

WJEC A-LEVEL PHYSICS • UNIT 1

PHYSICS



EXAM QUESTION PACK

1.7 PARTICLES AND NUCLEAR STRUCTURE

SCORE

/

PERCENTAGE

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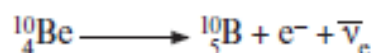
1. (a) Mesons, leptons and quarks are three groups of particles. State which of these groups are affected by:

(i) the weak nuclear force; [1]

.....
(ii) the strong nuclear force. [1]

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- (b) The following interaction shows a β^- decay for a beryllium nucleus.



(i) State the name of the $\bar{\nu}_{\text{e}}$ particle. [1]

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(ii) Explain how lepton number and charge are conserved in this interaction. [2]

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- (c) (i) Write down the number of neutrons in:

I. ${}_{4}^{10}\text{Be}$ II. ${}_{5}^{10}\text{B}$ [1]

- (ii) On the level of baryons the interaction can be written as:



Show clearly that there is a change in quark flavour in this interaction. [2]

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7. (a) Quarks and electron neutrinos are fundamental particles whereas protons and neutrons are not. Explain this statement. [2]

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- (b) (i) State why it is that electron neutrinos are very difficult to detect. [2]

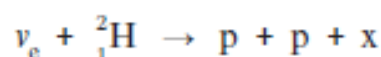
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- (ii) Electron neutrinos can be detected when they interact with deuterium nuclei, ${}^2_1\text{H}$, that are present in heavy water. The following reaction is observed.



- Identify particle x and justify your answer using the conservation laws. [3]

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- (c) When a positron and an electron meet they annihilate to produce two gamma ray photons.



- State which force is responsible for this interaction, giving your reasoning. [2]

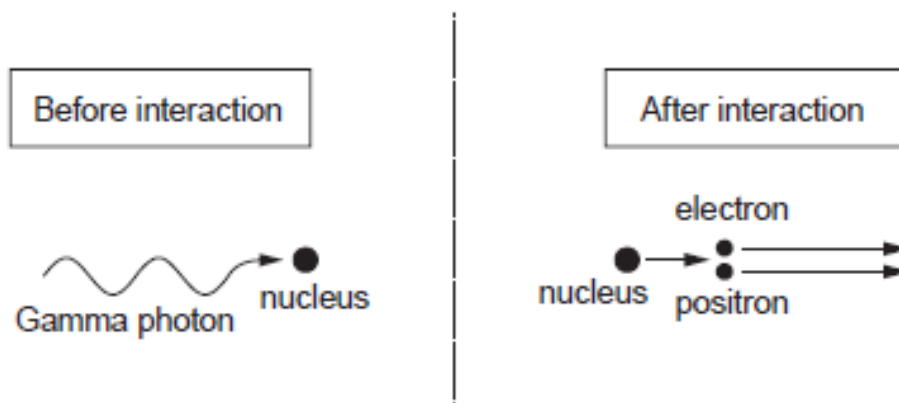
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3.

5. The following interaction can take place when a gamma photon encounters a stationary nucleus.



The energy of the gamma photon “creates” a positron-electron pair and the nucleus gains some momentum in the direction of the original gamma photon.

- (a) Show that this interaction can only take place if the energy of the gamma photon is greater than 1.02 MeV . [3]

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- (b) The actual energy of the incident gamma photon is 1.03 MeV . Assuming that the kinetic energy of the nucleus after the interaction is negligible, explain briefly why the kinetic energies of the positron and electron are approximately 0.005 MeV each. [2]

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- (c) Use the kinetic energies of 0.005 MeV and conservation of momentum to show that the speeds of the positron and electron are $4.2 \times 10^7\text{ ms}^{-1}$ and that the momentum of the nucleus after the collision is $4.7 \times 10^{-22}\text{ kg ms}^{-1}$. [4]

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- (d) The momentum of the nucleus ($4.7 \times 10^{-22}\text{ kg ms}^{-1}$) is essential otherwise conservation of momentum would be impossible. Deduce whether or not the assumption in part (b) is valid (the mass of the nucleus is $3.3 \times 10^{-25}\text{ kg}$). [2]

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4. (a) The table shows information about some sub-atomic particles.

Particle	Symbol	Quark combination	Charge / e	Baryon number
proton	p	uud	$+1$	1
delta particle	Δ^{++}	uuu		
electron	e^{-}	no quarks present		
pion	π^{-}		-1	

- (i) Complete the table.

[3]

- (ii) Identify the lepton in the table.

[1]

- (b) JJ Thomson, when studying the properties of cathode rays in 1897, discovered the electron. In the early 20th century, Ernest Rutherford, carrying out a series of experiments on radioactive substances, discovered the proton. The following interaction between protons and electrons has been observed by using high energy particle accelerators.



Show how charge and lepton number are conserved in the above interaction.

[2]

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- (c) The Δ^{++} decays in about 6×10^{-24} s as shown below.



- (i) Show clearly that both up-quark number and down-quark number are conserved in this decay. [2]

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- (ii) Give two reasons for believing that this decay is a strong force interaction. [2]

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- (d) During a press conference, the spokesman for a nuclear research centre was asked the question:

'You have discovered many new particles, none of which have had any discernible impact on society. How do you justify the huge expense of continuing with these experiments?'

In response, the spokesman referred to the work of JJ Thomson and Ernest Rutherford. Suggest why the spokesman responded in this way. [2]

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5.

5. (a) Subatomic particles can be classified as either hadrons or leptons. Giving examples of each, fully describe the differences and similarities between these two groups. Include the types of interaction they undergo and how one of the groups can be further subdivided. [6 QER]

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- (b) Electron capture occurs when an electron interacts with a proton in the nucleus of an atom. The following interaction occurs:



- (i) Identify the particle, x , explaining how you used the relevant conservation laws. [3]

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- (ii) Describe the change in quark flavour during electron capture. [1]

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- (iii) State and explain which interaction is responsible for this decay. [1]

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6. (a) The anti- Δ^{++} is an anti-baryon and a first-generation particle which has a charge of $-2e$. Explain why the only possible quark make-up of the anti- Δ^{++} is $\bar{u}\bar{u}\bar{u}$. [1]

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- (b) The anti- Δ^{++} has a lifetime of approximately 6×10^{-24} s and decays into a π meson and another anti-baryon. Deduce the quark make-up of the π meson and the anti-baryon and name them. [2]

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- (c) State which force is responsible for the decay of the anti- Δ^{++} into a π meson and anti-baryon, giving a reason for your answer. [2]

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- (d) In 2011, a highly respected international research collaboration reported that they had measured neutrinos travelling at speeds greater than that of light. This report was met by caution from the scientific community and then the result was disproved. Explain briefly why the result was met with caution and how the results might have been disproved. [3]

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7. (a) Explain briefly what is meant by conservation of mass-energy.

[2]

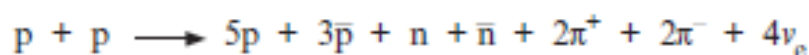
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(b) It is suggested that a collision between two protons, each of kinetic energy 3 GeV produces the following interaction:



Determine which, if any, of the conservation laws are violated (the rest mass-energy of a proton or a neutron ≈ 1 GeV). [4]

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Marking Scheme

1.

Question			Marking details	Marks available					
				AO1	AO2	AO3	Total	Maths	Prac
1	(a)	(i)	Quarks and leptons and mesons – all required	1			1		
		(ii)	Quarks and mesons	1			1		
	(b)	(i)	Anti-[electron] neutrino Accept: [electron] anti-neutrino		1		1		
		(ii)	Lepton number: $0 = 0 + 1 - 1$ must be in this order or described: lepton number is 0 on LHS. Electron has lepton number of +1, anti-electron neutrino has a lepton number of -1. [1] Accept $4 = 4 + 1 - 1$ must be in this order. Charge: B has one more proton than Be, but appearance of e^- means that charge is conserved or $+4 = +5 - 1$ [+ 0] must be in this order Or: $0 \rightarrow 1 - 1 + 0$ must be in this order or described or $n = p + e^- + \text{anti-neutrino}$ so $d = u + e^- + \text{anti-neutrino}$ so $-\frac{1}{3} = \frac{2}{3} - 1 + 0$ [1]		2		2		
	(c)	(i)	$^{10}_4\text{Be}$ has 6 neutrons and $^{10}_5\text{B}$ has 5 neutrons	1			1		
		(ii)	LHS: udd [1] RHS: uud [1] N.B. bod if udd $\rightarrow$ uud + e^- + anti-neutrino seen Award 1 mark if above seen with quarks assigned to either the e^- and/or anti-neutrino Award 1 mark for $d \rightarrow u$ or d in $n \rightarrow u$ in p or similar Award 1 mark if equation written the wrong way around		2		2		
			Question 1 total	3	5	0	8	0	0

2.

Question			Marking details	Marks available					
				AO1	AO2	AO3	Total	Maths	Prac
7	(a)		Protons and neutrons are each made up of 3 quarks (1) Quarks and neutrinos are not made up of other particles (1)	2			2		
	(b)	(i)	No strong force / no electromagnetic force /only interact by weak force (1) They are uncharged (1)	2			2		
		(ii)	Conservation of charge $0 + 1 \rightarrow 1 + 1 - 1$ (1) Conservation of lepton $1 + 0 \rightarrow 0 + 0 + 1$ (1) x is an electron (1)		1 1	1	3		
	(c)		Electromagnetic (1) Presence of photons / gamma rays (1)		1	1	2		
			Question 7 total	4	3	2	9	0	0

3.

Question			Marking details	Marks available					
				AO1	AO2	AO3	Total	Maths	Prac
5	(a)		$E = [2 \times] 9.11 \times 10^{-31} \times c^2$ or $m = \frac{9.11 \times 10^{-31}}{1.66 \times 10^{-27}} [= 0.000549 \text{ u}] [1]$ Conversion to eV i.e. dividing by 1.6×10^{-19} or $\times 931 [1]$ 1.025 MeV seen or $2 \times 9.11 \times 10^{-31} \times \frac{(3 \times 10^8)^2}{1.6 \times 10^{-19}}$ or $2 \times 0.000549 \times 931 [1]$		3		3	3	
	(b)		Excess energy or $0.01 \text{ MeV} [1]$ Equal amounts shared by electrons & positron due to equal (light) masses $[1]$		2		2		
	(c)		$0.5 \times 9.11 \times 10^{-31} \times v^2 = 0.005 \times 10^6 \times 1.6 \times 10^{-19}$ seen or equivalent: $(0.5 \times 9.11 \times 10^{-31} \times (4.2 \times 10^7)^2)$ giving 0.005 MeV or 4.19×10^7 seen $[1]$ Momentum of gamma ray $[= \frac{E}{c}] = 5.49 \times 10^{-22} [\text{Ns}] [1]$ Momentum of electron or positron $= 9.11 \times 10^{-31} \times 4.2 \times 10^7 = 3.8 \times 10^{-23}$ or $7.6 \times 10^{-23} [1]$ $5.49 \times 10^{-22} - 2 \times 4.2 \times 10^7 \times 9.11 \times 10^{-31}$ seen $[1]$		4		4	3	
	(d)		KE calculated ($3.35 \times 10^{-19} \text{ J}$ or 2.1 eV) $[1]$ Correct conclusion – negligible $[1]$ No ecf			2	2	1	
			Question 5 total	0	9	2	11	7	0

4.

Question			Marking details	Marks available																														
				AO1	AO2	AO3	Total	Maths	Prac																									
4	(a)	(i)	<table><tr><th>Particle</th><th>Symbol</th><th>Quark Combination</th><th>Charge/s</th><th>Baryon Number</th></tr><tr><td>Proton</td><td>p</td><td>uud</td><td>+1</td><td>1</td></tr><tr><td>Delta particle</td><td>Δ^{++}</td><td>uuu</td><td>+2</td><td>1</td></tr><tr><td>Electron</td><td>e^-</td><td>No quarks present</td><td>-1</td><td>0</td></tr><tr><td>Pion</td><td>π^-</td><td>$\bar{u}d$ or $d\bar{u}$</td><td>-1</td><td>0</td></tr></table> [3 × 1] marks for each correct row (ignoring row for proton)	Particle	Symbol	Quark Combination	Charge/s	Baryon Number	Proton	p	uud	+1	1	Delta particle	Δ^{++}	uuu	+2	1	Electron	e^-	No quarks present	-1	0	Pion	π^-	$\bar{u}d$ or $d\bar{u}$	-1	0		3		3		
Particle	Symbol	Quark Combination	Charge/s	Baryon Number																														
Proton	p	uud	+1	1																														
Delta particle	Δ^{++}	uuu	+2	1																														
Electron	e^-	No quarks present	-1	0																														
Pion	π^-	$\bar{u}d$ or $d\bar{u}$	-1	0																														
		(ii)	Electron	1			1																											
	(b)		Charge: LHS: $-1 + 1 (=0)$ RHS: $-1 + 2 - 1 (=0)$ [must be shown how 0 is determined on both sides] (1) Lepton Number: LHS: $1 + 0 (=1)$ RHS: $1 + 0 + 0 (=1)$ [must be shown how 1 is determined on both sides] (1)		2		2																											
	(c)	(i)	Up Quark: Δ^{++} contains 3 up quarks (uuu) = proton contains 2 up quarks (uud) + pion contains 1 up quark (u $\bar{d}$) (1) Down Quark: Δ^{++} contains 0 down quarks = proton contains 1down quark (uud) + pion contains 1 antidown quark (u $\bar{d}$). (1) Alternative for first mark: equation in quark form $uuu \rightarrow uud + u\bar{d}$		2		2																											
		(ii)	Any 2 × (1) from: - Very short lifetime / decays quickly / ref to 6×10^{-24} s - No change in u or d quark number (or flavour) - Only quarks or hadrons involved - No γ (or photon) or no neutrino involvement	2			2																											
	(d)		No practical use for electron or proton or both when they were discovered (1) Now many uses and one example given for either electron or proton (1)			2	2																											
			Question 4 total	3	7	2	12	0	0																									

5.

Question			Marking details	Marks available				Maths	Prac
				AO1	AO2	AO3	Total		
5	(a)		Differences Hadrons H1 Made up of quarks H2 Affected by strong interaction H3 e.g. protons / neutrons / mesons Leptons L1 Fundamental particles L2 Not affected by strong interaction L3 e.g. electron / electron neutrino Similarities S1 Both have a rest mass / gravitational attraction S2 Both can be affected by the weak interaction S3 Both can be affected by the electromagnetic interaction Sub group G1 Hadrons can be split into Baryons and mesons G2 Baryons contain 3 quarks G3 Mesons contain a quark antiquark pair 5 – 6 marks 2 points from each of H L S and G <i>There is a sustained line of reasoning which is coherent, relevant, substantiated and logically structured.</i> 3 – 4 marks 1 point from each of H L S and G <i>There is a line of reasoning which is partially coherent, largely relevant, supported by some evidence and with some structure.</i> 1 – 2 marks 3 points from any group <i>There is a basic line of reasoning which is not coherent, largely irrelevant, supported by limited evidence and with very little structure.</i> 0 marks <i>No attempt made or no response worthy of credit.</i>	6			6		
	(b)	(i)	Charge +1 -1 = 0 + 0 (1) Lepton number 0 +1 = 0 +1 (1) Hence, x is an uncharged lepton, ... Hence Particle identified as an electro neutrino (1)		3		3		
		(ii)	u changes to d / uud to udd		1		1		
		(iii)	Weak interaction because of the presence of a neutrino / change in quark flavour	1			1		
			Question 5 total	7	4	0	11	0	0

6.

Question			Marking details	Marks available					Maths	Prac
				AO1	AO2	AO3	Total			
6	(a)		$-\frac{2}{3} - \frac{2}{3} - \frac{2}{3} = -2$ seen or statement that this is the only way to get a charge of $-2(e)$		1		1			
	(b)		$\overline{u}\overline{u}\overline{u} \rightarrow \overline{u}\overline{u}\overline{d} + \overline{u}\overline{d}$ or $\overline{u}\overline{u}\overline{u} + \overline{u}\overline{u}$ or $\overline{u}\overline{u}\overline{u} + \overline{d}\overline{d}$ [1] [any order of quarks in the baryon and meson] Anti-proton or anti- Δ^+ and π^- OR anti- Δ^{++} and π^0 [1]			2	2			
	(c)		Strong force [1] no ecf Short time or conservation of u and d and no photon or accept ONLY quarks / hadrons involved or no neutrinos and no photons or no flavour change and no photons [1]			2	2			
	(d)		Any 3 x (1) valid points: -contradicts current theories (relativity) or can't travel faster than the speed of light ✓ -current theories well established ✓ -further experiments ✓ -by other groups / scientists / peer review ✓ -due to instrument problems (timing delay) / systematic errors ✓			3	3			
			Question 6 total	0	1	7	8	0	0	0

7.

Question			Marking details	Marks available				Maths	Prac
				AO1	AO2	AO3	Total		
7	(a)		Mass can be converted to energy (or vice versa or $E = mc^2$) (1) So mass-energy cons used if change of mass (1) i.e. short concluding comment stating briefly mass-energy conservation (rather than simple energy conservation) also accept $m_0c^2 + E$ conserved (or similar)	2			2		
	(b)		Baryon number OK [$1+1 = 5-3+1-1+0+0+0$] or $2=2$ (1) Accept U and D conservation : $4U + 2D = 4U + 2D$ Or Quark number: $6 = 6$ Lepton number not OK [$0+0 \neq 0+0+0+0+0+4$] or $0 \neq 4$ (1) Charge conservation OK [$1+1 = 5-3+0+0+2-2+0$] or $2=2$] (1) Mass energy not OK not enough energy to produce products (1) If not 4 correct conclusions 3max.			4	4		
			Question 7 total	2	0	4	6	0	0

