Thermal Physics

A-level overview

isaacphysics.org
https://isaacphysics.org/pages/remote_learning

Heat Capacity

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 or 1K
- Water has a high specific heat capacity: 4180 $\mathrm{Jkg^{-1}K^{-1}}$
- 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

Mixtures example 1

Specific heat capacities: water 4180$Jkg^{-1}K^{-1}$, iron 435$Jkg^{-1}K^{-1}$

What is the final temperature when you mix 2.1kg of water at 87°C with 6.4kg of water at 15°C?

Mixtures example 2

Specific heat capacities: water $4180 Jkg^{-1}K^{-1}$, iron $435 Jkg^{-1}K^{-1}$

100g of iron pellets are immersed in 3kg of 15.0°C water, and the temperature rises to 18.0°C. What was the initial temperature of the pellets?

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. **A shower heater heats 35g of water each second using a 3.2kW heater. If the water goes in at 17**°C, at what temperature does it come out**?**

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

Mixtures example 3

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

What will the final temperature be if 40g of ice at -17°C is dropped into 150g of water initially at 25°C?

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 water can 1MJ boil?**

2. **How much energy needs to be given to 1.5kg of ice at -17°C to heat it to boiling point?**

Gases

Gas laws

$$pV = nRT$$
$$pV = Nk_BT$$

p (Nm^{-2}) pressure, V (m^3) volume, T (K) absolute temperature

n is number of moles, $N = nN_A$ number of molecules

R = 8.31 JK^{-1}mol^{-1} k_B = 1.38x10^{-23} JK^{-1} = $\frac{R}{N_A}$ N_A=6.02x10^{23}

Temperature in kelvin = Temperature in °C + 273

Amount of gas proportional to $\frac{pV}{T}$

If no gas leaks $\frac{p_1V_1}{T_1} = \frac{p_2V_2}{T_2}$

Density

Let mass of molecule be *m* (kg) and mass of mole be M_r (kg)

$$pV = nRT, \qquad \text{Density } \rho = \frac{\text{mass}}{\text{volume}} = \frac{nM_r}{V} = \frac{pM_r}{RT}$$

$$pV = Nk_BT, \qquad \text{Density } \rho = \frac{\text{mass}}{\text{volume}} = \frac{Nm}{V} = \frac{pm}{k_BT}$$

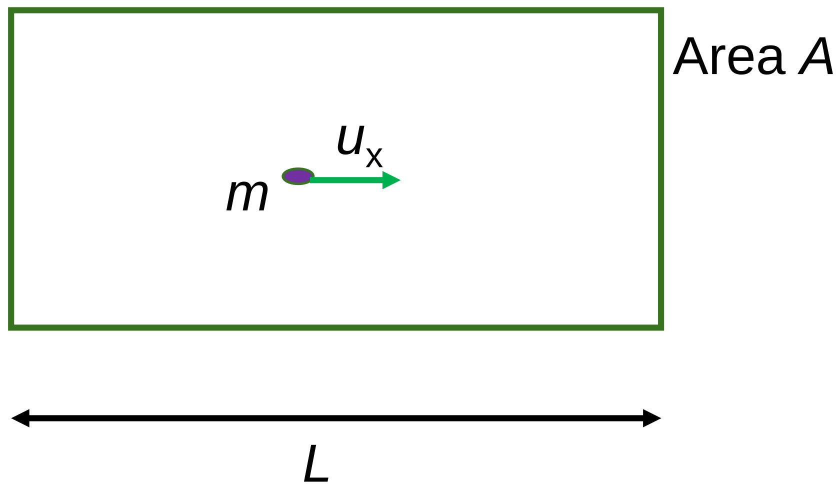
Gas practice

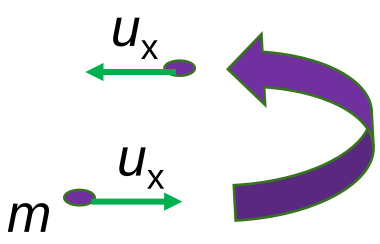
1. $30 cm^3$ of gas at 101kPa and 275K is compressed to $17 cm^3$. If the pressure is now 190kPa, what is the new temperature?

2. How many nitrogen molecules (m=4.65×10^{-27}kg) would there be in $300 cm^3$ of nitrogen at 101kPa and 35°C?

3. Calculate the density of helium (M_r=4.00g) at 101kPa and 17°C.

Kinetic theory





Time for round trip

Frequency of collisions

Momentum change

Momentum change each second

Pressure

Kinetic theory 2

$$c^2 = u_x^2 + u_y^2 + u_z^2$$

$$p = \frac{Nmu_x^2}{V}$$

$$\overline{c^2} = \overline{u_x^2} + \overline{u_y^2} + \overline{u_z^2}$$

$$\overline{c^2} = 3\overline{u_x^2}$$

$$pV = \frac{Nm\overline{c^2}}{3}$$

Mean kinetic energy

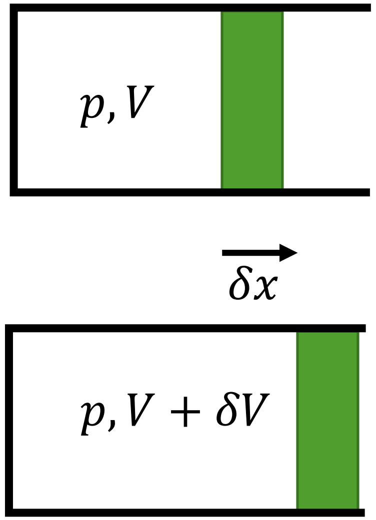
$$pV = Nk_BT = \frac{Nm\overline{c^2}}{3}$$

$$3k_BT = m\overline{c^2}$$

$$\text{Average kinetic energy} = \frac{m\overline{c^2}}{2} = \frac{3k_BT}{2}$$

For one mole, kinetic energy $= \frac{3RT}{2}$, so molar heat capacity=$\frac{3R}{2}$

Work done by gas



cross section
area A

Work done by gas

= Force x distance

= pressure x area x distance

= $p\ A\ \delta x = p\ \delta V$

Work done on gas

= $-p\ \delta V$

Kinetic theory practice

1. Calculate the mean kinetic energy of an oxygen molecule at 30°C.

2. Calculate the energy needed to raise the temperature of 0.24m^3 of 101kPa air at 280K by 3K.

Links

A Level Topic Revision

https://isaacphysics.org/pages/a_level_topic_index#a_level_revision

Consolidation Programme

https://isaacphysics.org/pages/summer_programmes_2021