

# Physics AS Module 2 - Mechanics and Molecular Kinetic Theory - Summary Notes

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Autumn 2007

Summary revision notes for the AQA GCE Advanced Level in Physics (Specification A) Unit 2 Mechanics and Molecular Kinetic Theory. These are not a substitute for working through one's textbook but should help with summarising and with providing a different way of thinking about a topic. This first version may be riddled with mistakes.

It should also be noted that this is based on my class notes. Some textbook content is not included. This is only the necessary as determined by my teachers and further filtered by me.

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# 1 Kinematics

## 1.1 Measuring movement

### 1.1.1 Distance, displacement, speed and velocity

Distance is a scalar while DISPLACEMENT is a vector, meaning displacement depends on both its magnitude and direction - *displacement,  $s$ , is the distance travelled in a given direction.* Speed is the magnitude of velocity.

$$\text{speed (ms}^{-1}\text{)} = \frac{\text{distance travelled (m)}}{\text{time taken (s)}}$$

$$\text{average speed} = \frac{\text{total distance covered}}{\text{total time taken}}$$

VELOCITY can be found using

$$v = \frac{s}{t}$$

Whilst average velocity can be found using the total displacement and the total time taken, instantaneous velocity can be found by using very small time intervals - where  $\Delta t$  is very small in

$$v = \frac{\Delta s}{\Delta t}$$

### 1.1.2 Acceleration

Acceleration is the rate of change of velocity -  $\frac{\Delta v}{\Delta t}$

$$a \text{ (ms}^{-2}\text{)} = \frac{v - u}{t}$$

Because velocity is a vector, the magnitude (speed) doesn't have to be changing - a change of direction (anything not going in a straight line) also has a changing velocity and thus a changing acceleration.

## 1.2 Showing motion graphically

### 1.2.1 Displacement-time graphs

Any object's motion can be represented with a graph of displacement vs. time where velocity is the gradient

$$\frac{dy}{dx} = \frac{ds}{dt} = v$$

The **average velocity** can be found by finding the overall gradient of the graph, and the **instantaneous velocity** at a point can be found by drawing a tangent to the graph at the required value of  $t$ , or differentiating

$$\text{instantaneous velocity} = \frac{\Delta s}{\Delta t}$$

A curve in the graph shows non-uniform velocity (acceleration), a flat line means the object is stationary, and a straight line shows a constant velocity - the greater the gradient, the faster the speed.

.08s - average human response time.

Of course, true instantaneous velocity is impossible as the idea of movement requires a change in time and this would not be happening in such an 'instant'.

### 1.2.2 Velocity-time graphs

A graph of velocity vs. time allows the calculation of acceleration and displacement, as well as representing an object's motion.

The gradient of the graph represents acceleration

$$\frac{dy}{dx} = \frac{dv}{dt} = a$$

The area under the graph is the total displacement.

A curve in the graph shows non-uniform acceleration, a flat line means constant velocity, and a straight line shows a uniform acceleration - the greater the gradient, the faster the speed. A negative gradient would represent a deceleration or retardation. When asked for this in a question, do not give as a negative acceleration in general.

Negative velocity must be taken into account as velocity and displacement are vectors. The total area between the line of the graph and the  $x$ -axis gives the distance travelled and the positive area minus the negative area gives the final journey displacement.

At a-level physics no calculus is required and only  $\frac{1}{2}bh$  for a triangle and  $bh$  for a rectangle are expected for any calculations.

### 1.2.3 Acceleration-time graphs

If a body is stationary or moving with a constant velocity then on such a graph  $y = 0$  for all values of  $x$ .

## 1.3 Equations of uniformly accelerated motion

These equations apply to any object moving in a straight line (thus) with uniform acceleration. Often referred to as SUVAT given the variables involved.

displacement =  $s$ , initial velocity =  $u$ , final velocity =  $v$ , acceleration =  $a$ , time =  $t$

- $v = u + at$  for when  $s$  is not involved
- $s = \frac{1}{2}(v + u)t$  for when  $a$  is not involved
- $s = ut + \frac{1}{2}at^2$  for when  $v$  is not involved
- $v^2 = u^2 + 2as$  for when  $t$  is not involved.

## 1.4 Independence of vertical and horizontal motion

Suvat can't be used when objects are not moving in a straight line. However, **horizontal and vertical motion, that is motion at right angles, are totally independent** so we can use suvat and simpler equations on the two components. Often one component has constant velocity and critically  $t$  is the same for both.

## 1.5 Application - finding $g$ by a graphical method

The dropping of a steel ball can be used to calculate  $g$ , acceleration due to gravity taken as  $9.81\text{ms}^{-2}$  on earth at a-level. First, as with all suvat questions, write your data list

This is often used as an example on exam questions, so learn it.

$s = h$  (height of fall),  $u = 0 \text{ ms}^{-1}$ ,  $v = ?$ ,  $a = g$ ,  $t =$  time of fall from experiment

Using  $s = ut + \frac{1}{2}at^2$  we get

$$h = \frac{gt^2}{2}$$

We can fit this to the generic equation for a straight line  $y = mx + c$

$$h = \frac{g}{2}t^2 + c$$

$\therefore$  by plotting a graph of  $h$  vs.  $t^2$ , and gradient will be  $\frac{g}{2}$ . This allows us to find  $g$  by collecting data in the following table:

$h$ (m)	$t$ (ms) (three readings and an average)	$\bar{t}$ (s)	$(\bar{t})^2$ ( $\text{s}^2$ )
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## 2 Dynamics

### 2.1 Momentum

Galileo noticed that mass has INERTIA - it resists attempts to change its speed and a force must be applied to cause it to do so. To move faster it must gain momentum and to slow down it has to lose MOMENTUM

$$p = mv$$

Units are  $\text{kgms}^{-1}$  or  $\text{Ns}$  as appropriate to the question. Use the former when a direct mass times velocity calculation has been made.

Momentum is a vector with the same direction as the velocity part of the equation.

#### 2.1.1 Conservation of momentum

Momentum is a fundamental quantity in the universe that cannot be created or destroyed. *The total linear momentum of a system is constant provided that there is no resultant force acting.*

$$\sum p_{\text{before}} = \sum p_{\text{after}}$$

### 2.1.2 Collisions

The above law can be used when two objects collide. Ignoring resistive forces such as friction which remove momentum, the total momentum before the collision must be the same as the total momentum afterwards.

Because the objects are moving they must have kinetic energy

$$E_k = \frac{1}{2}mv^2$$

In an ELASTIC COLLISION, the no energy is transferred to the environment and the energy before the collision is the same as after. This is rare however. In an INELASTIC COLLISION, some kinetic energy is lost, commonly in heat due to friction and sound when the objects collide. Momentum, however, is conserved. This allows us to equate momentum even if energy has been lost and calculate velocities before and after collisions. We can also determine whether or not the collision was elastic.

## 2.2 Newton's Laws of Motion

### 2.2.1 Newton's first law

*“Every object will continue to move with uniform velocity [in a straight line] unless it is acted upon by a resultant, external force.”*

This comes directly from Galileo's inertia. This law can more clearly be observed in space where gravity and friction are not interfering with continuous movement.

### 2.2.2 Newton's second law

*“The rate of change of an object's linear momentum is directly proportional to the resultant, external force. The change in momentum takes place in the direction of the force.”*

$$F \propto \frac{\Delta(mv)}{\Delta t}$$

If mass does not change and we measure force in newtons then we can use the corrupted form of the above

$$F = ma$$

This law shows why a car must be stopped slowly in order to create a smaller, and safer force. A lessar deceleration would create a smaller force in the second equation too. IMPULSE is another consequence of this law. It is the idea of creating a large force by increasing the time taken for momentum to change and is applied in sports as 'timing'.

### 2.2.3 Newton's third law

*“If an object, A, exerts a force on a second object, B, then B exerts an equal but opposite force back on A.”*

This can easily be misinterpreted. The key is to remember that the forces act upon different bodies giving forces in pairs. The forces on any one body do not have to be balanced and equal.

## 3 Vectors

Scalar quantities only need a magnitude, and a unit, to define them. Vector quantities also need a direction.

### 3.1 Adding vectors

#### 3.1.1 Graphical 'tip-to-tail' method

By representing vectors with an arrow we can add multiple vectors together. The length of the arrow is proportional to its magnitude while the angle it is placed at to the horizontal shows its direction. Vectors are laid 'tip-to-tail' and the shape is connected up with another line. This line is the resultant vector. If the loop is closed then there is no resultant and the vectors are in equilibrium.

#### 3.1.2 Parallelogram method

Two vectors are drawn from the same point and then the rest of the parallelogram is constructed. The resultant is the diagonal of the shape. This method may be useful for forces on a moving body.

#### 3.1.3 Geometric method

A combination of trigonometry (including the sine and cosine rules) and Pythagoras' theorem can be used to add vectors together. A sketch following the rules for the above will allow this to be done.

$$\sin \theta = \frac{\text{opp}}{\text{hyp}}, \quad \cos \theta = \frac{\text{adj}}{\text{hyp}}, \quad \tan \theta = \frac{\text{opp}}{\text{adj}}$$

$$a^2 = b^2 + c^2 - 2bc \cos A$$

$$a^2 + b^2 = c^2$$

## 3.2 Components of vectors

Vectors can be split into components at right angles using trigonometry. It is best to learn the following quick trig. rules in order to make calculations faster. For a vector  $V$  at angle  $\theta$  to the horizontal

$$\text{vertical component} = V \sin \theta$$

$$\text{horizontal component} = V \cos \theta$$

If an object is acted upon by multiple forces, RESOLVE each one into its components and then add the vertical and horizontal, considering direction. Then form a triangle from the vertical and horizontal resultants to find the overall resultant.

For a better discussion of this consult mechanics textbooks. This is more of a maths topic than a physics one.

## 4 Turning moments

Forces can cause objects to rotate and flip about a pivot as well as move. When a force does not act through the centre of mass it may cause rotation. Moments are usually measured in Nm ('newton metres').

*The moment, or turning effect, of a force about a point is equal to the force multiplied by the perpendicular distance from the pivot to the line of action of the force.*

$$\text{moment} = Fs$$

The PRINCIPLE OF MOMENTS is *for a body in equilibrium, the sum of the anticlockwise moments about any point must be equal to the sum of the clockwise moments about that point.* Additionally for static equilibrium there must be no resultant force on the object causing any movement up or down or left or right.

### 4.1 Couples

Every couple has its moment. ~ D. Duckworth

If two forces of equal magnitude  $F$  act an equal distance either side of a pivot in opposite directions they will cause an object to spin. If the total distance between them is  $d$  then the moment of the couple is  $Fd$ .

## 5 Work, energy and power

### 5.1 Work

WORK is done when a force moves through a distance and is measured in joules (J)

$$W = Fs$$

If a force does not cause movement then it does no work. Sometimes the force is not parallel to movement and in such a case only one component of the force, that parallel to the displacement, does all the work.

$$W = Fs \cos \theta$$

## 5.2 Energy

ENERGY in physics is defined as the ability to do work and is also measured in joules. There are many different equations for energy depending on the situation. Energy is a fundamental quantity that like momentum is always conserved in an isolated system. In fact, *the total energy in an isolated system is constant.*

## 5.3 Power

POWER is the rate at which work is done. High power represents lots of work in a short time. Power is measured in joules per second ( $\text{Js}^{-1}$ ) or watts (W)

$$\text{power} = \frac{\text{work done}}{\text{time taken}}$$

$$P = \frac{W}{t}$$

This is often expressed as

$$E = Pt$$

Alternatively by combining  $W = Fs$  and  $P = \frac{W}{t}$  we can also get the useful

$$P = Fv$$

Mass is now seen as a type of energy. If fully converted, this equation gives the amount of energy received.  $c$  is the speed of light in a vacuum,  $3 \times 10^8 \text{ms}^{-1}$

$$E = mc^2$$

# 6 Thermal energy

## 6.1 Specific heat capacity, $c$

When different materials are heated to the same temperature, they store different quantities of heat energy. The definition of SPECIFIC HEAT CAPACITY is *the amount of energy needed to raise the temperature of one kilogram of a material through 1K.* It is measured in  $\text{J kg}^{-1} \text{K}^{-1}$

$$\Delta Q = mc\Delta T$$

## 6.2 Specific latent heat, $l$

When a substance is changing state (melting, boiling etc.) then heat energy applied will not cause the temperature of the substance to rise: instead all of the thermal energy will go into changing the substance's state. SPECIFIC LATENT HEAT is defined as *the quantity of heat energy required to change the state of one kilogram of a substance without a change in temperature*. It is measured in  $\text{J kg}^{-1}$

$$\Delta Q = ml$$

A different specific latent heat value is needed for each change of state for each substance. However, the specific latent heat of a change is the same as the reverse - for example the specific latent heat of fusion is the same as the s.l.h. of melting.

At a change of state, bonds are broken, particles gain more freedom and move further apart and INTERNAL ENERGY increases. Internal energy is defined as the sum of the potential and kinetic energy of all particles in the substance.

## 7 The Gas Laws

An IDEAL GAS is one in which molecules are far apart (negligible forces between them) and thus they obey the following laws. There are no collisions, attraction or repulsion between the molecules and they cannot be turned into liquids. Real gases that are hot at low pressure behave much like ideal gases.

The following variables are considered. Temperature must be on the kelvin scale for much of this to work.

pressure =  $p$ , volume =  $V$ , number of moles =  $n$ , number of molecules =  $N$ , temperature (K) =  $T$

### 7.1 Boyle's Law

At constant temperature and mass

$$p \propto \frac{1}{V}$$

This leads to a straight line on a graph of  $p$  vs.  $\frac{1}{V}$

### 7.2 The Pressure Law

At constant volume and mass

$$p \propto T$$

This leads to a straight line on a graph of  $p$  vs.  $T$  when  $T$  is measured on the kelvin scale. When measured in degrees celsius, the line can be extrapolated backwards to the root of the kelvin scale, -273 degrees or the theoretical ABSOLUTE ZERO where all motion stops and gas exerts no pressure.

Converting between celsius and kelvin requires adding or subtracting 273 at a-level. The actual value of absolute zero is -273.15K.

### 7.3 Charles' Law

At constant pressure and mass

$$V \propto T$$

This leads to a straight line on a graph of  $V$  vs.  $T$

### 7.4 Amount law

At constant volume and temperature

$$p \propto N$$

### 7.5 Combined gas law

The laws above can be combined, introducing a constant, to

$$pV = nRT$$

or

$$pV = NkT$$

For a constant mass of gas,

$$\frac{pV}{T} = \text{constant}$$

Thus in situations where a gas changes condition, we can use

$$\frac{p_1 V_1}{T_1} = \frac{p_2 V_2}{T_2}$$

With this equation, different units may be used for pressure and volume as the relationship still exists as long as temperature is still measured in kelvin.

#### 7.5.1 Moles and molar mass

A MOLE is defined as a quantity of gas containing Avagadro's number,  $N_A$ , of molecules where  $N_A = 6.02 \times 10^{23}$ .

The MOLAR MASS,  $M$ , is the mass of one mole of molecules for a particular gas, e.g. for  $O_2$  the molar mass is  $32\text{g mol}^{-1}$ .

$$n \text{ (mol)} = \frac{m \text{ (g)}}{M \text{ (g mol}^{-1}\text{)}}$$

### 7.5.2 Gas law constants

The Boltzmann constant,  $k$ , is the quantity of energy per molecule per degree kelvin and is equal to  $1.38 \times 10^{-23} \text{ J K}^{-1}$ . Multiplying this by Avagadro's number gives us the amount of energy per mole of gas,  $R$  - the molar gas constant.  $R = N_A k = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$

## 8 Kinetic Theory of Ideal Gases

This theory uses Newtonian mechanics to explain pressure and temperature in an ideal gas.

### 8.1 (Some) assumptions

- Gases consist of a very large number of molecules so statistical methods can be employed
- The molecules are moving rapidly and randomly
- Their motion obeys Newton's laws of motion
- All collisions between molecules and between molecules and the walls of their container are perfectly elastic
- There are no intermolecular forces
- Molecules have negligible volume compared to their container (they are points in space).

### 8.2 Equations

$$p = \frac{1}{3} \rho \overline{c^2}$$
$$pV = \frac{1}{3} m N \overline{c^2}$$

The full derivation of these equations must be learnt as it could be asked for on the exam.

## 9 Comparing models for the behaviour of gases

$$pV = NkT \qquad pV = \frac{1}{3} m N \overline{c^2}$$

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

Comparing this to the equation for kinetic energy gives us

$$\overline{E_k} = \frac{1}{2} m \overline{c^2} = \frac{3}{2} kT$$

for one molecule of gas. For one mole, which is more useful, we get  
However,

$$U = \frac{3}{2} RT$$

$$\Rightarrow \overline{E_k} \propto T$$

We can thus say that at the same temperature the particles of all gases have the same kinetic energy. However, gas particles move at different speeds because kinetic energy depends on mass as well as velocity.