Physics Pre-U Exam Notes

Nuclear and Particle Physics

The equation:

$$N = N_0 e^{-\lambda t}$$

is just a solution to the simple differential equation that governs decay:

$$\frac{dN}{dt} = -\lambda N$$

you can check it by differentiating the top expression's sides wrt t and getting the original expression given right above.

Nuclear decay is *spontaneous* (not dependent on any external factor such as temperature or pressure), and random (cannot be predicted).

There exists an equation for decrease in intensity of nuclear radiation passing through matter due to "attenuation" losses; that is, scattering or absorption. Given that it intuitively satisfied the boundary conditions that the loss through a given slice of a material is dependent on the intensity you started with, you can use the same equation as the first one, but with N replaced with I, with lambda replaced with mu, with t replaced with x (distance into the material).

You estimate lower bound on size of nuclei from closest approach by equating kinetic energy to electrical potential energy, as all of the former is transformed into the latter during closest approach.

Binding energy is the work you need to do separate all the nucleons from a nuclear form to infinitely far apart. It's the same as the energy form of the mass deficit.

Part of the standard model's job is to classify all known elementary particles. Each particle has certain properties (mass, charge, spin) and the antiparticle tends to have opposite properties (except for mass). We know these exist because they're predicted by Dirac's equations of electron movement (with a positive and negative solution), and they were detected experimentally in things like cloud chambers, where we saw that in an E-field, a particle had the same curve shape (and thus mass) as the electron, but in the opposite direction (opposite charge).

Antiparticles also have opposite *spin* to regular particles. *Spin* is a property of matter that tells us about it's magnetic behaviour. Originally, we saw that electrons had a north pole and south pole, and thought it might be because they're spinning like planets. It was proved this classical intuition would lead to a rate of spinning >*c*. And so now, spin still refers to the magnetic properties of particles, but has nothing to do with the classical interpretation.

When you create matter via energy annihilation (two photons colliding) then you also create antimatter to preserve conservation of charge and spin (amongst others). But then where is the antimatter that corresponds to all the matter we see all the time? Open problem in physics —"baryon asymmetry".

When high-energy physics had it's day in the the mid 20th century, "elementary" particles were being discovered left right and centre. And so, quarks were theorised as a way to explain the composition of *hadrons* (protons, neutrons). There are 6 different types of quarks, of which up/down are two.

These conservation laws are powerful predictive tools (which, ultimately, is what physics is all about). For example, when we observed beta decay (neutrons decaying into protons and electrons), we found that electrons are released at a variety of energies. This shouldn't be the case, as the conservation of momentum says that when a stationary neutron decays, the electron should have one fixed energy when it leaves the two body frame with a constant total energy. But it had a range. So another particle must be carrying away the deficit (in the opposite direction). This, we called the neutrino.

There are three types, or, "generations" of neutrinos—tau, mu and electron neutrino. Similar for electrons. Together, electrons and neutrinos comprise leptons.

The standard model documents three families of elementary particles: quarks (building blocks of hadrons), leptons (electrons, neutrinos) and force carriers/bosons (photons for EM, gluons for strong). Note that quarks and gluons have never been directly detected.

Hadrons come in two types: baryons and mesons. Baryons are anything made of three quarks (so protons and neutrons are both baryons, a subset of hadrons, comprised of quarks). Mesons contain two quarks: one quark and an antiquark (same mass, opposite charge and spin) and are therefore very unstable, pions and K mesons are examples.

So, to recap:

- Hadrons (made of quarks)
  - Baryons (3 quarks—proton, neutron)
  - Mesons (2 quarks—K meson, pion)
- Leptons
  - Electrons
  - Neutrinos
  - Muons
- Bosons (force carriers)
  - Photons
  - Gluons

In addition to conserve of energy, momentum and charge, nuclear transformations must satisfy conservation of *baryon and lepton number, where antiparticles have opposite baryon and lepton numbers*.

The most commonly found isotopes of elements are the most stable ones. You determine which are most stable by plotting a graph of binding energy per nucleon against nucleon number, and some isotopes will have a larger BE/nucleon and so will be more stable.

Helium 4,2—an alpha particle—is unusually stable.

The strong interaction (gluon exchange) only acts over a very short range—because you can only receive gluons from particles you're adjacent to—shorter than EM repulsion, certainly. And so, as you add more protons (going up the elements) EM increases commensurately, repelling other protons on the other side an additional amount, but protons on the other side can't benefit from increased gluon exchange. Thus, you need to start "diluting" the repulsive force by compensating —this is done by adding extra neutrons to provide gluons without EM repulsion. This is why the neutron/proton ratio increases with time.

A neutron *is not* a proton and electron bound together (think about quark structure). It is a separate entity to the proton, but decays to form a proton and neutron. We know this as the product of uncertainties of the positions & momenta of particles is a small constant, and so if a neutron were really just a proton and electron, we'd know the proton/electron's position to a very high degree of uncertainty, and so the uncertainty in momentum would be enormous, allowing for momenta that correspond to the electron having enough KE to leave the proton-neutron complex, and thus contradicting the initial assumption.

Astrophysics & Cosmology

Remember FILP—flux is intensity (power per unit area) and luminosity is power.

We gauge enormous distances, those much further than the milky way, using standard candles. These are either Cepheid variable stars, or type 1a supernovae. Cepheid variables are special in that their absolute brightness is related to the frequency with which they pulsate. So, we observe their pulsation rate on Earth and thus calculate their absolute brightness (actual luminosity). We also know their apparent brightness (observed luminosity) and so can calculate their distance as stars that are further away have a higher ratio of actual to apparent brightness.

Supernovae are deaths of stars caused by instability in the balance between gravity (pulling matter in) and heat-induced pressure (pushing matter outwards). Instead of frequency of pulsation, here, we use time taken for light to disappear/fade (it's an explosion of course). This is, of course, related to actual brightness, and we can compare that to the observed brightness to find distance. Thus, we know the distance to many galaxies that are "far, far away".

Both Wein's displacement law (most common wavelength emitted is inversely proportional to surface temperature) and Stefan's law (intensity is proportional to temperature^4), and related by Stefan's constant—a sigma. When they say scientists "measured the flux" of a star, they mean it's apparent brightness—its power per unit area where r is length we're observing it from. Luminosity (power) is an absolute value of the star at it's surface, but flux varies with how far you are from the star.

When looking to find distance to a star via parallax, just do 1/angle change when you orbit the sun to get the distance in parsecs (3.1e16 metres—it's actually defined as the distance where 1 AU subtends 1 arcsecond).

Cepheid variables are not the *same thing* as standard candles, but just a type of them. Any object that we can compute the distance of by looking at its actual vs observed luminous flux (power/area) becomes a known distance, a benchmark, this way.

A spectrometer is an instrument that converts the pure light we get from a source into a spectrum, separating the original light out into its components. Thus, we see that our original light *did* have a component at, say, 525nm, which corresponds to an energy transition in, say, Helium. And, our original light did not have a component, but instead has a black line at, 675nm, which corresponds to a known energy transition in, say, Carbon. So we know our source doesn't contain carbon. This is how we can get a sense of the elemental composition of different celestial entities. The spectrum of a specific element—say, hydrogen, *always looks the same* (no shit, as every hydrogen atom is identical).

An emission spectrum is lines where light has been emitted, and the rest is black. An absorption spectrum is lines where, when light is passed through a cool sample of the material, energy has been absorbed. Understandably, they are inverses of each other.

Assuming that all galaxies, as macroscopic entities, have the same elemental composition (which they largely do—e.g. stars of particular sizes are made of particular ratios of hydrogen and helium), shouldn't the spectra of all stars look the same, as they contain the same elements? Why are the black absorption lines in spectra from some sources in place different to others? Why are the black absorption lines of distant galaxies closer to the red-end of the visible spectrum than those of the sun? *Because they're moving away*. And when we look closer into this phenomenon, we find that galaxies in *all directions* are receding, and that the more distant the galaxy (distance measured by standard candles), the *more* the absorption is shifted towards the red-end of the spectrum. Leads to a clear conclusion: the universe is *expanding*.

This red-shift is to do with the *expansion of space itself* and NOT the movement of galaxies away from us *through space*, is called *cosmological* red-shift. We assume that the galaxies are not moving away from us *through space*. This value of:

$$\frac{\Delta\lambda}{\lambda} \approx \frac{\Delta f}{f}$$

is given the name *z*—the cosmological red shift. The space in between them is expanding by a factor of 1+*z*.

Hubble's parameter, H_0, is the constant of proportionality relating the distance of something from us and how fast it's receding. It's thought to be around 71 km/s/mpc right now, which, when reduced, becomes:

$$2.3 \times 10^{-18} s^{-1}$$

That's the scale factor of expansion. It relates km to mpc, and can be thought of how much any arbitrary length is increasing by. For example, each metre is increasing by that factor every second. Therefore, if we take the units of increase as "size of current universe" and divide by rate of expansion, we get how long it would take to reach this size if the universe was always expanding at a constant rate, which we know is (approximately) true (accelerating expansion only causes a tiny deviation). This is the age of the universe, and why it's the reciprocal of bubble's constant.

When we say the universe is "flat", in cosmology, we mean that the pythagorean theorem holds in three spatial dimensions of the universe. It would not, for example, hold on the surface of a sphere, where the angles in a triangle do not add up to 180 degrees. We have observed that this theorem (dummy theorem to describe property, others could also be used) holds over enormous distances, with little deviation (as mass and energy curve spacetime, but despite these small local deviations we've found the universe is approximately flat).

Put simply, astronomy is a sub-field of physics that records celestial events—stellar life cycles, galactic collisions, supernovae, etc. Astrophysics uses physical theories to explain these happenings. Cosmology is concerned with examining the universe using physics—its age, origins, properties, behaviour.

Hubble's theory of universal expansion, when extrapolated backwards, lends itself to the obvious conclusion that the universe must have started expanding from one point source at a point in the past. Shortly after the universe began from a singular point, it cooled down to 3000K, a point where photons were emitted via the addition of electrons to protons. These photons spread out through the then tiny universe. So, their remnants should be ubiquitous now, and should be of a predictably higher wavelength due to expansion of space. And, indeed, we detected this very phenomenon, providing strong evidence in support of the big bang theory.

When asked about how red-shift leads to ideas of the Big Bang, say these points:

- Red-shift of light received from distant galaxies shows that they are receding (moving away) relative to us.
- Further they are, faster they are receding (Hubble's Law), and galaxies in *all directions* are moving away, suggesting that the universe is expanding. By this, we mean that *space itself* is expanding.

- If you *program the expansion into a computer* and *work backwards*, then you get *space shrinking*, and the universe *starting at one small fixed point*, and then expanding outwards.
- This theory of how the universe began is called *the Big Bang theory, where that fixed point is a unique point where space and time began*.

Refinements to the big bang model suggest that, early on, there was some asymmetric/clumping of matter (such as stars), which is why matter isn't evenly distributed evenly today, and neither is temperature (see the iconic COBE satellite image of temperature distribution around the universe).

A geostationary orbit must orbit the centre of the earth (any orbit does, as that's where the attraction comes from), and so if you want it to start above England, and be attracted towards the centre of the earth, it'll take a path that has a "vertical" component, and so won't be above the same point every time. Therefore, staying above the equator is the only way that you can have it have a period of 24 hours and stay above the same place over time.

We gain all our information about stars from their electromagnetic spectra. From their colour, we learn their surface temperature, from their absorption spectrum we learn about their elemental composition and speed of recession (red-shift comparisons).

ALWAYS LOOK AT HOW MANY MARKS. IF YOU THINK YOU'VE FULLY ANSWERED THE QUESTION, BUT STILL NOT HIT YOUR 1.5* THE MARK POINTS, THEN ADD A FEW SEMI-RELATED OBSERVATIONS IN CASE THE MARK SCHEME IS UNPREDICTABLE.

Total energy in an orbit is always conserved. If you lose kinetic energy in an orbiting system, the radius of orbit gets larger so that the negative GPE term is less negative, and so the whole system conserves energy overall. This makes sense—if you don't have much KE, you need to be very far away for your small velocity to successfully keep you in orbit—if you were very close, you'd just come crashing down onto the planet.

Radioactive carbon dating has a high uncertainty because carbon has a very long half-life, and so not much decays over human life-spans, and so the error in measurement of activity is a larger proportion compared to the change in activity/number of nuclei.

Moving objects have energy in the form of translational KE and rotational KE, so if a ball rolls down a ramp, not all the mgh will be used to increase translational speed, some will be used to give it rotational energy.

<u>Capacitance (and some Electric Fields)</u>

Work through the calculus by hand, it's very helpful. Given that capacitance is charge stored per volt, and that voltage is energy per unit charge, you should be able to derive the expressions for energy stored in a capacitor via integration, as well as the equations for capacitor discharge (analogous to boundary conditions for nuclear decay).

Capacitance adds linearly in parallel, and via the reciprocal rule in series (like conductance), and this can be derived by considering charge and voltage in these circuits. When you have two capacitance in a circuit together (and only those), then charges are distributed across them such that the voltage at each end is equal—there is no potential difference.

Test for exponential if in a given time, it decreases/increases by the same proportion. So to check if a damping is exponential, you know that the period of a lightly damped oscillator doesn't change, and so look at the ratio of the magnitudes of the peaks, it'll decay via a constant ratio.

To show that the *magnitude* of the potential gradient is equal to the electric field strength at a point in a uniform electric field (there's actually a minus sign in the end for it to be physically equivalent):

$$W = \int F \, dr$$

$$\Rightarrow W = q \int E \, dr$$

$$V = \frac{W}{q}$$

$$\Rightarrow V = \int E \, dr$$

$$\Rightarrow \frac{dV}{dr} = E$$

A uniform electric field is one where the force per unit charge is the same at every point in the field (E is the same because dV/dr is the same since the equipotentials are evenly spaced).

Field lines are vertical arrows, equipotentials are horizontal lines.

When handling equipotentials and field lines (which should always be normal to each other), make sure to take care about *sign*, since it matters which direction you're going in when determining work done etc.

The energy supplied by a battery while charging a capacitor is not the same as the total energy stored by a capacitor, because it becomes harder to add charge to the capacitor as you add charge to it (increase electron repulsion) and so more energy is required to add a unit charge as time goes on. You can see this by drawing a Q-V graph, where the energy stored is QV/2, but the total energy supplied is QV from the cell.

The reason that less charge is added per second by a capacitor is qualitatively, yes, to do with electron repulsion, but, more concretely, you can mention how since pd across the capacitor is rising, pd across circuit is smaller and resistance of the circuit is the same, so less current flows and so the capacitor charges more slowly.

Drawing electric fields: The field lines are always perpendicular to charged objects because when another test charge is brought in, it needs to feel an electrical force at right angles (directly away, and not in some weird direction). This means that when you surround a charged particle by an earthed plate you can draw the field lines from the charge to the plate by making sure it's perp. to both. The region near the charge and the plate is approximately linear, because it looks like a uniform electric field at that point. The region outside the plate, however, has a potential of 0V only at infinity, since it's obeying the inverse square law in that region. That's why the equipotentials are linear in the region near the earthed plate, but not evenly spaced outside of it. That's also why the 50V lines is 3/4 the way to the earthed plate on the right, but the potential at B is only around 320V (nonlinear decrease at the point).

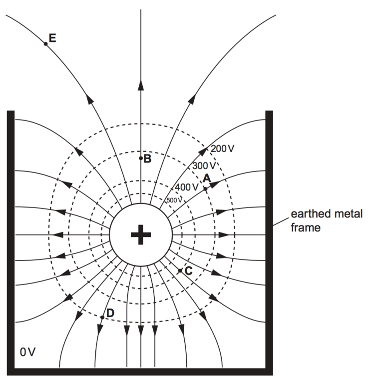


Fig. 3.1 (actual scale)

The reason internal resistance doesn't affect charge stored on a capacitance is because the final charge only depends on emf; volts lost internally will mean that it takes longer to charge, but when fully charged pd across capacitor will be the emf.

Tough capacitance problems:

- In a series circuit, because a capacitance is gaining charge moved from one end of the circuit to the other, all the capacitors in a series circuit will have the same charge on them (since for the finite charge to get from one, it must be taken from another).
- Similarly, in a parallel circuit, the voltage across each branch is the same, but the charge splits up.

<u>Kepler's Laws (learn these)</u>

1. F: The sun is at one focus of the ellipse that is the Earth's orbit around it.
2. A: The area swept out by the line joining the sun to a planet is constant per unit time.
3. P: The period of revolution squared is proportional to the *mean* radius of revolution cubed.

<u>PAST PAPER NOTES</u>

On elastic/inelastic collisions and energy/momentum conservation: an elastic collision is defined as one where the total kinetic energy *before* and *after* is the same (and momentum is conserved, too). Note that this does not mean that it is the same *during* the collision process.

In an *inelastic* collision, one object hits another, and moves away as one giant particle. Here, momentum is conserved but it is not elastic as kinetic energy is not conserved—this is *perfectly inelastic*, as the KE is lost to material compression, heat or sound.

EM waves are transverse and can move through a vacuum, but water and seismic waves are also transverse, and cannot. The only distinguishing feature of theirs is that they can all be polarised, unlike longitudinal waves.

A *control rod is used to absorb neutrons* and a *moderator to slow them* down in nuclear fission, because slow electrons are more easily absorbed.

When light moves into a material of higher optical density and slows down, its wavelength decreases but frequency remains the same. This makes sense because if frequency changed, energy wouldn't be conserved as E=hf.

Think of a circuit as a pipe full of electrons, each pushing the ones next to it, as opposed to just one electron moving through a wire. This way, you remember that current only flows through a section of the circuit if there is a potential difference across that section to make *all* those electrons move.

Emf is defined as the potential difference across a cell when no current is flowing through it; or, in other words, *the chemical energy within it that is transferred to electrical energy given per unit charge* that flows through the cell. PD, on the other hand, is just the difference in energy per unit charge across a component of a circuit—so *electrical energy to other forms.*

A voltmeter measures the potential difference across whatever it is parallel to, even if that's just air.

When citing conservation principles, describe how "X can be neither created or destroyed". K1 and K2 work on conservation of charge and energy, respectively.

SHM is defined by the boundary conditions that *acceleration* must be proportional to displacement, but in the *opposite direction*. It's helpful to note that the acceleration is directed towards a *fixed point*, and has a *minus sign*.

Networks of resistors in parallel tend to be effective not just because they maintain (approximate) resistance if one breaks down, but also because each resistor has less current flowing through it, and so the system is capable of handling a higher power before failing.

USE DECIMALS, NOT FRACTIONS, IN PHYSICS. THIS IS NOT A MATHEMATICS EXAM.

When you're looking to decompose a wave into its constituent frequencies, just look at the lowest frequency, and count how many times you have smaller frequencies within one cycle of the lowest frequency.

Lambda=ax/D is an approximation because small angle approximation is used, but also if the two point sources have different lengths to the screen; i.e., if one has to travel further than the other its intensity will be reduced (diffraction is going on since the slits have non-negligible size and are not *just* point sources. This variation in intensity makes the situation more complex than assumed by the formula.

When listing points, list *any you can think of from first principles, no matter how weak*. Then, sort them according to relevance afterwards.

Difference between progressive and standing waves. Progressive waves transfer energy, standing waves don't. This is because progressive waves change position, standing waves do not. Points on progressive waves have varying phase and constant amplitude. Points on a standing wave have constant phase and varying amplitude.

When talking about the photoelectric effect, remember that we must only shine *monochromatic light (one wavelength=one frequency)* onto the *photocell (surface that emits photoelectrons).*

The fact that we get photoelectrons of uniform energies when shining monochromatic light onto the photocell is surprising because if light were a wave, electrons would absorb different amounts of light before escape, leading to a variety of energies in the photoelectrons ejected. The fact that individual electron energy depends *only* on frequency is strong evidence for 1:1 interaction of photons.

The de Broglie wavelength of electrons (And other particles) was a construct created to explain the diffraction/interference of electrons when fired through slits. Even if you fire individual electrons through slits, they arrive as particles, but, over time, with many electrons fired, create the wave-like pattern of photons.

Use a micro-ammeter when determining stopping voltage of electrons exhibiting the photoelectric effect! Draw the diagram as below (see, in particular, how the photocell is drawn).

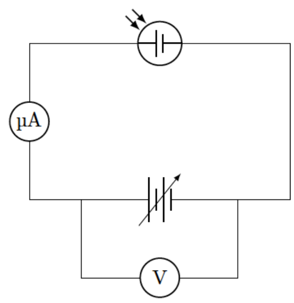


Figure 9.1: Measuring stopping potential

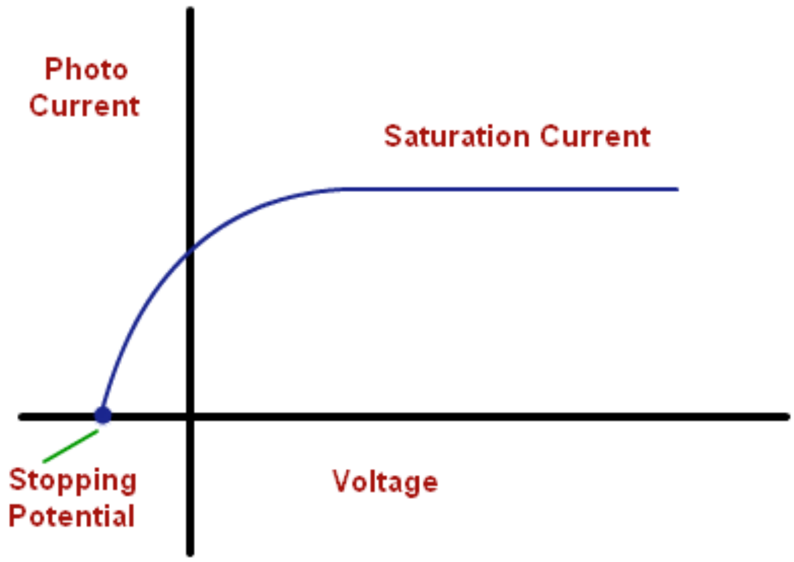
Voltmeters always show the resistance of the thing that they're parallel to (even if you need to imagine that it's air).

When talking about how you'd do a practical in physics, you need to give the same amount of detail as you would in biology/chemistry—you get marks for explaining the method you'd use to do something as well as the apparatus you'd need!

A standing wave is made of waves with the same frequency travelling in opposite directions, interfering with each other, transferring no energy, including nodes and antinodes.

In nuclear decay equations, you can't just write beta- or electron, you have to show the man number (0) and the atomic number (-1) for each species.

When doing a photoelectric experiment, and you plot current registered in the micro-ammeter against voltage across metal plates, and you get the graph below. A negative voltage is one inhibiting flow, and vice versa. You get a "stopping potential" which corresponds to a threshold frequency that gives electrons enough energy to overcome the work function of the metal. But still, most electrons don't make it to the other end as there isn't enough energy to get there. Then, as you increase voltage, you accelerate them, until all the electrons excited make it to the other end, which causes the saturation current. A lower *intensity* of light shone on the surface would have the same stopping potential (as it's the same frequency), but a lower saturation current as less electrons are excited in the first place (though, those that *are* excited have the same energy as before—as we can see from the same stopping voltage, and *this* is what's surprising. When you get to a high enough voltage, you can ionise the air in between to create a spark gap, but



otherwise, an electric field can't excite the electrons in the shell of metal atoms (which is why capacitors can *store* charge without it jumping across immediately!).

A carrier wave is the one that matches the recombinant ("amplitude modulated") wave's granular frequency, and the signal wave is one that matches the overall shape that you're trying to wave (you're trying to convey a signal). In other words, the carrier wave is the medium through which the single is carried, and the overall wave is the amplitude modulated wave.

When describing the setup of the photoelectric effect:

- Zinc metal plate, UV lamp.
- Detector of emitted electrons.
- *microAmmeter to detect small currents from electrons emitted.*
- Vary power supply until ammeter reads 0 to find stopping voltage.

The observations that surprising classical wave theories about the photoelectric effect:

- Instantaneous emission, even at very low intensities (shows 1:1)
- There exists a threshold frequency of emission (photon energy depends on freq.)
- Kinetic energy of emitted electrons independent of intensity (all photons have same energy)
- Photoelectric current is directly proportional to intensity (only one photon absorbed per electron)

When describing photoelectric effect:

- Monochromatic light hits the surface of a metal and causes ejection of electrons.
- Photons of light individually give energy to electrons so they can escape the metal, and are detected as a current flowing through the circuit.
- Energy left here used in KE of electrons, where all the energy comes from the original frequency of the photon.

Alpha particle experiment diagram needs alpha source, gold sheet, detector.

(1) Fire particles at foil *through vacuum*, move detector around the foil, record counts at each angle. (2) The low number of deflected particles show that the charge in the nucleus is concentrated into a small volume of space, and the fact that (3) some alpha particles are deflected *backwards* means that it has the same charge as the alpha—the nucleus is positive.

In any junction, the algebraic sum of currents is 0 (K1L).

Spontaneous means not affected by external factors like temperature or pressure.
Random means unpredictable; slight variations in decay in a given time interval.

You can prevent exposure to nuclear fallout by moving away from places where there's been an incident/are cosmic rays, get your house insulated from radiation, use shielding, reduce unnecessary exposure and make sure nuclear waste is safely disposed a long distance away.

When you diffract an electron through a material, you usually get a circular diffraction pattern. This is because diffraction through a particular sheet gives standard lines, but there are many layers at different angles, finally combining to give rings.

Malleable means something can be beaten into sheets, like copper being beaten into a tray.

When describing the stress/strain graph of a polymer uncoiling, you have three distinct regions:

- Long chain molecules are initially coiled. It is difficult to move them from this state, initially.
- They begin to uncoil as they straighten out by bond rotation—this is easy.
- As they are totally uncoiled, it becomes very difficult to extend them further as that involves breaking bonds inside the molecule.

When describing movement of air molecules around a pressure node, you say that, during one half of the cycle, the molecules are moving away, and towards during the next half, causing the pressure on the node to vary, and it's hence a pressure antinode.

Uranium chain reaction generating energy (bang out 3 steps in exam):

- U235 is used; neutrons bombard causing fission.
- Release more neutrons—> chain reaction.
- Each step releases energy used to heat water and move turbines attached to a generator.
- The product Thorium is *not necessarily more stable* than the reactant—you don't know how quickly that decays further.

The elastic strain is always recovered when removing the load from a material, even it has gone past its yield point—draw a line from the point where you remove the load down to the x-axis, parallel to the original linear region to show how this energy is recovered.

When things absorb energy (like during a collision), the energy can go into what's called "internal energy".

When asked about how E/B fields are used in tandem to select for velocity in a mass spec:

- E/B fields drawn at right angles to each other
- E/B forces in opposite directions on moving particle
- Slow velocity bends in direction of E, fast in direction of B

- Only one velocity moves straight through, so all particles coming straight through have that one velocity.

510nm wavelength of light is green light.

When describing the standing wave explanation for electron orbitals/shells:

- Energy levels are fixed/discrete and each has its own principle quantum number, *n*.
- The standing electron waves set up are the fixed modes.
- The number of standing waves allowed in a quantum level is the same as the principle quantum number: $2\pi r = n\lambda$, where lambda is the de Broglie wavelength of the electron.
- Packets of energy (usually in the form of photons) can be taken in or emitted between levels.
- Angular momentum is quantised.

Indeterministic: it is not possible to predict exactly the future state of a system from its present/current state/value/momentum/speed.

When describing how we came up with the existence of the antineutrino, you say that the range of energies of beta particles emitted in radioactive decays of a specific type meant that, since energy was being conserved in these decays (energy per decay was constant), another particle had to carry away the variable amounts of energy so total energy remained constant.

Planning practicals will never be something super complicated; for example, measuring the time period of SHM for large angles was as simple as releasing to a given angle measured (using a protractor), and using a stopwatch to look at how long the first few oscillations take. Use a long string to *make sure you minimise uncertainty in measurement times*. Also mention repeats, and throw in a sophisticated measuring technique (light gate/digital recording+ analysis) for an extra mark or two as an alternative to your own method.

GPE is described as the *amount of work done moving a mass from infinity to the point it is at currently.*

A good explanation for the Bohr atom is explains not just why the energy levels are quantised, but why the ground state, the first energy level, is stable, because Rutherford's planetary atomic model couldn't explain that—Rutherford's model would have electrons radiate away energy until they collapsed into the nucleus, making the atom unstable, which we know it isn't.

- Electrons can be seen as standing waves that form around nuclei.
- Energy level is associated with the number of standing waves.
- Because these can only form as complete, integer wavelengths, intermediate values not allowed, explaining the discrete nation of electronic shells.
- See the hydrogen equation to see how empirically, we notice that energy levels are quantised.
- Electrons release energy when they jump form one state to the other, releasing energy that corresponds to the jump.
- The bottom state corresponds to $2\pi r = \lambda$, so since you're at n=1, you can't drop any further and *hence the electrons don't collapse into the nucleus.*

The reason you need a vertical circle to be spinning at a minimum speed for the thing it's spinning to not just fall down is because you need the thing to have a certain contact force with whatever is keeping it in a circle (the floor of a ride/the string holding a ball), and for that thing to exert a force on the revolving object, the object needs to be accelerating at more than *g,* (because otherwise all the force required to keep it in a circle is coming from gravity), and so that's the minimum acceleration for the object to not just fall straight down (boundary condition is force from contact object being >=0).

Similarities between G/E fields: both are conservative, both have potential (energy), both have radial field lines and uniform field patterns, both obey inverse square law of force wrt distance from source.

You can't use parallax for very great distances because telescopes have a peak angular resolution. Thus using standard candles, like cepheid variable stars, where the period of pulsation is related to their luminosity, allows us to calculate distances to things much further away than parallax can, because we can compare their apparent brightness with their actual brightness (seen from period of pulsation).

The peak binding energy per nucleon is for iron (valley of stability), which is approx. mass number 60, and has a binding energy per nucleon of 8-10MeV.

To get an estimate of the wavelength of a light source, use a diffraction grating/double slit. Take a grating with a known separation, put a *bright* monochromatic light source in and measure the angle at which the first order maximum on occurs on the screen using a protractor/spectrometer. Then use the formula to work out the wavelength. Improve accuracy by repeating with different grating distances and taking the mean of the wavelengths calculated.

You can show something is exponential by either looking at how each successive reading is ta constant fraction of the previous one, or by taking ln of each reading and showing a constant decrease.

Speed stays constant in circular motion because the accelerating force is perpendicular to its motion, and so no work is done on the electron to increase its kinetic energy.

The reason we use electromagnets to create the magnetic fields in practical applications is because we can vary the field strength by altering the current through the magnets, and also because we know exactly what the field strength is, since we created it.

Relativity of simultaneity refers to the fact that two events that are seen as simultaneous by one observer may occur at different times for another observer, one that is in relative motion to the first one.

<u>Electromagnetism</u>

When thinking of a magnetic field, think of lines going through a horizontal coil of wire. The density of lines is flux density, and so the total amount of lines through the surface is flux density times area enclosed by the coil. And if you repeat this with several layers, you get flux linkage=NBA.

There *is no such thing as a magnetic field*. Magnetism is just a consequence of electric fields and special relativity. When things move, they "slim down" in a stationary reference frame by length contraction. So, in a current, moving electrons come closer together and thus charge density increases. This means that, to a test charge next to the moving charge at some time, the force on it is higher since there is a larger charge density than if it were the same distance from the electrons in the current when it was at rest. But one axiom of special relativity is that you shouldn't be able to disagree on forces on an object, no matter which reference frame you're looking from, because that would mean that not all reference frames are equivalent (an underlying assumption of special relativity), and because measurements of acceleration are invariant of reference frame. Thus, we must have some force produced by the moving charge that's been contracted (the current) to counteract the excess electric force it's producing on the test charge due to a higher charge density, in order to maintain relativistic invariance of electric forces. This "new force" that only appears when charge is moving, is what we call "magnetism". *This* is why electricity and magnetism are mentioned side by side, because one is merely a consequence of another! Now, the whole topic is more nuanced than this, because it also must include dipoles in permanent magnets as well as how electron spin fits in, but this simple thought experiment gives good intuition for why the concepts are so deeply linked.

The left hand rule is calibrated for movement of positive particles. Remember to point the current finger in the opposite direction to electron flow when looking at an actual circuit.

The hall effect is just the balance of the electrical and magnetic forces on a moving charge going through a sheet perpendicular to an applied B-field, where the hall voltage is the voltage across the vertical plane of the sheet where the electrical force applied balances that of the B-field.

Understanding of rotors, motors, the motor effect, etc., is not required.

Flux density is defined using F=BIL, as the force per unit current in a wire of unit length.

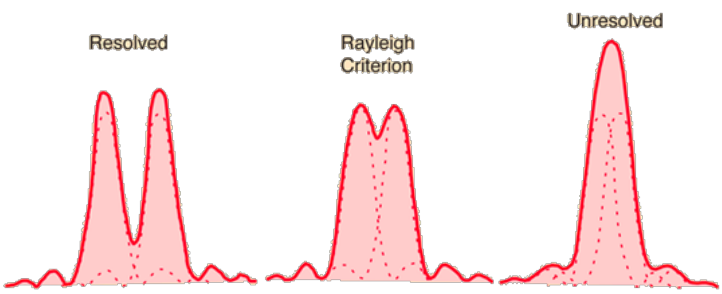
100A is a lot of current that would lead to a wire melting (depending on thickness and material, of course), but it also causes a lot of power loss. This can be prevented by thickening the wire, making it from something that has a higher MP, use a superconductor so that you can get the same current at low temperatures.

Lenz's law is a consequence of the conservation of energy because a magnet moving freely through a coil will generate a current in the coil, acting as a source of energy. If it weren't damped, where would that energy have come from? The magnetic field from the induced current acts as an opposing external force to the motion of the magnet so that it can remove the energy that is being added to the electrical system in the form of current, thus conserving energy overall.

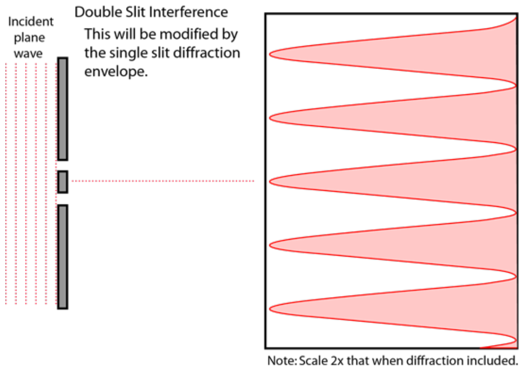
<u>Superposition & Slits</u>

Coherence is a necessary condition for any visible interference between the waves, because otherwise you get no regular pattern since the interference is constantly changing.

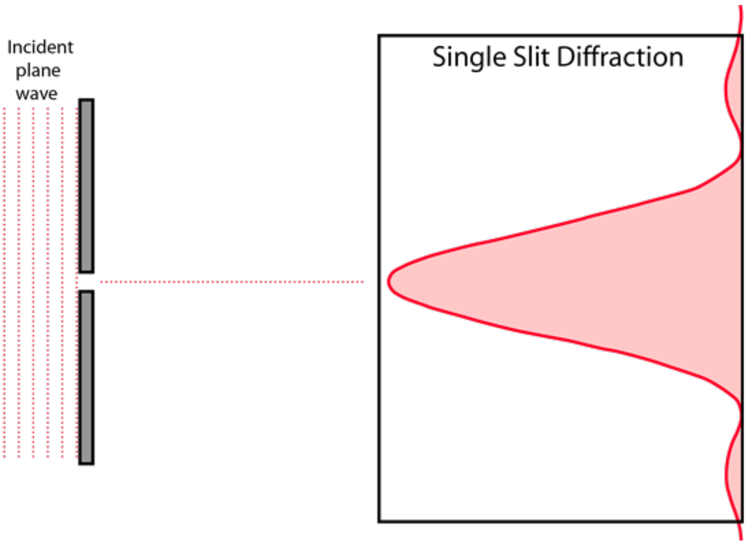
The Rayleigh criterion is a condition that must be satisfied for a telescope/imaging device to tell two objects apart. As light from two distance objects enters the lens of the telescope, they both diffract, producing intensity wave-forms on the screen, as usual. If the maximum of one coincides with the minimum of the other, you can *just* about tell them apart as originating from different sources (and thus tell the two object apart when interpreting the screen reading).

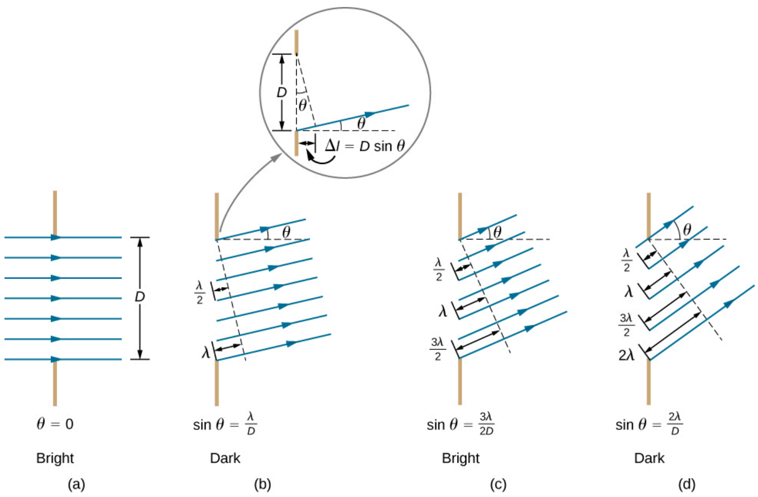


Every diffraction pattern we observe for multiple slits is a combination of two *distinct* phenomena at play: interference of *separate* slits, and diffraction *within* a slit. Interference of two rays leads to the pattern below because the two rays have the same amplitude and so their maxima are always the same height. *This* is for two *point sources*, which, of course, slits are not (they have a width) which leads to diffraction within the slits, which is why we must superpose the interference and diffraction patterns.



And you combine that effect with the effect of single slit diffraction, which produces this pattern because you have all parts of the wave (infinite wavelets) spreading out and interfering with each other. Diffraction/interference, for Pre-U are separate, but really, diffraction is an emergent phenomenon that comes out as a consequence of lots and lots of small-scale interference. It should make sense that the intensity of the single slit dies down as you get further from the centre, because when you shine a torch through a slit, you only see intensity in the centre, really (dies down very fast—use intuition).





The reason you have decreasing intensity of orders as you get further from the centre is because in the centre, every single ray/wavelet is constructively interfering. For the n=1 maximum, barely above half are constructively interfering, and so on—see diagram below.

The double slit pattern is the double slit interference superposed with the single slit diffraction pattern, where the single slit diffraction pattern is the "envelope function", where you trace out the double slit interference below the single slit diffraction.

If you have a minimum from within each single slit, but expect a maximum from the double slit interference pattern, you won't get it since there's effectively no net light coming from the individual slits. This (single slit min, double slit max) is called a "missing order".

<u>Kinetic Theory/Thermodynamics</u>

We use RMS speed as a gauge for how fast particles are moving simply because velocity is a vector, and so the straight average velocity is zero since we have particles moving randomly in all directions all the time.

When handling RMS speed of molecules, remember that you're looking at a distribution. That speed is simply a good estimate of the average speed of the particles, but, as with any distribution, there are many with more, and many with less, than this speed.

The efficiency of a heat engine is the *net* useful work done *by the gas* divided by the total heat *input (and ONLY the input—the heat output is waste that serves to increase entropy and isn't useful, and doesn't have the potential to be used for work, either).*

Efficiency of actual gas' Carnot cycle is lower than the theorised version because you're modelling it as an ideal gas, which it isn't, and the actual Carnot cycle will not be the same shape as the theoretical cycle—will cut corners. Friction will also reduce force applied and remove energy from the system as waste.

A Carnot cycle is a closed, reversible thermodynamic cycle that shows a heat engine doing work upon being given energy input.

Brownian motion of particles is when small particles, things like dust or smoke, barely visible under a microscope, move randomly through space because of constant collisions with fluid molecules around them that exert forces on them.

The "internal" energy of a gas refers to the sum of the kinetic and potential energies of the molecules in the gas. It refers to the random kinetic energy of the molecules, and not the translational velocity, because then interpretations of internal energy would vary from person to person.

The area enclosed by a Carnot cycle is the net work output in one cycle by the ideal gas.

The first law of Thermodynamics states that the change in internal energy of the system is a sum of the heat added *to the system*, and work done *on the system.*

<u>Derivation Notes</u>

Gravitational force is negative because it's attractive. Likewise, even though energy can't be negative, gravitational potential energy is *defined* as the energy required to move an object from infinity to a certain radius, *r*. Since gravitation is attracted, there is no energy "required", but instead energy “given out”, as the force does the work *with us*, as opposed to *against us*. Hence, the derivation for gravitational potential energy from gravitational force:

$$E = \int F\,dr$$

$$F_g = \frac{-GMm}{r^2}$$

$$\Rightarrow E_g = -\int_{\infty}^{r} \frac{-GMm}{r^2} dr$$

$$\Rightarrow E_g = -(\frac{GMm}{r} - 0)$$

<u>Simple Harmonic Motion</u>

Velocity and displacement are related by a graph that looks like a horizontal ellipse, since velocity is at a maximum (and negative maximum) when displacement=0, and at a minimum when displacement=amplitude.

Describe oscillations in terms of *energy*. Free oscillations are when there is repetition of the same forwards and backwards motion, with *no loss of energy to external forces,* or no frictional force involved. Forced oscillation is when an external *periodic* force makes an object oscillate/maintains or increases the amplitude of oscillation/add energy to the system. Damped oscillation is when external (frictional) forces remove energy from the system and the oscillations die down/amplitude decrease.

Resonance is when a driver (external force) has the same frequency as the natural frequency of the system, causing a large increase in the amplitude of its oscillations.

On damping and driving frequencies: when you have a low driving frequency, amplitude of oscillations is close to amplitude of driver, and when you have a driving frequency that matches natural frequency of system, resonance occurs and amplitude increases quickly until frictional forces proportional to amplitude increase to damp away energy from the system at the same rate it’s added. This is the system’s maximum amplitude. As you then increase frequency of oscillation the amplitude decreases to near zero because the mass being driven doesn’t have any time to actually accelerate between cycles of driving pushing it back and forward, so it’s amplitude is very low because no energy is actually added to the oscillations. *As you have more damping, the “natural frequency” of the system (i.e. the frequency at which the maximum amplitude occurs) decreases, and so the peak on the amplitude-frequency graph shifts slightly left—though natural frequency refers to the frequency of max. amplitude when undamped.)*

Derivation of the moment of inertia:

$$THIN\,RING$$

$$I = \sum m_i r_i^2$$

$$\Rightarrow I = r_i^2 \sum m_i$$

$$\Rightarrow I = MR^2$$

$$DISK$$

$$dm = 2\pi x dx \rho t$$

$$I = \int_0^R r^2 dm = \int_0^R x^2 2\pi x \, dx \rho t$$

$$\Rightarrow I = 2\pi\rho t \int_0^R x^3 \, dx$$

$$\Rightarrow I = 2\pi\rho t \int_0^R \frac{x^4}{4} \, dx$$

$$\Rightarrow I = 2\pi\rho t \left[\frac{x^4}{4} \right]_0^R$$

$$\Rightarrow I = 2\pi\rho t \frac{R^4}{4}$$

$$M = \pi R^2 \rho t$$

$$\Rightarrow I = \frac{MR^2}{2}$$

This is an important step. In the same way that a cartesian integral is summing the products of y-values and many small "dx" to get an overall area, this integral is summing the *products of the* radii (analogous to y-values) and masses (analogous to small dx), which is what we want—the total moment of inertia is the sum of all the little moments of inertia, which is what this integral gives us. The rest after this is just algebra, and this is the important physical bit.

When asked to define "moment of inertia about its central axis", give the formula—or the integral—defining each of the terms and labelling them on a diagram.

Circular motion: at no point in the derivation do you need a "ds" term, you should instead just use "vdt to represent that distance".

Pre-release notes—Particle Physics

Extract 1—Models of the Nucleus

The strong nuclear force is repulsive at very short ranges, but more attractive than the EM force is repulsive on the scale of the nucleus, which is why it's held together. It also falls off very quickly, so that it is virtually non-existent outside of the nucleus—which is why different nuclei don't clump together.

The weak force is responsible for radioactive decay. We don't have stable nuclei made of just neutrons because they would come close enough to each other until they repelled (strong force repels strongly as shorter than nuclear range), and they'd decay to protons as a result of the weak force.

Liquid drop models simulates nucleons of nuclei as atoms in a drop of liquid, where strong force is analogous to London dispersion forces between atoms. At very short range, electron cloud overlap is repulsive, but at moderately short range (intermolecular), electron clouds polarise each other and cause attraction, just as strong force does.

Nuclei cannot grow indefinitely because strong force quickly falls off with distance compared to the EM force.

The surface tension (tendency to bond with adjacent water molecules over other molecules) of a liquid drop is an important feature of the model—it captures the fact that the forces on a water molecule at the surface of the drop are different to the forces on a molecule at the centre of the drop, just as strong force on surface nucleons is weaker than total strong force on central nucleons.

Shell model is nucleons orbiting in shells *inside* nucleus, just as electrons orbit a nucleus from the *outside*. Movement between shells corresponds to decays.

Close packed model resembles metallic structure, where all the nuclei are stuffed in, density gradually falls off at edges, as opposed to instantly in the liquid drop model. This model is better for explaining how nuclei rotate.

LQM: nucleus outer surface electrons have higher energy, and so t wants to reduce surface area to reduce that energy differential. In a charged liquid drop, the EM force wants to shatter it.

excited states:

spin a liquid drop, and the bulge shows it's rotating fast and is high energy, same with the bulge vibration that can release energy

The reason you can't have a neutron on its own is because it can decay by itself into protons as the proton has a lower mass

binding energy curve explained by LQM:

em energy in a nucleus varies with Z^2

surface energy N^2
strong energy N

mass number A

energy = A - A^(2/3)]]]weuzsaecker formula, volume energy is positive,

coulomb vs strong force for valley of stability graph—

Es=c1V- c2A

where everything is related to Z or N where A—Z+n, A—V^(2/3)

E(em)=c3*z^2/v^(1/3)

balance between hydrogen bonds holding drop together and positive charge repelling it giving the binding energy per nucleon.

Extract 3—Strangeness

In the 1970s, when growing the standard model, we found a new type of particle that was heavy (contained quarks) and took a long time to decay (was stable—thus mediated by the strong interaction). These particles were always produced in pairs, and so we created a new property to explain this—the existence of "strangeness".

Strangeness is not conserved during decays of the weak interaction, as quarks change during this, and it is a property derived from the strange quark.

Strange quarks decay into other, lighter, strange nuclei, and when they can't, they have to wait to decay by the weak interaction. They have the same charge as down quarks—quark numbers are not always conserved—only baryon and lepton number. Strange quarks have strangeness -1.

Strangeness is always conserved in a strong interaction.

Strong force is quarks changing type, and cannot make a strange suddenly turn to a down quark, but the weak force *can* do this—it was why it was invented.

Flavour is the *type* of quark—top, charm, strange, are all different *flavours* of quark.

Weak interaction is mediated by: W-, W+, Z0.

Extract 4

curved particles in a magnetic field questions will come up, simple conservation questions will come up, particle accelerators, how good particle models are in bubble chambers, you don't see any neutral particles because they don't ionise anything which is what the helium can

drift chamber is a fancy spark chamber—large range of fine wires with fine voltage, as particles pass they cause voltages and current flows. you have thousands of little wires, where each one has an alternating voltage, and as a particle goes through it sparks (causes current to flow) in different places, and all of the array is computed, and reconstructs the path by measuring the times each was sparked.

Mendeleev predicted new elements by categorising them, and Gell-mann tried to build these tables to do the same thing, and thus the omega-minus to exist was predicted to exist—a triple strange. the periodic table is now the orbital/electronic shell model, and the quark model explains these funny patterns in the same way.