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Thermal Physics and Matter

GCSE overview

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Density

- **Density is the mass of each unit of volume of a material.**
- $\text{Density} = \frac{\text{Mass}}{\text{Volume}} \qquad \rho = \frac{m}{V}$
- **Density is measured in kg/m³ or g/cm³.**
- **Water has a density of about 1.00g/cm³ or 1000kg/m³.**
- $\frac{1\text{g}}{\text{cm}^3} = \frac{0.001\text{kg}}{(0.01\text{m})^3} = \frac{0.001\text{kg}}{0.000001\text{m}^3} = \frac{1000\text{kg}}{\text{m}^3}$

Measuring Density

- Regular solid object
  - measure side lengths
  - calculate volume
- Liquid
  - measure volume in measuring cylinder
- Irregular solid object
  - insert object into beaker already full of water (or Eureka can)
  - catch the spilled water in a measuring cylinder
- Mass measured on balance
  - ensure balance is zeroed

Density practice

1. Calculate the density of a solid if a 3cm x 2cm x 5cm block has a mass of 55g.

2. Calculate the mass of 300cm^3 of an oil which has a density of 700kg/m^3.

3. What is the volume of a stone which displaces 32g of the oil mentioned in q2?

Internal energy

- Internal energy is the total potential and kinetic energies of the molecules/atoms in a substance.
- Internal energy increases when you
  - raise the temperature (this mainly increases the kinetic energy)
  - change the state from solid to liquid or liquid to gas (this mainly changes the potential energy)
- You can raise the internal energy by
  - putting the object in contact with something at a higher temperature (heating it), or
  - applying a force to compress it (doing work on it)

Heat capacities

- Specific heat capacity *c* = energy required to raise the temperature of 1kg of the material by 1°C.
- Water has a high specific heat capacity: 4180 J/(kg°C)
- Equation: $E = mc\Delta T$, where *m* is mass, ΔT is temp. change
- Sometimes this equation is used together with
  - $E = VIt$ if the material is electrically heated
    V is the voltage, *I* is the current, *t* is the time
  - $E = Pt$ if you know the *P*, the power of the heater

Heat capacity practice

1. Calculate the energy released when 2.5kg of water cools from 85°C to 40°C. shc of water = 4180 J/(kg°C)

2. A 2.00kg block of aluminium was heated using a 12V, 6A heater from 25°C to 35°C in 320s. Calculate the specific heat capacity of aluminium.

3. How much water could a 3kW heater heat each second if it needs to raise the temperature of the water by 30°C?

States of matter

- Solid – eggs in crate – as temperature increases, atoms vibrate more vigorously. Shape and volume fixed.
- Melting – regular arrangement breaks down, molecules can translate – higher potential energy as attracting molecules are now further apart.
- Liquid – maggots in a tray – as temperature increases, atoms move more quickly. Volume fixed, but shape is not.
- Boiling – molecules break free of the bulk – higher potential energy as molecules are now further apart and faster
- Gas – balls in a pin ball machine – as temperature increases, molecules move more quickly (have higher mean kinetic energy). No fixed volume.
  - Average kinetic energy proportional to temperature above absolute zero.

Latent heat

- Specific latent heat of fusion = energy required to change 1kg of the material from solid to liquid without changing its temperature.
- Specific latent heat of vaporization = energy required to change 1kg of the material from liquid to gas without changing its temperature.
- Equation: $E = mL$, where L is specific latent heat in J/kg

Latent heat practice

Specific heat capacity of ice = 2100 J/(kg°C)
Specific heat capacity of water = 4180 J/(kg°C)
Latent heat of fusion of ice = 33.5 kJ/kg
Latent heat of vaporization of water = 2.26 MJ/kg

1. How much ice can 1MJ melt?

2. How much energy needs to be given to 1.5kg of water at 17°C to heat it to boiling point and then boil it?

Gas pressure

- Gas pressure depends on
  - frequency of collisions between molecules and the walls
  - speed of the molecules
- When volume is halved
  - pressure doubles as molecules hit the walls twice as often, even though they are not travelling any faster
  - pressure and volume are inversely proportional if temp constant
  - Boyle's Law $p_1V_1 = p_2V_2$ where 1 means 'before', 2 means 'after'
- When temperature is raised
  - pressure increases as kinetic energy of molecules rises (proportional to temperature in kelvin), and this means that
    - molecules strike the walls more often, and
    - when they do strike, there is a larger momentum change

Boyle's law – example and practice

› Calculate the new pressure if $10cm^3$ of gas initially at 101kPa is compressed to $8cm^3$.

1. Calculate the new volume if 24L of gas reduces in pressure from 101kPa to 90kPa.

2. Calculate the extra pressure to reduce the volume of 50L of gas to 8L. Assume the starting pressure is 101kPa.

Pressure

- **Pressure measures how tightly a force is 'focused' on a point.**
- $\text{Pressure} = \frac{\text{Force}}{\text{Area}}$ $p = \frac{F}{A}$ **Unit: N/cm² or N/m² = Pa**

$$\frac{1\text{N}}{\text{cm}^2} = \frac{1\text{N}}{(0.01\text{m})^2} = \frac{1\text{N}}{0.0001\text{m}^2} = \frac{10000\text{N}}{\text{m}^2} = 10\,000\text{Pa}$$

Low Pressure = little damage	High Pressure = lots of damage
Same force, large surface area	Same force, small surface area
Flat end of drawing pin	Sharp end of drawing pin
Snow shoes, wide wheels on tractors	most tools, ice skates, nails

Hydraulics

› **Liquid flows until pressures are equal.**

Left cylinder	Pressure	Right cylinder
Force		Force
Area		Area

Pressure practice

1. Atmospheric pressure is 101kPa. What is the force on a 5.0cm x 7.0cm window in a space station?

2. The pressure needed to damage a wood block is 3kN/cm^2. What force is needed on a 1mm^2 pin to push a hole?

3. I wish to lift a 20kN car using a force of 20N. If the control cylinder has a cross section area of 10cm^2, what will be the area of the cylinder under the car?

Pressure at depth

Extra pressure at depth d in fluid of density ρ is given by

$$p = \rho g d$$

Example: depth of water needed to add one atmosphere (101kPa) of pressure

Pressure at depth practice

1. What is the total pressure 50m below the surface of seawater ($\rho = 1030$ kg/m³)?

2. Air near the ground has a density of 1.2 kg/m³. What will be the drop in pressure when you climb a 310m building?

3. Complete the diagram to show the level of the water in the other tubes

Links

GCSE Topic Revision

https://isaacphysics.org/pages/gcse_topic_index#gcse_revision

Consolidation Programme

https://isaacphysics.org/pages/summer_programmes_2021