

1

Under certain conditions a photon may be converted into an electron and a positron.

- (a) State the name of this process.

(1)

- (b) For the conversion to take place the photon has to have an energy equal to or greater than a certain minimum energy.

- (i) Explain why there is a minimum energy.

(2)

- (ii) Show that this minimum energy is about 1 MeV.

(1)

- (iii) Explain what happens to the excess energy when the photon energy is greater than the minimum energy.

(1)

- (iv) A photon has an energy of 1.0 MeV.

Calculate the frequency associated with this photon energy.

State an appropriate unit in your answer.

frequency = _____ unit = _____

(4)

(Total 9 marks)

2 Which equation shows the process of annihilation?

- A

$\pi^- + \pi \longrightarrow \gamma$

☐
- B

$p + \bar{p} \rightarrow \gamma + \gamma$

☐
- C

$\beta^- + p \longrightarrow \gamma$

☐
- D

$\gamma + \gamma \longrightarrow \beta^+ + \beta^-$

☐

(Total 1 mark)

3 (a) The table gives information about some fundamental particles.

Complete the table by filling in the missing information.

particle	quark structure	charge	strangene	baryon number
	uud		0	
Sigma ⁺	uus	+ 1		
	u $\bar{d}$		0	0

(7)

(b) Each of the particles in the table has an antiparticle.

(i) Give **one** example of a baryon particle **and** its corresponding antiparticle.

particle _____

antiparticle _____

(1)

(ii) State the quark structure of an antibaryon.

(1)

- (iii) Give **one** property of an antiparticle that is the same for its corresponding particle and **one** property that is different.

Same _____

Different _____

(2)

(Total 11 marks)

4

- (a) Pair production can occur when a photon interacts with matter. Explain the process of pair production.

(2)

- (b) Explain why pair production cannot take place if the frequency of the photon is below a certain value.

(3)

- (c) Energy and momentum are conserved during pair production. State two other quantities that must also be conserved.

(2)

(Total 7 marks)

5

Cosmic rays are high-energy particles coming from Space. They collide with the air molecules in the Earth's atmosphere to produce pions and kaons.

(a) Pions and kaons are mesons. Identify the quark–antiquark composition for a meson.

Tick (✓) the correct answer in the right-hand column.

	✓ if correct
qqq	
q $\bar{q}\bar{q}$	
q $\bar{q}$	
qq	

(1)

(b) A positron with a kinetic energy of 2.0 keV collides with an electron at rest, creating two photons that have equal energy.

Show that the energy of each photon is 8.2×10^{-14} J.

(3)

(c) Calculate the wavelength of a photon of energy 8.2×10^{-14} J.

wavelength = _____ m

(2)

- (d) Show that the speed of the positron before the collision was about $2.7 \times 10^7 \text{ m s}^{-1}$.

(3)

- (e) Calculate the de Broglie wavelength of the positron travelling at a speed of $2.7 \times 10^7 \text{ m s}^{-1}$.

wavelength = _____ m

(2)

- (f) The separation between the carbon atoms in graphite is about 0.15 nm.

Discuss whether electrons travelling at $2.7 \times 10^7 \text{ m s}^{-1}$ can be used to demonstrate diffraction as they pass through a sample of graphite.

(4)

(Total 15 marks)

6

Under certain conditions a γ photon may be converted into an electron and a positron.

(a) What is this process called?

(1)

(b) (i) Explain why there is a minimum energy of the γ photon for this conversion to take place and what happens when a γ photon has slightly more energy than this value.

(ii) Using values from the data sheet calculate this minimum energy in MeV.

(3)

(c) Under suitable conditions, a γ photon may be converted into two other particles rather than an electron and positron.
Give an example of the two other particles it could create.

(1)

(Total 5 marks)

7

(a) State the name of the antiparticle of a positron.

(1)

(b) Describe what happens when a positron and its antiparticle meet.

(2)

(Total 3 marks)

Mark schemes

1

(a) pair production ✓

1

(b) (i) energy of photon needs to provide
at least the rest masses ✓

OR at least the rest energy ✓

of the electron and positron / of (both) particles / of particle and antiparticle ✓

Of the electron and positron / of (both) particles of particle and antiparticle ✓

Can't score 2nd mark without having scored 1st
(allow particles or products)

TO on any suggestion of particles have KE

2

(ii) minimum energy = $2 \times 0.510999 = 1.021998$ (MeV) ✓

must see working

and final answer must be at least 3 sf

allow detailed argument in reverse

0.5 MeV close to 0.511 MeV

Or $E=mc^2$ leading to 1.024875 MeV

Or $2 \times 5.5 \times 10^{-4} \times 931.5 = 1.02$ MeV

1

(iii) (electron / positron have) kinetic energy ✓

thermal energy n/e

Momentum n/e

1

(iv) (attempts to convert energy to joules)

energy = $1.0 \times 10^6 \times 1.60 \times 10^{-19} = 1.6 \times 10^{-13}$ (J) ✓

Condone power 10 error on MeV

conversion to J

(use of $E = hf$)

Their energy $\div 6.63 \times 10^{-34} = f$ ✓

Must see subject or their f on answer line consistent with working

$f = 2.4 \times 10^{20}$ ✓ cao

Hz (condone s^{-1}) ✓

Capital H and lower case z (for symbol)

Allow word written as Hertz (h lower case)

4

[9]

2

B

[1]

3

(a)

particle	quark structure	charge	strangeness	baryon number
proton✓	uud	+ 1✓	0	1✓
sigma ⁺	uus	+1	-1✓	1✓
π ⁺ ✓	u $\bar{d}$	+1✓	0	0

7

(b) (i) examples:
proton, antiquarks✓

1

(ii) consists of 3 antiquarks✓

1

(iii) same (rest) mass (energy)✓
difference eg baryon number/charge✓

2

[11]

4

(a) photon interacts with (orbital) electron/nucleus/atom ✓
energy of photon used to create particle antiparticle pair ✓
to conserve momentum photon needs to interact with interacting particle ✓

2

(b) energy of photon depends on frequency ✓
if energy/frequency is below a certain value there is not enough energy ✓
to provide mass/rest energy of particles ✓

3

(c) any two ✓ ✓
eg charge
lepton number
baryon number
strangeness

2

[7]

5

(a) q $\bar{q}$ ✓

1

(b) Total energy = 2keV + 2 × 511 keV = 1024 keV✓

= 1024 × 1.6 × 10⁻¹⁹ = 1.64 × 10⁻¹³J✓

Energy of each photon = 1.64 × 10⁻¹³/2 = 8.19 × 10⁻¹⁴ (J) ✓

First mark for calculating the total energy in keV.

Second mark is for converting correctly into joules.

Third mark is for dividing by two so ecf for incorrect conversion into joules. Student must show at least 3sf.

3

(c) $\lambda = \frac{hc}{E} = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{8.19 \times 10^{-14}}$ ✓

= 2.43 × 10⁻¹² (m) ✓

First mark for the correctly rearranged equation or correct values substituted into equation.

Correct answer only scores 2 marks, ecf from 1 (b)

2

(d) E_k = 2 keV = 2000 × 1.6 × 10⁻¹⁹ J = 3.2 × 10⁻¹⁶J✓

$v = \sqrt{\frac{2E_k}{m}} = \sqrt{\frac{2 \times 3.2 \times 10^{-16}}{9.11 \times 10^{-31}}}$ ✓

= 2.65 × 10⁷(m s⁻¹) ✓

First mark for converting KE into joules.

Second mark for rearranging equation correctly or substituting correct values into equation.

Third mark for correct answer, must be to at least 3sf.

3

(e) $\lambda = \frac{h}{mv} = \frac{6.63 \times 10^{-34}}{9.11 \times 10^{-31} \times 2.65 \times 10^7}$ ✓

= 2.75 × 10⁻¹¹(m) ✓

First mark for rearranging equation correctly or substituting correct values into equation.

Second mark for correct answer.

2

(f) Recognition that separation is 1.5×10^{-10} m and compared to 0.28×10^{-10} (ecf)✓

wavelength is about 5 times less than gap width✓

$$\sin \theta = \frac{\lambda}{d} = 0.2 \rightarrow \theta \sim 11^\circ \checkmark$$

yes (diffraction would be observable)✓

Or words to that effect

4

[15]

6

(a) pair production **(1)**

1

(b) (i) the γ ray must provide enough energy to provide for the (rest) mass **(1)**
any extra energy will provide the particle(s) with **kinetic** energy **(1)**

(ii) $(0.511 + 0.511) = 1.022$ (MeV) **(1)**

3

(c) any pairing of a particle with its corresponding antiparticle (e.g. $p + \bar{p}$) **(1)**

1

[5]

7

(a) electron

B1

1

(b) they annihilate (condone disappear/destroy or eliminate each other)

B1

forming (two) gamma ray(s)/radiation or photon(s)
(i.e. condone singular)
NOT just energy

B1

2

[3]