Topic 8: Nuclear & Particle Physics

0.8 Specification notice:

Mathematical skills that could be developed in this topic include using appropriate units in calculations.

8.Q Exam questions

A series of experiments was carried out in the 1970s to investigate the structure of protons using the linac at Stanford, USA.

* Explain how an electron is accelerated in a linac.

(6)

Explain how an electron is accelerated in a linac? (6)

This question assesses a student's ability to show a coherent and logically structured answer with linkages and fully-sustained reasoning.

Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning.

The following table shows how the marks should be awarded for indicative content.

IC points	IC mark	Max linkage mark available	Max final mark
6	4	2	6
5	3	2	5
4	3	1	4
3	2	1	3
2	2	0	2
1	1	0	1
0	0	0	0

Indicative content:

IC1: set of (metal drift) tubes (in a line)

IC2: electrons accelerated by electric field/potential difference

IC3: acceleration takes place in the gaps between tubes

IC4: adjacent tubes connected to opposite terminals of a power supply or opposite charge/polarity

IC points 1 and 4 may be awarded with well-drawn diagram

IC6 accept reference to distance between centres/ends of tubes must increase to give a fixed alternating frequency

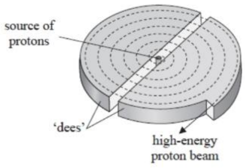
IC5: power supply/p.d./electric field is alternating (so that as electron emerges from one tube the next tube is positive)

IC6: time spent in each tube must be the same so as the electrons travel faster the tubes must be longer / gaps between get longer

- Set of tubes in a line
- Electrons accelerated by electric field
- Acceleration takes place in the gaps between tubes
- Adjacent tubes connected to thermals of a power supply with opposite polarity
- Power supply is alternating (so that as electron emerges from one tube the next tube is positive)
- Time spent in each tube must be the same so as the electrons travel faster the tubes must be longer

Proton beam therapy is being introduced in the UK as a new cancer treatment.

A beam of protons is accelerated by a cyclotron to an energy of 23 MeV and is then focused onto a tumour.



* Explain how the cyclotron produces the high-energy proton beam.

(6)

Explain how the cyclotron produces the high-energy proton beam (6)?

This question assesses a student's ability to show a coherent and logical structured answer with linkage and fully-sustained reasoning. Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning.
The following table shows how the marks should be awarded for indicative content.

Number of indicative points seen in answer	Number of marks awarded for indicative points
6	4
5-4	3
3-2	2
1	1
0	0

Indicative content

- There is an alternating p.d./E-field
- P.d./E-field accelerates protons between dees
- Magnetic field perpendicular to plane of dees
- Proton path curved by magnetic field
- As velocity of protons increases radius of path in dees increases
- The time for which a proton is in a dee remains constant
  Or the frequency of p.d./E-field is constant

Guidance on how the mark scheme should be applied: The mark for The following table shows how the marks should be awarded for structure and lines of reasoning

	Number of marks awarded for structure and lines of reasoning
Answer shows a coherent and logical structure with linkage and fully sustained lines of reasoning demonstrated throughout	2
Answer is partially structured with some linkages and lines of reasoning	1
Answer has no linkage between points and is unstructured	0

Number of IC points	**Possible linkage marks**
0, 1	0
2, 3	1
4, 5, 6	2

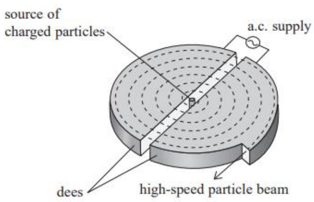
IC2 accept 'in the gap' for between dees. Accept increases E_k for accelerates

IC3 accept vertical or upwards for perpendicular to plane.

IC5 accept reference to $r = p/BQ$

- There is an alternating E-field
- E-field accelerates protons between dees
- Magnetic field perpendicular to plane of dees
- Proton path curved by magnetic field which causes a centripetal force
- As velocity of protons increases radius of path in dees increases
- The time for which a proton is in a dee remains constant

(b) The structure of a cyclotron is shown.



(i) Explain how the cyclotron produces a beam of high energy particles.

You should refer to the alternating potential difference and the magnetic field.

(4)

Electric field / p.d. accelerates particles
Or Electric field / p.d. gives particles energy **(1)**

Magnetic field / force at right angles to particles path **(1)**

Magnetic field/force maintains circular motion (whilst in dees)
Or Particle experiences centripetal force / acceleration (whilst in dees) **(1)**

p.d. switches every half cycle
Or Polarity of dees switches every half cycle
Or p.d. switches when particle is in dees **(1)**

p.d. has a constant time period
Or p.d. has a constant frequency
Or period is independent of speed of particle **(1)**

The discovery of the Higgs particle was an important contribution to our understanding of particle physics.

(a) Describe the standard model for subatomic particles. You should identify the fundamental particles and the composition of the particles we can observe.

(5)

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• fundamental – quarks and leptons	(1)	MP2 and 3 could be given for a named particle and its quark composition
• Baryons made of 3 q	(1)	
• Mesons made of quark and antiquark	(1)	Can be inferred if either set named
• 6 quark **Or** 6 leptons	(1)	
• Each particle has an antiparticle	(1)	

- **Fundamental - quarks and leptons**
- **Baryons made of 3 quarks**
- **Mesons made of quark and antiquark**
- **Each particle has an antiparticle**
- **There are 6 quarks and 6 leptons**

8.130 Understand what is meant by nucleon number (mass number) and *proton number (atomic number)*

What is the nucleon number?	The same as the mass number and is the total number of protons and neutrons in the nucleus (also is the number of baryons) *This is not the same as the relative atomic mass number as they take into account isotopes*

8.131 Understand how large-angle alpha particle scattering gives evidence for a nuclear model of the atom and how our understanding of atomic structure has changed over time

What was the order in which the model of the atom was developed and by who?	• Dalton model - John dalton (1803) • Plum pudding - J.J thomson (1897) • Nucleus - Geiger & mardsen (Rutherford as well) [1909-1911] • Shells - Niels bohr (1913) • Quantum mechanical model - Erwin schrodinger (kinda) [1926] • Neutrons - James chadwick (1932)
What are the results of the results of the Rutherford alpha scattering Gold Foil Experiment? What does these mean? + Mnemonic	• Most α particles pass through undeflected -> most of the atom is empty space. • A very small number are deflected through an angle greater than 90° -> This suggests the nucleus is very small and is where the mass and charge of the atom is concentrated therefore the atom consists of a **small dense charged nucleus** • Some a-particles deflected through small angles of less than 10° -> This suggests there is a charged nucleus in the centre with a small diameter • Some α particles **deflected marginally** and even fewer **bounced back ->** most of the mass of the atom is concentrated in the nucleus rather

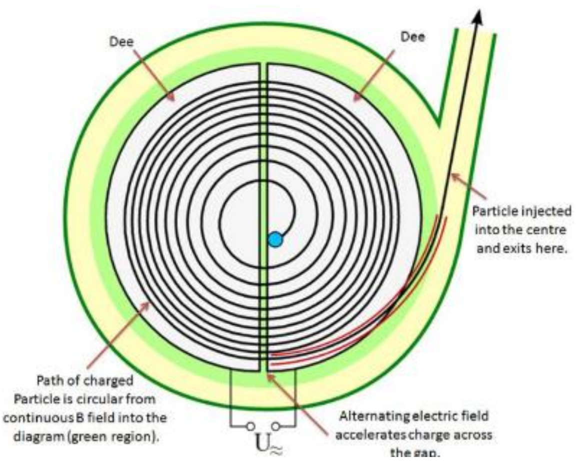
	than throughout the atom ● This backscattering couldn't be explained by the plum pudding model. *MASS - Mr Adams Sees Stars* *Its advised to say charged instead of positively charged as the deflection of the alpha particle could have been caused by the positive charge of the nucleus or the attraction of an electron in the atom*
What conclusion from the observation would be made using an aluminium foil (Al) instead of gold foil (Au) for the alpha scattering experiment? Rutherford also carried out the experiment with aluminium ($^{27}_{13}Al$) foil. The aluminium foil had the same thickness as the gold foil and the alpha particles had the same initial kinetic energy. The following observations were made. Observation 1: The fraction of alpha particles scattered at any particular angle for aluminium foil was always much less than for gold foil. Observation 2: The alpha particles scattered from aluminium foil had less kinetic energy than the alpha particles scattered from gold foil. Explain how these observations can be used to deduce how an aluminium nucleus compares to a gold nucleus.	● The fraction of alpha scattering is less for Al so the force of repulsion from Al nucleus is less ● Therefore the charge on an Al nucleus is less than Au ● The KE is less for scattered alpha for Al so recoiling nucleus must have more KE ● The mass of an Al nucleus is less than mass of Au nucleus An explanation that makes reference to the following points: Observation 1 • (the fraction of alpha scattering is less for aluminium) so the force of repulsion is less (at a given distance) **(1)** • therefore the charge on an aluminium nucleus is less than on gold nucleus **(1)** Observation 2 • (the E_k is less for scattered alpha for aluminium) so recoiling nucleus must have some/more kinetic energy **(1)** • The mass of an aluminium nucleus is less than mass of a gold nucleus **(1)**
Explain, with reference to the properties of the alpha particle, why a relatively large force is needed to deflect alpha particles through a large angle?	● Due to the large mass and speed and therefore large momentum ● The alpha particle would have a large change in momentum when deflected through large angles which requires a large force

Describe how the model of the atom changed, as a consequence of the alpha scattering experiments?	- Before scattering experiment was the plum pudding model where the atom mass was distributed equally - After experiment it was discovered that there is a very small nucleus containing most of the mass of the atom - The atom was mostly empty space - The nucleus was charged

8.132 Understand that electrons are released in the process of thermionic emission and how they can be accelerated by electric and magnetic fields

Describe thermionic emission ?	This is the emission of charged particles from a metal surface due to thermal energy overcoming the electrostatic forces holding electrons in the atom
Which equations is commonly equated in thermionic emissions questions?	$1mv^2$=KE - V=W/Q -> VQ=W -> W=eV $1mv^2$=eV

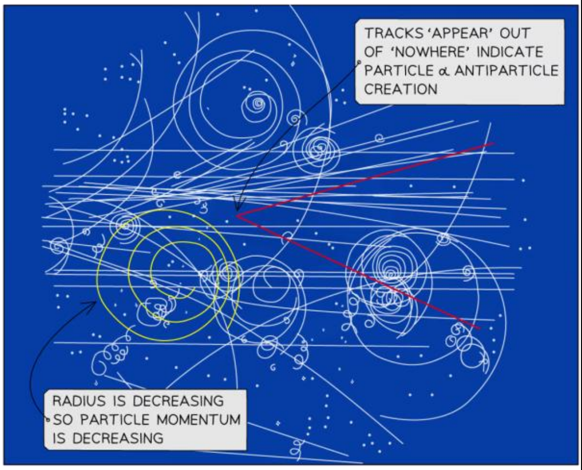
8.133 Understand the role of electric and magnetic fields in particle accelerators (linac and cyclotron) and detectors (general principles of ionisation and deflection only)

How does a cyclotron work?	The electric field flips frequently is such that each time a particle reaches the next ‘dee’ it is accelerated 

8.134 Be able to derive and use the equation $r = \frac{p}{BQ}$ for a charged particle in a magnetic field

What is the derivation for r = p/BQ	● $F = mv^2/r$ ● F = Bqv ● p = mv ● mv2/r=Bqv ● mv/r = Bq ● r = mv/Bq ● r = p/Bq

8.135 Be able to apply conservation of charge, energy and momentum to interactions between particles and interpret particle tracks

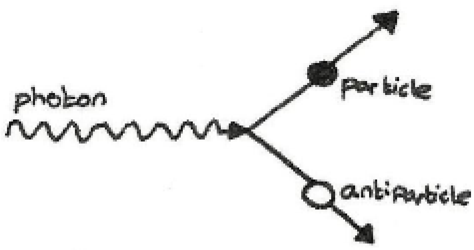
Explain how **observations and measurements** from a photograph of a bubble chamber or any modern detector can be used to establish information about particles  	● A track being shown means the particle is either positively or negatively charged ● The track having a radius of curvature means the particle has momentum via p=Bqr a. A smaller radius means the particle has a smaller momentum and vice versa ● If the radius of a track is decreasing (i.e spiralling closer inwards) the particles momentum is decreasing via p=Bqr therefore the velocity of the particle is decreasing therefore the KE of the particle is also decreasing due to it ionising other particles in its path ● Depending on the question via FLHR you can find out the charge of the particle as the B field would be perpendicular to the velocity of the particle via F=Bqv *For questions like this make sure you remember charge, energy and momentum has to be conserved so mention observations for all 3* *Don't mention about lepton or baryon number as you cannot deduct from observation*

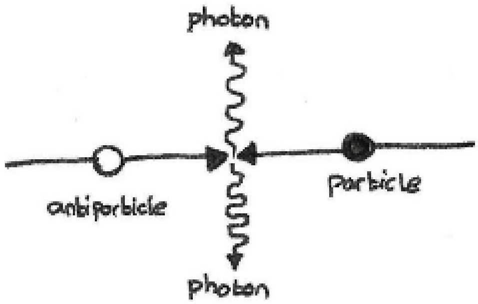
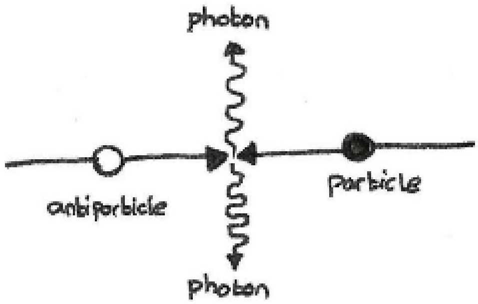
8.136 Understand why high energies are required to investigate the structure of nucleons

What is required for an electron to collide	● High energy electrons and because

with nucleons and what is the equation for the diameter of a nucleon	of it their de Broglie wavelength becomes smaller ● $\lambda = h/p \approx$ nucleon diameter *In particle physics you will likely be asked to explain effects based on the de broglie wavelength to which the wavelength is inversely proportional to a particle momentum and velocity*

8.137 Be able to use the equation $\Delta E = c^2 \Delta m$ in situations involving the creation and annihilation of matter and antimatter particles

What is pair production (creation)?	When a photon interacts with a nucleus or atom and has enough energy to produce a particle and its antiparticle  The path of the particle-antiparticle is in opposite directions as they are oppositely charged and hence the B force is oppositely direction. However they have the same radius as they each have the same mass and hence same momentum *It should be stressed that: any extra energy becomes kinetic energy and the photon has to interact with something as it's massless*

What is annihilation?	When a particle meets its equivalent anti-particle they both are destroyed and their mass is converted into energy in the form of two gamma ray photons  *These particles are moving in opposite directions to conserve momentum*
What is the equation used for annihilation and why?	$2hf_{min} = 2E_0 = 2mc^2$ As two particles make two photons 
What is the minimum energy required of a photon to undergo pair production? What happen above this energy?	The total rest energies of the particles involved. For a particle-antiparticle pair, it would be: $hf_{min} = 2E_0 = 2mc^2$ Above this, excess energy goes into kinetic energy.

8.138 Be able to use MeV and GeV (energy) and MeV/c^2, GeV/c^2 (mass) and convert between these and SI units

8.139 Understand situations in which the relativistic increase in particle lifetime is significant (use of relativistic equations not required)

What is the script for proving special relativity using pions from Mr Adams?	- Pions decay rapidly - due to their high speed special relativity predicts that time runs more slowly - Therefore pions from the upper atmosphere have a longer lifetime than stationary pions - Therefore more pions reach the Earth's surface before decaying than expected

8.140 Know that in the standard quark-lepton model particles can be classified as:

● baryons (e.g. neutrons and protons) which are made from three quarks

● mesons (e.g. pions, kaon) which are made from a quark and an antiquark

● leptons (e.g. electrons and neutrinos) which are fundamental particles

● photons and that the symmetry of the model predicted the top quark

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<td>Sketch the family tree of particles and give examples for end branches</td>
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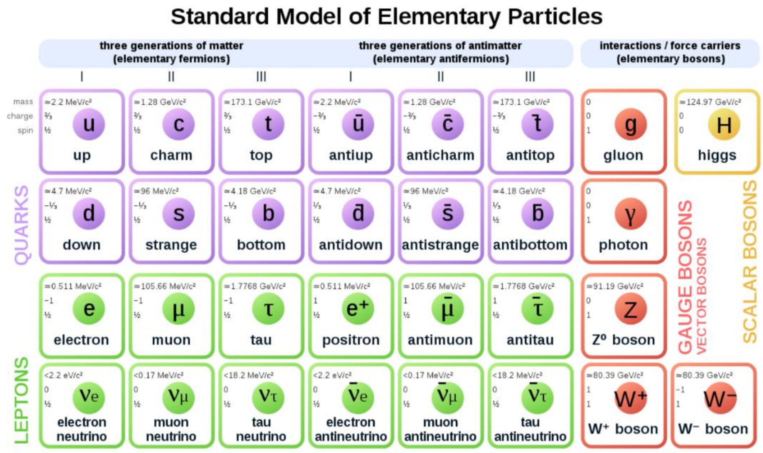
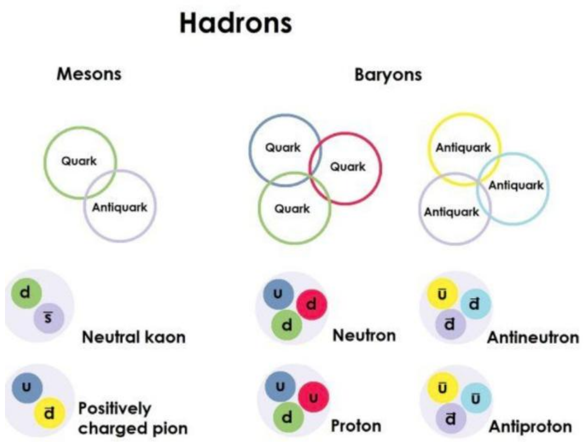
- Leptons - electrons,muon,tau,neutrino
- Quarks - up, down,strange, charm, top, bottom
- Hadrons are baryons and mesons
- Baryons - proton, neutron made up of 3 quarks
- Mesons - pion, kaon made up of a quark and antiquark
- There are particles which don’t take part which are photons, bozons, gluon and higgs





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8.141 Know that every particle has a corresponding antiparticle and be able to use the properties of a particle to deduce the properties of its antiparticle and vice versa

What are the similarities and differences between a particle and its antiparticle	Similarities: • Same mass (same rest mass) • -> Same energy via $E=mc^2$ Usually same momentum Differences: • Opposite charge • Opposite lepton or baryon number

8.142 Understand how to use laws of conservation of charge, baryon number and lepton number to determine whether a particle interaction is possible

Which particles have a positive,negative and neutral baryon number (B)?	• Baryon number = +1 for Proton, neutron etc • Baryon number = -1 for antiproton, antineutron etc • Baryon number = 0 for mesons, leptons
Which particles have a positive, negative and neutral charge (Q) ?	• Charge = +1 for protons, positrons • Charge = -1 for electrons • Charge = 0 for neutrons,photons, neutrinos • The charge on quarks is partial so like an up is $+\frac{2}{3}$ and down is $-\frac{1}{3}$ and the opposite applies to its anti particle
Which particles have a positive,negative and neutral lepton number (L)?	• Lepton number = +1 for all leptons i.e electrons, muon, tau, neutrino • Lepton number = -1 for all anti-leptons i.e positron, antielectron neutrino/electron antineutrino • Lepton number = 0 for all particles that are not leptons i.e hadrons *Try not to make the mistake that an electron lepton number is -1 as its charge is negative because its L is +1 and a positron is -1*

8.143 Be able to write and interpret particle equations given the relevant particle symbols.

What 5 properties are conserved in particle physics edexcel?	• Momentum (P) • Mass-energy [E] • Charge (Q) • Baryon number (B) • Lepton number (L)
When writing or interpreting particle equations with relevant symbols should you be aware of?	• Always remember that Lepton (L), Baryon (B) and Charge (Q) properties need to be conserved for a reaction to occur
What are most of the general symbols that a particle equation question could give you? Including: Electron,positron,kaon,pion,proton,neutron,neutrino,electron neutrino, anti-electron neutrino, up quark, down quark and photons	• e^- = electron • e^+ = positron • k = kaon • π = pion • p^+ = proton • n = neutron • v = neutrino • v_{e-} = electron neutrino • $\underline{v}_{e-}$ = anti electron neutrino /electron antineutrino • u = up quark • d = down quark • **λ** = photons *Mesons such as kaons or pions would have a +, - or 0 above them to indicate charge as most are unstable* *Most antiparticles would have a bar above their symbol e.g* $\underline{v}_{e-}$ *anti-electron neutrino*