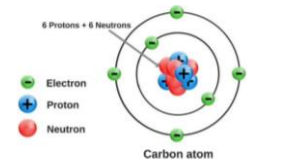
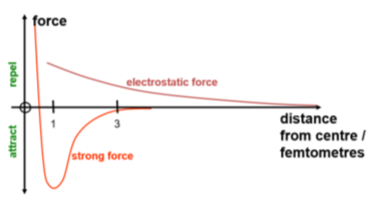
Subject: A-level Physics	Topic: Quantum	Year Group: 12

Atomic structure

1	At the centre of every atom is a nucleus that contains protons and neutrons. Protons and neutrons are called nucleons. Electrons orbit the nucleus.	
2	The specific charge of a particle is the ratio of its charge to mass	

Forces in the nuclei

1	The protons in the nucleus repel one another due to the electromagnetic force, pushing the nucleus apart.	
2	The strong nuclear force (SNF) is attractive and pulls the nucleus together.	
3	The SNF acts between protons and neutrons whereas the electromagnetic force acts between protons only.	
4	The range of the electromagnetic force is infinite whereas the SNF is short ranged.	
5	SNF is attractive up to about 3 fm after which it falls rapidly to zero. Below 0.5 fm the strong nuclear force is actually repulsive.	
6	In stable nuclei the SNF and the electromagnetic force are balanced. In unstable nuclei these forces are not balanced.	

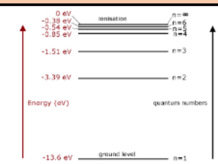
Photons and electronvolts

1	Einstein proved that EM radiation travels as photons which are packets (quanta) of energy,
2	The energy of photons is often given in electronvolts (eV) rather than Joules as their energies are very small and the Joule is quite a big unit.
3	To convert between the two units do the following, energy in eV = energy in Joules / 1.6×10^{-19} energy in Joules = energy in eV x 1.6×10^{-19}

Unstable nuclei

1	Large unstable nuclei emit alpha (α) particles to become stable.	
2	They are made of 2 protons and 2 neutrons and so cause the nucleon number of the atom to decrease by 4 and the proton number to decrease by 2. The general decay equation is,	${}^{A}_{Z}X \longrightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}\alpha$
3	Nuclei can also become stable is by beta-minus decay.	
4	In this process a neutron in the nucleus changes into a proton. A beta-minus particle (an electron) is emitted from the nucleus along with an antineutrino.	
5	The general decay equation is,	${}^{A}_{Z}x \longrightarrow {}^{A}_{Z+1}y + {}^{0}_{-1}e + {}^{0}_{0}\overline{v_e}$

Energy levels

1	Electrons in atoms can only exist in certain well-defined energy levels.	
2	The lowest energy level is n = 1 and is called the ground state.	
3	When an electron is in any other energy level (other than the ground state) we say it is excited.	
4	To excite to a higher energy level an electron must absorb the exact energy difference between the two levels.	
5	This energy could come from absorbing a photon with the exact right energy or colliding with a free electron and absorbing some of their kinetic energy.	
6	When electrons de-excite to lower energy levels the energy they lose is emitted as a photon.	
7	If the electron gains enough energy it can be removed from the atom. We say the atom has been ionised.	

Key equations

1	Specific charge	$Specific\ charge = \frac{Q}{m}$
2	Photon energy	$E = hf = \frac{hc}{\lambda}$
3	Energy levels	$\Delta E = E_1 - E_2 = hf$
4	Wave speed	$c = f\lambda$

Key Vocabulary

1	Nucleon (or mass) number	The number of protons and neutrons in the nucleus.
2	Atomic (or proton) number	The number of protons in the nucleus.
3	Isotope	Atoms with the same number of protons but different numbers of neutrons.
4	Specific charge	The ratio of charge to mass.
5	Electronvolt	The work done (or energy change) of an electron when it moves through a potential difference of 1 V.
6	Ionisation energy	The energy needed to remove an electron from the ground state of an atom.

Fluorescent lamps

1	Fluorescent lamps contain mercury vapour.
2	A high voltage is applied across the lamp which accelerates free electrons passing through the lamp. These then collide with the electrons in the mercury vapour atoms, causing them to excite.
3	Each excited electron then de-excites, emitting a photon of energy equal to the energy difference between the levels. These photons are in the UV region of the EM spectrum.
4	The lamp has a phosphorus coating which absorbs the UV photons, exciting the coating's electrons. These atomic electrons de-excite indirectly to lower energy levels, emitting lower energy photons.

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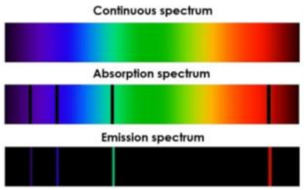
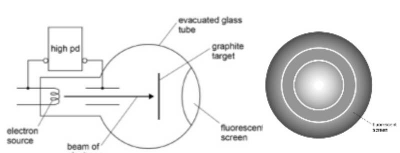
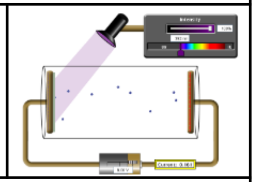
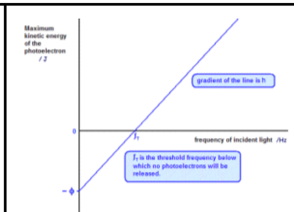
Spectra

1		If you shine light from a fluorescent lamp (or a star) into a diffraction grating you will get an **emission** line spectrum. Each spectral line corresponds to an electron falling down to a lower energy state.
2	**Absorption** line spectra occur when light with a continuous spectrum passes through a cold gas. Photons of specific frequencies are absorbed by electrons in the atoms of the cold gas, exciting them to higher energy levels. These frequencies are then missing from the spectrum.	
3	Line spectra provide evidence that electrons in atoms are in discrete energy.	

Wave-particle duality

1	All particles display wave and particles properties.	
2	Proof for light …	**Behaves as wave:** diffraction (e.g. interference pattern) **Behaves as particle:** photoelectric effect
3	Proof for electrons …	**Behaves as particle:** deflected in electric fields **Behaves as wave:** diffraction pattern (see below)
4	This diagram shows an electron diffraction tube and the diffraction pattern that is produced.	
5	In the diffraction tube an e^- beam hits a thin graphite target. After passing through the graphite target the e^- strikes a fluorescent screen and produce the pattern shown above. This proves electrons behave as waves because …	• Particle behaviour would only produce a circle of light • The electrons must have diffracted as they pass through spaces between atoms of the crystals proving their wave property

The photoelectric effect

1	Metals contain free electrons.	
2	The free electrons near the surface of the metal absorb light energy.	
3	If these electrons absorb enough energy they will overcome their attraction to the positive metal ions and the electron will be released from the metal's surface.	
4	This provides evidence for the particle nature of light because …	For a given metal no photoelectrons are emitted if the radiation is below a certain frequency, regardless of its intensity.
		When electrons are emitted from the metal surface their energy depends on the frequency of the light, not on its amplitude.
		If the light used is above a certain frequency electrons are emitted immediately.
5	Electrons are only released when the light is above a certain frequency called the threshold frequency. The emitted electrons have a range of different energies. Here's why … (from AQA mark scheme)	
6	Energy is needed to remove an e^- from the surface of the metal. The work function, φ, is the minimum energy needed by an electron to escape from the surface. Light consists of photons , each of energy $E = hf$. One photon is absorbed by one electron. An electron can escape (from the surface) if $hf > \varphi$. KE of an emitted electron cannot be greater than $hf - \varphi$. An electron below the surface needs to do work/uses energy to reach the surface. Kinetic energy of such an electron will be less than $hf - \varphi$.	
7	A graph of E_{kmax} against frequency can be used to determine the threshold frequency, work function and Planck's constant. Gradient = h Y-intercept = - ϕ X-intercept = f_o	

Key equations

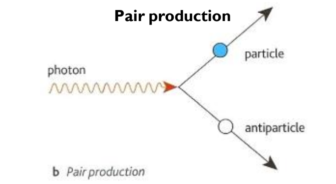
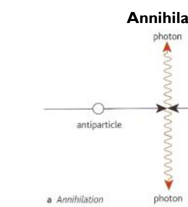
1	De Broglie wavelength	$\lambda = \dfrac{h}{mv}$
2	Kinetic energy	$E_K = \dfrac{1}{2}mv^2$
3	Photoelectric effect	$hf = \phi + E_{Kmax}$
4	Threshold frequency	$f_o = \dfrac{\phi}{h}$
5	Stopping potential	$V_{stop} = \dfrac{E_{Kmax}}{e}$

Key Vocabulary

1	Threshold frequency, f_o	The minimum frequency of radiation needed to liberate an electron from the surface of a materials.
2	Work function, ϕ	The minimum frequency of radiation needed to liberate an electron from the surface of a materials.
3	Stopping potential	The potential difference needed to stop the fastest moving photoelectrons in the photoelectric effect.

Subject: A-level Physics	Topic: Particles	Year Group: 12

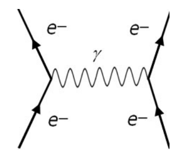
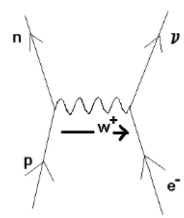
Antiparticles

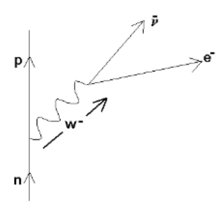
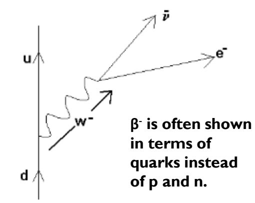
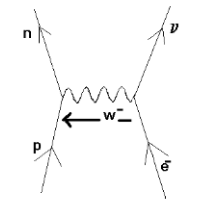
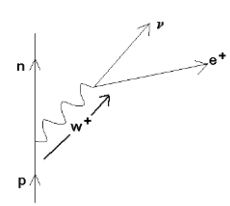
1	Every particle has an antiparticle. Particles and their antiparticles:	• Have the same rest mass and rest energy as each other. • Have exactly opposite charge to each other.
2	In **pair production** energy is converted into a particle and its antiparticle. The photon's energy needs to provide at least the <u>rest</u> masses of the particle and antiparticle.	
3	When a particle and its antiparticle meet they annihilate. Their masses are converted into energy in the form of two photons.	 $p + \overline{p} \rightarrow \gamma + \gamma$

Hadrons and leptons

1	All particles can be classified as hadrons or leptons.	
2	**Hadrons** are particles that experience the strong nuclear force. They are made up of smaller particles called quarks. Hadrons can be further divided into two groups:	
3	**Baryons**	Composed of three quarks. Examples: proton (uud) and neutron (udd) The most stable baryon is a proton. All baryons ultimately decay to become a proton. Antibaryons are made up of three antiquarks. Baryons have a baryon number of 1, antibaryons have a baryon number of -1. Anything else = 0.
4	**Mesons**	Composed of a quark and an antiquark. All mesons are unstable. Pions are the lightest mesons. Kaons are heavier and more unstable. They have strangeness and they decay into pions.
5	**Leptons** are fundamental particles. Electrons are stable leptons. Neutrinos are also leptons. Muons are like heavy electrons that eventually decay into electrons. Leptons have a lepton number of 1, antileptons = -1.	

Feynman diagrams

1	Feynman diagrams are used to show particle interactions.	• Exchange particles are shown by wiggly lines, other particles by straight lines. • Incoming particles start at the bottom of the page. • The baryons stay on one side of the diagram, leptons on the other.
2		Feynman diagram for two electrons repelling one another.
3	Electron Capture	In electron capture the nucleus captures an orbital electron, changing the p and e^- into a neutron and neutrino. In an e-p collision, an e^- collides at high speed with a p. Although very similar, their particle interactions are different.

4	β^- decay	6	β^- decay
5	Electron-proton collision	7	β^+ decay

Key Vocabulary

1	Rest energy	The amount of energy that would be made if all the mass of a particle was changed into energy.
2	Hadrons	Particles that experience the strong nuclear force.
3	Leptons	Fundamental particles that do not feel the strong nuclear force.

Conservation rules

1	In all particle interactions the following things are conserved:	• Energy • Momentum • Charge • Baryon number • Lepton number • Strangeness (but not in weak interactions)
2	Strange particles are created via the strong interaction, in which strangeness is conserved. Strange particles have to be created in pairs. Strange particles decay through the weak interaction.	
3	To see if a reaction can occur check if all the above quantities total the same on the LHS and RHS of the reaction. If not, the reaction cannot occur.	

Exchange particles

1	All forces are caused by exchange particles.
2	A force arises when the exchange particle moves between the other particles.
3	There are four fundamental interactions: **strong, electromagnetic, weak and gravity**.

4

	Exchange particle	**Particles affected**
Weak nuclear force	W or Z boson	All
Strong force	Pions (π^+, π^- and π^0)	Hadrons only
Electromagnetic	Photons	Charged