> of substance <u>rises</u>, internal energy <u>increases</u>
   - due to increase in <u>kinetic energy</u> of molecules (increase in speed of motion)
2. when substance changes from <u>solid</u> to <u>liquid state</u>, internal energy increases
   - due to increase in potential energy of molecules: work is done to increase the spacing between molecules is stored as p.e.
   - k.e. constant, since temperature constant

heat capacity C of an object

The amount of heat required to raise the temperature of the object by 1K or 1°C.

- SI unit is J K^{-1} or J $°C^{-1}$
- different substances have different heat capacities

$$C = \frac{Q}{\Delta\theta}$$



temperature changes by θ°C

Q joules of heat

specific heat capacity c of an object

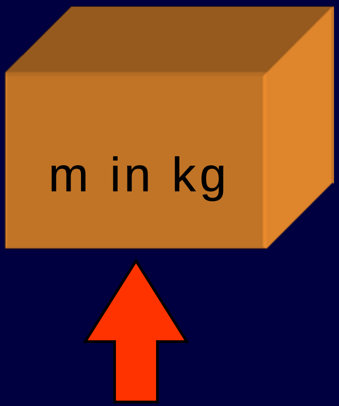
The amount of heat required to raise the temperature of 1 kg of the substance through 1 K or 1 °C.

- SI unit is J/(kg K)$^{-1}$ or J kg^{-1} K^{-1} or J kg^{-1} °C^{-1}

- substances with a high specific heat capacity warm up (or cool) more slowly than substances with a lower heat capacity because they must absorb (or lose) more heat to raise (or lower) the temperature

$$c = \frac{Q}{m\Delta\theta}$$

$$Q = mc\Delta\theta$$



Example 1

An electric heater of power 800 W raises the temperature of 4.0 kg of a liquid from 30 °C to 50 °C in 100 s. Calculate

(a) the heat capacity of the 4.0 kg liquid;

[Ans: 4000 J/°C or 4000 J °C^{-1}]

(b) the specific heat capacity of the liquid.

[Ans: 1000 J/(kg°C) or 1000 J kg^{-1} °C^{-1}]

One state

Example 2

A 2kW steel kettle of mass 1 kg contains 1.5 kg of water at 30 °C. What is the time taken to boil the water, if the specific heat capacity of steel is 460 J/(kg°C), and the specific heat capacity of water is 4200 J/(kg°C)? [Ans: 237 s]

specific heat capacity

effects and applications of the high specific heat capacity of water

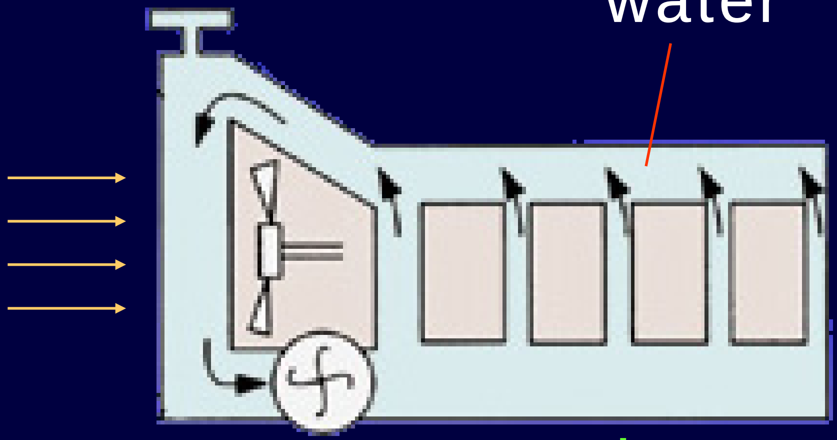
Water has a high specific heat capacity compared to other substances.

- water needs a lot of energy to warm it up; once it is warm, it holds a large store of thermal energy
- loss of a large amount of energy causes a small drop in temperature
- temperature of sea rises and falls very slowly

effects and applications of the high specific heat capacity of water

The high specific heat capacity of water (as well as its relative cheapness and availability) accounts for its use

- as the circulating liquid in central heating systems
- as a cooling liquid in car engines
- as hot water bottles to keep people or things warm

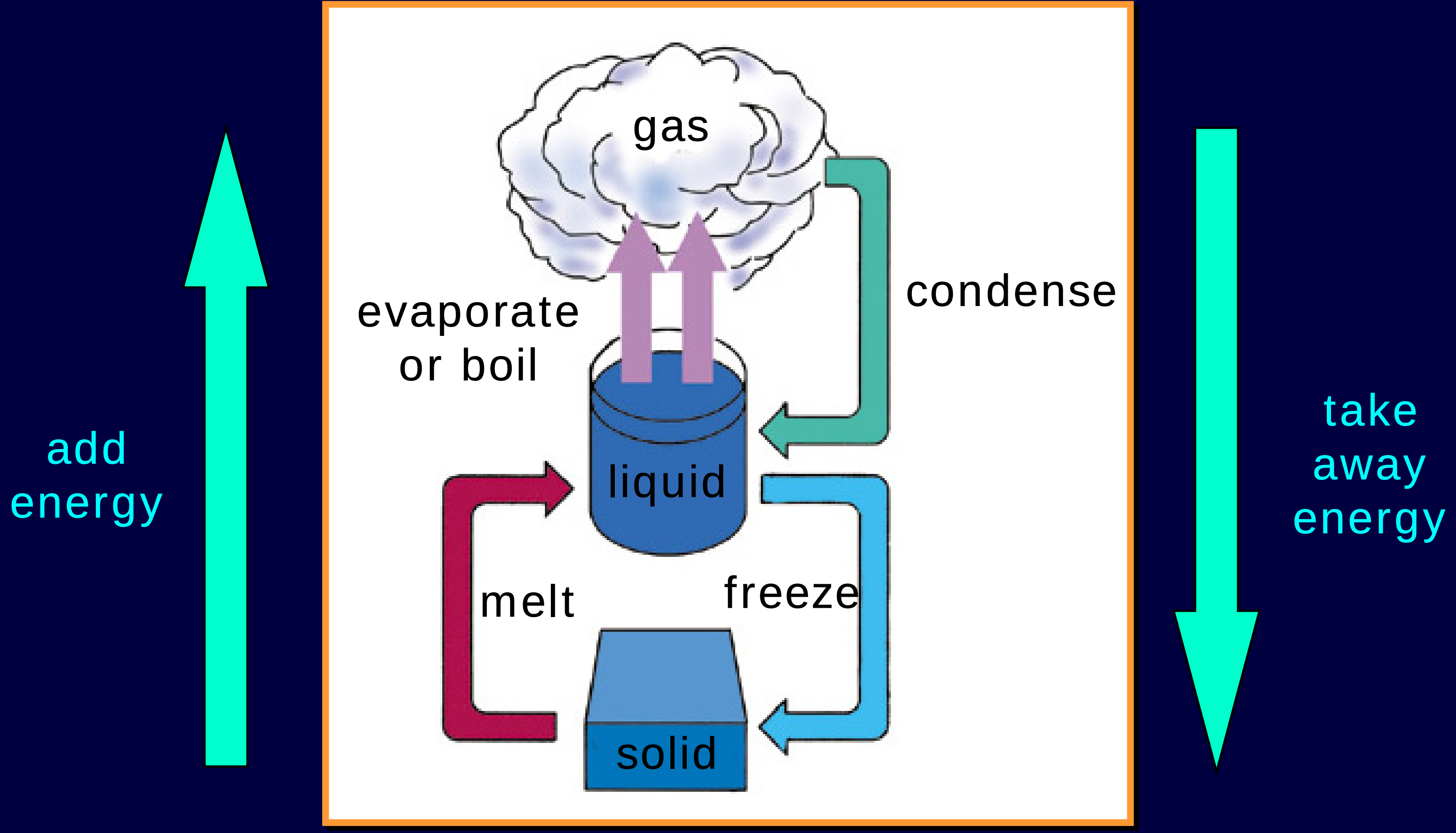


car engines

hot water bottle

melting, boiling and evaporation

Energy is involved in changes of state.



At each stage, what is the change in internal energy, k.e. and p.e.?

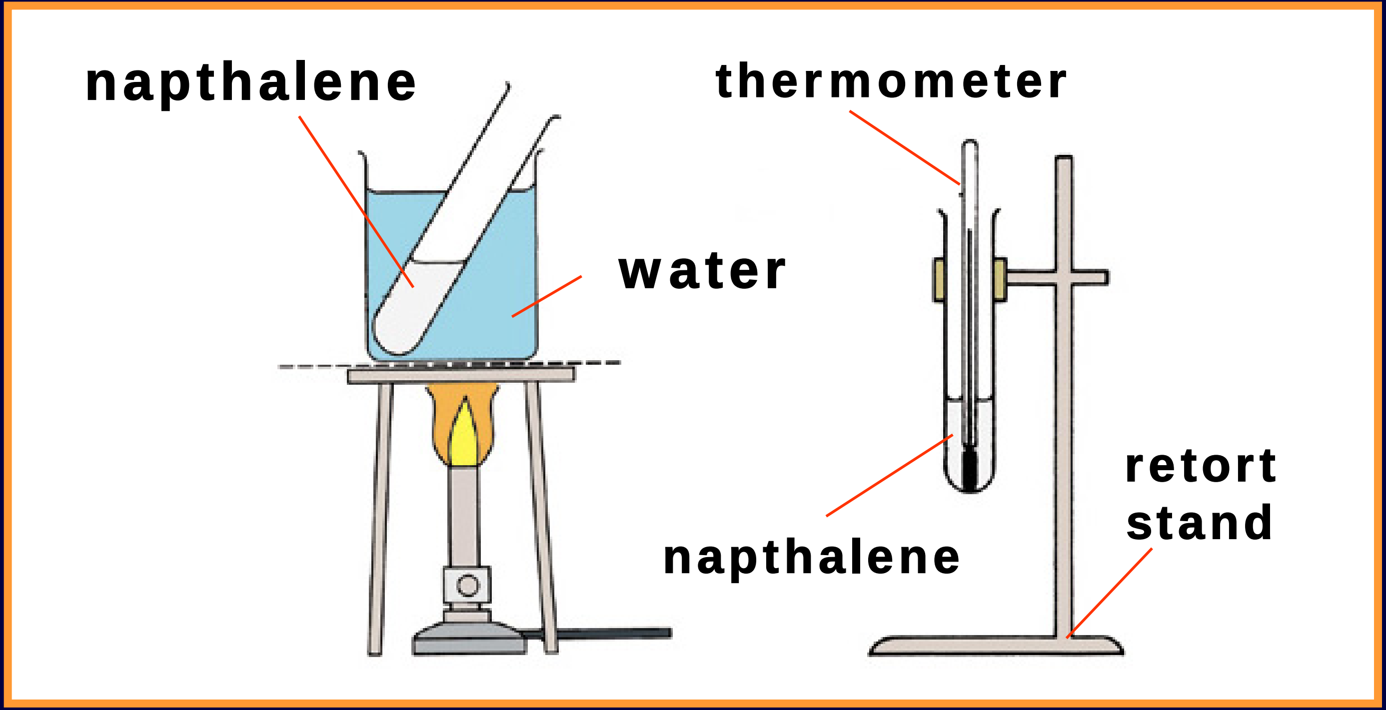
melting and freezing (solidification)

Melting	Freezing
A process in which a substance changes its state from solid to liquid	A process in which a substance changes its state from liquid to solid
For a pure substance, melting occurs at a definite (constant) temperature - melting point	For a pure substance, freezing occurs at a definite (constant) temperature - freezing point

Different substances have different melting and freezing points.

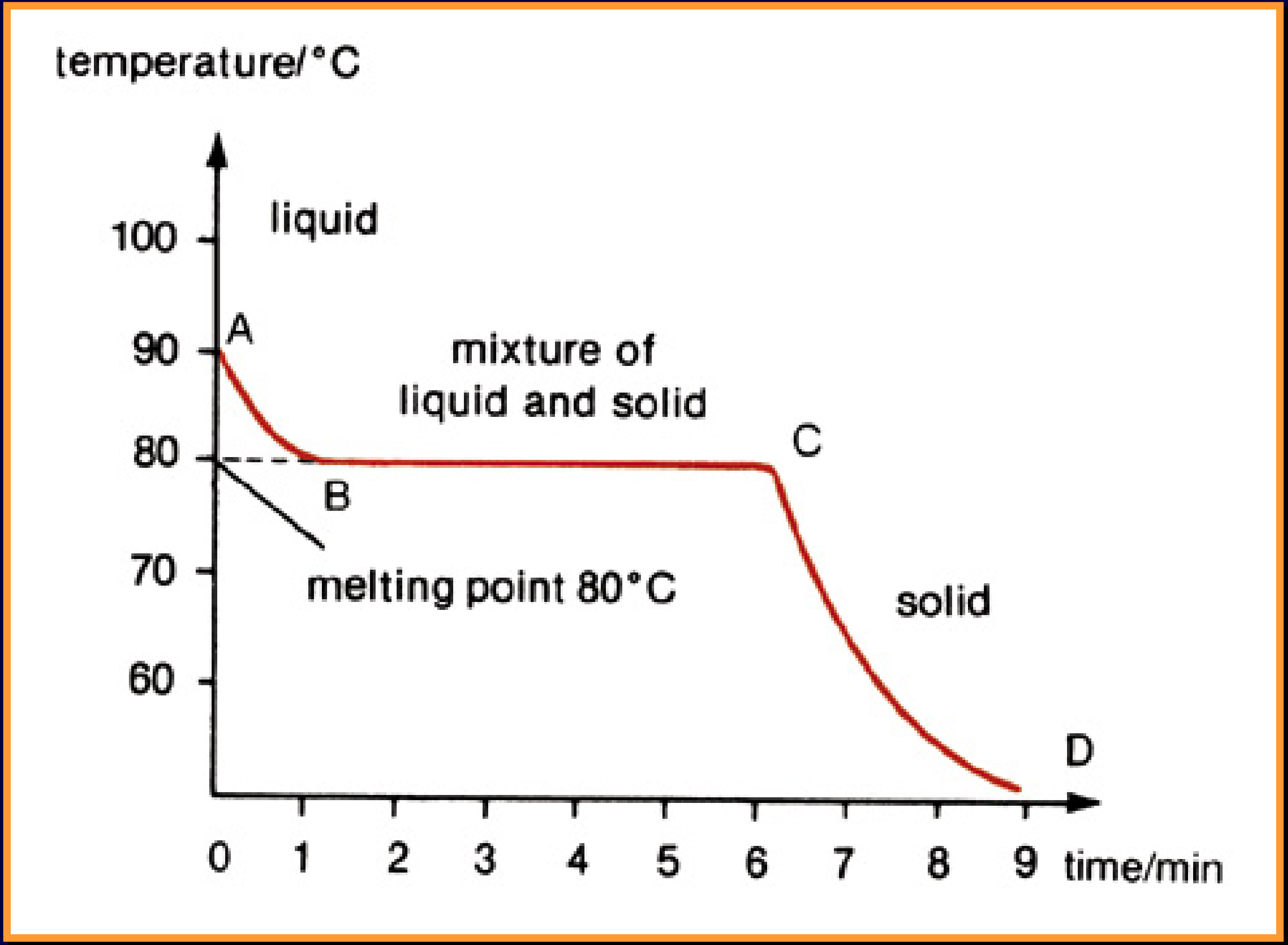
melting point

The melting point for a substance can be determined by conducting an experiment and plotting the cooling curve.



determination of melting point of naphthalene

The horizontal line indicates the melting point.



cooling curve of naphthalene

latent heat of fusion

The heat that is absorbed without a change in temperature is termed latent heat of fusion (melting) of the substance.

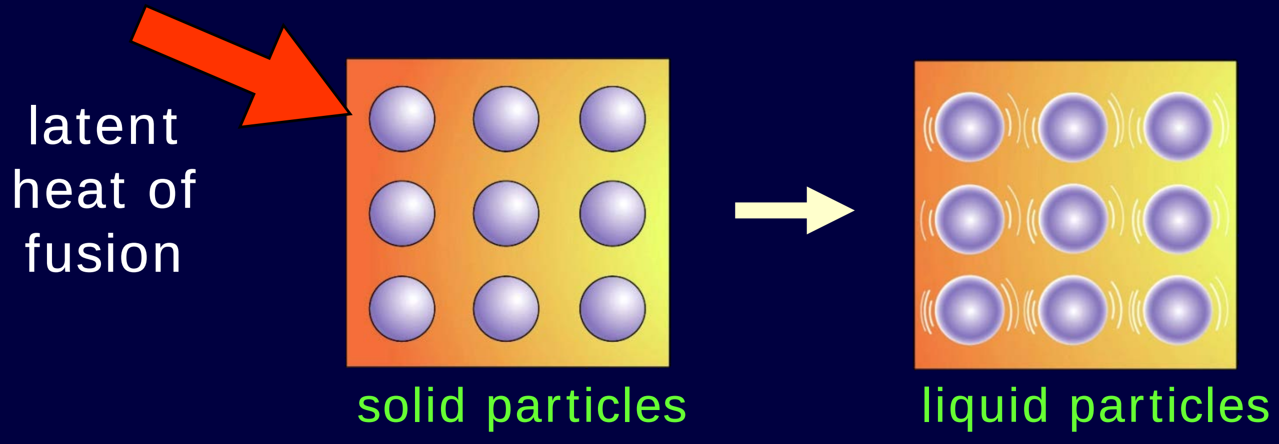
When a liquid freezes, latent heat is released without any change in its temperature.

latent heat in terms of molecular behaviour (melting)

The total energy in molecules (or internal energy in substance) consists of:

- kinetic energy of molecules that depends on temperature
- potential energy of molecules that depends on the force between the molecules and their distance apart

latent heat in terms of molecular behaviour (melting)



- as solid melts into liquid, molecules in liquid state have a wider range of movement than in the solid state; latent heat of fusion is absorbed; potential energy increases
- as liquid becomes gas, energy (latent heat of vaporisation) is required to separate molecules against their mutual attraction; no increase in kinetic energy because there is no rise in temperature

effect of impurities on the melting point of water

Any impurities added to pure water will lower the melting (freezing) point of the mixture.

- salt is commonly used for lowering the melting point of water by about 4 °C
- antifreeze substances are applied to car cooling systems to prevent water inside from freezing and expanding

effect of pressure on the melting point of water

Pressure applied to ice lowers the melting (freezing) point.

- when ice changes to water, its volume decreases
- high pressure applied to ice causes the volume to decrease; helps ice to melt
- applications include ice-skating, two pieces of ice taken from the freezer sticking together and snow squeezed into a snowball

boiling and condensation

Boiling	Condensation
A process in which a substance changes its state from the liquid state to the gaseous state	A process in which a substance changes its state from gaseous to liquid state
For a pure substance, boiling occurs at a definite (constant) temperature - boiling point	For a pure substance, condensation occurs at a definite (constant) temperature - condensation point

latent heat of vaporisation

The heat that is gained or released without any rise in temperature is called the latent heat of vaporisation.

When a liquid boils, latent heat is gained without any change in its temperature.

effect of impurities on the boiling point of water

Any impurities added to pure water will raise the boiling point of the mixture.

- mixture needs higher temperature to boil
- salt is commonly used for raising the boiling point of water by about 1 °C

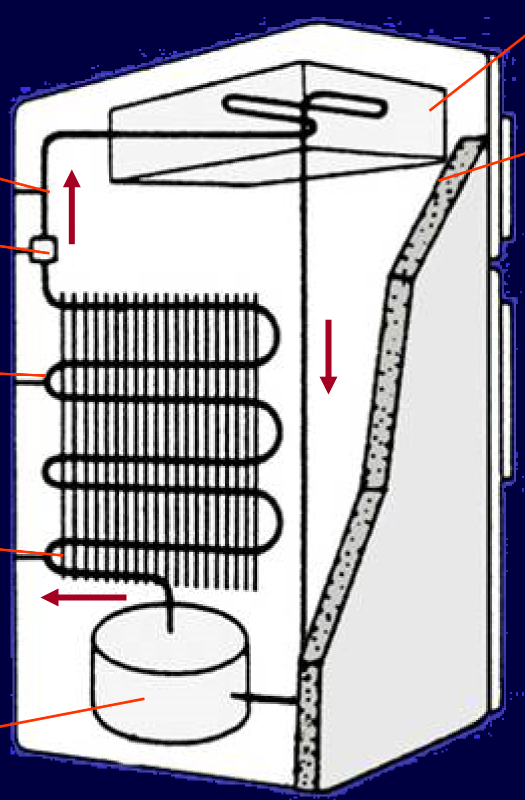
effect of pressure on the boiling point of water

Pressure applied to water increases the boiling point.

- when water changes to steam, its volume increases
- high pressure applied to water opposes expansion (boiling); helps water to boil at higher temperature than 100 °C

the refrigerator

The household refrigerator uses a gas called freon which is liquefied under pressure. [Refer textbook]

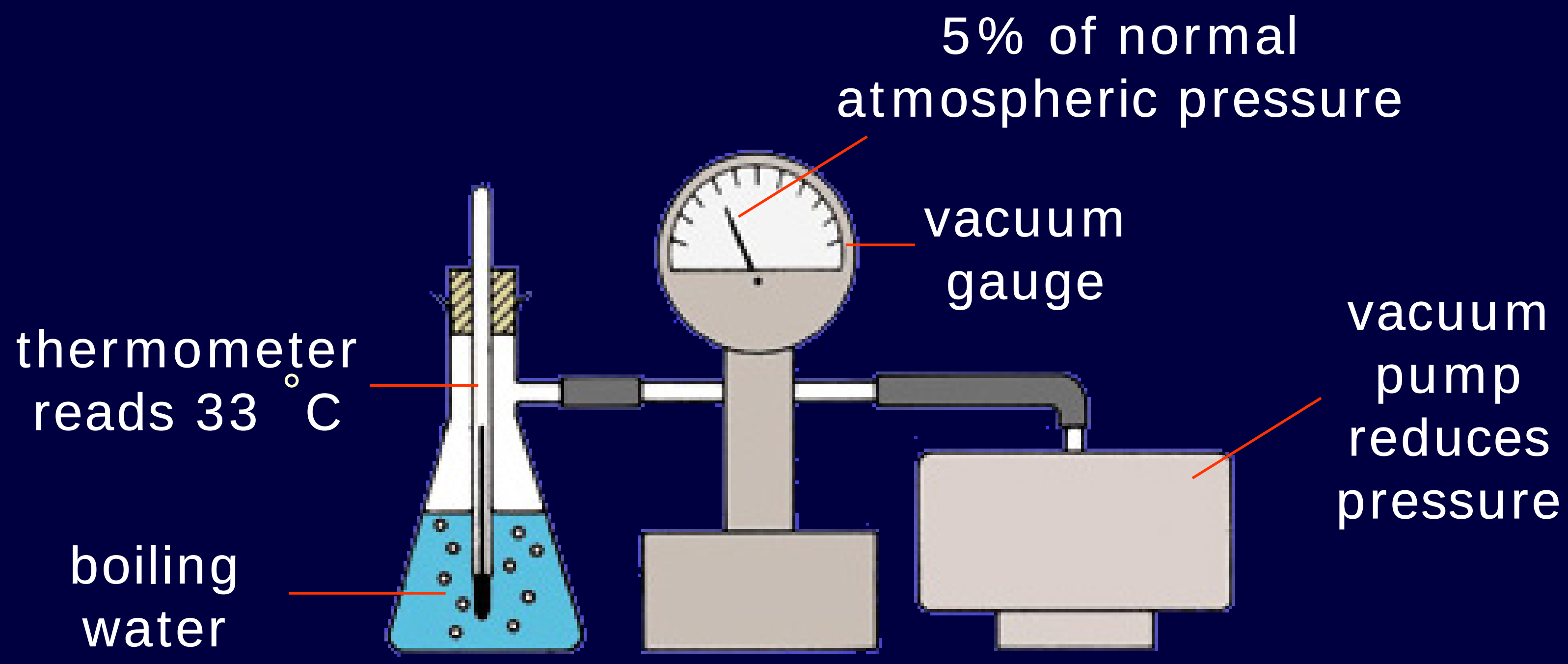


An adjustable thermostat is used to control the temperature in the refrigerator.

boiling under reduced pressure

An experiment can be conducted to show the effect of pressure on the boiling point.

- increased pressure increases boiling point
- reduced pressure decreases boiling point



boiling under reduced pressure

Boiling at low temperatures

- requires less energy to boil off unwanted water
- is cheaper because less fuel is used
- applications include production of sugar and evaporated milk

boiling under increased pressure

- increased pressure increases boiling point
- applications include the autoclave pressure cooker and aerosol sprays

aerosol

pressure cooker

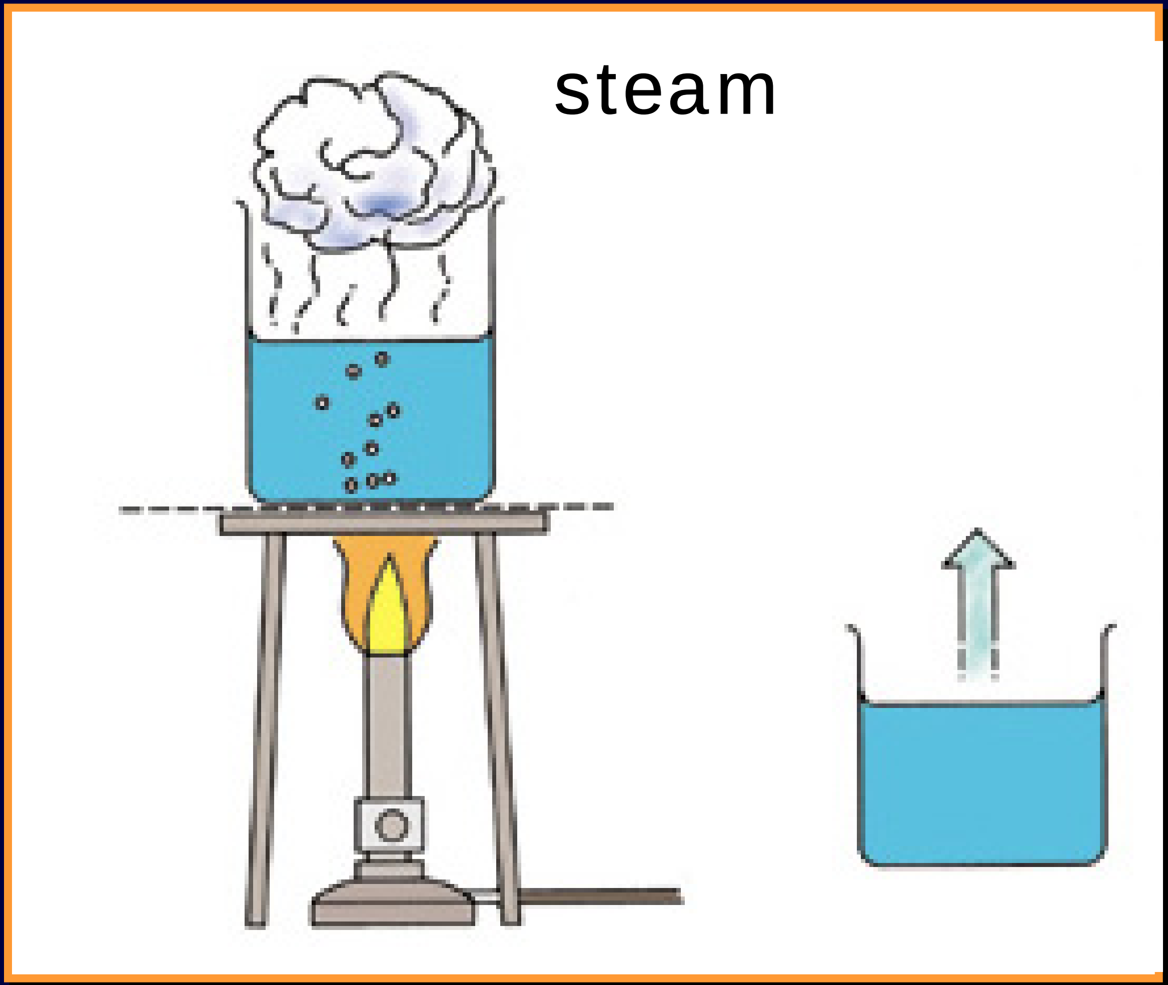
effect of pressure and impurities on <u>water</u>

	Melting Point	Boiling Point
Effect of impurities	decreases	increases
Effect of higher pressure	decreases	increases

effect of pressure on other substances

	Melting Point	Boiling Point
Effect of higher pressure	**<u>increases</u>**	increases

evaporation and boiling



boiling evaporation

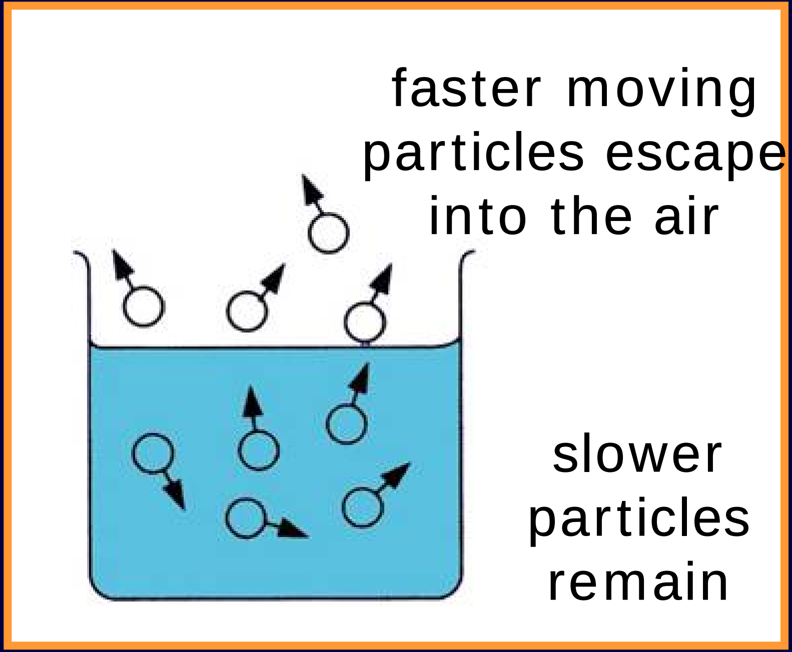
Boiling	Evaporation
A process in which a substance changes its state from the liquid state to the gaseous state	Evaporation is a process whereby the water changes into vapour without boiling
Quick	Slow
Bubbles are formed	No bubbles formed
Occurs throughout the liquid	Takes place only from the exposed surface of the liquid
Occurs at a definite temperature --- boiling point	Occurs at all temperatures
Source of energy needed	Energy supplied by surroundings

Factors Affecting Rate of Evaporation	
Temperature	Higher temperature ⇒ faster rate of evaporation
Area of exposed surface	Greater exposed surface area ⇒ faster rate of evaporation
Humidity of surrounding air	Higher humidity ⇒ slower rate of evaporation
Motion of air	Greater motion of the air ⇒ faster rate of evaporation
Pressure	Lower external pressure ⇒ faster rate of evaporation
Nature of liquid	Lower boiling point ⇒ faster rate of evaporation

explanation of cooling by evaporation

Cooling by evaporation can be explained by using kinetic theory. The particles of a liquid are in continuous motion at different speeds.

- average kinetic energy of particles is proportional to the temperature of the liquid
- occurs when faster-moving particles escape from the surface of the liquid, leaving behind particles having slower speeds



- average speed (kinetic energy) remaining in the liquid decreases and temperature falls

specific latent heat of fusion and vaporisation

Specific Latent Heat of Fusion (l_f)	Specific Latent Heat of Vaporisation (l_v)
The quantity of heat needed to change a unit mass of the substance from **solid state to liquid state** without a temperature change	The quantity of heat needed to change a unit mass of the substance from **liquid state to vapour state** without a temperature change
SI unit is J/kg	SI unit is J/kg

$$Q = m \times l_f$$

$$Q = m \times l_v$$

Problem solving strategy

- **Law of conservation of energy**
- thermal energy supplied ➔ $E = P \times t$
- change in temperature ➔ $Q = mc\Delta\theta$
- change of state ➔ $Q = ml$

Key steps

1. Apply law of conservation of energy using word equation
2. Apply equations for thermal energy using suitable formulae and symbols
3. Simplify equations
4. Substitute values and solve equation

Case 1

heat **supplied** (by electrical heater or other source) = thermal energy gained for temperature change of body A + thermal energy used for change of state of body B + + +

$$P \times t = mc\Delta\theta + ml \quad + + +$$

Change one state

Case 2

thermal energy **lost** for temperature **drop** and/or change of state in bodies 1 and 2 = thermal energy **gained** for temperature **rise** and/or change of state of bodies 3 and 4

E.g.

$$(m_1 c_1 \Delta\theta_1 + m_2 l_2) = (m_3 c_3 \Delta\theta_3 + m_4 l_4)$$

cooling, freezing = warming, melting

Case 3

combinations of **Case 1** and **Case 2**

Change two state

Example 3

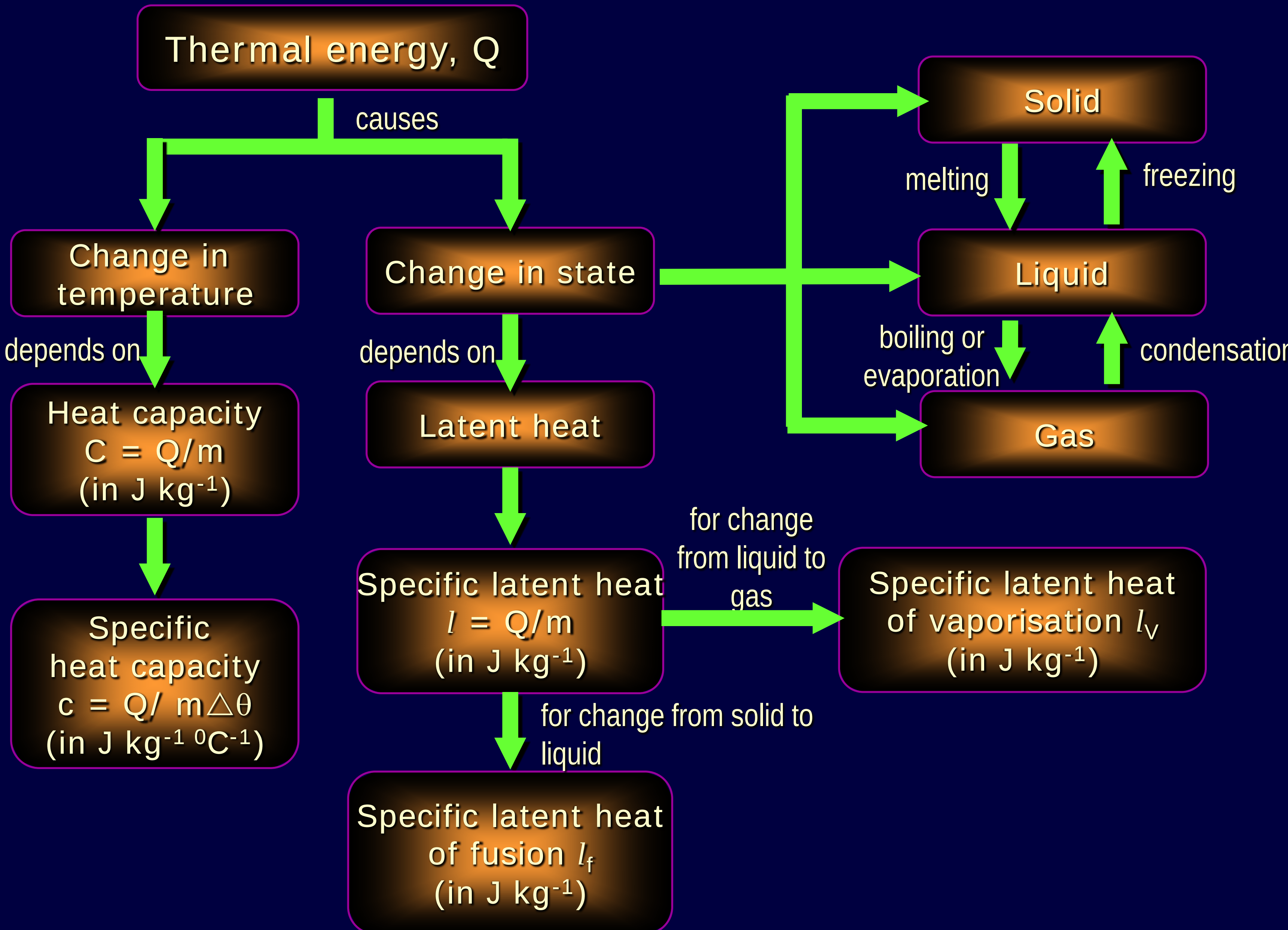
What is the amount of energy required to change 10 g of ice at 0 °C to water at 20 °C?

[Specific latent heat of fusion of ice = 336 J/g, specific heat capacity of water = 4.2 J/(g°C).]

[Ans: 4200 J]

Example 4

A glass contains 250 g of hot tea at 90 °C. What is the minimum amount of ice at 0 °C needed to cool the drink to 0 °C? [Specific latent heat of fusion of ice = 336 J/g, specific heat capacity of tea = 4.2 J/(g°C).] [Ans: 281 g]


Thermal energy, Q
causes
Change in temperature
depends on
Heat capacity
C = Q/m
(in J kg-1)
Specific heat capacity
c = Q/ m△θ
(in J kg-1 0C-1)
Change in state
depends on
Latent heat
Specific latent heat
l = Q/m
(in J kg-1)
for change from liquid to gas
Specific latent heat of vaporisation lv
(in J kg-1)
for change from solid to liquid
Specific latent heat of fusion lf
(in J kg-1)
Solid
melting
freezing
Liquid
boiling or evaporation
condensation
Gas