How to be a Physicist

Writing up Clear Solutions

Communication is an important life (transferable) skill—yes, even for a physicist! Communication is not just about speaking. When you write essays or work out science problems, the conclusions are important but do not tell the whole story. The phrase "show your working" is about communication, and is important because it will tell the reader about your reasoning.

With exams looming, you may hear the message that if you get the answer wrong and you don't show any working, you will lose more marks than you would if you showed your working, and it is easy to identify where you made the mistake. This is true, but this shouldn't be why you do it.

Your written work should be easy to follow for anyone looking at it (e.g. an examiner! / teacher / friend or you when you come to revise in a few months). Get into the habit early. You will find it helps you to **think and plan logically** and makes life easier for everyone involved.

A good solution will often have a healthy mix of diagrams, words, equations, symbols and numbers.

Diagrams

Diagrams are often a good place to start a question. It's a clear way to summarise all the key data and helps you to picture what is going on.

Check your diagram: (i) is a good size; (ii) is meaningful but not unnecessarily cluttered; (iii) is complete and consistent in notation; (iv) uses a ruler for straight lines.

Words

Words are a crucial part of telling any story. They help set up a problem and explain why you use a particular equation and state it before first use. For example, "by conservation of energy: $\Delta\text{KE} = \Delta\text{PE}$".

Symbols

There must be a logical flow to the work. If one line implies another, use symbols to connect them:

$\implies$	"implies that"	used between lines of working, when arranging equations
$\therefore$	"therefore"	used at the end of a series of working, when expressing a final result

Label equations you are going to use again with stars or numbers, and refer to them later. For example, "substituting for 't' from (*) into (**) gives:".

Numbers

At the end of the day, we'll usually be interested in a numerical result, and this is when to substitute in numbers – at the end! Simple numbers and fractions are exceptions to this rule. Most physics is done without a calculator. There are several good reasons for doing this, including:

- Intermediate evaluation and rounding can lead to errors
- It removes the "worry" about how many significant figures to write out
- It's quicker: try writing 'g' out ten times, then write out "$9.81\,\mathrm{m\,s^{-2}}$" ten times.
- Most importantly, it allows you to change a variable (e.g. an angle) and not repeat the whole calculation.

When evaluating answers or quoting numerical values, remember to think about **significant figures** and don't forget **units**.

Thinking

Physics is not simply "doing" maths. To be good at physics, it helps to be mathematically fluent, but the true skill of a physicist is to turn a real-life situation into an appropriate model, and then search for the simplest path to solving it.

Physics is mostly not a test of memory. There are however a few facts and formulae that are so fundamental they must be committed to memory. Nevertheless, it is much better to be confident in deriving others from first principles.

There are a number of tricks that can help with this.

Dimensional analysis

Formula triangles are dead, dimensional analysis is king! Formula triangles require too much memory and are for people who struggle with basic algebra.

Dimensional analysis only requires you to remember the quantities involved and their units (dimensions). Since you must know the associated units anyway, with practice, this will actually be simpler. It can also be used to check 'new' relationships.

Let's look at two examples:

Example 1

Say you're unsure which of these is correct:

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

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

Since we know the dimensions of the quantities: distance [m]; acceleration [m s^{-2}]; velocity [m s^{-1}]; time [s], we can quickly check which is dimensionally correct:

$$[\mathrm{m}] = [\mathrm{m\,s^{-2}}] \times [\mathrm{s}] + [\mathrm{m\,s^{-1}}] \times [\mathrm{s}]^2 \qquad = [\mathrm{m\,s^{-1}}] + [\mathrm{m\,s}] \tag{3}$$

$$[\mathrm{m}] = [\mathrm{m\,s^{-1}}] \times [\mathrm{s}] + [\mathrm{m\,s^{-2}}] \times [\mathrm{s}]^2 \qquad = [\mathrm{m}] + [\mathrm{m}] \tag{4}$$

Example 2

I'm asked to find the specific heat capacity of something, and am told that it has units of $\mathrm{J\,kg^{-1}\,K^{-1}}$. If I'm provided with energy, mass and change in temperature, it is easy to form the correct equation:

$$\mathrm{J\,kg^{-1}\,K^{-1}} = \frac{[\mathrm{J}]}{[\mathrm{kg}] \times [\mathrm{K}]} \tag{5}$$

$$\implies \text{specific heat capacity} = \frac{\text{Energy}}{\text{mass} \times \text{change in temperature}} \tag{6}$$

Caution: dimensional analysis cannot tell you anything about constants. These must be remembered!

Conservation laws

Physical 'things' don't simply disappear or appear from nowhere. This familiar principle can be applied to many problems, particularly when we know what we have at the start and want to find out what we have at the end of a process, but there may be something quite complicated happening in the middle. Consider the following problem: We could go about this by looking at forces, using $F =$

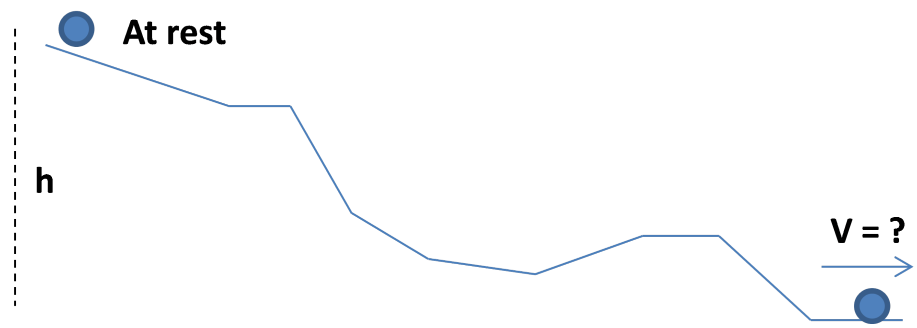

Figure 1: A ball on a slope

ma to find the acceleration to plug into an equation of motion, or we could simply realise that energy is conserved in this system, which simply means that lost potential energy is converted to kinetic. Thus:

$$\frac{1}{2}mv^2 = mg\Delta h \tag{7}$$

$$\implies v = \sqrt{2g\Delta h} \tag{8}$$

Other examples

- Kirchhoff's Laws are obvious when you think about them, e.g. the number of electrons (charge carriers per unit time) that enters a junction equals the number that leave the junction (node).
- Radioactive decay is simply a matter of balancing the number of nucleons and charges on each side of an equation.
- Momentum is always conserved, as is angular momentum. (This is why the solar system is spinning.)

Other tricks of the trade

Modelling

Modelling is an important skill. It may not be perfect, but if it will give us a reasonable estimate, it's probably good enough. There is usually a pay-off between complexity and accuracy, and if you have to triple the complexity for a small increase in accuracy, is it actually worthwhile? Physicists start with the simplest model that does the job, and only add extra bits if and when it becomes necessary. If we're neglecting air-resistance or drag, then the actual shape of an object may not matter. We just imagine a point that acts as if it contains all the mass of the object – the centre of mass.

Alternative methods

There's more than one way to skin a cat, and there's often more than one way to solve a particular problem. The obvious/intuitive way is likely the long way. Keep an open mind and be on the lookout for alternate ways that you can approach the problem that will save you some work.

Simplification

Look for symmetries, draw (imaginary) reflections, decide where to take zero from, or ask the opposite question; for example, electrons flowing clockwise around a loop have the same effect as positive charges flowing anticlockwise.