Cambridge Advanced Subsidiary Level Notes
9702 Physics

Abrar Faiyaz Rahim, degrees pending

Contents

1 Physical quantities and units

1.1 Physical quantities

Understand that all physical quantities consist of a numerical magnitude and unit.

To quantify reality, we measure things such as length and time. These measurements must be done relative to something – which are the units of that thing. Length is measured in metres – a metre is a certain length equal to $1/10^7$ of the Earth's circumference.

Make reasonable estimates of physical quantities included within the syllabus

1.2 SI units

Recall the following SI base quantities and their units: mass (kg), length (m), time (s), current (A), temperature (K)

Self explanatory.

Express derived units as products or quotients of the SI base units and use the derived units for quantities listed in this syllabus as appropriate

There are quantities aside from those described above – which come from quantities consisting of some product or quotient of the above quantites. Let's consider the case of speed, which is the result of distance divided by time, which hence has unit: m/s, as [m] is that of length and [s] is that of time.

Use SI base units to check the homogeneity of physical equations

Units of left hand side of equation must be the same as that of the right hand side. Let's consider the equations for kinetic energy, E_k and gravitational potential energy E_p.

$$E_p = mgh$$

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

In the case where the two are equal,

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

On the LHS we have [kg][N/kg][m], that is [N m], and since [N] = [kg m/s^2], this is [kg m^2/s^2]. And on the RHS we have [kg][m/s]^2 which simplifies to [kg m^2/s^2].

Recall and use the following prefixes and their symbols to indicate decimal submultiples or multiples of both base and derived units: pico (p), nano (n), micro (μ), milli (m), centi (c), deci (d), kilo (k), mega (M), giga (G), tera (T)

Prefix	**Power of 10**
pico (p)	10^{-12}
nano (n)	10^{-9}
micro (μ)	10^{-6}
milli (m)	10^{-3}
centi (c)	10^{-2}
deci (d)	10^{-1}
unit	10^{0}
kilo (k)	10^{3}
mega (M)	10^{6}
giga (G)	10^{9}
tera (T)	10^{12}

1.3 Errors and uncertainties

Understand and explain the effects of systematic errors (including zero errors) and random errors in measurements

Another factor that uncertainty depends on is *error*. Errors arise from imperfections in equipment or the person carrying out the experiment. There are three types of error:

1. Systematic error: These are errors due to faults in the instruments being used to measure. For example, the spring in a used force meter may be worn out and hence give a consistently higher reading. Parallax errors are those which arise

when readings are taken at an angle from the markings on the instrument, causing the reading to be taken to seem higher or lower than what it should be. *Systematic error is often corrected by recalibrating the instrument or by correcting the technique used.*

2. *Zero error*: The zero on a ruler might not be at the beginning of the ruler. This will introduced a fixed error into any reading unless it is allowed for. This is a type of systematic error. *Zero error is compensated for by adding or subtracting a certain value – the value that the zero mark on the apparatus is offset by.*

3. *Random error*: When a judgement has to be made by a human observer, a measurement may sometimes be above or below the true value. *Random errors can be reduced by making multiple measurements and taking the results.*

Understand the distinction between precision and accuracy

Measurements can never be perfect, since we can infinitely improve the *accuracy* of a measurement. The *accuracy* of a measurement is how close it is to the *true value*. The *true value* is the actual value of the thing being measured, which will always be truly unknown. Only in theory can the we find exact values without any *uncertainty*

The *uncertainty* in a reading is an estimate of the difference between the reading and the true value of the quantity being measured. This often comes down to the smallest possible reading possibly to be taken by a certain instrument, or, in certain cases, half of that.

Consider that a reading of 2.6 cm is taken using a ruler. The lowest possible reading that can be taken from that ruler is 0.1 cm. This is the *precision* of the ruler – the smallest change in value that can be measured by it. Thus, using this ruler, we cannot determine if the measurement made is 2.61 cm or 2.67 cm. So, the reading is recorded (2.6 ± 0.1) cm, because the true value may be any of these.

However, if the reading to be taken comes out to be between two markings on the instrument, say, between the markings for 1.1 cm and 1.2 cm. We hence record the reading as (1.05 ± 0.05) cm.

In the above cases, the value that is being added or subtracted from the reading seen is the uncertainty. This is written

$$x \pm \Delta x$$

where Δx is the uncertainty of a reading x.

We may also express uncertainties in two other ways, *fractional* and *percentage uncertainties*.

$$(\text{fractional uncertainty}) = \frac{\Delta x}{x}$$

$$(\text{percentage uncertainty}) = \frac{\Delta x}{x} \times 100\%$$

Assess the uncertainty in a derived quantity by simple addition of absolute or percentage uncertainties

---

When we take two readings to make one measurement, for example measuring length in such a way that we take two readings from a metre rule and then subtract the larger reading from the smaller one. Here, the uncertainty from the instrument has an effect twice, thus the reading taken has twice the uncertainty. Mathematically, for two readings A and B:

$$A = A_{\text{measured}} \pm \Delta A$$

$$B = B_{\text{measured}} \pm \Delta B$$

$$A + B = A_{\text{measured}} + B_{\text{measured}} \pm (\Delta A + \Delta B)$$

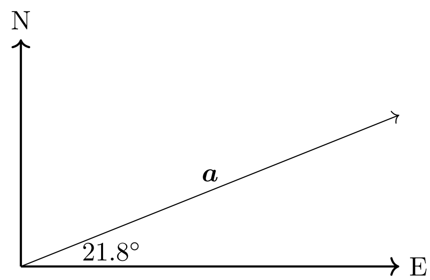
When quantities are raised to a power, its absolute uncertainty is multiplied by that power.

1.4 Scalars and vectors

Understand the difference between scalar and vector quantities and give examples of scalar and vector quantities included in the syllabus

---

A *scalar* is a quantity that has only a magnitude. A *vector* is a quantity that has both magnitude and direction. We show the direction of a vector using the angle it makes with another direction.



The above diagram shows a vector $\boldsymbol{a}$, which has magnitude $|\boldsymbol{a}|$, and lies 21.8° from East. Or, we may separate it into two *components* mathematically, shown later.

Add and subtract coplanar vectors

Consider vectors $\boldsymbol{a}$ and $\boldsymbol{b}$, such that $\boldsymbol{a}, \boldsymbol{b} \in \mathbb{C}$. Their sum and difference is simply the algebraic sum and difference,

$$\boldsymbol{a} + \boldsymbol{b}$$

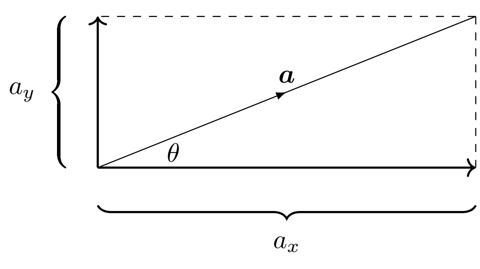
and

$$\boldsymbol{a} - \boldsymbol{b}$$

respectively.

Represent a vector as two perpendicular components

A vector can be represented as two perpendicular components, an x-component which is horizontal and y-component which is vertical. Again, observe the case of vector $\boldsymbol{a}$, only here, the angle of the vector is represented as a general case of θ.



Thus the components are

$$\sin\theta = \frac{a_y}{\boldsymbol{a}}$$
$$\implies \boxed{a_y = \boldsymbol{a}\sin\theta}$$

$$\cos\theta = \frac{a_y}{\boldsymbol{a}}$$
$$\implies \boxed{a_y = \boldsymbol{a}\cos\theta}$$

The equations boxed above apply for any vector.

2 Kinematics

2.1 Equations of motion

Define and use distance, displacement, speed, velocity and acceleration

Acceleration is the rate of change of velocity of an object, whose unit is [ms^{-2}]. *Velocity* is the rate of change of displacement of an object, whose unit is [ms^{-1}]. *Speed* is the scalar of velocity; the rate of change of distance. *Displacement* is the vector form of distance, i.e., it is the position of an object from a certain point, with unit [m].

Below are the mathematical symbols corresponding to the above quantities:

Quantity	**Symbol**
displacement	s
initial velocity	u
final velocity	v
acceleration	a
time	t

Use graphical methods to represent distance, displacement, speed, velocity and acceleration

We can plot the distance travelled, displacement, speed, velocity or acceleration of an object against time on a graph. This allows us to visualise an object's motion. The gradient of a graph is the quantity found when its vertical axis is divided by its horizontal axis, and the area under a graph is the quantity found when the two quantities are multiplied.

Since the variables are *suvat*, the following equations are often referred to as the suvat equations.

Determine displacement from the area under a velocity-time graph

Note that, the area of under a speed-time graph is the object's distance travelled.

Determine velocity using the gradient of a displacement-time graph

Note that, the gradient of a distance-time graph gives speed.

Determine acceleration using the gradient of a velocity-time graph

Note that, the gradient of a speed-time graph would give the magnitude of acceleration.

Derive, from the definitions of velocity and acceleration, equations that represent uniformly accelerated motion in a straight line

From the definition of acceleration,

$$\begin{aligned} a &= \frac{\text{(change in velocity)}, \Delta v}{t} \\ a &= \frac{v-u}{t} \\ \implies & \boxed{v = u + at} \end{aligned} \tag{1}$$

which comes from the gradient of a velocity-time graph.

Average velocity, v_{avg} is as follows:

$$\begin{aligned} v_{\text{avg}} &= \frac{s}{t} \\ s &= v_{\text{avg}} \\ & \boxed{s = \left(\frac{u+v}{2}\right) t} \end{aligned} \tag{2}$$

where v_{avg} comes from the area under a velocity-time graph.

Substituting equation (1) into equation (2), we find

$$\boxed{s = ut + \frac{1}{2}at^2}$$

From the first and third equations, we can derive a fourth equation. First, we make t the subject of the first equation,

$$t = \frac{v-u}{a}$$

which we substitute into the third equation,

$$s = u\left(\frac{v-u}{a}\right) + \frac{1}{2}a\left(\frac{v-u}{a}\right)^2$$

which simplifies down to,

$$\boxed{v^2 = u^2 + 2as}$$

We may also substitute $t = (v - u)/a$ into equation (2), which gives the same result.

Solve problems using equations that represent uniformly accelerated motion in a straight line, including the motion of bodies falling in a uniform gravitational field without air resistance

---

We must identify the variables provided, using it to find those unknown. Each equation of motion has 4 variables in use, and one absent. Thus we can find one variable out of suvat, given 3 of them.

- $v = u + at$ lacks s.
- $s = \left(\frac{u+v}{2}\right) t$ lacks a.
- $s = ut + \frac{1}{2}at^2$ lacks v.
- $v^2 = u^2 + 2as$ lacks t.

Describe an experiment to determine the acceleration of free fall using a falling object

---

By timing a falling object, we may determine the acceleration of free fall, g. Seeing that $u = 0$, we see that

$$s = \frac{1}{2}at^2$$

Having measured the distance it falls, a is the remaining unknown in the above equation, the value of which is the same as g.

Describe and explain motion due to a uniform velocity in one direction and a uniform acceleration in a perpendicular direction

---

An object thrown has two components to its velocity, the vertical and horizontal. The vertical component of its velocity is affected by gravitational acceleration, whereas the horizontal component is not affected by any acceleration.

To solve problems of this kind, we separate the displacements, velocities and acceleration into their perpendicular components, and solve accordingly.