Cambridge Advanced Subsidiary Level Notes
9702 Physics

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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

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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

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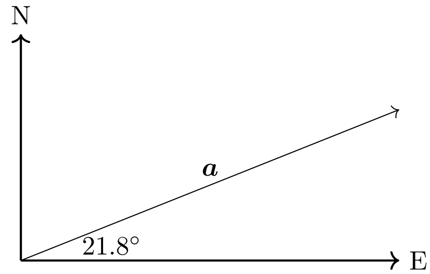
A *scalar* is a quantity that has only a magnitude. A *vector* is a quantity that has both magnitude and direction. We show the direction of a vector using the angle it makes with another direction.



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,

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

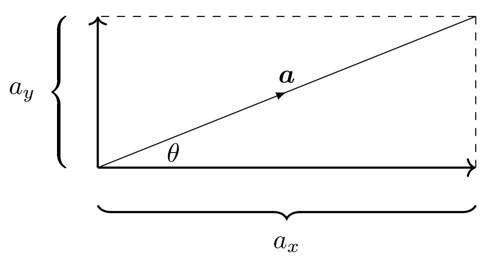
and

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

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,

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

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

Average velocity, v_{avg} is as follows:

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

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

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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

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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

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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.

3 Dynamics

4 Forces, density and pressure

5 Work, energy and power

6 Deformation of solids

7 Waves

7.1 Progressive waves

Describe what is meant by wave motion as illustrated by vibration in ropes, springs and ripple tanks

Self explanatory.

Understand and use the terms displacement, amplitude, phase difference, period, frequency, wavelength and speed

Displacement is the property of a particle of a wave that corresponds to how far that particle is from its equilibrium position. *Amplitude* is the maximum displacement of the particles in a wave.

Phase is the property of a particle that measures at which point in its motion that particle is. It is measured in degrees. For two particles, the difference in what phase they are in is their *phase difference*.

Period is the time taken for a complete wavelength of a wave to propagate.

Frequency is the number of waves propagated per second.

Wavelength is the length of a complete wave.

Speed is the distance per unit time covered by a wave.

Understand the use of the time-base and y-gain of a cathode-ray oscilloscope (CRO) to determine frequency and amplitude

Easy enough.

Derive, using the definitions of speed, frequency and wavelength, the wave equation $v = f\lambda$

We know,

$$\text{(speed)} = \frac{\text{(distance)}}{\text{(time)}}$$

we also know a wave travels a distance of one whole wavelength in a time equal to one period, thus

$$\text{(wave speed)} = \frac{\text{(wavelength)}}{\text{(period)}}$$

$$v = \lambda/T$$

since $f = T^{-1}$

$$\boxed{v = f\lambda}$$

Understand that energy is transferred by a progressive wave

Self explanatory.

Recall and use intensity = power/area and intensity $\propto$ (amplitude)^2 for a progressive wave

Self explanatory.

7.2 Transverse and longitudinal waves

Compare transverse and longitudinal waves

Transverse waves are those where direction of oscillation is perpendicular to that of wave propagation. *Longitudinal* waves are those where direction of oscillation is parallel to that of wave propagation.

7.3 Doppler effect for sound waves

Understand that when a source of sound waves moves relative to a stationary observer, the observed frequency is different from the source frequency (understanding of the Doppler effect for a stationary source and a moving observer is not required)

Self explanatory.

Use the expression $f_o = f_s v/(v \pm v_s)$ for the observed frequency when a source of sound waves moves relative to a stationary observer

$$\boxed{f_o = \frac{f_s v}{v \pm v_s}}$$

Above is the Doppler effect equation, *where the plus sign applies to a receding source and the minus sign to an approaching source.* Here, f_o is the observed frequency, f_s is frequency of source, v is velocity of wave, and v_s is velocity of source. Note that

- The frequency f_s of the source is not affected by the movement of the source.
- The speed v of the waves as they travel through the air (or other medium) is also unaffected by the movement of the source.

7.4 Electromagnetic spectrum

State that all electromagnetic waves are transverse waves that travel with the same speed c in free space

$$c = 3 \times 10^8 \text{ ms}^{-1}$$

Recall the approximate range of wavelengths in free space of the principal regions of the electromagnetic spectrum from radio waves to γ-rays

type of EM wave	range of wavelength / m
radio	$> 10^6$ to 10^{-1}
microwaves	10^{-1} to 10^{-3}
infrared	10^{-3} to 7×10^{-7}
visible	7×10^{-7} to 4×10^{-7}
ultraviolet	4×10^{-7} to 10^{-8}
X-rays	10^{-8} to 10^{-14}
γ-rays	10^{-10} to 10^{-16}

Recall that wavelengths in the range 400–700 *nanometres in free space are visible to the human eye*

7.5 Polarisation

Understand that polarisation is a phenomenon associated with transverse waves

A transverse wave that oscillates only along one plane is said to be *plane polarised*.

Recall and use Malus's law ($I = I_0 \cos^2\theta$) to calculate the intensity of a plane-polarised electromagnetic wave after transmission through a polarising filter or a series of polarising filters (calculation of the effect of a polarising filter on the intensity of an unpolarised wave is not required)

Malus's law is as follows

$$\boxed{I = I_0 \cos^2\theta}$$

where I is intensity post-polarisation and I_0 is intensity pre-polarisation and θ is angle between plane polarised wave incident on Polaroid and transmission axis of Polaroid itself.

8 Superposition

9 Electricity

9.1 Electric current

Understand that electric current is a flow of charge carriers

Self explanatory.

Understand that the charge on charge carriers is quantised

Charge is measured in coulombs (C). In most cases, the charge carriers are electrons. Each electron has a charge of $q = -1.6 \times 10^{-19}$ C. However, we *quantise* this charge on an electron to be -1.

Recall and use $Q = It$

$$Q = It$$

where Q is the charge flowing past a point, I is the current and t is the time taken for the charge to flow past that point.

Use, for a current-carrying conductor, the expression $I = Anvq$, where n is the number density of charge carriers

$$I = Anvq$$

is an equation for current in terms of the electrons present per unit volume of the conductor. Here, A is the cross sectional area of the conductor and v is the average drift velocity of the charge carriers

9.2 Potential difference and power

Define the potential difference across a component as the energy transferred per unit charge

Self explanatory.

Recall and use $V = W/Q$

$$V = W/Q$$

where V is potential difference (voltage), W is energy transferred and Q is total charge transferred.

Recall and use $P = VI$, $P = I^2R$ and $P = V^2/R$

$$P = VI$$
$$P = I^2R$$
$$P = V^2/R$$

are equations used to find power, P, or other variables.

9.3 Resistance and resisitivity

Define resistance

Resistance is defined as the ratio to potential difference to current.

Recall and use $V = IR$

$$V = IR$$

is an equation where R is the resistance across two points in a current carrying circuit.

Sketch the I–V characteristics of a metallic conductor at constant temperature, a semiconductor diode and a filament lamp

For a metallic conductor, its I-V characteristic curve would be a straight line that passes through the origin, as resistance ($1/R$ is the gradient of the characteristic curve) is constant at constant temperature for this case.

For a semiconductor diode, the current is the same as for a metallic conductor, but only for positive voltages, and current is zero for negative voltage or vice versa.

In case of a filament lamp, as current increases and the filament heats up and the resistance increases. As a result, resistance increases, and hence gradient of the curve decreases and keeps decreasing, however, the curve never becomes horizontal.

Explain that the resistance of a filament lamp increases as current increases because its temperature increases

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Self explanatory.

State Ohm's law

Ohm's law states that the electric current through a conductor is directly proportional to the voltage across it, given that the conductor is at a constant temperature.

Recall and use $R = \rho L/A$

Consider a length of wire with length L and cross sectional area A. The resistance of the wire is as follows

$$R \propto L/A$$

thus,

$$R = kL/A$$

This constant of proportionality k, is unique for every material and is said to be the *resistivity*, ρ of the material. It has unit ohm meter (Ωm).

Understand that the resistance of a light-dependent resistor (LDR) decreases as the light intensity increases

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Self explanatory.

Understand that the resistance of a thermistor decreases as the temperature increases (it will be assumed that thermistors have a negative temperature coefficient)

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10 D.C. circuits

10.1 Practical circuits

Recall and use the circuit symbols shown in section 6 of this syllabus

Refer to the syllabus.

Draw and interpret circuit diagrams containing the circuit symbols shown in section 6 of this syllabus

Skill issue.

Define and use the electromotive force (e.m.f.) of a source as energy transferred per unit charge in driving charge around a complete circuit

Self explanatory.

Distinguish between e.m.f. and potential difference (p.d.) in terms of energy considerations

In case of emf, the work is done to convert energy from some form (chemical in case of batteries, kinetic in case of a dynamo, etc.) to electrical form. In case of pd, the work is done to convert energy from electrical to some other form (heat in the case of resistors, light in the case of a lamp, etc.).

Understand the effects of the internal resistance of a source of e.m.f. on the terminal potential difference

The emf source of a circuit often has some resistance, as some work is done in tranferring energy to other forms as work is done to drive the charge around the force itself. This resistance is known as the internal resistance.

Consider a circuit with a battery of emf E and internal resistance r, which is connected to a resistor of resistance R, and the current in the circuit is I. Thus, we can write

$$\begin{aligned} E &= I(R+r) \\ &= IR + Ir \end{aligned}$$

We cannot measure E, if we measure the potential difference across the terminals of the battery, we get *terminal pd* V, which is the same as the pd across the external resistor. We thus have

$$V = IR$$

which is less than E by Ir. Hence,

$$V = E - Ir$$

10.2 Kirchhoff's laws

Recall Kirchhoff's first law and understand that it is a consequence of conservation of charge

Kirchhoff's first law states that the current entering a junction in an electrical circuit equals the total current leaving the junction.

Recall Kirchhoff's second law and understand that it is a consequence of conservation of energy

Kirchhoff's second law states that the sum of the emfs around any loop in a circuit is equal to the sum of the pds around the loop.

Derive, using Kirchhoff's laws, a formula for the combined resistance of two or more resistors in series

Consider resistors of resistance R_1 and R_2 connected in series to a source of emf V and have potential differences V_1 and V_2. Thus we have $V = IR$, $V_1 = IR_1$ and $V_2 = IR_2$. We now derive

$$\begin{aligned} V &= V_1 + V_2 \\ \implies IR &= IR_1 + IR_2 \\ \implies R &= R_1 + R_2 \end{aligned}$$

So, if we have n resistors in series, their combined resistance is

$$\boxed{R_1 + R_2 + \cdots + R_n}$$

Now consider these resistors connected in parallel, which have current I_1 and I_2 flowing through them. By Kirchhoff's first law

$$I = I_1 + I_2$$

we also know $I = V/R$, $I_1 = V/R_1$ and $I_2 = V/R_2$. We now derive

$$\begin{aligned} V/R &= V/R_1 + V/R_2 \\ \implies 1/R &= 1/R_1 + 1/R_2 \end{aligned}$$

So for n resistors in parallel, their combined resistance is

$$\boxed{1/R = 1/R_1 + 1/R_2 + \cdots + 1/R_n}$$

Use the formula for the combined resistance of two or more resistors in parallel

Use it lol.

Use Kirchhoff's laws to solve simple circuit problems

Do it.

10.3 Potential dividers

Understand the principle of a potential divider circuit

A *potential divider* is a cicruit that splits the potential difference from a source into two parts, using two resistances in series to each other.

Consider a circuit with two resistors of resistance R_1 and R_2 in series to a source of emf V. The pd across the two resistors are V_1 and V_2, which are

$$V_1 = \left(\frac{R_1}{R_1 + R_2}\right)(V)$$

$$V_2 = \left(\frac{R_2}{R_1 + R_2}\right)(V)$$

Note that,

$$V = V_1 + V_2$$

so the emf voltage is being divided.

Recall and use the principle of the potentiometer as a means of comparing potential differences