Questions

Q1.

The equation $\Delta E = c^2\Delta m$ can be used with data at the back of this paper to calculate

☐ **A** the kinetic energy of an electron.

☐ **B** the energy produced when a lambda particle decays.

☐ **C** the energy of the photons produced when a proton and an antiproton annihilate.

☐ **D** the mass of uranium that produces 50 MJ of energy in a nuclear reactor.

(Total for question = 1 mark)

Q2.

A proton has a mass of 1.67×10^{-27} kg.

Which of the following shows the conversion of this mass to GeV/c^2 ?

☐ **A** $\dfrac{1.67 \times 10^{-27} \times 1.60 \times 10^{-10}}{(3.00 \times 10^8)^2}$

☐ **B** $\dfrac{1.67 \times 10^{-27} \times 1.60 \times 10^{-19}}{(3.00 \times 10^8)^2}$

☐ **C** $\dfrac{1.67 \times 10^{-27} \times (3.00 \times 10^8)^2}{1.60 \times 10^{-10}}$

☐ **D** $\dfrac{1.67 \times 10^{-27}}{1.60 \times 10^{-10} \times (3.00 \times 10^8)^2}$

(Total for question = 1 mark)

Q3.

Which of the following particle equations is correct for the decay of a proton within a nucleus?

☐ **A** $p \rightarrow n + \beta^+$

☐ **B** $p \rightarrow p + \beta^+$

☐ **C** $p \rightarrow n + \beta^+ + \nu$

☐ **D** $p \rightarrow p + \beta^+ + \nu$

(Total for question = 1 mark)

Q4.

A high energy proton collides with a stationary proton and a π^0 particle is produced.
The equation for the reaction is

$$p + p \rightarrow p + p + \pi^0$$

(i) Explain why the proton must have a high energy in order for this reaction to occur.

(2)

....

....

....

....

(ii) The rest mass of the π^0 is $\frac{1}{7}$ of the rest mass of a proton.
In this reaction the total kinetic energy of the particles decreases.
Calculate the minimum decrease in kinetic energy if the reaction is to occur.
rest mass of proton = 938 GeV/c^2

(2)

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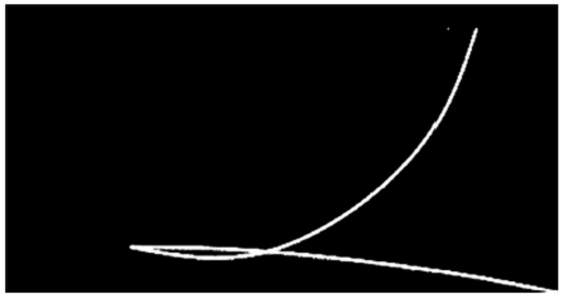
....

Minimum decrease in kinetic energy = ...

Q5.

The bubble chamber photograph shows tracks made by a proton and a pion. The proton and pion were both created by the decay of a lambda particle. No other particles were produced.



The rest mass of the lambda particle is 1115 MeV / c^2.

(i) Calculate this mass in kg.

(3)

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Mass = ... kg

(ii) The rest mass of a proton is 940 MeV / c^2. The rest mass of a pion is 140 MeV / c^2.

The kinetic energy of the lambda particle just before decay is 4.95 GeV.
Calculate the total kinetic energy of the proton and pion in MeV.

(3)

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Total kinetic energy = ... MeV

(Total for question = 6 marks)

Q6.
Hadrons are a group of particles composed of quarks. Hadrons can be either baryons or mesons.

(a) (i) State the quark structure of a baryon.

(1)

....

(ii) State the quark structure of a meson.

(1)

....

(b) State **one** similarity and **one** difference between a particle and its antiparticle.

(2)

Similarity

....

....

Difference

....

....

(c) (i) The table gives some of the properties of up, down and strange quarks.

Type of quark	Charge/e	Strangeness
u	+2/3	0
d	−1/3	0
s	−1/3	−1

One or more of these quarks combine to form a K^+, a meson with a strangeness of +1.

Write down the quark combination of the K^+.

(1)

....

(ii) The K^+ can decay in the following way

$$K^+ \rightarrow \mu^+ + \nu_\mu$$

K^- is the antiparticle of the K^+.

Complete the equation below by changing each particle to its corresponding antiparticle in order to show an allowed decay for the K^- meson.

(2)

$$K^- \rightarrow$$

(iii) The rest mass of the K^+ is 494 MeV/c^2.

Calculate, in joules, how much energy is released if a K^+ meets and annihilates a K^-.

(3)

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....

....

Energy = ... J

(Total for Question = 10 marks)

Mark Scheme

Q1.

Question Number	Answer	Mark
	C	1

Q2.

Question Number	Acceptable answers	Additional guidance	Mark
	The only correct answer is C $\frac{1.67 \times 10^{-27} \times (3.00 \times 10^{8})^2}{1.60 \times 10^{-10}}$	A,B and D all contain numerical errors	1

Q3.

Question Number	Acceptable answers	Additional guidance	Mark
	The only correct answer is C A *is not correct because lepton number is not conserved* B *is not correct because charge conservation is not obeyed* D *is not correct because charge conservation is not obeyed*	$p \rightarrow n + \beta^{+} + \nu$	1

Q4.

Question Number	Acceptable Answer	Additional guidance	Mark
(i)	An explanation that makes reference to the following points: • energy conserved (1) • so energy needed over and above rest energy of proton in order to provide the mass of the π^0 particle (1)		**(2)**

Question Number	Acceptable Answer	Additional guidance	Mark
(ii)	• calculates rest energy of π^0 (1) • 134 GeV (1)	Example of calculation: $E_k = \frac{938\text{ GeV}}{7} = 134\text{ GeV}$	**(2)**

Q5.

Question Number	Acceptable answers	Additional guidance	Mark
(i)	• Converts eV to J **(1)** • use of $\Delta m = \Delta E / c^2$ **(1)** • mass = 1.98×10^{-27} (kg) **(1)**	<u>Example of calculation</u> $m = \frac{1115 \text{ V} \times 1.6 \times 10^{-19}\text{C} \times 10^6}{(3 \times 10^8)^2(\text{ms}^{-1})^2}$ $m = 1.98 \times 10^{-27}$ kg	3
(ii)	• Converts prefix G to M **Or** M to G **(1)** • Determines total energy / mass of lambda before decay **(1)** • kinetic energy = 4985 MeV **(1)**	<u>Example of calculation</u> 4.95 GeV = 4950 MeV Total Energy and mass before decay = 4950 + 1115 = 6065 MeV Total after = 140 + 940 + E_k E_k = 6065 – 1080 = 4985 MeV	3

Q6.

Question Number	Answer		Mark
(a)(i)	Three quarks **Or** three antiquarks (accept the letter q to represent quarks)	**(1)**	**1**
(a)(ii)	Quark and an antiquark (accept the letter q to represent quarks)	**(1)**	**1**
(b)	Similarity: they have the same mass **Or** same magnitude of charge Difference: opposite charge	**(1)** **(1)**	**2**
(c)(i)	Up and antistrange (in words or symbols, and can be in either order)	**(1)**	**1**
(c)(ii)	μ^- $+\square_\mu$ $K^- \rightarrow \mu^- + \square_\mu$	**(1)** **(1)**	**2**
(c)(iii)	Energy = 2 × 494 MeV eV to J conversion Energy = 1.58×10^{-10} (J) (division by c^2 and subsequent multiplication by c^2 is not penalised) <u>Example of calculation</u> Energy = $2 \times 494 \times 10^6$ eV $\times 1.6 \times 10^{-19}$ J eV^{-1} Energy = 1.58×10^{-10} J	**(1)** **(1)** **(1)**	**3**
	Total for question		**10**