Rewarding Learning

Centre Number

71	

Candidate Number

ADVANCED
General Certificate of Education
2009

Physics

Assessment Unit A2 3A

assessing

Module 6: Particle Physics

[A2Y31]

WEDNESDAY 10 JUNE, MORNING

A2Y31

TIME

1 hour.

INSTRUCTIONS TO CANDIDATES

Write your Centre Number and Candidate Number in the spaces provided at the top of this page.
Answer **all five** questions.
Write your answers in the spaces provided in this question paper.

INFORMATION FOR CANDIDATES

The total mark for this paper is 50.
Quality of written communication will be assessed in question **5**.
Figures in brackets printed down the right-hand side of pages indicate the marks awarded to each question.
Your attention is drawn to the Data and Formulae Sheet which is inside this question paper.
You may use an electronic calculator.
Question **5** contributes to the synoptic assessment requirement of the Specification.
You are advised to spend about 40 minutes in answering questions **1–4**, and about 20 minutes in answering question **5**.

For Examiner's use only	
Question Number	Marks
1	
2	
3	
4	
5	
Total Marks	

4678

If you need the values of physical constants to answer any questions in this paper, they may be found on the Data and Formulae Sheet.

Examiner Only

Marks	Remark

Answer **all five** questions

1 The radius of a nucleus can be obtained using **Equation 1.1**.

$$r = r_0 A^{1/3}$$ **Equation 1.1**

(a) (i) State what each of the terms in **Equation 1.1** represents.

r_0 = ______________________________ [1]

A = ______________________________ [1]

(ii) An isotope of the element beryllium (Be) has 4 protons and 5 neutrons.
Electron diffraction experiments have revealed that this isotope has a nuclear radius of 2.50×10^{-15} m.
Use these data to calculate a value for r_0 in femtometre (fm).

r_0 = ______________ fm [3]

(iii) Using **Equation 1.1** and your value of r_0 from **(a)(ii)**, determine the **numerical** values of the gradient and the intercept of the graph of $\log_{10} r$ against $\log_{10} A$ shown in **Fig. 1.1**.

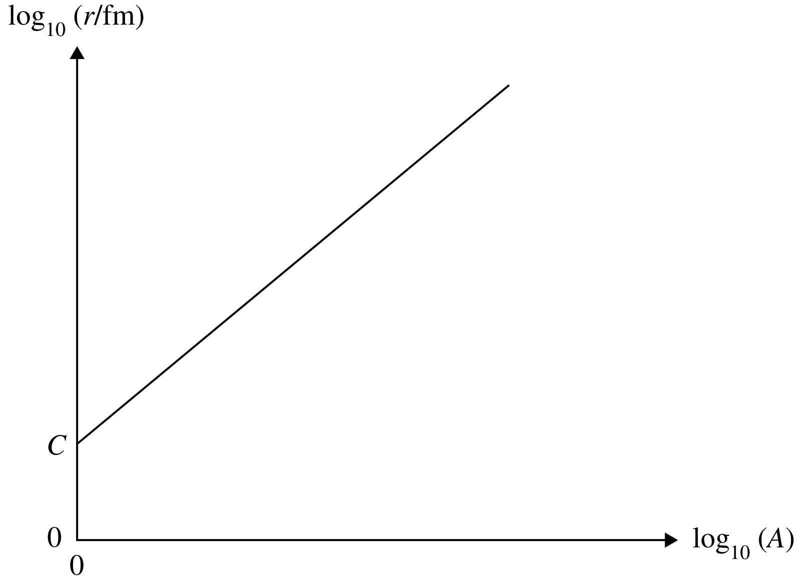

Fig. 1.1

Intercept C = ____________________

Gradient = ____________________ [3]

Examiner Only	
Marks	Remark

2 Nuclear fusion offers significant potential advantages as a future source of energy as compared to fossil fuels or fission.

Examiner Only	
Marks	Remark

(a) Outline one potential advantage offered by nuclear fusion.

____

____ [1]

(b) The advantages of nuclear fusion are only theoretical because practical fusion reactors are still in the development stage. One experimental reactor is the Joint European Torus (JET) reactor in the UK. In this facility a plasma is heated to a temperature of about 100 million kelvin.

(i) What is meant by the term **plasma** in this context?

____

____ [1]

(ii) Name the method of confinement used for the hot plasma in the JET fusion reactor and explain why the plasma confinement is necessary.

Method of confinement ______________________________________ [1]

Explanation ____

____ [1]

(iii) Why does the plasma need to have such a high temperature?

____

____ [1]

Examiner Only	
Marks	Remark

The JET reactor fuses deuterium and tritium, which are isotopes of hydrogen, in the reaction described by **Equation 2.1**.

$${}^{2}_{1}\text{H} + {}^{3}_{1}\text{H} \rightarrow {}^{4}_{2}\text{He} + {}^{1}_{0}\text{n} + Q$$ **Equation 2.1**

Table 2.1

Particle symbol	Particle name	Particle mass
${}^{2}_{1}\text{H}$	Deuterium	2.014102u
${}^{3}_{1}\text{H}$	Tritium	3.016049u
${}^{4}_{2}\text{He}$	Helium–4	4.002603u
${}^{1}_{0}\text{n}$	neutron	1.008665u

(iv) **Table 2.1** provides information on the particles involved in this fusion reaction. Use this information to find the quantity of energy Q released. Give your answer in MeV.

Q = ______________ MeV [4]

3 **(a)** Particle accelerators are used to investigate the structure of matter. They increase the speed of particles which are then made to collide with a suitable target particle. **Fig. 3.1** illustrates the main features of a linear accelerator (linac). In this linac an electron beam enters tube A and travels through the four tubular electrodes shown. Alternate electrodes are connected to the same terminal of the a.c. supply.

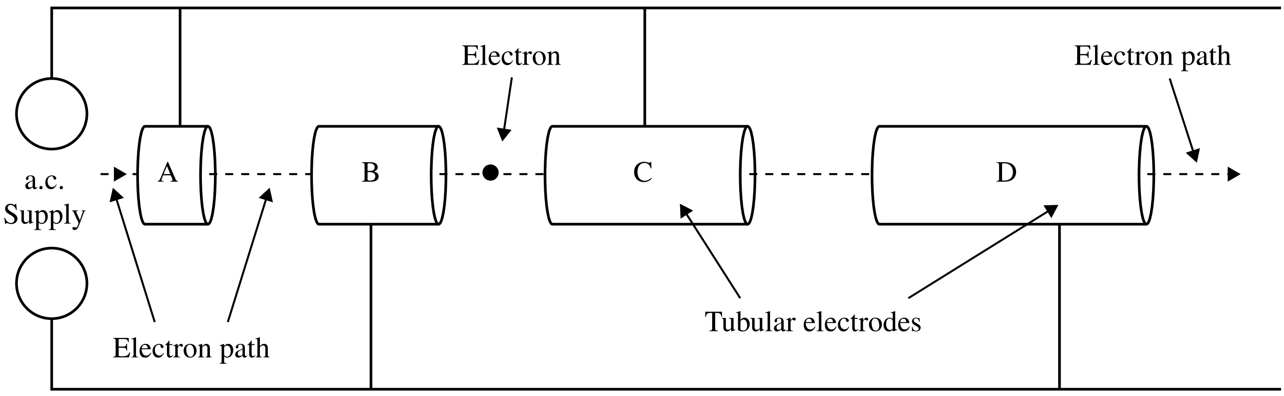

Fig. 3.1

Examiner Only	
Marks	Remark

(i) In the terminals (the circles) of the AC supply of **Fig. 3.1**, indicate the polarity at the instant shown in **Fig. 3.1** with the electron at the position shown between tube B and tube C.
Explain why you have indicated the polarity in this way.

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____

____

____ [2]

(ii) Why is it necessary for the length of the tubular electrodes to increase?

____

____ [1]

Examiner Only	
Marks	Remark

(b) What is the change in electron kinetic energy, in joules, in the time it takes for an electron leaving A to emerge from D? The a.c. supply to the electrodes is maintained at 200 kV.

Kinetic energy change = ________________ J [2]

(c) The Low Energy Antiproton Ring (LEAR) accelerator at CERN is able to produce anti-hydrogen atoms.

(i) **Fig. 3.2** is a simple representation of normal hydrogen. In the boxes on **Fig. 3.3**, name the corresponding particles in the anti-hydrogen representation.

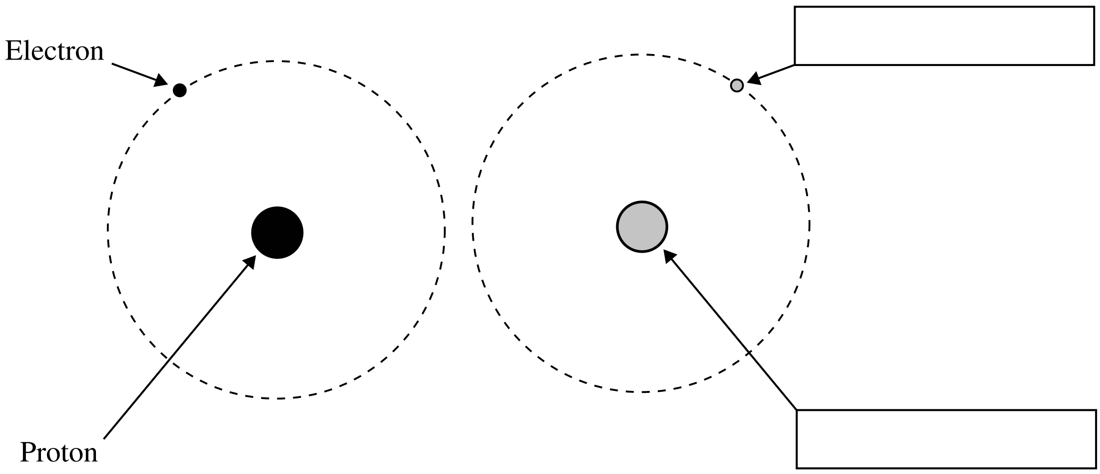

Fig. 3.2 **Fig. 3.3**

[1]

(ii) State one difference and one similarity between each corresponding pair of particles that make up the atoms in **Fig. 3.2** and **Fig. 3.3**.

____

____

____

____ [1]

Examiner Only	
Marks	Remark

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(Questions continue overleaf)

Examiner Only	
Marks	Remark

4 The electron, the neutron and the proton are the sub-atomic particles that exist in ordinary matter.

(a) The neutron and proton belong to a class of particle called baryons. What do all baryons have in common that no other class of particle does?

____

____ [1]

(b) Below are equations representing two decays and a suggested reaction involving particles.

$K^0 \rightarrow \pi^+ + \pi^-$ Decay 1

$\Lambda^0 \rightarrow p + \pi^-$ Decay 2

$K^- + p \rightarrow \pi^+ + \pi^-$ Reaction 1

The table of **Fig. 4.1** gives three quantum numbers for the particles in the equations.

Particle	**Charge**	**Baryon No.**	**Strangeness**
Kaon (K^0)	0	0	+1
Kaon minus (K^-)	–1	0	–1
pion-plus (π^+)	+1	0	0
pion-minus (π^-)	–1	0	0
Lambda (Λ^0)	0	+1	–1
Proton (p)	+1	+1	0

Fig. 4.1

(i) **(1)** Which of the two decays (if any) does **not** involve the strong interaction? Indicate your answer by placing a tick in the appropriate box.

Decay 1 ☐

Decay 2 ☐

Decays 1 and 2 ☐

Neither decay ☐ [1]

(2) Explain your answer.

____

____ [1]

(ii) Explain why Reaction 1 is not possible.

____

____ [1]

(iii) Complete the **Table 4.1** below showing the gauge boson and its associated force.

Table 4.1

Force	Gauge Boson
Strong	
	W^+ W^- Z^0
Gravitational	
	photon

[2]

Examiner Only	
Marks	Remark

Examiner Only	
Marks	Remark

5 In part (b)(i) of this question you should answer in continuous prose. You will be assessed on the quality of your written communication.

Four Carbon Allotropes

Diamond, graphite, Buckminsterfullerene (buckyballs) and carbon nanotubes are four different forms of carbon. Although they are all made from the same basic carbon atom, their structures and properties vary enormously.

(a) Diamond is the only transparent form of carbon.
Calculate the speed of light in diamond, given its refractive index is 2.42.

Speed = ______________ $m\,s^{-1}$ [2]

(b) The repetitive structure of the buckyball was revealed using a technique known as electron microscopy, which relies on the diffraction of an electron beam. **Fig. 5.1** illustrates the structure deduced.

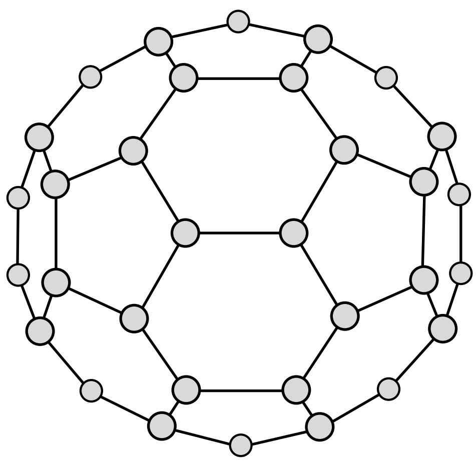

Fig. 5.1

Examiner Only	
Marks	Remark

(i) Explain why an electron diffraction pattern is achieved. Explain also why the electron wavelength must be similar to the separation of the carbon atoms in the buckyball.

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____ [3]

Quality of written communication [1]

(ii) The minimum separation of the carbon atoms is 0.10 nm. Calculate the speed of electrons if they are to have an associated wavelength of this magnitude.

Speed = _______________ $m\,s^{-1}$ [3]

(c) **Fig. 5.2** illustrates the structure and dimensions of a carbon nanotube of circular cross-section and diameter 1.2 nm and length 80 μm.

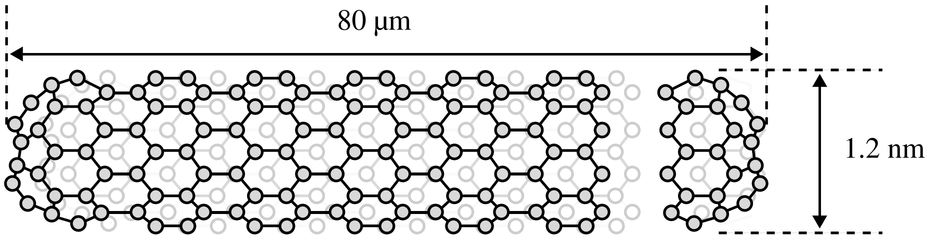

Fig. 5.2

(i) Given that the Young Modulus for a nanotube is 1.1×10^{12} Pa, calculate the tensile force that will cause a 0.15 μm increase in the length of this nanotube.

Force = ________________ N [3]

(ii) Calculate the strain energy in the nanotube when stretched by 0.15 μm.
Assume the nanotube obeys Hooke's law.

Energy = ________________ J [2]

Examiner Only	
Marks	Remark

(d) Graphite is a good electrical conductor under normal circumstances.
An experiment was performed to see if it obeys Ohm's law.
The data was collected using the circuit in **Fig. 5.3**.
The voltage–current characteristic of a graphite rod is given in **Fig. 5.4**.

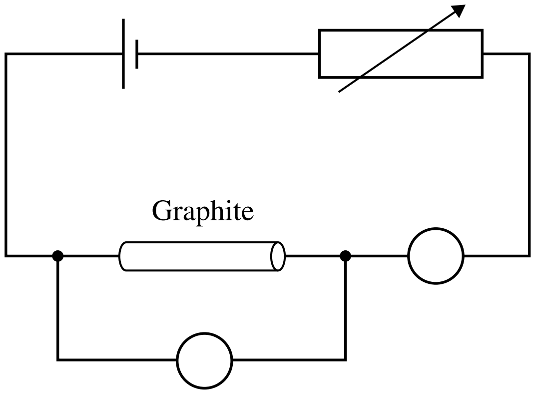

Fig. 5.3

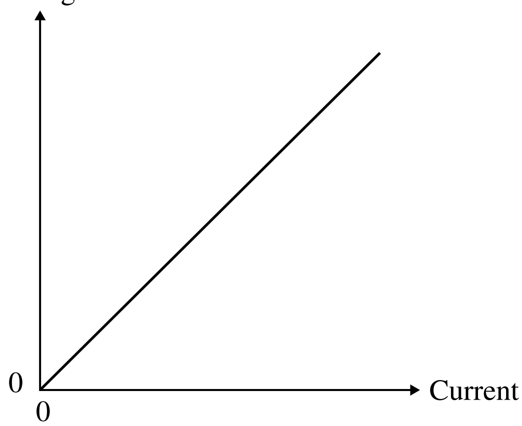

Fig. 5.4

(i) On the circuit diagram of **Fig. 5.3**, label the milliammeter mA and the millivoltmeter mV. [1]

(ii) Explain how **Fig. 5.4** confirms that graphite is an ohmic conductor.

____

____

____ [1]

(iii) Graphite has a resistivity of $7.8 \times 10^{-6}\,\Omega\,m$ and a charge carrier density of $1.1 \times 10^{29}\,m^{-3}$. Calculate the drift speed of the electrons in a sample of graphite 80 mm in length when there is a voltage of 26 mV across it.

Electron drift speed = ______________ $m\,s^{-1}$ [4]

Examiner Only	
Marks	Remark

GCE Physics (Advanced Subsidiary and Advanced)

Data and Formulae Sheet

Values of constants

speed of light in a vacuum	$c = 3.00 \times 10^{8}\ \mathrm{m\ s^{-1}}$
permeability of a vacuum	$\mu_0 = 4\pi \times 10^{-7}\ \mathrm{H\ m^{-1}}$
permittivity of a vacuum	$\varepsilon_0 = 8.85 \times 10^{-12}\ \mathrm{F\ m^{-1}}$ $\left(\dfrac{1}{4\pi\varepsilon_0} = 8.99 \times 10^{9}\ \mathrm{F^{-1}\ m}\right)$
elementary charge	$e = 1.60 \times 10^{-19}\ \mathrm{C}$
the Planck constant	$h = 6.63 \times 10^{-34}\ \mathrm{J\ s}$
unified atomic mass unit	$1\ \mathrm{u} = 1.66 \times 10^{-27}\ \mathrm{kg}$
mass of electron	$m_e = 9.11 \times 10^{-31}\ \mathrm{kg}$
mass of proton	$m_p = 1.67 \times 10^{-27}\ \mathrm{kg}$
molar gas constant	$R = 8.31\ \mathrm{J\ K^{-1}\ mol^{-1}}$
the Avogadro constant	$N_A = 6.02 \times 10^{23}\ \mathrm{mol^{-1}}$
the Boltzmann constant	$k = 1.38 \times 10^{-23}\ \mathrm{J\ K^{-1}}$
gravitational constant	$G = 6.67 \times 10^{-11}\ \mathrm{N\ m^{2}\ kg^{-2}}$
acceleration of free fall on the Earth's surface	$g = 9.81\ \mathrm{m\ s^{-2}}$
electron volt	$1\ \mathrm{eV} = 1.60 \times 10^{-19}\ \mathrm{J}$

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USEFUL FORMULAE

The following equations may be useful in answering some of the questions in the examination:

Mechanics

Momentum-impulse relation	$mv - mu = Ft$ for a constant force
Power	$P = Fv$
Conservation of energy	$\frac{1}{2}mv^2 - \frac{1}{2}mu^2 = Fs$ for a constant force

Simple harmonic motion

Displacement	$x = x_0 \cos \omega t$ or $x = x_0 \sin \omega t$
Velocity	$v = \pm\omega\sqrt{x_0{}^2 - x^2}$
Simple pendulum	$T = 2\pi\sqrt{l/g}$
Loaded helical spring	$T = 2\pi\sqrt{m/k}$

Medical physics

Sound intensity level/dB	$= 10\ \lg_{10}(I/I_0)$
Sound intensity difference/dB	$= 10\ \lg_{10}(I_2/I_1)$
Resolving power	$\sin\theta = \lambda/D$

Waves

Two-slit interference	$\lambda = ay/d$
Diffraction grating	$d \sin\theta = n\lambda$

Light

Lens formula	$1/u + 1/v = 1/f$

Stress and Strain

Hooke's law	$F = kx$
Strain energy	$E = \langle F \rangle x$ ($= \frac{1}{2}Fx = \frac{1}{2}kx^2$ if Hooke's law is obeyed)

Electricity

Potential divider	$V_{out} = R_1V_{in}/(R_1 + R_2)$

Thermal physics

Average kinetic energy of a molecule	$\frac{1}{2}m\langle c^2\rangle = \frac{3}{2}kT$
Kinetic theory	$pV = \frac{1}{3}Nm\langle c^2\rangle$

Capacitors

Capacitors in series	$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$
Capacitors in parallel	$C = C_1 + C_2 + C_3$
Time constant	$\tau = RC$

Electromagnetism

Magnetic flux density due to current in

(i) long straight solenoid	$B = \frac{\mu_0 NI}{l}$
(ii) long straight conductor	$B = \frac{\mu_0 I}{2\pi a}$

Alternating currents

A.c. generator	$E = E_0 \sin\omega t = BAN\omega \sin\omega t$

Particles and photons

Radioactive decay	$A = \lambda N$ $A = A_0 e^{-\lambda t}$
Half life	$t_{\frac{1}{2}} = 0.693/\lambda$
Photoelectric effect	$\frac{1}{2}mv^2_{max} = hf - hf_0$
de Broglie equation	$\lambda = h/p$

Particle Physics

Nuclear radius	$r = r_0A^{\frac{1}{3}}$