Edexcel Physics A-level

Topic 9: Thermodynamics

Key Points

Temperature Changes

When an object is **heated**, whilst in a **constant state**, the temperature of the object will increase. This increase depends on the **energy** being transferred, the **mass** of the substance being heated and a property of the material known as the specific heat capacity.

Specific heat capacity is defined as the energy required to raise the temperature of 1kg of a given substance by 1 Kelvin, without changing its state.

The equation linking these factors is:

$$\Delta E = m\,c\,\Delta\theta$$

Where 'c' is specific heat capacity measured in $Jkg^{-1}K^{-1}$

Changes of State

For an object to **change state**, the particle arrangement of the substance must be changed. For this to happen, there must be a transfer of energy in order for **bonds** to be broken or created. The amount of energy required depends on the **mass** of the substance as well as the specific latent heat of the given substance.

In general, **specific latent heat** is the energy required to change the state of 1kg of a substance **without a change in temperature**.

There are two forms of specific latent heat:

1. **Specific latent heat of fusion** is used for the transition between solid and liquid
2. **Specific latent heat of vaporisation** is used for the transition between liquid and gas

$$\Delta E = m\, l$$

Where 'l' is specific latent heat measured in Jkg^{-1}.

Internal Energy

The **internal energy** of a substance is defined as the **sum** of the **randomly distributed potential** and **kinetic** energies of the particles that make up the substance.

When a substance undergoes a **temperature** change, the **kinetic energy** of the particles increases, resulting in an **increase** in the total internal energy of the substance.

This is because **temperature** is a measure of the **average kinetic energy** of the particles in the substance.

Kelvin and Absolute Zero

When carrying out thermodynamic calculations, the **Kelvin** scale of temperature must be used. The Kelvin scale is an **absolute scale** meaning it is based off the value of absolute zero.

At **absolute zero**, the particles in a substance will have **zero kinetic energy**.

To **convert** between the Kelvin scale and the Celsius scale:

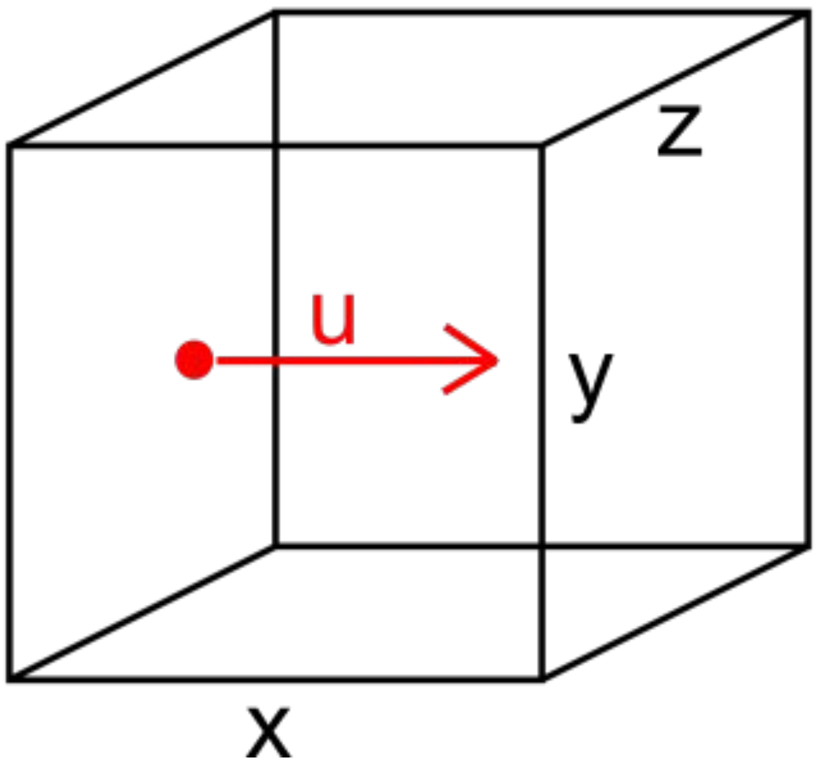
$$\text{Celsius} \xrightarrow{+273} \text{Kelvin}$$

$$-273°C = 0K$$

Assumptions in Kinetic Theory

- The motion of molecules is **random**
- Collisions between molecules are **elastic**
- The time taken for a collision is **negligible** compared to the time between collisions
- Molecules move in **straight** lines (at constant speed) between collisions
- All particles are **identical** and have same mass/volume
- **Intermolecular forces** are negligible (except during collisions)

Derivation of Force



Derivation of Force

1. Considering a single molecule with velocity 'U', we want to find the pressure it exerts on the wall:	$P = \frac{F}{A}$
2. First considering the force:	$F = \frac{\Delta mu}{t}$
3. In an elastic collision, the rebound velocity is the same as the collision velocity, except in the opposite direction so:	$F = \frac{-2mu}{t}$
4. We don't know the time taken for a collision, but we know that in the time taken to travel from one side of the box and back again, the collision has occurred, so we can say that:	$t = \frac{d}{u}$ $t = \frac{2x}{u}$
5. Combining the expression for force and time gives:	$F = \frac{-mu^2}{x}$

Derivation of Pressure

6. Substituting this force into the expression for pressure, and then dividing by the area of face 'yz' gives:	$P = \frac{F}{A}$ $P = \frac{-mu^2}{xyz}$
7. Then, noticing that the dimensions 'xyz' combined are equivalent to the volume (V) of the box, gives:	$P = \frac{mu^2}{V}$
8. However, this only considers the velocity of one molecule. Considering the root mean square speed of all 'N' molecules (and taking into account that this only represents the velocities in one of the three axis of motion possible) we get a final result of:	$P = \frac{1}{3} \frac{NmC_{rms}^2}{V}$

Boyle's Law

Boyle's law links the **pressure** and **volume** of a gas. It states that as volume decreases, the pressure on a gas at **constant temperature** increases. This can be expressed in equation form:

$$pV = Constant$$

By considering the particles in a **fixed quantity** of a substance, Boyle's Law can be explained:

- As the volume decreases, the particles become closer together
- This causes the **rate of collisions** to increase
- An increase in the rate of collisions leads to an increased **rate of change of momentum**
- Consequently the **force** on the container walls, and so the **pressure**, increases

Charles' Law

Charles' law links the **temperature** and **volume** of a gas. It states that as temperature increases, the volume of a gas at **constant pressure** increases. This can be expressed in equation form:

$$V/t = Constant$$

By considering the particles in a **fixed quantity** of a substance, Charles' Law can be explained:

- As temperature increases, the **average kinetic energy** of the particles increases
- Since the pressure is constant, the **rate of change of momentum** must remain constant
- To achieve this the **rate of collisions** should remain constant, but since particles are travelling faster, for this to happen they must become more separated
- This results in an increase in **volume**

Pressure Law

The pressure law links the **temperature** and **pressure** of a gas. It states that as temperature increases, the pressure of a gas of **constant volume** increases. This can be expressed in equation form:

$$p/t = Constant$$

By considering the particles in a **fixed quantity** of a substance, the Pressure Law can be explained:

- As temperature increases, the **average kinetic energy** of the particles increases
    - This means the particles are moving **faster** and so there is a higher **rate of collisions**
- Since the particles are moving faster and the rate of collisions is higher, the **rate of change of momentum** of the particles is increased
    - Consequently, the force on the container, and so the **pressure**, is increased

The Ideal Gas Law

If you combine **Boyle's Law**, **Charles' Law** and the **Pressure Law** into one equation, you produce the **ideal gas** law:

$$Constant = \frac{pV}{T}$$

The constant is dependant on the **number of moles** of gas in the given sample. A mole is a unit used to represent the **amount** of a gas. If the pressure and temperature are constant, a certain volume of gas will contain the **same** number of molecules, regardless of what gas it is. This number of molecules is known **Avogadro's constant**.

To replace the constant in the above equation with the number of moles (n), you must also use the **molar gas constant**, denoted by 'R':

$$pV = nRT$$

Another form of this equation is shown below, where N is the number of molecules and k is the Boltzmann constant.

$$pV = NkT$$

Kinetic Energy of a Gas Molecule

You can derive the equation for the kinetic energy of a gas molecule by equating the ideal gas equation and kinetic theory model equation as shown below:

$$pV = \tfrac{1}{3}Nmc_{rms}^2 \qquad pV = nRT$$

$$\tfrac{1}{3}Nmc_{rms}^2 = nRT$$

$$(n = N/N_A)$$

$$\tfrac{1}{3}Nmc_{rms}^2 = NRT/N_A$$

$$\tfrac{1}{3}mc_{rms}^2 = RT/N_A$$

$$(k = R/N_A)$$

$$\tfrac{1}{3}mc_{rms}^2 = kT$$

$$\tfrac{1}{2}mc_{rms}^2 = \mathbf{3/2\ kT}$$

Black Body Radiators

A **black body radiator** is a perfect emitter and absorber of all possible wavelengths of radiation. The following two laws can be applied to black body radiators:

- **Stefan-Boltzmann law** - the luminosity (L /power output) of a black body radiator is directly proportional to its surface area (A) and its absolute temperature (T) to the fourth power.

$$L = \sigma A T^4$$

- **Wien's law** - the peak wavelength (λ_{max}) of emitted radiation is inversely proportional to the absolute temperature (T) of the black body radiator.

$$\lambda_{max} T = 2.898 \times 10^{-3} \text{ m K}$$