RECOGNISING ACHIEVEMENT

SPECIMEN

Advanced GCE

PHYSICS B (ADVANCING PHYSICS)

Unit G495: Field and Particle Pictures

Specimen Paper

G495 QP

Candidates answer on the question paper.

Additional Materials:
Electronic calculator
Data, Formulae and Relationships booklet

Time: 2 hours

Candidate Name

Centre Number

Candidate Number

INSTRUCTIONS TO CANDIDATES

- Write your name, Centre number and Candidate number in the boxes above.
- Answer **all** the questions.
- Use blue or black ink. Pencil may be used for graphs and diagrams only.
- Read each question carefully and make sure you know what you have to do before starting your answer.
- Do **not** write in the bar code.
- Do **not** write outside the box bordering each page.
- WRITE YOUR ANSWER TO EACH QUESTION IN THE SPACE PROVIDED.

INFORMATION FOR CANDIDATES

- The number of marks is given in brackets [] at the end of each question or part question.
- ✎ Where you see this icon you will be awarded marks for the quality of written communication in your answer.
- You may use a calculator.
- You are advised to show all the steps in any calculations.
- The total number of marks for this paper is **100**.

FOR EXAMINER'S USE		
Section	**Max.**	**Mark**
A	**19**	
B	**43**	
C	**38**	
TOTAL	**100**	

This document consists of **29** printed pages and **3** blank pages and an Insert.

[Turn Over

Answer **all** the questions.

Section A

1 Protons and neutrons are each made up of a different combination of three quarks.

The u quark has a charge of $+\frac{2}{3}$e. The u quark has a charge of $-\frac{1}{3}$e.

State the combination of three quarks needed to make

(a) a proton

.... **[1]**

(b) a neutron.

.... **[1]**

2 A nucleus of hydrogen-3 can be formed when a neutron is absorbed by a nucleus of hydrogen-2.

$$ {}^{2}_{1}\mathrm{H} + {}^{1}_{0}\mathrm{n} \rightarrow {}^{3}_{1}\mathrm{H} $$

The table gives the masses of the three particles in atomic mass units (u).

particle	mass/ u
${}^{1}_{0}\mathrm{n}$	1.008 67
${}^{2}_{1}\mathrm{H}$	2.001 41
${}^{3}_{1}\mathrm{H}$	3.001 60

Show that about 1×10^{-12} J of energy is released for each nucleus of hydrogen-3 created in this way.

u = 1.7×10^{-27} kg

$c = 3.0 \times 10^{8}$ m s^{-1}

[3]

3 A mercury discharge lamp emits ultraviolet photons of frequency 1.2×10^{15} Hz.

(a) Show that the energy of the ultraviolet photons is about 8×10^{-19} J.

$h = 6.6 \times 10^{-34}$ J s

[1]

(b) Fig. 3.1 gives some of the energy levels of the mercury atom.

Draw an arrow to show the energy level transition which causes the emission of these ultraviolet photons.

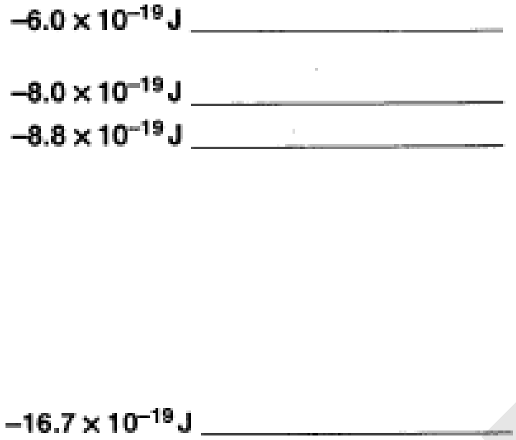


Fig. 3.1

[1]

(c) Here are some statements (**A**, **B** and **C**) about the energy levels shown in Fig. 3.1.

A They are all negative because the electrons in the atom are bound to the nucleus.

B They are all negative because electrons have a negative charge.

C Electrons in different energy levels have the same de Broglie wavelength.

Which **one** of these statements is correct?

answer .... **[1]**

4 The surface of an isolated conducting sphere is at a negative potential of -160 kV,

The radius of the sphere is 0.1 m.

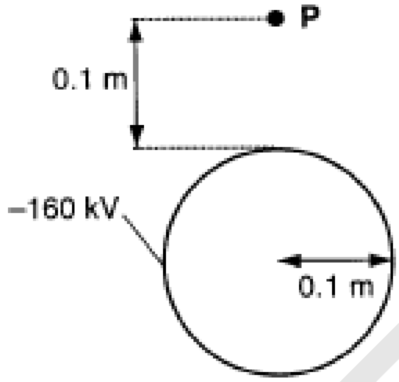


Fig. 4.1

(a) Draw an arrow through point **P** to show the direction of the electric field at that point.

[1]

(b) Here is a list of potentials.

-320 kV **-160 kV** **-80 kV** **-40 kV**

P is at a distance of 0.1 m from the surface of the sphere.

State which is the best value for the potential at **P**.

potential = ...kV **[1]**

(c) Draw a line on Fig. 4.1 to show the shape of the equipotential which passes through point **P**.

[2]

5 Fig. 5.1 shows a single coil of wire in the uniform field between opposite poles of a pair of magnets.

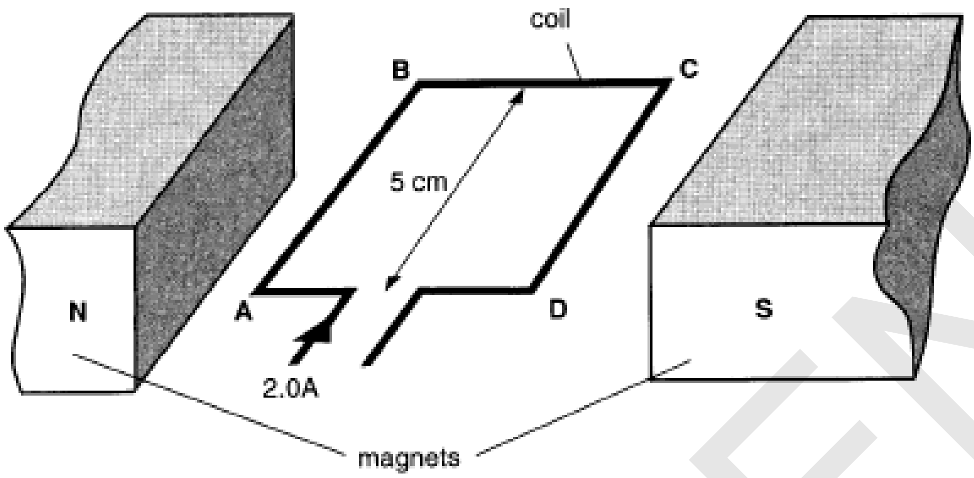


Fig. 5.1

The average flux density between the poles is 25 mT.

(a) Calculate the vertical magnetic force on side **AB** when it carries a current of 2.0 A.

The length of side **AB** is 5.0 cm.

force = ... N **[2]**

(b) Here are three statements about the magnetic force on side **BC** when the coil carries a current.

A It has the same value and direction as the force on side **AB**.

B It has the same value but the opposite direction to the force on side **AB**.

C There is no magnetic force on side **BC**.

State which **one** of the three (**A**, **B** or **C**) is correct.

answer .... **[1]**

[Turn Over

6 The graph of Fig. 6.1 shows the variation of binding energy per nucleon with the total number of nucleons in a nucleus.

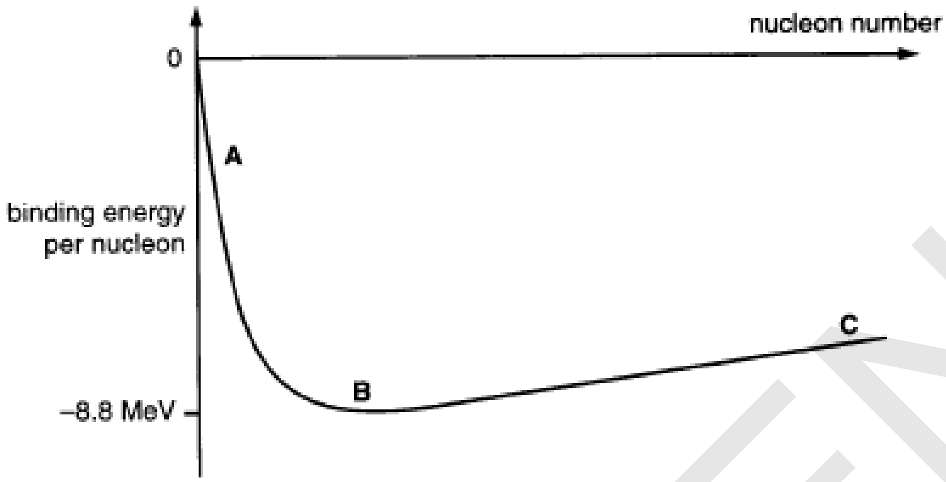


Fig. 6.1

Three regions (**A**, **B** and **C**) are marked on the graph.

State the region (**A**, **B** or **C**) which

(a) contains the nucleon number 56

.... **[1]**

(b) contains nuclei which can be used to provide energy by nuclear fusion

.... **[1]**

(c) contains nuclei which undergo nuclear fission.

.... **[1]**

7 The graph of Fig. 7.1 shows the variation of **electric field strength *E*** with **distance *r*** from a charged particle.

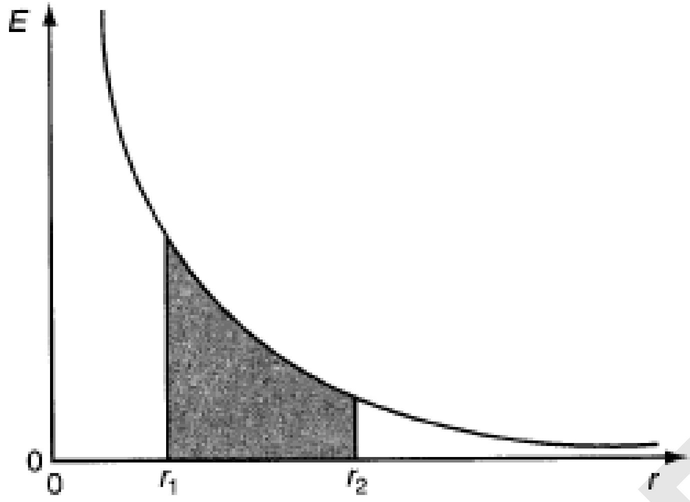


Fig. 7.1

Here are some statements about the shaded area shown on the graph.

A The area gives the average electric force between points r_1 and r_2.

B The area gives the work needed to move an electron from r_1 to r_2.

C The area gives the potential difference between points r_1 and r_2.

State which **one** of the three (**A**, **B** or **C**) is correct.

answer .... **[1]**

[Section A Total: 19]

Section B

8 This question is about the changing magnetic fields in transformers.

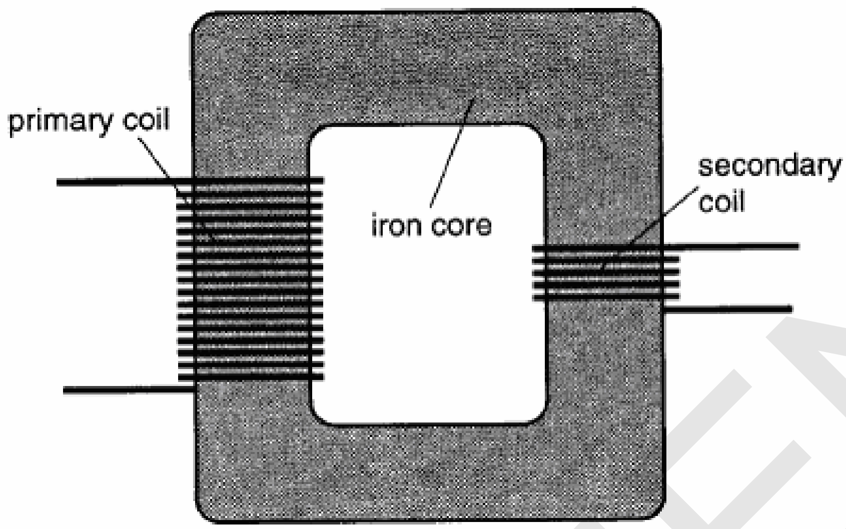


Fig. 8.1

An iron core is wound with primary and secondary coils of insulated copper wire to make a transformer, as shown in Fig. 8.1.

(a) On Fig. 8.1, sketch **two** complete loops of magnetic flux which pass through the secondary coil when there is a current in the primary coil.

[2]

(b) The ends of the secondary coil are connected to an oscilloscope to obtain the emf-time graph of Fig. 8.2

On the axes of Fig. 8.2, sketch the variation with time of the magnetic flux in the secondary coil.

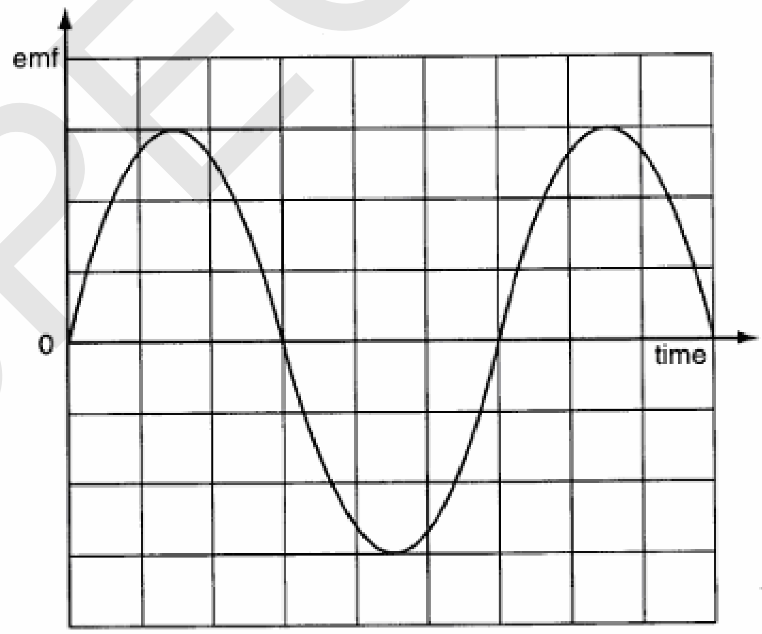


Fig. 8.2 **[2]**

(c) For an ideal transformer, the magnetic flux in the secondary coil is the same as the magnetic flux in the primary coil.

Use this to explain why the quantity $\dfrac{\text{emf across the coil}}{\text{turns of wire in the coil}}$

Has the same value for both primary and secondary coils in an ideal transformer.

[2]

(d) In a real transformer, eddy currents in the iron core will alter the flux in the two coils.

Explain why eddy currents are set up in the core and suggest why this alters the flux in the core.

✎ *You will be awarded marks for the quality of your written communication.*

[4]

[Total: 10]

Turn Over

9 This question is about triggering the rapid release of gamma rays from a nucleus.

Fig. 9.1 shows some of the energy levels for a nucleus of hafnium-178.

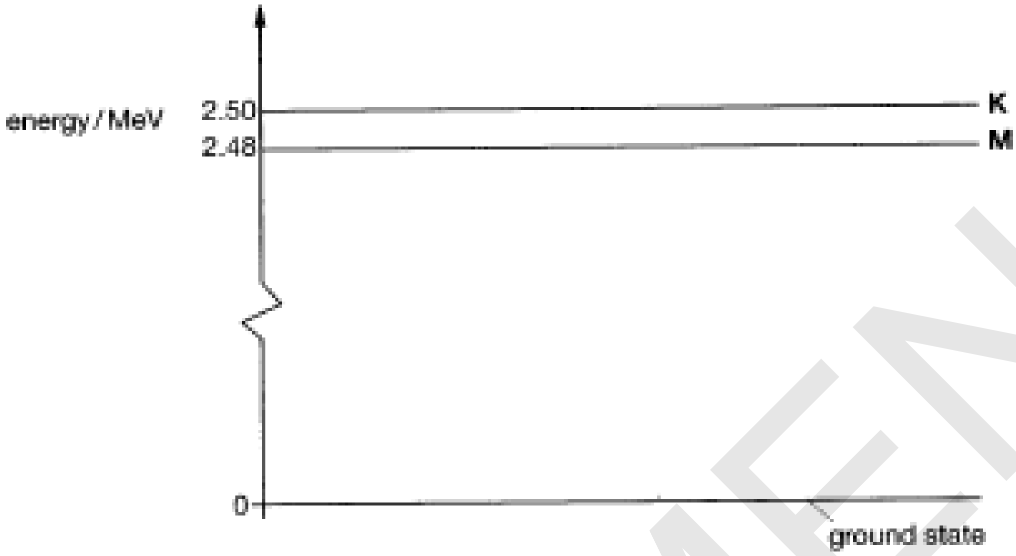


Fig. 9.1

(a) Halfium-178 is created by bombarding a target of tantalum-181 with high energy protons from an accelerator. The process is represented by the equation below.

$$^{181}_{73}\mathrm{Ta} + {}^{1}_{1}\mathrm{p} \rightarrow {}^{178}_{72}\mathrm{Hf} + \mathrm{X}$$

Calculate the nucleon number and proton number of particle X, and hence identify it.

[1]

(b) Some of the hafnium-178 nuclei created are in the excited state labelled **M** in Fig. 9.1. Nuclei in state **M** decay very slowly, with a decay constant of 7.1×10^{-10} s^{-1}.

In a recent experiment, a sample of 5.0 ng of hafnium-178 was created in state **M**.

Calculate the **activity** of the sample. Include the unit of your answer.

$1 \text{ u} = 1.7 \times 10^{-27}$ kg

activity = ... unit .... **[5]**

(c) The sample of hafnium-178 in state **M** was exposed to a one second pulse of X-ray photons of wavelength 6.2×10^{-11} m.

(i) Calculate the energy of each X-ray photon in MeV.

$c = 3.0 \times 10^{8}$ m s^{-1}

$h = 6.6 \times 10^{-34}$ J s

$e = 1.6 \times 10^{-19}$ C

photon energy = ... MeV [3]

(ii) The X-ray photons are absorbed by the sample, raising some nuclei to the energy level **K**. These nuclei have a larger decay constant than those in level **M**.

State and explain what will happen to the activity of the sample of hafnium. .

[3]

[Total: 12]

10 This question is about accelerating particles to high energies.

Particles are accelerated in a ring-shaped evacuated tube as shown in Fig. 10.1.

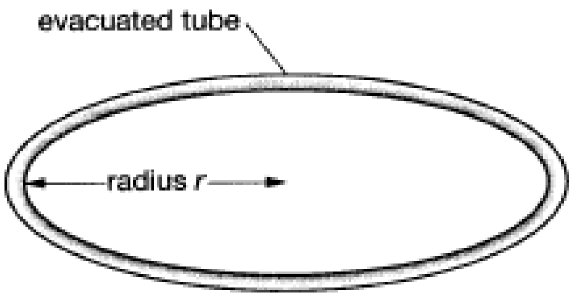


Fig. 10.1

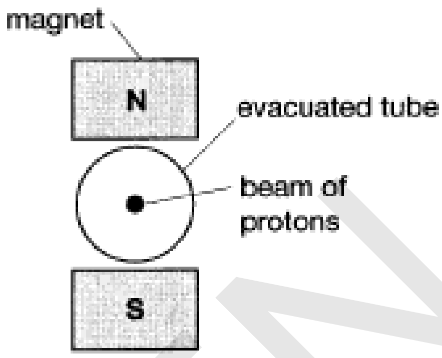


Fig. 10.2

(a) A particle accelerator of this type at CERN accelerates protons to a total energy of 270 GeV.

Use the relationship $E_{rest} = mc^2$ to show that the energy 270 GeV is about 300 times the rest energy of the protons.

$m_p = 1.7 \times 10^{-27}$ kg

$e = 1.6 \times 10^{-19}$ C

$c = 3.0 \times 10^{8}$ m s^{-1}

[3]

(b) Fig.10.2 shows the magnets above and below the evacuated tube. These force protons moving along the tube to follow a circular path.

(i) Low energy protons of mass *m* and charge *q* move at speed *v* through the magnetic field of flux density *B*. By using the expressions for the centripetal force and magnetic force on the protons, show that the radius *r* of the circular path is given by the expression

$$r = \frac{mv}{Bq}.$$

[2]

(ii) Protons with a large total energy *E* move at almost the speed of light *c*.

In these conditions, the radius *r* of the circular path is given by the expression $B = \frac{E}{cqr}$

Calculate the magnetic flux density required to keep the 270 GeV protons in a circular path of radius 1.8×10^{3} m.

$c = 3.0 \times 10^{8}$ m s^{-1}

$e = 1.6 \times 10^{-19}$ C

flux density = ...T **[2]**

(c) In an experiment, protons and antiprotons travel in opposite directions through the evacuated tube.

(i) Suggest why protons and antiprotons travel in opposite directions through the evacuated tube.

[1]

(ii) Sometimes, when a proton and an antiproton collide, a particle called the **Z** is created.

The Z particle is unstable and decays quickly into a positron and an electron.

Complete the equation for the decay of the Z particle, showing nucleon and charge numbers.

$$^{0}_{0}\mathrm{Z} \rightarrow$$

[2]

(iii) The experiment shows that the Z particle has a rest energy of 93 GeV.

Suggest how this is determined by the experiment.

[1]

[Total: 11]

11 This question is about calculating the risk to workers exposed to radioactive materials.

Disposable surgical instruments are sterilised by gamma photons from a sample of cobalt-60. The instruments in their airtight plastic bags are packed into boxes and placed on the conveyor belt, as shown in Fig.11.1.

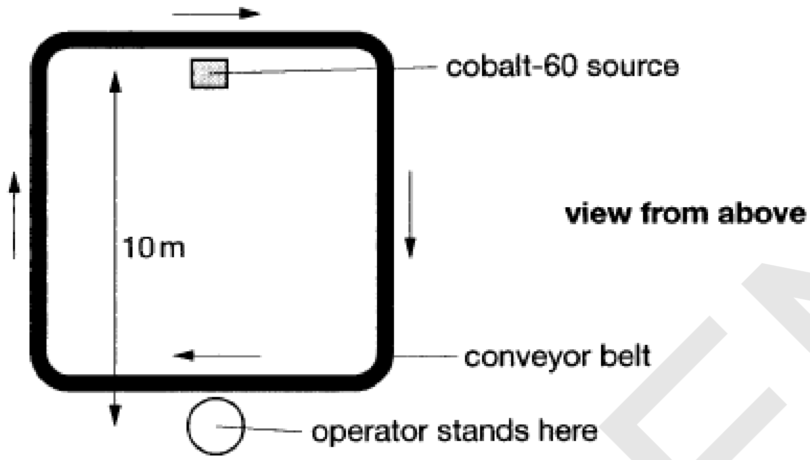


Fig. 11.1

(a) Operators are required to stand on a spot that is 10 m from the cobalt-60 source. Boxes that they load onto the conveyor belt pass much closer to the cobalt-60, and are exposed to a high intensity of gamma photons. The intensity I of gamma photons at a distance d from a source which emits photons at a rate A is given by the expression

$$I = \frac{A}{4\pi d^2}$$

(i) The source emits gamma photons at a rate of 2.4×10^{16} Bq.

Show that the intensity of gamma photons for the operators would be about 2×10^{13} Bq m^{-2} in the absence of shielding.

[1]

(ii) Explain why the intensity of gamma photons decreases with increasing distance from the source.

[2]

(iii) A nucleus of cobalt-60 releases a beta particle when it decays, quickly followed by a pair of gamma photons.

Explain why the beta particles contribute very little to the absorbed dose of the operator.

[1]

(b) In order to reduce the intensity of gamma photons for the operators to a safe level, a 1.2 m thick wall of concrete is placed between them and the source, as shown in Fig. 11.2.

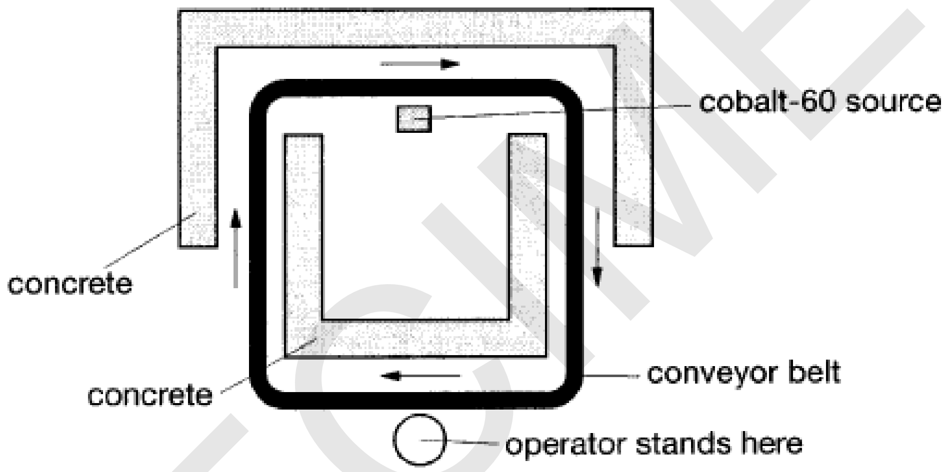


Fig. 11.2

(i) The intensity of the photons is halved for each 4.0×10^{-2} m thickness of concrete that they pass through.

Show that the 1.2 m thickness of concrete reduces the intensity of gamma photons for the operator to about 2×10^{4} Bq m^{-2}.

[2]

[Turn Over

(ii) Each operator presents an average area of 0.80 m^2 for absorption of the gamma photons.

If all the photons are absorbed by an operator of mass 75 kg, show that the absorbed dose of the operator is below the recommended safe limit of 4.0×10^{-6} Sv per day.

energy of photons = 1.8×10^{-13} J

quality factor of gamma photons = 1

[4]

[Total: 10]

[Section B total: 43]

Section C

The questions in this section are based on the Advance Notice article.

12 This question is about the energy and momentum of 5.4 MeV alpha particles (lines 9–13 in the article).

(a) 5.4 MeV alpha particles have an energy of 8.6×10^{-13} J.

Show that they are travelling at a speed of about 2×10^{7} m s^{-1}.

mass of alpha particle = 6.6×10^{-27} kg

[2]

(b) Fig. 12.1 shows an alpha particle being emitted at 2×10^{7} m s^{-1} from a nucleus of $^{210}_{84}Po$.

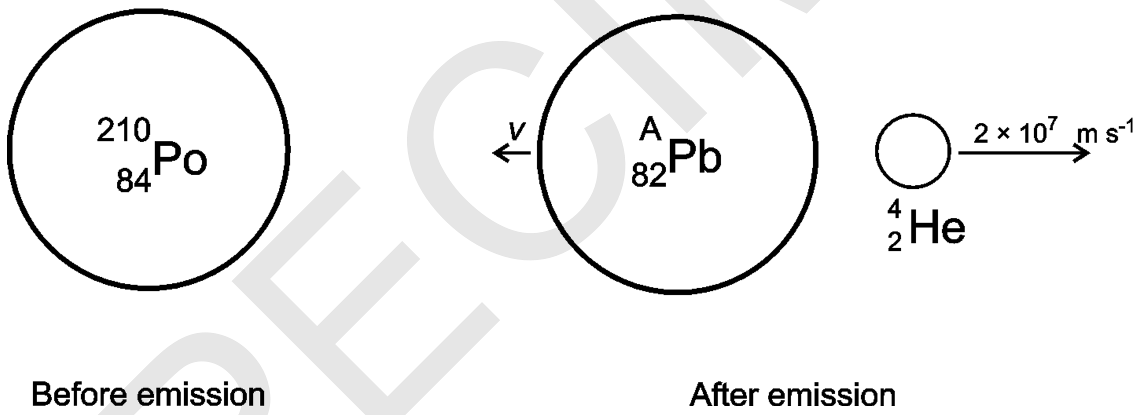


Fig. 12.1

(i) Write down the mass number A of the lead (Pb) nucleus produced in the decay.

mass number = ... **[1]**

(ii) Show that the lead nucleus in Fig. 12.1 is recoiling at a speed v of about 3×10^5 m s^{-1}.

[2]

(iii) Explain why the article is justified in stating (line 12 in the article) that nearly all the energy is given to the alpha particle.

.

[2]

[Total: 7]

13 This question is about the changes during beta decay (lines 16–24 in the article).

An example of beta decay is the decay of bismuth-210 to polonIum-210.

$$^{210}_{83}\mathrm{Bi} \rightarrow {}^{210}_{84}\mathrm{Po} + {}^{0}_{-1}\mathrm{e} + \overline{\nu}$$

(a) How does this equation show that the anti-neutrino $\overline{\nu}$ is uncharged?

[1]

(b) Explain why uncharged particles such as neutrons or neutrinos are harder to detect than charged particles such as alpha or beta particles.

[1]

[Turn Over

(c) (i) Suggest reasons why most physicists were reluctant to abandon the principle of conservation of energy in nuclear reactions, as Niels Bohr had suggested (lines 26-27 in the article).

✎ *You will be awarded marks for the quality of your written communication*

(ii) Suggest reasons why Pauli's suggestion of an extremely tiny, uncharged particle (lines 27 – 31 in the article) was not immediately accepted.

[6]

[Total: 8]

14 This question is about the detection of neutrinos.

In Reines & Cowan's experiment (lines 40 –70 in the article), the positron created in the reaction $\bar{\nu} + {}^{1}_{1}\text{p} \rightarrow {}^{1}_{0}\text{n} + {}^{0}_{+1}\text{e}$ annihilates with an electron to produce a pair of gamma photons as shown in Fig. 14.1.

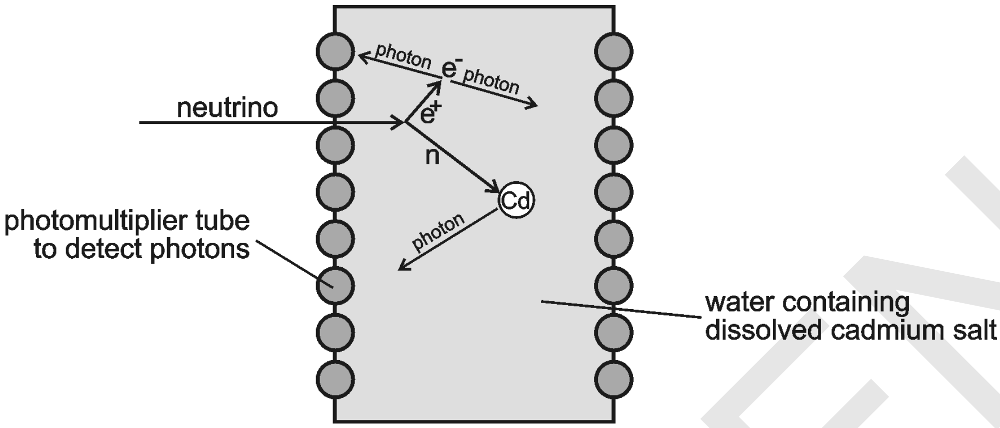


Fig. 14.1

(a) Explain why the detector uses **two** banks of photomultiplier tubes to detect the photons produced by the positron annihilation.

[1]

[Turn Over

(b) Reines and Cowan made their measurements over nearly a fortnight, and repeated the experiment over two days with the reactor off. Fig. 14.2 shows the results they obtained, where each 'count' consists of the pair of photons of part (a) followed by the later photon of part (b).

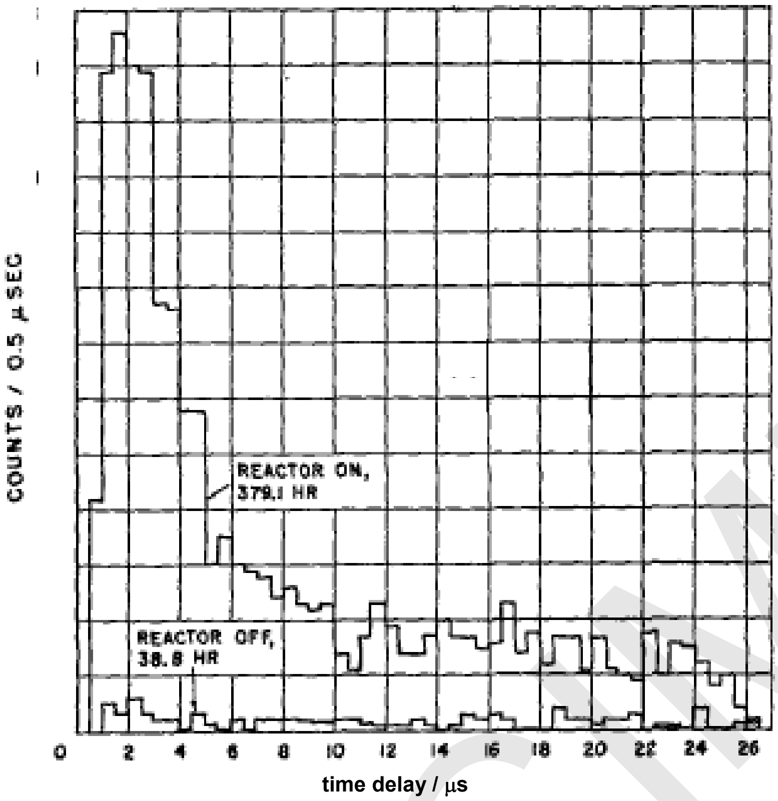


Fig. 14.2

(i) Explain why values on the lower, 'noise' graph need to be multiplied by about 10 for proper comparison with the upper, 'signal' graph.

[1]

(ii) Explain clearly how the results show that Reines and Cowan had shown the presence of neutrinos despite the signal to noise problem described in the article (lines 57 - 70 in the article).

[3]

(c) Reines and Cowan performed their experiments in nuclear reactors in Hanford and in Savannah River.

(i) Describe how scientific understanding of neutrinos benefited from the American nuclear weapons programme in the 1950s.

[2]

(ii) Suggest reasons why a government proposal to build a facility with both military and pure science objectives would be controversial today.

[2]

[Total: 9]

[Turn Over

15 This question is about the Homestake neutrino detector (lines 82–96 in the article).

(a) Argon-37 atoms were created in the Homestake neutrino detector at a steady rate of about 12 per month for many years. The decay constant of argon-37 is 2.3×10^{-7} s^{-1}.

Show that the half life of argon-37 is about a month (2.6×10^{6} s).

[1]

(b) Suggest difficulties that Ray Davis will have met in measuring the count rate of decaying argon-37 atoms in the Homestake detector (lines 82 –88 in the article).

✎ *You will be awarded marks for the quality of your written communication.*

[4]

[Total: 5]

16 **(a)** This question is about movement of photons and neutrinos in the Sun's core (lines 98– 114 and Fig. 5 in the article).

Show that a photon travels a total distance of about 4×10^{20} m in 40 000 years.

$c = 3.0 \times 10^{8}$ m s^{-1}, 1 year = 3.2×10^{7} s

[2]

(b) By comparison with diffusion of gas molecules (lines 105 – 114 and Fig. 4 in the article), it is believed that photons travel about 4 × 1020 m to the Sun's surface.

Explain why solar neutrinos may arrive at the Earth 40 000 years sooner than photons produced as a consequence of the same fusion reactions. No calculations are necessary.

[2]

(c) Measurements of solar neutrinos detected at the Earth give results about one-third of those expected. Physicists were concerned about this large difference (lines 87 – 96 in the article).

Suggest and explain reasons for their concern.

Your answer should make reference to

- the accepted model of energy production in the Sun (lines 98 – 99 in the article)
- possible sources of uncertainty in the experiments
- the consequence of a real difference between the current rate of solar energy production and that inferred from reactions 40 000 years ago.

[5]

[Total: 9]

[Section C Total: 38]

[Paper Total: 100]

BLANK PAGE

BLANK PAGE

BLANK PAGE

OXFORD CAMBRIDGE AND RSA EXAMINATIONS

Advanced GCE

PHYSICS B (ADVANCING PHYSICS) G495 MS

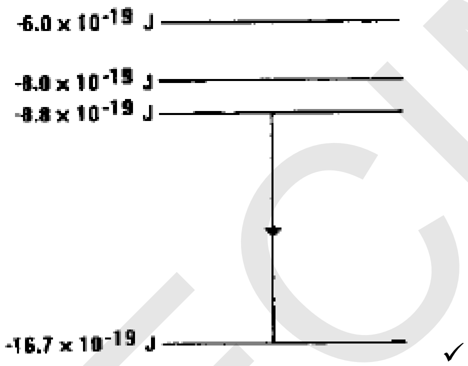
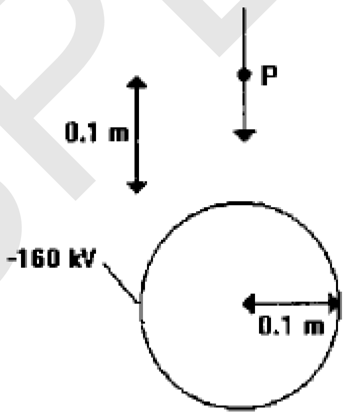
Unit G495: Field and Particle Pictures and Advances in Physics

Specimen Mark Scheme

The maximum mark for this paper is **100**.

This document consists of **10** printed pages and **2** blank pages.

Section A

Question Number	Answer	Max Mark
1(a) (b)	In any order: uud ✓ Accept +2/3e, +2/3e,-1/3e In any order: udd ✓ Accept +2/3e, -1/3e,-1/3e	[1] [1]
2	mass change = 3.0001 60 – 2.001 41 – 1.008 67 = -0.008 48 ✓ m = 0.008 48 × 1.7 × 10^{-27} = 1.44 × 10^{-29} kg ✓ E (=mc^2) = 1.44 × 10^{-29} × (3 × 10^8)^2 = 1.3 × 10^{-12} J ✓ ecf from previous stage throughout Accept reverse calculation	[3]
3(a) (b) (c)	E = hf = 6.6 × 10^{-34} × 1.2 × 10^{15} = 7.9 × 10^{-19} J ✓ Ignore direction of arrow  ✓ A ✓	[1] [1]
4(a) (b) (c)	 Vertical <u>and</u> downwards ✓ -80 kV ✓ At right angles to field arrow ✓ Complete circle through P centred on sphere ✓ Ignore arrows on equipotential	[1] [1] [2]

Section A		
Question Number	**Answer**	**Max Mark**
5(a)	5 cm = 5×10^{-2} m, 25 mT = 25×10^{-3} T ✓ $F = ILB = 2.0 \times 5 \times 10^{-2} \times 25 \times 10^{-3} = 2.5 \times 10^{-3}$ N ✓ Ecf incorrect conversion	**[2]**
(b)	C ✓	**[1]**
6(a)	B ✓	**[1]**
(b)	A ✓	**[1]**
(c)	C ✓	**[1]**
7	C ✓	**[1]**
	Section A Total	**[19]**

Section B		
Question Number	**Answer**	**Max Mark**
8(a)	Flux lines stay within iron ✓ Two complete and separate loops which do not overlap.✓ Ignore breaks where loops cross coils	[2]
(b)	Correct shape (sinusoidal) and period (by eye), any constant amplitude ✓ Correct phase (90° ahead or behind)	[2]
(c)	$V_p = N_p \dfrac{d\Phi}{dt}, V_s = N_s \dfrac{d\Phi}{dt}$ owtte✓ $\dfrac{d\Phi}{dt} = \dfrac{V_p}{N_p} = \dfrac{V_s}{N_s}$ owtte✓	[2]
(d)	any of the following, maximum [3 ✓✓✓] • Change of flux/field in the core • Sets up emf across core • Causing current to flow • Creating flux/field in core • Which opposes original change of flux/statement of Lenz's Law 'Reduces the flux' is neutral. QWC: clear organised answer	[3]
	Total	**[9]**
9(a)	Alpha (particle) / helium (nucleus) / α ✓	[1]
(b)	mass of nucleus = 178 ×1.7×10^{-27} kg = 3.0×10^{-25} kg ✓ $\text{nuclei} = \dfrac{\text{mass of sample}}{\text{mass of nucleus}}$ eor ✓ e.g. nuclei = 5 × 10^{-12}/3.0 × 10^{-25} = 1.7 × 10^{13} $A = \lambda N$ ✓ EITHER A = 7.1 × 10^{-10} × 2 × 10^{16} = 1.4 × 10^{7} OR A = 7.1 × 10^{-10} × 1.7 × 10^{16} = 1.2 × 10^{7} ✓ Bq✓ Accept 2.98×10^{-25}, or 2.97×10^{-25}, or 2.96×10^{-25} Award mark for eor, not final answer Ecf 9 b ii Accept s^{-1} but not Hz for Bq	[5]
(c)(i)	$f=c/\lambda$ = 3 × 10^{8} / 6.2 × 10^{-11} = 4.8 × 10^{18} Hz ✓ $E= hf$ =6.6 × 10^{-34} × 4.8 × 10^{18} = 3.2 × 10^{-15} J ✓ E= 3.2 × 10^{-15} / 1.6 ×10^{-19} (= 2 × 10^{4} eV) ✓ ecf incorrect f ecf incorrect E	[3]

Section B		
Question Number	**Answer**	**Max Mark**
9(c)(ii)	larger decay constant ⇒ greater probability of decay ✓ (Can discuss in term of $A = \lambda N$) Nuclei in level K will decay at a greater rate than those in level M. ✓ (Can refer to shorter half-life) Overall activity of sample will increase✓ Needs comparison with nuclei in level M stated or implied	**[3]**
	Total	**[12]**
10(a)	Calculation of energy from mass: $E = mc^2$ ✓ Conversion of J to eV ✓ Comparison of mass or energy ✓ EITHER $1.7 \times 10^{-27} \times (3.0 \times 10^8)^2 = 1.53 \times 10^{-10}$ J $1.53 \times 10^{-10} / 1.6 \times 10^{-19} = 9.56 \times 10^8$ eV $270 \times 10^9 / = 282 \approx 300$ OR $300 \times 1.7 \times 10^{-27} = 5.10 \times 10^{-10}$ J $5.10 \times 10^{-10} \times (3.0 \times 10^8)^2 = 4.59 \times 10^{-8}$ J $4.59 \times 10^{-8} / 1.6 \times 10^{-19} = 2.87 \times 10^{11}$ eV (287 GeV) Accept correct alternative calculation	**[3]**
(b)(i)	$F = mv^2/r$ ✓ $F = qvB$ so $qvB = mv^2/r$ ✓ $R = mv/Bq$ $qvB = mv^2/r$ is ✓✓	**[3]**
(ii)	$B = E/cqr = 4.3\times10^8 / 3 \times10^8 \times 1.8\times10^3 \times 1.6\times10^{-19}$ = 0.5 T ✓m✓e	**[2]**
(c)(i)	Opposite charges (allow magnetic force to be in opposite directions) ✓ NOT different charge	**[1]**
(ii)	${}^0_0Z \rightarrow {}^0_{-1}e + {}^0_{+1}e$ ✓✓ Award [✓] if one error. Accept β for e	**[2]**
(iii)	EITHER find the energies of electron and positron and finding that they add to 93 GeV ✓ OR energy of proton and antiproton / colliding particles must add to (at least) 93 GeV ✓ Any plausible technique	**[1]**
	Total	**[12]**
11(a)(i)	$2.4 \times 10^{16} / 4\pi \times 100 = \underline{1.9} \times 10^{13}$ ✓	**[1]**

Section B		
Question Number	**Answer**	**Max Mark**
11(a)(ii)	any of the following, maximum [2✓] • Photons fired out from source in all directions • Getting more spread out as they travel out • So photons passing through unit area decreases with increasing distance from source • All photons per second pass through surface of sphere radius d • Fraction per unit area through this surface is $1/4\pi d^2$ NOT photons are absorbed / lose energy / decay NOT inverse square law	**[2]**
(iii)	beta absorbed by air / have limited range owtte ✓	**[1]**
(b)(i)	Number of half-thicknesses = $1.2 / 4.0 \times 10^{-2} = 30$✓ $I = I_0(0.5)^n$ eor $I = 1.9 \times 10^{13} \times (0.5)^{30} = \underline{1.8} \times 10^4$ Bq m^{-2} ✓ Accept calculation using $I = I_0 e^{-\mu x}$ $2\times10^{13} \Rightarrow \underline{1.9}\times10^4$ Bq m^{-2}	**[2]**
(ii)	energy= intensity × area × time× photon energy eor✓ $1.8 \times 10^4 \times 0.8 \times 3600 \times 8 \times 1.8 \times 10^{-13}$ $= 7.5 \times 10^{-5}$ J $\approx 1 \times 10^{-4}$ J ✓ $\text{dose} = \dfrac{\text{energy} \times \text{quality factor}}{\text{mass}}$ eor✓ dose = $7.5 \times 10^{-5} / 75 = 1.0 \times 10^{-6}$ Sv ✓ 2×10^4 Bq m^{-2} gives 8.3×10^{-5} J 1.9×10^4 Bq m^{-2} gives 7.9×10^{-5} J ecf incorrect energy 1×10^{-4} J $\Rightarrow 1.3\times10^{-6}$ Sv accept reverse calculation	**[4]**
	Total	**[10]**
	Section B Total	**[43]**

Section C		
Question Number	**Answer**	**Max Mark**
12 (a)	$\frac{1}{2}mv^2 = 8.6\times 10^{-13}$ J $\Rightarrow v = \sqrt{\dfrac{2\times 8.6\times 10^{-13}}{6.6\times 10^{-27}}}$ ✓m $= 1.6\times 10^{7}$ m s^{-1} ✓e Evidence of calculation required for second mark ora from $v=2\times 10^{7}$ m s^{-1}	**[2]**
(b)(i)	206✓	**[1]**
(ii)	$0=206v + 4\times 2\times 10^{7}$ m s^{-1}✓ $\Rightarrow v = (-)\ 3.9\times 10^{5}$ m s^{-1}✓ (Evidence of calculation required for second mark.) First mark is application of conservation of momentum Using 1.6×10^{7} m s^{-1} $\Rightarrow v = 3.1\times 10^{5}$ m s^{-1} Can use masses in kg Can refer to same *p* to justify *m/v* relationship Arithmetic method OK	**[2]**
(iii)	*v* smaller, *m* bigger ✓ (this factor occurs) twice in v^2 and once in *m so* $\frac{1}{2}mv^2$ smaller ✓	**[2]**
	Total	**[7]**
13(a)	Reference to proton-electron (beta) charge balance✓	**[1]**
(b)	Not ionising (and detectors observe ionisation)✓	**[1]**
(c)(i)	Up to three of the following points: [3✓] Or other : • Principle of Conservation of Energy was established by respected physicists • Using Conservation of Energy had previously always given good predictions/ explanations of phenomena owtte (Can give specific example) • Calculations using Conservation of Energy had always been successful (Can give specific example) • Removing a fundamental foundation of theoretical physics is extremely unsettling • It is difficult to abandon something that you have grown up with and become used to	
(ii)	Up to three of the following points: [3✓] Or other : • Difficult to imagine any particle smaller than the (tiny) electron • Neutron/proton/electron model of the atom had been successful without it • You shouldn't just invent imaginary particles to fudge a solution to a problem • It takes a long time to adjust to new ideas **Mark both parts together with a maximum of five marks** QWC: SPG	**[6]**
	Total	**[8]**

Section C

Question Number	Answer	Max Mark
14(a)	annihilation produces 2 photons in opposite directions ✓ Could refer to coincidence counting	**[1]**
(b)(i)	'Noise' count is recorded over a time which is about 10 × smaller than signal graph. ✓	**[1]**
(ii)	Values on signal graph significantly greater than / >> 10 × largest value on 'noise' ✓ 'Noise' graph does not show any (significant) peak ✓ Time delay (2 μs) corresponds to prediction ✓	**[3]**
(c)(i)	(Both) reactors were built to produce nuclear weapons✓ Further development, e.g. too expensive to construct separate experiment, could use equipment already there, could discuss with fellow scientists working there.	**[2]**
(ii)	Any two distinct points, or any one point developed • The pure scientists may be opposed to military research✓for personal pacifist reasons✓ • The public may be opposed to military research✓ as above✓ or may be opposed to pure science✓ as waste of public money✓ • Military research needs to be secret ✓so pure science could compromise national security✓ • Pure science experiments / reporting could be limited✓ by security restrictions in military establishments✓ Other distinct valid suggestions or explanations should be credited similarly in (ii)	**[2]**
	Total	**[9]**
15(a)	$T_{1/2}$ = ln 2/2.3×10^{-7} s^{-1} =3.0×10^{6} s (= 34.9 days) ≈ 2.6 ×10^{6} s ✓	**[1]**
(b)	Very little Ar-37 present Extremely low count rate✓ Hard to distinguish from background ✓ Possible noise present (from radioactive minerals) ✓ vast volume of C_2Cl_4 dilutes/spreads out owtte Ar-37✓ QWC: appropriate form and style Any three valid distinct points.	**[1]** **[3]**
	Total	**[5]**

Section C		
Question Number	**Answer**	**Max Mark**
16(a)	Distance = $3.0 \times 10^8 \times 3.2 \times 10^7 \times 40\,000$ m = 3.8×10^{20} m ✓m✓e Evidence of calculation required for second ✓	**[2]**
(b)	Neutrinos and photons travel at similar speed in vacuo ✓ Neutrinos not slowed by travel through Sun ✓ Photons slowed by about 40 00 years (from part a) ✓ Any **two** points	**[2]**
(c)	Any of the following points: *Paradigm related:* Scientists reluctant to abandon theoretical model ✓ Theoretical model previously successful ✓ No alternative solar model available ✓ *Data related* Experiments have very low count rates ✓ (Low count) implies low signal:noise ratio (Q15) ✓ (Low signal:noise ratio) suggests large uncertainty ✓ *Consequence related:* If current core activity is low, future output will be low ✓ One-third output is huge reduction✓ Life on Earth will cease to exist with such low solar power✓ Any five points Other distinct valid suggestions or explanations should be credited similarly	**[5]**
	Total	**[9]**
	Section C Total	**[38]**
	Paper Total	**[100]**

Assessment Objectives Grid (includes QWC)

Question	AO1	AO2	AO3	QWC	Total
1	2				**2**
2	2	1			**3**
3	2	1			**3**
4	2	2			**4**
5	2	1			**3**
6	3				**3**
7		1			**1**
8(a)	2				**2**
8(b)		2			**2**
8(c)		2			**2**
8(d)		3		**1**	**4**
9(a)	1				**1**
9(b)	1	4			**5**
9(c)	2	4			**6**
10(a)	1	2			**3**
10(b)	1	3			**4**
10(c)	2	2			**4**
11(a)	2	1	1		**4**
11(b)		1	5		**6**
12(a)	1	1			**2**
12(b)	1	4			**5**
13(a)	1				**1**
13(b)		1			**1**
13(c)			5	**1**	**6**
14(a)		1			**1**
14(b)			4		**4**
14(c)			4		**4**
15(a)	1				**1**
15(b)			3	**1**	**4**
16(a)	2				**2**
16(b)		2			**2**
16(c)			5		**5**
Totals	**31**	**39**	**27**		**100**

BLANK PAGE

BLANK PAGE