Mastering essential pre-university physics

Authors' hints and notes for teachers

A1 – Using and Re-arranging Equations

This is a vital skill. If the students can apply their GCSE mathematics knowledge to their Physics, and if they can recognize the equations, then there is much of A-level they can already tackle. It is also worth the student building up their physics alphabet, and you may wish to encourage them to compile a list of quantities, including the letters used to represent them and the units they are measured in. This can be added to during the course of their Sixth Form studies.

Do use the opportunity to insist that units are given, and that a sensible number of significant figures are used. Typically, the student should carry 4 significant figures throughout the working. Final answers should be given to the number of significant figures of the least accurate datum – nearly always 2 significant figures in sheet A1.

Do note that questions A1.9 onwards involve two stages. This may need to be pointed out to the student so that they don't become perplexed. The student can approach them in one of two ways. Taking A1.9 as an example, most students find it easier to use the method which would be found on an A-level mark scheme:

A1.9 $V = IR$ = 5.0 A × 2.0 Ω = 10 V, so P $= IV$ = 5.0 A × 10 V = 50 W.

However you can also keep the quantities algebraic until the end, as is more suitable for advanced problems and undergraduate study:

A1.9 $P = IV = I \times IR = I^2R$ = 5.0^2 × 2.0 = 50 W.

A2 – Derived and Base SI Units

Students will be new to algebra based on units, and will need practice to become familiar with this idea. However, it is very powerful, enables work to be checked quickly, and allows the student to spot new relationships which could be useful to them in independent research or in practical investigations.

As examples, do note how much easier it is to visualise momentum when you realise that its unit is the **N s**, and accordingly it gives the force needed to stop an object in one second; whereas kinetic energy is in **N m** and gives the force needed to stop an object in one metre (A2.33b).

Hopefully, students will notice that at the end of the table, the N C^{-1} and the V m^{-1} are the same, which will be useful to them when they cover electric fields.

You may also wish to use A2.33d as a springboard for discussion of the link between stress (which has the same units as pressure) and energy stored per unit volume in a stretched material. Equally, Bernoulli's equation $p + ½ \rho v^2$ = constant can be seen to make sense when considering a cubic metre of fluid. The total energy is constant, and this comprises energy involved in the compression (numerically equal to p for one cubic metre) and the motion.

A3 – Standard Form and Prefixes

This should all be standard stuff. While it is vital that the student does not rely on it as a crutch, do point out the role of the ENG button on their calculator, which can make A3.5 and A3.8 easier.

A4 – Converting Units

Please remind students that 1.34 mm^2 = 1.34 (mm × mm) = 1.34 (10^{-3} m × 10^{-3} m) = 1.34 × 10^{-6} m^2. It is not equal to 1.34 × 10^{-3} m^2.

Unit conversion ought to be a doddle, but is often the bane of students' and teachers' lives. The remedy is to give them a reliable method to solve the problem. Here is a suggestion for A4.9:

A4.9 9600 μm^2 = 9600 × $(10^{-6}\ m)^2$ = 9600 × 10^{-12} m^2 = 9.6 × 10^{-9} m^2.

1 cm^2 = $(10^{-2}\ m)^2$ = 10^{-4} m^2, therefore the answer is 9.6 × 10^{-9} / 10^{-4} cm^2 = 9.6 × 10^{-5} cm^2.

One final point. The base unit of mass is the kilogram. Accordingly, before substituting into an equation such as $F = ma$, it is vital to turn 3 mg into 3 × 10^{-6} kg, not 3 × 10^{-3} g.

A5 – Gradients and Intercepts of Graphs

Please be really strict with units! Graph A's gradient is 6.0 m s^{-1}, not just 6.

Alert your students to watch for tricks: Graph C's gradient is not –2 kg m s^{-2}, but rather –2000 kg m s^{-2} because the x-axis is calibrated in milliseconds.

Graph D's intercept is not 10.0 V, because the y-axis of this graph does not coincide with a zero current (i.e. the origin).

gradient: gradient = Δy / Δx = –2 V / 50 A = –0.04 Ω

y-intercept: V = I × gradient + intercept;

So, intercept = V – I × gradient = 10 V – 50 A × (–0.04 Ω) = 12 V.

Note the way in which the x-axis of graph E has been labelled. A student would be equally able to write it as $Time^2$ / s^2, but I think that the form given is clearer. $Time^2$ / s is of course wrong.

A6 – Equations of Graphs

Hopefully, after a reminder that straight lines have the functional form $y = mx + c$ where m is the gradient and c the y-intercept, the students should find this sheet straightforward.

It may help the student to replace the quantities plotted with x and y. Thus:

A6.3,4 $s = ½\, gt^2$, so $y = ½gx = ½gx + 0$, so the gradient is $½g$ and the y-intercept is zero.

Then do extend the logic. For example, suppose you had $s = ut + ½at^2$, and had measured s and t (with a constant, but u unknown), challenge the students as to what they should plot. Hopefully they will realise that if you set $y = s/t$ and $x = t$, the equation becomes $y = u + ½ax$. The intercept is then the initial velocity, and the gradient is half the acceleration.

A7 – Area Under the Line on a Graph

Ensure the students are careful with units. Graph A has an area measured in m s^{-2} × s = m s^{-1}.

Take care with graph D – it doesn't have a 'true' x-axis – the base of the graph corresponds to a current of 6 A. There is thus 6 A × 25 s = 150 C of charge 'hidden' under the graph.

Graph E will require estimation. You can work out the worth of each rectangle as 500 N × 0.2 m = 100 J, and then count the rectangles which are more than half under the line.

A8 – Area Under the Line on a Graph II

All credit to Miss Crowter for recognising that students needed extra practice with this concept. Notice too that in this sheet, unit prefixes change:

Graph B displacement = mean velocity × time = 4 m s^{-1} × 0.4 μs = 1.6 μm = 1.6 × 10^{-6} m.

Graph E medium size rectangles worth 1 kN × 0.05 μs = 0.05 mN s = 5 × 10^{-5} kg m s^{-1}.

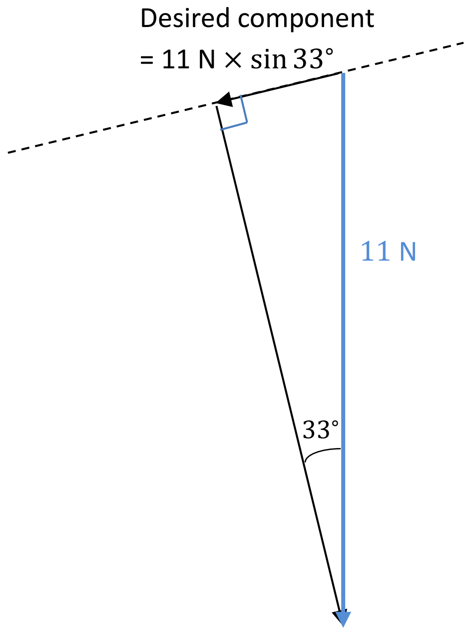
While technically frowned upon, it may be worth doing a bit of prefix algebra of the kind k × k = M or even k × μ = m, and so on. Note that $V = IR$ becomes even more practically useful when you measure I in mA and R in kΩ.

B1 – Components of a Vector

This is an essential skill that needs drumming into the head of any A-level physics student. Given that they passed GCSE Maths, they already have the knowledge – they just need to apply it reliably at speed in different contexts.

For example, in B1.1 - 1.4, you are finding the components (the hypotenuse is already known). It is simply a matter of knowing whether to multiply by sine or cosine. For this, note that COS is ClOSe. In B1.3, you are trying to find the side closest to the angle, so use cosine. The others use sine.

B1.6 is likely to cause trouble. How, after all, do you assign components to a vector (11 N) which is already vertical? However here we are looking for components perpendicular and parallel to the slope. A large diagram is essential to the solution.



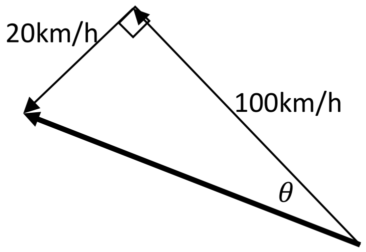
Similar vigilance is required in B1.9.

B1.10 has proved difficult to interpret. All the question is asking, is 'How much further south does the fly get each second?'

B2 – Adding Vectors

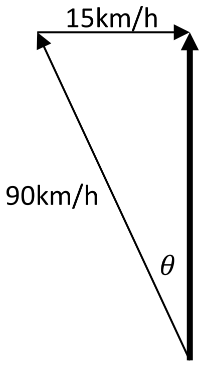
Please drum into students the need to draw a clear vector diagram for questions like this. When the question specifies that the answer is a direction, the student must be specific. "A bearing of 340°", or "3.4° N of W" or "32° above the horizontal" are all acceptable forms of answer. "9.2°" by itself is not, that is, unless it accompanies a labelled angle on a clear diagram.

Note the difference in situation between B2.2d and B2.3b. In the first case we are calculating the hypotenuse of the triangle, whereas in the second, the hypotenuse is 90 km/h.



B2.2d

In this case, if we wished to work out θ we would calculate $\operatorname{atan}(\frac{20}{100})$.



B2.3b

Now the hypotenuse is known, and we are calculating the North pointing vector using $\sqrt{90^2 - 15^2}$ km/h. The angle θ is now equal to $\operatorname{asin}(15/90)$. Contrast this with the inverse tangent used in B2.2d.

B2.3b is also instructive as a case where the vector sum is not the hypotenuse, and so it would seem that the 'resultant' is not the 'resultant'. Confusion arises because in the context of Newton's Second Law, we use 'resultant' to mean 'vector sum', but in questions like those in B1, we use 'resultant' in a very special case where it is the vector sum of two perpendicular components – in this context the resultant is always the hypotenuse. In B2.3b, the vector sum is the North pointing vector, but it looks very like a component rather than a resultant when the triangle is drawn. Personally, I try to avoid the use of the word 'resultant' altogether: except when I'm writing questions such as B2.4, that is. Feel free to castigate me in front of your class saying, "He should have said 'vector sum' shouldn't he?"

B3 – Uniform Accelerated Motion in One Dimension

Little needs saying about this kind of question, as teachers are very well versed in preparing students for these.

Questions do arise as to whether $g = +9.8$ m s^{-2}, or $g = -9.8$ m s^{-2}. It is best to use common sense. In B3.1, we know it is going downwards, so I would usually regard s and v as positive for a falling object, and accordingly I can take $g = +9.8$ m s^{-2}. However, in B3.2, the rugby ball is initially going upwards, but with a downwards acceleration. Accordingly, I would usually take u to be positive, and g negative; however, you could also solve the problem with $g = +9.8$ m s^{-2}, but then in that case, you must take $u = -16$ m s^{-1}.

If you fancy a challenge, give your class these three facts and get them to solve all the questions just using these facts (no s, u, v, a, t):

- displacement = average velocity × time
- change in velocity = acceleration × time
- average velocity = (initial velocity + final velocity)/2

B3.1 Change in velocity = 9.8 m s^{-2} × 0.25 s = 2.45 m s^{-1}.
Average velocity = (0 + 2.45)/2 = 1.225 m s^{-1}.
Displacement = 1.225 m s^{-1} × 0.25 s = 0.31 m (2 sf)

B3.4 is really nasty if you go about it the wrong way. You can use $s = ut + ½at^2$, but then you end up solving a quadratic, which you might find distasteful. Alternatively, you can find the final velocity first using $v^2 = u^2 + 2as$, and then substitute this into $t = (v - u)/a$.

B3.7 repays further discussion. Runways actually have to be a lot longer than this to cover the braking distance should a pilot decide to cancel a take-off. However real runways are not quite long enough to allow a pilot to cancel at any time up to take-off. For any aircraft and local conditions, there is a 'decision speed' called V1. Once this speed is reached, the pilot has to commit to take off even though they haven't got enough speed to get off the ground yet. If an engine fails just after V1, the manoeuvre requires great skill on the part of the pilot. If you only have one engine, then it is a case of 'hello hedge'.

B4 – Trajectories

The key point here is that students must not confuse horizontal and vertical motion. Within each equation used, every term must refer the same kind of motion. Thus $s_v = u_v t + ½a_v t^2$, where 'v' means vertical. Alternatively, $s_h = u_h t + ½a_h t^2$, which usually simplifies to $s_h = u_h t$, since no horizontal acceleration is usually present. When working out B4.2, it is essential to take $u_v = 0$ and not $u_v = 4.0\ \mathrm{m\ s^{-1}}$.

The first stage in any problem is to work out the time. You will have to work out B4.4 before you can evaluate B4.3. Similarly B4.8 and B4.10 must be worked out before you can attempt B4.7 and B4.9.

B4.13 – B4.15 concern motion which is not initially horizontal. Some A-level syllabi will not test this scenario. Here the first stage is to work out the u_v and u_h by resolving the initial velocity into horizontal and vertical components.

B5 – Moments

Clear diagrams are essential for all problems. Without them, students all too easily assume that all distances are measured from 'the pivot', and they get really confused when there is more than one support (such as in B5.6).

Remind your class that the weight of an object acts as if it is all at the centre of gravity. For symmetrical objects, the centre of gravity will be at the centre or half way along. This may seem obvious, but in the absence of it being stated in the question, students sometimes forget to include the weight at all.

B5.5 makes students think because they want to measure to the pivot, and they don't know where it is.

> One approach is to say that the pivot is at position x. The weight is accordingly $(x - 10)$ cm from the pivot, while the centre of gravity is $(50 - x)$ cm from the pivot. To balance, we then have to solve
>
> $(x - 10) \times 2.0 = (50 - x) \times 0.92.$
>
> Simpler algebra is involved if we remember that the force upwards on the ruler at the pivot must be 2.92 N as it must support the weight and the ruler. If the pivot is distance y from the centre of the ruler, then we can neglect the 2 N force (it acts through the centre of our co-ordinates). The 0.92 N force is 40 cm away. Thus
>
> $0.92\ \mathrm{N} \times\ 40\ \mathrm{cm} = 2.92\ \mathrm{N} \times y.$
>
> Do remember that the answer to the question is not y. You need to specify the location on the ruler (e.g. at the $50\ \mathrm{cm} - y$ mark).

B5.8 Please do it the quick way by subtracting your answer for B5.7 from the total weight. Don't use moments again!

B5.10 The angle complicates matters. There are two methods of proceeding.

- i) The closest approach of the rod to the hinge is 80 cm × sin (30°) = 40 cm. Thus the 'perpendicular distance from the hinge to the line of action of the force' is 40 cm. Once you know this, you can write T × 40 cm = 30 kg × 9.8 N kg^{-1} × 40 cm.
- ii) The rod must exert an upwards force on the corner of the sign equal to half the weight of the sign (as the point is twice as far away from the hinge as the centre of gravity). This force is equal to T sin 30° (the vertical component of the tension in the rod). Thus half the weight of the sign is T sin 30°.