**Chapter 1: Introduction to Leaving Cert physics**

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# **1: Wonder in Science**

*I have no special talent. I am only passionately curious.*

Albert Einstein

*The most beautiful thing we can experience is the mysterious*

Einstein

I am passionate about physics. I want you to be passionate about it too. But this won’t happen if we rely solely on the leaving cert physics and the standard textbooks as our source of information. I want this to be a textbook like no other. I want it to be about putting a sense of wonder back into the subject. Knowing how the nature works does not take away from the sense of mystery and the awe we experience; it can only add to it. ***So why does wonder never feature in our science curriculum, and why does nobody ever talk about this?***

For years I used to think that I was the only one who thought like this. But slowly I began to realise that I wasn’t alone.

Consider the following:

*Students today are often immersed in an environment where what they learn is subjects that have truth and beauty embedded in them but the way they’re taught is compartmentalised and it’s drawn down to the point where the truth and beauty are not always evident.*

*It’s almost like that old recipe for chicken soup where you boil the chicken until the flavour is just . . . gone.*

David Bolinsky (award-winning medical illustrator and animator)

*Modern education is like being taken to the world's greatest restaurant & being forced to eat the menu.*

Murray Gell-Mann, Nobel Prize winning physicist - we will encounter him again later in our course).

It’s worth noting that he also believed that physics at high school was “the dullest course I had ever taken”, and he only applied to study physics at university “to please my father”. I like Gell-Mann.

*I devour popular science, finding its history and its wonder a constant delight. . . .* ***It is a mystery how so many science teachers can be so bad at their jobs that most children of my acquaintance cannot wait to get shot of the subject.***

Simon Jenkins (British author and newspaper columnist)

*If I can get girls to see a piece of themselves — their hair, a foot, their face and eyes, a finger — as connected to an exploding star, maybe that connection will stay with them as they start to encounter the inevitable challenges of a science career. So they won’t turn their backs on it when things get tough.*

Astronomer Aomawa Shields

*Science is built up of facts as a house is of stones, but a collection of facts is no* *more a science than a pile of stones is a house.*

Henri Poincare, *La Science et l’Hypothese* (1908)

Unfortunately that’s exactly what our science education entails; learning off this ‘collection of facts’. We educators take this incredibly exotic jungle of knowledge called *science* and distil it until all the wonder and context has been boiled off; we are left with nothing but the uncomfortable union of cold facts and equations lying in a bed of sludge. We use this residue to form the basis of our syllabus and textbooks and then force our students to learn it ‘off by heart’ so that it can all get vomited back up once more come exam time.  
And then we wonder why so many young people don’t like science.

It’s really such a shame that *the wonder of Science* only seems to be celebrated by artists, poets and writers. Why do scientists and science teachers (and in particular those who are responsible for drafting the science syllabi) hide from it so much?

Imagine if we had the following as one of our keys ideas in science education:

*The goal is for the public to appreciate the order and beauty of the abstract and natural worlds which is there, hidden, layer-upon-layer. To share the excitement and awe that scientists feel when confronting the greatest of riddles. To have empathy for the scientists who are humbled by the grandeur of it all.*

[Charles Simonyi Professorship in the Public Understanding of Science](http://www.simonyi.ox.ac.uk/index.shtml)

Why can’t we simply accept that by acknowledging and then highlighting the wonder that lies at the heart of the subject we would in fact be offering a more honest reflection of science is about? It is a source of *infinite* wonder. It would be impossible for any science-fiction writer to conjure up even a fraction of what we now know to be true in the world of science. Students the world over consider physics to be ‘hard’. It may well be, but I for one am convinced that many of the concepts which cause so much trouble aren’t innately difficult but rather it is the counter-intuitive nature that is the issue. And without addressing that we will always find it difficult to help the student get a firm grasp of what’s going on. E = mc2 is a very straightforward formula to use but what causes difficulty to students isn’t the maths; it’s the idea that mass can be there at a particular moment in time, and a second later it’s just gone. This is the type of thing that normally only takes place in Harry Potter novels. What’s it doing in a physics course? Yet physics is replete with ideas like this. Things which just don’t happen in our normal world, and which we therefore think can’t happen, do in fact happen all the time in physics. We do not have the option of refusing to accept an idea simply because it sounds crazy. But don’t take my word for it. “We are all agreed that your theory is crazy. The question which divides us is whether it is crazy enough to have a chance of being correct. My own feeling is that it is not crazy enough.” This time it’s Nobel Prize-winning physicist Neils Bohr. He was talking about something called Quantum Physics. And if you’re not familiar with that term before now, boy are you in for a treat.

Humans have evolved from single-celled organisms? ‘Rubbish’!

We are almost completely empty space and this notion of solidity is an illusion? “Don’t be ridiculous”!

It turns out that - to quote biologist J.B.S. Haldane – the universe is not only queerer than we suppose; it is queerer than we *can* suppose.

Where in Accounting or Business Studies or Religion are you likely to come up with a concept as mind-blowing as the following?

*Hold up your hand: You are looking at stardust made flesh. The iron in your blood, the calcium in your bones, the oxygen that fills your lungs each time you take a breath – all were baked in the fiery ovens deep within stars and blown into space when those stars grew old and perished. Each one of us was quite literally made in heaven. Modern science has shown us that we are more intimately connected to the stars than anyone dared to guess.*

American astrophysicist and science communicator extraordinaire Carl Sagan

*I am among those who think that science has great beauty. A scientist in his laboratory is not only a technician: he is also a child placed before natural phenomena which impress him like a fairy tale. We should not allow it to be believed that all scientific progress can be reduced to mechanisms, machines, gearings, even though such machinery also has its beauty.*

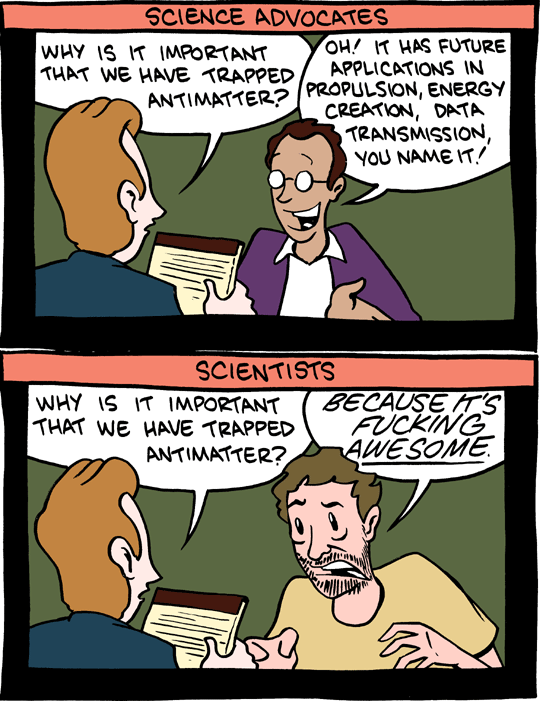
Marie Curie, Curie was the first woman to win a Nobel prize. But she is also the only person to win two Nobel prizes in two different science fields.

*The more clearly we can focus our attention on the wonders and realities of the universe, the less taste we shall have for destruction.*

. . .

*If a child is to keep alive his inborn sense of wonder . . . he needs the companionship of at least one adult who can share it, rediscovering with him the joy, excitement and mystery of the world we live in.*

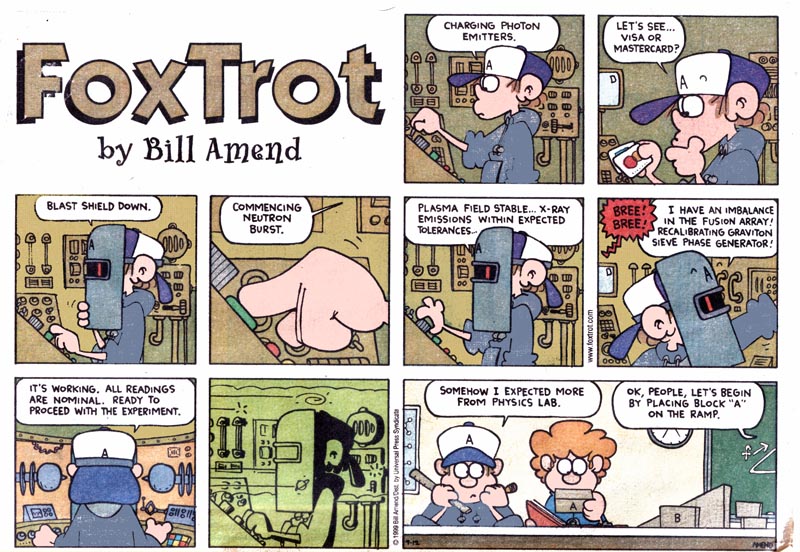
Rachel Carson, American marine biologist and author of *Silent Spring* (google it).



<http://smbc-comics.com/index.php?db=comics&id=2088#comic>

*Physics is like sex: sure, it may give some practical results, but that's not why we do it.*

Richard Feynman



## **What have we got to lose: science education is crap anyway!**

The irony is that our Science education is not even remotely successful in what it sets out to do. Research has shown that many students actually know *less* science after they finish their secondary level schooling than before they began.

*Conservatives say teaching sex education in the public schools will promote promiscuity. With our education system? If we promote promiscuity the same way we promote math or science, they’ve got nothing to worry about.*Beverly Mickens

*We are deprived by our stupid schooling system of most of the wonders of the world, of the skills and knowledge required to navigate it, above all of the ability to understand each other. Our narrow, antiquated education is forcing us apart like the characters in a Francis Bacon painting, each locked in our boxes, unable to communicate.*

George Monbiot (British author, environmentalist and newspaper columnist)

*I know nothing more terrible than the poor creatures who have learned too much . . . What they have acquired is a spider’s web of thoughts too weak to furnish sure supports, but complicated enough to produce confusion.*

Ernst Mach (Mach was a major influence on Albert Einstein and it is after him that the term *Mach Number* is named).

*One had to cram all this stuff into one’s mind for the examinations, whether one liked it or not. This coercion had such a deterring effect on me that, after I had passed the final examination, I found the consideration of any scientific problems distasteful to me for an entire year.*

Einstein

## **Telling science as a s*tory***

*Neglecting the rich history of science when teaching it is a missed opportunity to connect the subject to the world around us.*

Science teacher [Andrew Holding](https://www.theguardian.com/teacher-network/teacher-blog/2014/mar/25/lesson-science-history-engage-students)

Science is a story. It is traditionally said to have begun as the middle ages ended. In fact it played a large part in the *ending* of the Middle Ages and the beginning of the Renaissance period in Europe (it actually began 2000 years before that). But we shouldn’t tell the stories just because it might be entertaining. Nor should we do it just to give students a better sense of how science works. There is solid research to suggest that telling science in story format has sound *pedagogical* *value* (meaning that it helps students to understand and remember the underlying concepts).

*Everybody loves a good story. Even small children who have difficulty focusing in class will sit with rapt attention in the presence of a good storyteller. But stories are not just fun. There are important cognitive consequences of the story format. Psychologists have therefore referred to stories as "psychologically privileged," meaning that our minds treat stories differently than other types of material.*

[Daniel T. Willingham](http://www.danielwillingham.com/daniel-willingham-science-and-education-blog/storify-make-science-tell-a-story), professor of cognitive psychology and neuroscience

So the concept is likely to be better understood and stored more securely in long term memory if it comes with a meaningful story attached. And usually that story will include how the related theory developed over time together with the difficulties that the scientists had in accepting the new theory. We can even go one step farther; it turns out that many of the difficulties that the students have today with any given concept often mirror the struggles that the scientists themselves had, so we end up reassuring our students that it is not that they lack the necessary *brainpower* to understand a concept, rather that the concept itself is to counterintuitive that it lay dormant for thousands of years before *anybody* could grasp it.

## **So what *is* Science?**

Science is many, many things. The following is just a sample.

**Science is *a cultural activity* – it is an integral part of what it means to be human**

*The awed wonder that science can give us is one of the highest experiences of which the human psyche is capable… to rank with the finest that music and poetry can deliver.*

Richard Dawkins

**Science can tell us who we are**

Science tells us as much about where we have come from as it does about the world we inhabit. This must not be downplayed. In this context *psychology* is probably the most important of all the sciences. So naturally there is no reference to psychology in any of the science syllabi or textbooks at junior cert or leaving cert level. Go figure.

**Science is *Maths***

Strange as it may seem, most of the progress in physics over the past few centuries has required the language of mathematics. It would be an interesting exercise to try and see where we would be today without it. The picture you get of physics from this syllabus is very much a ‘dumbed-down’ version and if you choose to take physics at third-level prepare yourself for a serious shock.

If it’s any consolation Einstein had trouble with maths also (“Do not worry about your difficulties in Mathematics. I can assure you mine are still greater”), although I suspect the maths he struggled with was a little more advanced than that which we will encounter.

**Science is *a tool used by the powerful to subjugate the weak***

Science is many things, but one which you definitely won’t be told about in this course is that it is a tool used to maintain the inequality between the haves and the have nots. It is an instrument used to develop the military technology which enforces this inequality and which in turn is fed by the unequal distribution of the world’s resources.

One of the ‘strengths’ of science lies in its refusal to acknowledge its role in this. Indeed the mere questioning of this can label the critic as an ‘outsider’ and consequently negate the message or its potential validity. Look no further than the manner in which the role played by war has influenced so many developments in science and note how it has conveniently been downplayed or ignored completely for the sake of a more sanitised and noble picture which you find in your school science text-book.  The philosopher and scientist C.S. Pierce put it best when he wrote “Find a scientific man who proposes to get along without any metaphysics [philosophy] . . . and you have found one whose doctrines are thoroughly vitiated by the crude and uncriticised metaphyiscs with which they are packed.”

**Scientists are not secular saints**

Great scientists in the past have been painted as being great people; it is as though science needed its secular saints to counteract religion’s (*secular* means non-religious). But scientists are human and this means that they come with all the flaws that the rest of us have. Isaac Newton may indeed have been a wonderful scientist, but he was also a rather unpleasant individual, particularly if you got on the wrong side of him. One of his biographers summed him up as “an eccentric, an egoist, a troublemaker and a mystery-monger, who tolerated no criticism; was uncompromising, vengeful and conniving, but was also the greatest genius ever to have lived.”

Or how about Einstein? By 1914 his marriage to his wife of 11 years, Mileva Marić, was failing and he only agreed to remain married for the sake of their children if she agree to the following list of conditions:

* that my clothes and laundry are kept in good order;
* that I will receive my three meals regularly in my room;

You will obey the following points in your relations with me:

* you will not expect any intimacy from me, nor will you reproach me in any way;
* you will stop talking to me if I request it;
* you will leave my bedroom or study immediately without protest if I request it.

Mileva accepted the terms but not surprisingly the marriage still didn’t last.

**Science is a way of generating knowledge in a manner that is different to all others**

“How do you know that?” is perfectly valid question in science; the answer should ultimately refer back to the results of an experiment. Appeals to authority are useless, referring to deities or faith are equally invalid. That is why we do experiments in science. Unfortunately however the experiments we do are experiments in name only; they are no more an experiment in the proper sense than baking a cake. Real experiments occur when you don’t know the outcome or even the best way to carry it out. In school however we follow a procedure laid down as in a cookbook. I suppose it’s (slightly) better than nothing.

**Physics is cool**

For a long time it was *not* cool to study science, or physics in particular. But this has changed in recent years. It’s difficult to attribute this change to any one factor, but television shows like *The Big Bang Theory* and *Mythbusters* probably played a part.

In Britain it’s not uncommon to hear people talk of the *Professor Cox effect*, named after the popular television presenter (and former pop singer) Brian Cox. YouTube has also played a large part; channels such as Veratasium, IFLScience (“I f@\*king love Science”), VSauce all have hundreds of thousands of subscribers and their uploaded videos regularly get over one million views. And one thing they all share in common is that they latch on to the concept of wonder and feed off it in the same way that we try to do here.

*I’m interested in elementary particles; any spare time I have, I bury my head in a physics textbook. The elements at the atomic and subatomic level make up everything. You, me, the buildings, our souls, our minds. I’m reading a lot about Einstein. I like theories. I want to understand string theory. I’m dying for someone to explain quarks to me!*

Actress Anne Hathaway

*A while ago I was reading an interview with the actress Cameron Diaz in a movie magazine. At the end the interviewer asked her if there was anything she wanted to know, and she said she’d like to know what E = mc2 really means. They both laughed, then Diaz mumbled that she’d meant it, and then the interview ended.*

David Bodanis, author of  *“*E = mc squared; A biography of the world’s most famous equation”



## **Science is *not* about certainty**

*We dance around a ring and suppose, But the secret sits in the middle and knows.*

Robert Frost

We give the impression that we know everything that needs to be known about Science and that all this information is summed up in textbooks. Nothing could be farther from the truth. The phrases ‘the more we know the more we know we know nothing’.

*We are all deeply conscious today that the enthusiasm of our forbearers for the marvellous achievements of Newtonian mechanics led them to make generalisations in this area of predictability which, indeed, we have generally tended to believe before 1960, but which we now recognise were false. We collectively wish to apologise for having misled the general educated public by spreading ideas about the determinism of systems satisfying Newton’s laws of motion that, after 1960, were to be proved incorrect.*

Sir James Lighthill (<http://thinkforyourself.ie/2009/01/07/an-interesting-quote/>)

*The last century was defined by physics. This was a century that began with the certainties of absolute knowledge and ended with the knowledge of absolute uncertainty.*

Jim Baggott (*The Quantum Story: A history in 40 moments)*

## **What we still don’t know**

*Why is there something rather than nothing?*

Leibniz

We are no close to answering this question now that we were when man first asked that question thousands of years ago.

*Aristotle said a bunch of stuff that was wrong. Galileo and Newton fixed things up. Then Einstein broke everything again. Now, we’ve basically got it all worked out, except for small stuff, big stuff, hot stuff, cold stuff, fast stuff, heavy stuff, dark stuff, turbulence, and the concept of time.*

― Zach Weinersmith, Science: Abridged Beyond the Point of Usefulness

Here are just some of the small details things that we don’t understand.

1. **Mass**  
   For starters it turns out that we have two separate concepts of mass, both of which we deal with on this course, but both of which are completely different. They are known as ‘inertial mass’ and ‘gravitational mass’ but have so little do with each other that they should have completely different names. Unfortunately they even have the same unit (kg). They only thing they do have in common is that you can put the value for one type into a formula for the other type and still get the right answer. We do this all the time in leaving cert physics, but there is no mention of this being in anyway strange, when in fact it couldn’t get any stranger.

And nobody (and I mean nobody) knows why this works.

1. **Energy**

*It is important to realize that in physics today, we have no knowledge what energy is.*

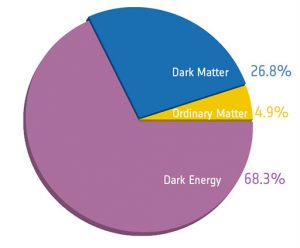
Richard Feynman

A biologist once wrote that nothing in biology makes sense except in the light of evolution. The same could be said for the concept of energy, except in this case it is not just biology but also chemistry and physics that it rules with an iron fist. And yet *energy* is presented as being just another definition to learn off. Admittedly we do need to know the *principle of conservation of energy* but not its significance, or more importantly, as alluded to above, the reason *why* it is so mysterious.

1. **Mass (again)**

**Approximately 27% of the mass in the universe is missing. We know it has to be out there, but we can’t find it. We call it ‘Dark Matter’.**

**So there’s that.**



1. **Energy (again)**

Approximately 27% of the energy in the universe is missing. We know it has to be out there, but we can’t find it. We call it ‘Dark Energy’.

So there’s that too.

1. **Magnetism**

*“Nobody knows* how a magnet can move a piece of metal without touching it . . .more astonishing still, nobody seems to care.”  
Bruno Maddux

And yet kids care. Magnetism fascinates kids. And it fascinated Einstein; he admitted that it was the starting point into his passion for wanting to know how the world works. And it continues to fascinate folk of all ages. In many ways our familiarity with magnetism has masked our wonder into the mechanisms of *how* it works. In this course we deal a little with the rules governing the influence of magnets on other objects but we never actually explain what magnetism *is* or how it works. Not because it’s too difficult (it’s not) but because that would be drifting dangerously into the world of wonder. And we daren’t go dare. For there be dragons.

1. **Gravity**  
   See above
2. **The atom**  
   Science doesn’t get any stranger than the astonishing world of the atom. But I can’t summarise it here because I simply wouldn’t even know where to begin
3. **The electron**

*‘The electron is a theory we use; it is so useful in understanding the way nature works that we can almost call it real.’*

Richard Feynman

I tend to quote Feynman a lot – he was da bomb.

1. **Light**  
   *All the fifty years of conscious brooding have brought me no closer to the answer to the question, What are light quanta? Of course, today every rascal thinks he knows the answer, but he is deluding himself.*

Einstein

*Sometimes I think I’d gladly be locked up in a dungeon ten fathoms below ground, if in return I could find out one thing: What is light?*

Galileo, from the play *Life of Galileo*, by Bertolt Brecht

This I love.

We can demonstrate that light is a *wave* (and students have to know the demonstration). This means, among other things, that it is spread out; part of the light-wave can be here and part of it can be over there.

But . . .

We can also demonstrate that light is a *particle* (and students have to know the demonstration). This means, among other thing, that it can’t be spread out; either all of it is here and none of it is over there or all of it is over there and none of it is over here.

Confused? You’re in good company – read the quotes above again and this time note that we are no closer to making sense of this now than we were one hundred years ago when we first discovered the problem (admittedly I’m being a bit generous in the use of the word ‘we’ here). There is no reference to this conundrum in the syllabus or textbooks (even though you do need to be able to describe the demonstrations, as mentioned above). The more you know about light the stranger it gets, but allow me to throw out one more nugget on this topic before we go; in the equation *E* = *mc*2 *E* is energy, *m* is mass and *c* represents the speed of light. What does the speed of light have to do with connecting energy and mass?

1. **Time** (Mr Deity)

I’m tired now.

Just watch this: <http://youtu.be/K2ujpzdeolA>

## **Science is NOT about you getting an H1 in your leaving cert**

Well maybe it is - just a little.

You getting an ‘A’ in your leaving cert is not my concern – it is yours. I will facilitate your learning in so far as I can. I will put all the material that you need into a form that makes it relatively straightforward for you to understand. I will explain concepts as best I can and do likewise for all of your questions.

I do not intend to motivate you. If I am doing my job correctly then most of you will want find out as much as you can about this world for your own sake and so and will end up taking responsibility for your own learning.

If on the other hand your intention is to do as little as possible then congratulations – this is also the ideal class for you; once you don’t disrupt anybody around you we’ll get on just fine. Of course your parents also need to be on board.

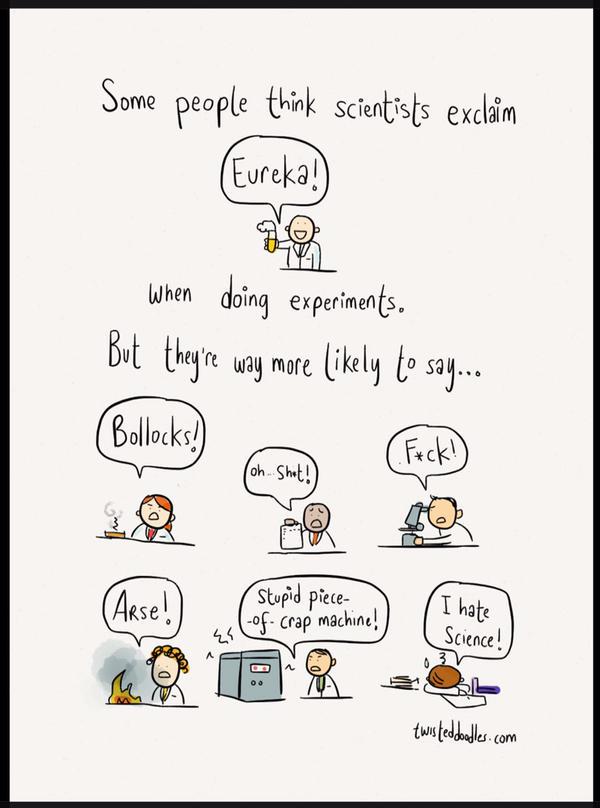
I tend to go off in tangents quite a bit when teaching. I therefore use my class notes as a means of keeping me on track so that any time we finish a chapter finished I can use the embedded exam questions as a checklist to make sure I didn’t forget anything. The questions are very comprehensive. They include just about every question that has appeared on a exam paper from 2002 – 2019 and most come with fully worked out solutions. Each section here begins with Ordinary Level questions and then proceeds to Higher Level questions. Feel free to contact me at any stage if you need further assistance.

One other part worth mentioning is the ‘Extra Reading’ section in the class notes. These originally featured as explanatory notes in the body of the notes themselves but over time they began to bulk up this section too much, so now I have them at the end of each chapter instead. If you see an asterisk beside a concept it means that I tease this idea out further at the end-section.

My job is to undo some of the damage which your education has wrecked. Hopefully your memory of this Physics class, and more importantly of Physics itself, will be a happy one.

So strap in.

Enjoy the ride.



# **2: Scientific notation, symbols, units and equations**

# Scientific notation

Scientific notation allows us to easily represent very big or very small numbers.

Some examples:

The speed of light is approximately three hundred million metres per second.

We write this number mathematically as follows:

300 000 000 m s-1 or, using scientific notation, 3 × 108 m s-1

It takes approximately 200 000 (2 × 105) joules of heat to boil a kettle and 50 000 000 (5 × 107) joules to heat a bath of water.

We can also use ***prefixes*** as shorthand for some scientific notation:

|  |  |  |
| --- | --- | --- |
| Prefix | Symbol | Factor |
| milli- | m | × 10-3 |
| micro- | μ | × 10-6 |
| nano- | n | × 10-9 |
| pico- | p | × 10-12 |
|  |  |  |
|  |  |  |
| kilo- | k | × 103 |
| mega- | M | × 106 |
| giga- | G | × 109 |
| tera- | T | × 1012 |
|  |  |  |

You will also find the information above on page 45 of the ***Formula & Tables*** book

|  |  |  |
| --- | --- | --- |
| **Examples** | | |
| 1 thousandth | .001 | 1 × 10-3 |
| 1 millionth | .000 001 | 1 × 10-6 |
| 1 billionth | .000 000 001 | 1 × 10-9 |
|  |  |  |
|  |  |  |
| 1 thousand | 1000 | 1 × 103 |
| 1 million | 1000 000 | 1 × 106 |
| 1 billion | 1000 000 000 | 1 × 109 |
|  |  |  |

For example 1 million joules = 1 × 106 J = 1 megajoule = 1 MJ

.0052 metres = 5.2 × 10-3 m = 5.2 millimetres = 5.2 mm

**Try to identify the name or the term using the clues below**

|  |  |
| --- | --- |
|  | 1 x 1012 firmas |
|  | 2 x 1012 bulls |
|  | 1 x 109 lows |
|  | 2 x 106 phones |
|  | 1 x 103 manjaros |
|  | 1 x 103 whales |
|  | 2 x 103  mockingbirds |
|  | 1 x 10 -3 pedes |
|  | 1 x 10-3 nnium |
|  | 1 x 10-3 taries |
|  | 2 x 10-6 scopes |
|  | 3 x 10-6 phones |
|  | 1 x 10-12 boos |

Answers

1. 1 terra firma
2. 1 terabull
3. 1 gigalow
4. 2 megaphones
5. 1 kilomanjaro
6. 1 kilowhale
7. 2 kilomockingbird
8. 1 millipede
9. 1 millennium (so 1 nnium = 106 years)
10. 1 military
11. 2 microscopes
12. 3 microphones
13. 1 picaboo

*Question: What is the unit for the level of beauty required to launch a single ship?*

*Answer: The millihelen*

**Why is any number to the power of 0 equal to 1?**

With a whole number exponent, it tracks how many times you've multiplied by the base. If the exponent is zero, then you haven't done any multiplications yet, so you're still at the beginning, which is 1.

# Symbols and units

*‘Maths is what you have left when you start with something interesting and take away the units.’*

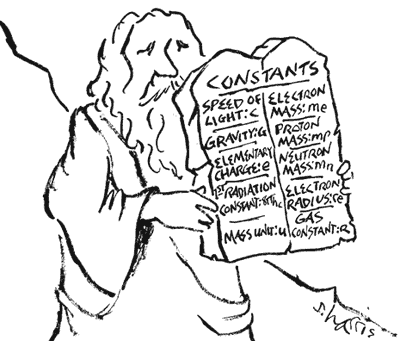
**Well I still get full marks for a maths question if I don’t write down the formula?**

Yes, students will be awarded full marks for formula and for substitution if they only present the correctly substituted formula.

However, there is a much greater risk of making an error in substitution if the student hasn't the original formula written down and that results in zero marks.

This error is quite common.

Best practice: write down the formula!!



## SI unit rules and style conventions

*"You, in this country, are subjected to the British insularity in weights and measures; you use the foot, inch and yard. I am obliged to use that system, but must apologize to you for doing so, because it is so inconvenient, and I hope Americans will do everything in their power to introduce the French metrical system. ... I look upon our English system as a wickedly, brain-destroying system of bondage under which we suffer. The reason why we continue to use it is the imaginary difficulty of making a change and nothing else; but I do not think in America that any such difficulty should stand in the way of adopting so splendidly useful a reform."*

Lord Kelvin (if only he knew . . .)

|  |  |  |
| --- | --- | --- |
|  | **Proper use** | **Improper use** |
| There should be a space between the number and the unit (or the unit’s prefix). | 18 m  18 km | 18m  18km |
|  |  |  |
| There should be **no space** between the prefix and the unit. | 18 km | 18 k m |
|  |  |  |
| **A space (or half-high dot) is used to signify the multiplication of units.**  (note that ms−1 refers to the reciprocal of milliseconds, not m/s) | 20m s-1  20 m·s-1 | 20 ms−1 |
|  |  |  |
| **All units are spelled out using lower case** | **newtons, joules,** volts, kilogram | Newtons, Joules, Volts |
|  |  |  |
| ***Symbols* for units are usually lowercase *unless they are symbols of units that derive from the name of a physicist – in which case they are uppercase.*** | kg, cm  N, J, V | Kg  n, j, v |
|  |  |  |
| **Variables and quantity symbols are in italic type.**  Unit symbols are in roman type.  Numbers should be written in roman type. | *v* = *u* + *at*  *t*= 3 s *T*= 22 K | v = u + at  t = 3 s  T = 22 K |
|  |  |  |
| Unit symbols are unaltered in the plural. | *l*= 75 cm | *l*= 75 cms |
|  |  |  |
| Unit symbols are not followed by a period unless at the end of a sentence. | The length of the bar is 75 cm.  The bar is 75 cm long. | The bar is 75 cm. long. |
|  |  |  |

<http://physics.nist.gov/cuu/Units/checklist.html>

<http://physics.nist.gov/cuu/pdf/typefaces.pdf>

The IUPAP 'red book' is the definitive source of information about symbols for physics quantities and units:

<https://iupap.org/wp-content/uploads/2014/05/A4.pdf>

## Physics variables

**Mechanics**

**Check that you know these by covering up one column at a time.**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Quantity** |  | **Symbol** |  | **Unit** |  | **Symbol** |  | **Equation** |
|  |  |  |  |  |  |  |  |  |
| Area |  | *a* |  | metres squared |  | m2 |  |  |
|  |  |  |  |  |  |  |  |  |
| Volume |  | *v* |  | metres cubed |  | m3 |  |  |
|  |  |  |  |  |  |  |  |  |
| Mass |  | *m* |  | kilogram |  | kg |  |  |
|  |  |  |  |  |  |  |  |  |
| Density |  | *ρ* |  | kilogram per metre cubed |  | kg m-3 |  | **ρ = m/v** |
|  |  |  |  |  |  |  |  |  |
| Displacement |  | *s* |  | metre |  | m |  |  |
|  |  |  |  |  |  |  |  |  |
| Velocity |  | *v* |  | metre per second |  | m s-1 |  | **v = d/t** |
|  |  |  |  |  |  |  |  |  |
| Acceleration |  | *a* |  | metre per second squared |  | m s-2 |  |  |
|  |  |  |  |  |  |  |  |  |
| Force |  | *F* |  | newton |  | N |  | ***F = ma*** |
|  |  |  |  |  |  |  |  |  |
| Momentum |  | *ρ* |  |  |  | kg m s-1 |  | ***ρ = mv*** |
|  |  |  |  |  |  |  |  |  |
| Pressure |  | *p* |  | pascal |  | Pa |  | **p = F/a** |
|  |  |  |  |  |  |  |  |  |
| Moment of a force |  |  |  | newton metre |  | N m |  |  |
|  |  |  |  |  |  |  |  |  |
| Torque (couple) |  | *T* |  | newton metre |  | N m |  | **T = F x d** |
|  |  |  |  |  |  |  |  |  |
| Energy |  | *E / Q / W* |  | joule |  | J |  |  |
|  |  |  |  |  |  |  |  |  |
| Work |  | *w* |  | joule |  | J |  | **W = F s** |
|  |  |  |  |  |  |  |  |  |
| Power |  | *p* |  | watt |  | W |  | **P = W/t** |
|  |  |  |  |  |  |  |  |  |
| Angle |  | θ (“theta”) |  | radian |  | rad |  |  |
|  |  |  |  |  |  |  |  |  |
| Angular velocity |  | ω (“omega”) |  | radian per second |  | rad/sec |  | **ω = θ/t** |

## 

**Heat and temperature**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Quantity** |  | **Symbol** |  | **Unit** |  | **Symbol** |  | **Equation** |
|  |  |  |  |  |  |  |  |  |
| Heat Capacity |  | C |  | joule per kelvin |  | J/K |  | **Q = c (△θ)** |
|  |  |  |  |  |  |  |  |  |
| Specific Heat Capacity |  | c |  |  |  | J/kg/K |  | **Q = mc△θ** |
|  |  |  |  |  |  |  |  |  |
| Latent Heat |  | l |  | joule per kilogram |  | J/kg |  | **Q = ml** |

**Waves, sound and light**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Quantity** |  | **Symbol** |  | **Unit** |  | **Symbol** |  | **Equation** |
|  |  |  |  |  |  |  |  |  |
| Frequency |  | f |  | hertz |  | Hz |  |  |
|  |  |  |  |  |  |  |  |  |
| Wavelength |  | λ (“lamda”) |  | metres |  | m |  |  |
|  |  |  |  |  |  |  |  |  |
| Velocity |  | v (or c for light) |  | metre per second |  | m/s |  | **v = f λ** |
|  |  |  |  |  |  |  |  |  |
| Intensity |  | I |  | watts per metre squared |  | W/m2 |  | **S.I. = P/A** |
|  |  |  |  |  |  |  |  |  |
| Sound Intensity Level |  |  |  | decibels |  | dB |  |  |

**Electricity**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Quantity** |  | **Symbol** |  | **Unit** |  | **Symbol** |  | **Equation** |
|  |  |  |  |  |  |  |  |  |
| Charge |  | Q |  | coulomb |  | C |  |  |
|  |  |  |  |  |  |  |  |  |
| Electric Field Strength |  | E |  | newtons per coulomb |  | N/C |  | **E = F/Q** |
|  |  |  |  |  |  |  |  |  |
| Potential Difference  (“voltage”) |  | V |  | volts |  | V |  | **W = V Q** |
|  |  |  |  |  |  |  |  |  |
| Capacitance |  | C |  | farads |  | F |  | **C = Q/V** |
|  |  |  |  |  |  |  |  |  |
| Current |  | I |  | amperes (amps) |  | A |  | **I = Q/t** |
|  |  |  |  |  |  |  |  |  |
| Power |  | P |  | watt |  | W |  | **P = VI** |
|  |  |  |  |  |  |  |  |  |
| Resistance |  | R |  | ohm |  | Ω |  | R = V/I |
|  |  |  |  |  |  |  |  |  |
| Resistivity |  | ρ |  | ohm-metre |  | Ω m |  | **ρ = RA /l** |
|  |  |  |  |  |  |  |  |  |
| Magnetic Flux Density |  | B |  | tesla |  | T |  | **F = BIL** |
|  |  |  |  |  |  |  |  |  |
| Magnetic Flux |  | φ Psi (“sigh”) |  | weber |  | W |  | **φ = BA** |
|  |  |  |  |  |  |  |  |  |
| Half-Life |  | T1/2 |  | second |  |  |  | **T1/2 = 0.693/λ** |

# Equations

Many of the maths questions on the Leaving Cert Physics paper rely on you being able to quickly recall short equations.

And yes these are all in the log tables, but if you are looking for an *A* or *B* grade then you don’t have time to go searching.

The variables have deliberately not been arranged in the order in which they would appear in the formula (because that would just be too easy).

To test yourself, cover the third column and see if you can come up with the relevant equation given the information in the second column.

If you come across any equations which I have omitted, please let me know and I will update the list.

Hangman takes on a new dimension if you can include equations by allowing spaces for division, power s(e.g. ^2) etc.

**Mechanics**

|  |  |  |
| --- | --- | --- |
|  | **Variables** | **Equation** |
|  |  |  |
| **Equations of motion** |  | v = u + at  s = ut + ½ at2  v2 = u2 + 2as |
|  |  |  |
| **Force, mass and momentum** | acceleration, force, mass | F = ma |
|  |  |  |
|  | weight , mass | W = mg |
|  |  |  |
|  | velocity, mass, momentum | ρ = mv |
|  |  |  |
| **Conservation of momentum** |  | m1 u1 + m2 u2 = m1 v3 + m2 v4 |
|  |  |  |
| **Pressure** | area, pressure, force | P = F/A |
|  |  |  |
|  | density, height, pressure | P = ρgh |
|  |  |  |
| **Boyle’s law** |  | P1V1= P2V2 |
|  |  |  |
| **Newton’s law of gravitation** | gravitational force between two masses |  |
| ***g* at different heights** | Gravitational field strength and distance above a planet | g = GM/ d2 |
|  |  |  |
| **Moment of a force** | distance, moment, force | Moment = Force x distance |
|  |  |  |
| **Torque** | force, distance, torque | T = F x d (between forces) |
|  |  |  |
| **Work, energy** | force, work, displacement | W = F s |
|  |  |  |
| **Kinetic energy** | velocity, mass energy | Ek = ½ mv2 |
|  |  |  |
| **Potential energy** | height, mass, energy | Ep = mgh |
|  |  |  |
|  |  |  |
| **Conservation of energy** |  | mgh = ½ mv2 |
|  |  |  |
| **Power** | time, power work | P = W/t |
|  |  |  |
|  |  |  |
| **Percentage efficiency** |  | Power Out / Power In x 100/1 |
|  |  |  |
| **Circular motion** | time, angular velocity, theta | ω = θ/t |
|  |  |  |
|  | linear velocity, angular velocity, radius | v = rω |
|  |  |  |
|  | acceleration,  angular velocity, radius, | a = rω2 |
|  |  |  |
|  | linear velocity, radius, acceleration | a = v2/r |
|  |  |  |
|  | force, angular velocity, radius, mass | F = mrω2 |
|  |  |  |
|  | mass, linear velocity, radius, force, | F = mv2/r |
|  |  |  |
|  | mass of planet, acceleration due to gravity, radius of satellite | g = GM/R2 |
|  |  |  |
|  | mass of a planet, radius,  periodic tiime |  |
|  |  |  |
| **Hooke’s law** | extension, restoring force | F = -k s |
|  |  |  |
| **S.H.M.** | acceleration and displacement | a = -ω2 s |
|  |  |  |
|  | periodic time and angular velocity | T = 2π/ω |
|  |  |  |
|  | frequency and periodic time | T = 1/f |
|  |  |  |
| **Simple pendulum** |  | T = 2π √ l/g |

**Waves, sound and light**

|  |  |  |
| --- | --- | --- |
| **Mirrors** | image distance, magnification, Object distance |  |
|  |  |  |
|  | image height, magnification, object height |  |
|  |  |  |
|  | image distance, magnification, object distance |  |
| **Refraction** |  |  |
|  |  |  |
|  | real and apparent depth |  |
|  |  |  |
|  | reversing direction and critical angle |  |
|  |  |  |
|  | refractive index and speeds |  |
|  |  |  |
|  | refractive index and critical angle |  |
| **Lenses** | image distance, mag,  object distance |  |
|  |  |  |
|  | image height, mag, object height |  |
|  |  |  |
|  | image distance, magnification, object distance |  |
|  | power, focal length |  |
|  |  |  |
|  | Addition of powers | PTotal = P1 + P2 |
|  |  |  |
| **Waves** | Wavelength, velocity, frequency | v = f λ |
|  |  |  |
| **Doppler Effect** |  |  |
|  |  |  |
|  | Area, Power, S Intensity | S.I. = Power / Area |
|  |  |  |
|  | Tension, Frequency, Length |  |
| **Wavelength of light** |  | nλ = d Sin θ |
|  |  |  |
| **Diffraction grating** | Distance between slits on a diffraction grating | d = 1/n |

**Electricity**

|  |  |  |
| --- | --- | --- |
|  | **Variable** | **Equation** |
| **Static electricity** | Coulomb’s Law | F = |
|  |  |  |
|  | Electric field strength | E = F/Q |
|  |  |  |
|  | Electric field strength | E = |
|  |  |  |
| **Potential difference** | charge, voltage, work | W = QV |
|  |  |  |
| **Capacitance** | charge, potential difference, capacitance | C= Q/V |
|  |  |  |
|  | Area, Capacitance Distance | C = εA/d |
|  |  |  |
|  | work/energy, voltage capacitance | W = ½ CV2 |
|  |  |  |
|  | current, charge, time | I = Q/t Q = It |
|  |  |  |
|  | power, current, voltage | P = VI |
|  |  |  |
| Ohm’s Law |  | V = IR |
|  |  |  |
|  | resistivity | R = ρl/A |
|  |  |  |
|  | wheatstone Bridge |  |
|  |  |  |
|  | current, time, energy, resistance, | Heat = I2Rt |
|  |  |  |
| Joule’s Law | current, power, resistance | Power = I2R |
|  |  |  |
|  | current, length, force, mag flux density | F = BIL |
|  |  |  |
|  | force, charge, velocity, mag flux density | F = Bqv |
|  |  |  |
|  | magnetic flux density, area, magnetic lux | φ = *BA* |
|  |  |  |
|  | induced emf | E = - N (dφ/dt) |
|  |  |  |
|  | Vrms, maximum voltage | Vrms= Vmax/(√2) |
|  |  |  |
|  | Irms, maximum current | Irms = Imax/(√2) |
|  |  |  |
| Transformer |  |  |

**Modern physics**

|  |  |  |
| --- | --- | --- |
|  | **Variable** | **Equation** |
|  |  |  |
| Force on an electron |  | mv2/r = Bev |
|  |  |  |
|  | Potential energy and  Kinetic energy of electron | eV = ½ mv2 |
|  |  |  |
| Photoelectric Effect |  | hf = φ + ½mv2 |
|  |  |  |
|  | Frequency,  Energy of a photon | E = hf |
|  |  |  |
|  | Wavelength,  Energy of a photon | E = hc/λ |
|  |  |  |
|  | Decay rate,  Decay constant  Number of atoms | dn/dt = λ N |
|  |  |  |
|  | Half life,  Decay constant | T1/2 = 0.693/λ |
|  |  |  |
|  | Energy,  Mass | E = mc2 |
|  |  |  |
|  |  | +  →  + K.E. |
|  |  |  |
| Pair Production |  | γ rays → e- + e+ + K.E. |
|  |  |  |
| Particle Annihilation |  | e- + e+ → 2γ + K.E. |

## Be familiar with the *Formula & Tables* book

**Pages 50 to 63 are the most important** - they contain most of the **formulas**that you need.

The **prefixes**used in SI units are on page 45.

The **fundamental physical constants** are given on pages 46 - 47.

The **Periodic Table** on page 79 and the first table on page 82.

Many of the maths questions on the leaving cert physics paper rely on you being able to quickly recall short equations so while most of these are available in the log tables, a good student shouldn’t need to look them up. To test yourself cover the third column in the next page and see if you can come up with the relevant equation given the information in the second column

Hangman takes on a new dimension if you can include equations by allowing spaces for division, powers (e.g. ^2) etc.

The variables have deliberately not been arranged in the order in which they would appear in the formula (because that would just be too easy)

**Formulas NOT in *Tables & Formula* book**

**Mechanics**

|  |  |  |
| --- | --- | --- |
| **Boyle’s law** | Volume of gas and pressure | pV= k OR p1V1= p2V2 |
| **Conservation of energy** | Gravitational potential energy and kinetic energy |  |
| **Weight** | Given |  |
| **Gravity & Circular Motion** | Velocity, radius of orbit and mass of central body |  |
| **Components of a vector** | Horizontal  and vertical | |

**Waves, Sound, Light**

|  |  |  |
| --- | --- | --- |
| **Mirrors & Lenses** | Magnification, Image height, Object height |  |
| **Refraction** | Real and apparent depth |  |
| **Sound intensity** | Sound intensity, area, power | Intensity, I = Power / Area |
| **Decibels** | Decibels and sound intensity | Double I = an increase of 3 dB |
| **Speed of sound** | Standing wave in tube closed at one end |  |
| **Grating formula** | Distance between slits on a diffraction grating | d = 1/n |

**Electricity**

|  |  |  |
| --- | --- | --- |
| **Electric field Strength** | Electric field Strength (due to *Q*) | E = |
| **Current/Charge** | Current, charge, time | Q = It OR I = Q/t |
| **Joule’s Law** | Power, current, resistance | () |
| **Magnetic Induction** | Induced E.M.F. in a coil with N turns |  |
| **Transformer** | Power in = Power out |  |

**Modern Physics**

|  |  |  |
| --- | --- | --- |
| **Force on an electron** | Electron moving in a magnetic field moves in a circle |  |
| **Ek of an electron** | Kinetic energy of electron (*V* is voltage) |  |
| **Half life** | Half-life, decay constant | T1/2 = 0.693/λ |
| **Walton** | Split nucleus and release energy | +  →  + K.E. |
| **Pair production** | Photon to particles (Note: *one* photon) | γ photon → e– + e+ + K.E. |
| **Particle annihilation** | Particles to photons (Note: *two* photons) | e- + e+ → 2γ photons + K.E. |