



Rewarding Learning

ADVANCED
General Certificate of Education
2022

Centre Number

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Candidate Number

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Physics

StemUp Model Solution

Assessment Unit A2 2
assessing

Fields, Capacitors and
Particle Physics



[APH21]

APH21

FRIDAY 10 JUNE, MORNING

TIME

2 hours.

INSTRUCTIONS TO CANDIDATES

Write your Centre Number and Candidate Number in the spaces provided at the top of this page.

You must answer the questions in the spaces provided.

Do not write outside the boxed area on each page or on blank pages.

Complete in black ink only. **Do not write with a gel pen.**

Answer **all nine** questions.

INFORMATION FOR CANDIDATES

The total mark for this paper is 100.

Quality of written communication will be assessed in question **7(a)**.

Figures in brackets printed down the right-hand side of pages indicate the marks awarded to each question or part question.

Your attention is drawn to the Data and Formulae Sheet which is inside this question paper.

You may use an electronic calculator.



- 1 **Fig. 1.1** shows a wire carrying a current of 1.4A into the plane of the page.

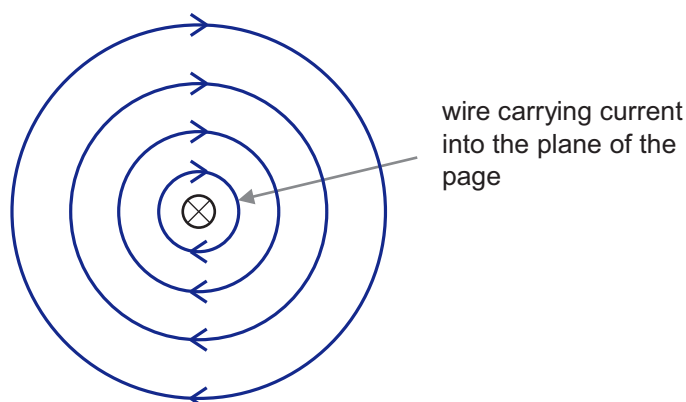


Fig. 1.1

- (a) (i) On **Fig. 1.1**, sketch the magnetic field that is produced around the wire due to the current. [3]
- (ii) The wire is placed between two magnetic poles as shown in **Fig. 1.2**. Draw an arrow to show the direction of the force on the current carrying wire produced by the two magnetic poles. [1]

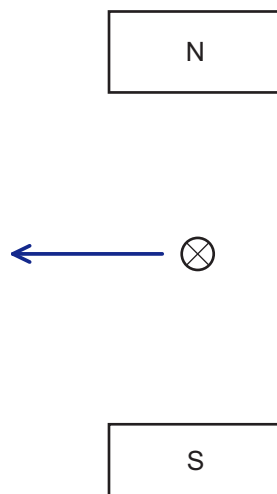


Fig. 1.2



- (b) Calculate the magnetic field strength due to the magnetic poles if the force on the wire is $5.6 \times 10^{-3} \text{ N}$ and the length of wire in the magnetic field is 3.0 cm.

$$F = BIl \quad \text{so} \quad B = F / Il$$

$$B = 5.6 \times 10^{-3} / (1.4 \times 0.030)$$

$$B = 0.133 \text{ T}$$

Magnetic field strength = 0.13 T

[3]

[Turn over]



- 2 **Fig. 2.1** shows a positively charged oil drop held stationary between two parallel horizontal plates X and Y. The plates are 0.025 m apart with a potential difference between them of 5.5 kV. The mass of the oil drop is 1.79×10^{-14} kg.

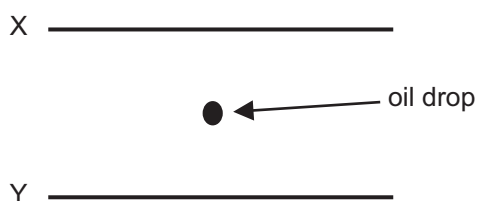


Fig. 2.1

- (a) Which plate is positively charged? Explain your answer.

Plate Y (the bottom plate) is positive. The weight of the drop acts downwards, so it must be balanced by an equal electric force acting upwards.

The drop is positive, so it must be repelled by the bottom plate and attracted to the top plate. Therefore Y is positive.

[4]



- (b) (i) Calculate the charge on the oil drop and the number of electrons that were removed from the oil drop when it was charged.

$$E = V / d = 5500 / 0.025 = 2.2 \times 10^5 \text{ V m}^{-1}$$

Stationary, so electric force = weight: $Eq = mg$

$$F = mg = 1.79 \times 10^{-14} \times 9.81 = 1.756 \times 10^{-13} \text{ N}$$

$$E = F / q \text{ so } q = F / E = 1.756 \times 10^{-13} / 2.2 \times 10^5$$

$$q = 7.98 \times 10^{-19} \text{ C}$$

$$n = q / e = 7.98 \times 10^{-19} / 1.6 \times 10^{-19} = 4.99$$

$n = 5$ electrons (whole number)

Charge on oil drop = 7.98×10^{-19} C

Number of electrons removed = 5 [6]

- (ii) Describe and explain what would happen to the oil drop if it gained an electron.

It moves down, towards plate Y. Its charge becomes less positive,

so the upward electric force is now less than the downward

weight. [3]



- 3 Four positive point charges of $2\text{ }\mu\text{C}$ are placed at the corners of a square of sides 0.04 m . Another positive point charge of $3\text{ }\mu\text{C}$ is placed in the centre of the square as shown in **Fig. 3.1**.

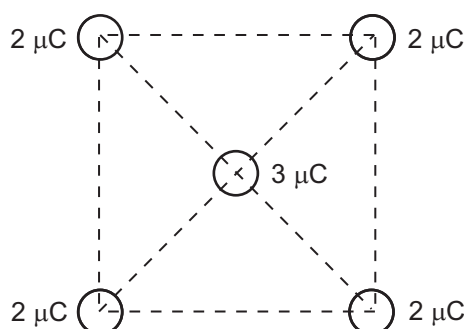


Fig. 3.1

- (a) State the magnitude of the resultant force on the $3\text{ }\mu\text{C}$ charge and explain your answer.

Zero. Each pair of opposite $2\text{ }\mu\text{C}$ charges is the same distance away, so they exert equal and opposite forces which cancel.

[2]

- (b) One of the $2\text{ }\mu\text{C}$ charges is removed as shown in **Fig. 3.2**.

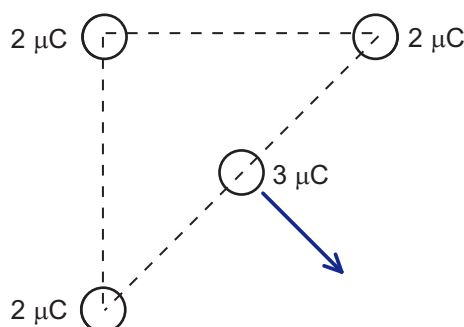


Fig. 3.2

- (i) Draw an arrow on **Fig. 3.2** to show the direction of the resultant force on the $3\text{ }\mu\text{C}$ charge.

[1]



(ii) Calculate the resultant force acting on the $3\mu\text{C}$ charge.

*The forces from the top right and bottom left charges cancel,
so the resultant is due to the top left charge only.*

$$r = \frac{1}{2} \times \sqrt{(0.04^2 + 0.04^2)} = 2.83 \times 10^{-2} \text{ m}$$

$$r^2 = 8 \times 10^{-4} \text{ m}^2$$

$$F = kq_1q_2 / r^2$$

$$F = 8.99 \times 10^9 \times 2 \times 10^{-6} \times 3 \times 10^{-6} / 8 \times 10^{-4}$$

$$F = 67.4 \text{ N (down and to the right)}$$

$$\text{Force} = \underline{67.4} \text{ N}$$

[5]

[Turn over]



- 4 (a) State Kepler's third law of planetary motion.

The square of the period of the orbit is proportional to the cube of the radius of the orbit ($T^2 \propto r^3$).

[2]

- (b) Two of Jupiter's natural satellites are Io and Europa. Io's orbit has a radius of 4.22×10^8 m and a period of 1.53×10^5 s. Europa's orbit has a radius of 6.71×10^8 m.

- (i) Calculate the period of Europa's orbit.

$$T_1^2 / r_1^3 = T_2^2 / r_2^3$$

$$T_2^2 = T_1^2 \times (r_2 / r_1)^3$$

$$T_2^2 = (1.53 \times 10^5)^2 \times (6.71 \times 10^8 / 4.22 \times 10^8)^3$$

$$T_2^2 = 9.41 \times 10^{10} \text{ s}^2$$

$$T_2 = 3.07 \times 10^5 \text{ s}$$

Period = 3.07×10^5 s

[4]



- (ii) There is a point between Jupiter and Europa where the gravitational field strength is zero. This point is at a distance of 6.68×10^8 m from the centre of Jupiter. The mass of Jupiter is 1.90×10^{27} kg. Calculate the mass of Europa.

At the null point the field strengths are equal:

$$GM_1 / r_1^2 = GM_2 / r_2^2$$

$$r_2 = 6.71 \times 10^8 - 6.68 \times 10^8 = 3 \times 10^6 \text{ m (from Europa)}$$

$$M / (3 \times 10^6)^2 = 1.90 \times 10^{27} / (6.68 \times 10^8)^2$$

$$M = 1.90 \times 10^{27} \times (3 \times 10^6)^2 / (6.68 \times 10^8)^2$$

$$M = 3.83 \times 10^{22} \text{ kg}$$

$$\text{Mass} = \underline{3.83 \times 10^{22}} \text{ kg}$$

[3]

[Turn over]



- 5 (a) An object with charge q moves through a magnetic field and follows a circular path of radius R .

- (i) If the magnetic field strength is B , show that the momentum p of the object is given by **Equation 5.1**.

$$p = qBR \quad \text{Equation 5.1}$$

The magnetic force provides the centripetal force: $F_m = F_c$

$$Bqv = mv^2 / R$$

$$\text{Dividing by } v: BqR = mv$$

$$\text{Momentum } p = mv, \text{ so } p = qBR$$

[3]

- (ii) Cosmic rays are sub-atomic particles arriving from outer space. Most cosmic rays are protons travelling close to the speed of light. The magnetic field strength of our galaxy is 1×10^{-10} T.

If the momentum of the proton is less than a critical value, it drifts in circles within the galaxy, but if the momentum exceeds this critical value, the proton will escape the galaxy.

If the radius of the galaxy is 5×10^{21} m, calculate the critical value of the momentum of the proton.

$$p = qBR$$

$$p = 1.6 \times 10^{-19} \times 1 \times 10^{-10} \times 5 \times 10^{21}$$

$$p = 8 \times 10^{-8} \text{ kg m s}^{-1}$$

$$\text{Momentum} = \underline{8 \times 10^{-8}} \text{ kg m s}^{-1}$$

[2]



- (b) Explain why the speed of a proton could not be calculated correctly using the momentum calculated in part (a)(ii) and the mass of a proton from the data sheet.

The protons travel close to the speed of light, so relativistic

effects apply: their mass increases above the rest mass given on

the data sheet.

[2]

[Turn over]



6 (a) A capacitor network is shown in Fig. 6.1.

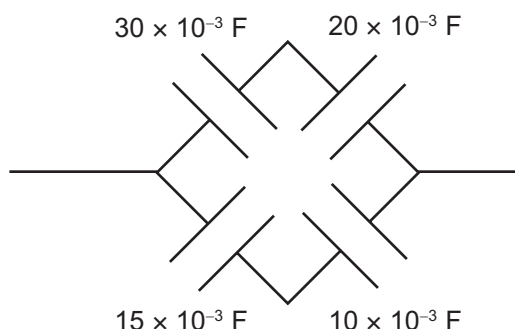


Fig. 6.1

Show that the total capacitance of the network is $18 \times 10^{-3} \text{ F}$.

Top branch, in series: $1/C = 1/(30 \times 10^{-3}) + 1/(20 \times 10^{-3})$

$$1/C = 33.3 + 50 = 83.3 \text{ F}^{-1} \quad \text{so} \quad C = 12 \times 10^{-3} \text{ F}$$

Bottom branch, in series: $1/C = 1/(15 \times 10^{-3}) + 1/(10 \times 10^{-3})$

$$1/C = 66.7 + 100 = 166.7 \text{ F}^{-1} \quad \text{so} \quad C = 6 \times 10^{-3} \text{ F}$$

The two branches are in parallel, so add:

$$C_T = 12 \times 10^{-3} + 6 \times 10^{-3}$$

$$C_T = 18 \times 10^{-3} \text{ F}$$

[4]



(b) The capacitor network is charged by connecting it to a 12V supply.

(i) Calculate the charge stored in the network.

$$Q = CV = 18 \times 10^{-3} \times 12$$

$$Q = 0.216 \text{ C}$$

$$\text{Charge} = \underline{0.22} \text{ C}$$

[3]

(ii) Calculate the energy stored on the network.

$$E = \frac{1}{2} CV^2$$

$$E = \frac{1}{2} \times 18 \times 10^{-3} \times 12^2$$

$$E = 1.296 \text{ J}$$

$$\text{Energy stored} = \underline{1.3} \text{ J}$$

[3]

[Turn over]



- (c) The capacitor network is then disconnected from the 12 V supply and discharged through the network of resistors shown in **Fig. 6.2**.

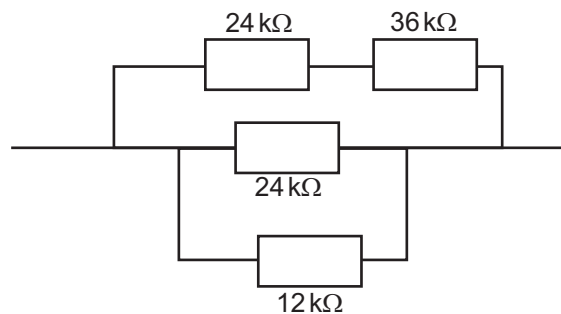


Fig. 6.2

- (i) Calculate the initial discharge current.

Top branch, in series: $R = 24 + 36 = 60\text{ k}\Omega$

The three branches are in parallel:

$$1/R_T = 1/60 + 1/24 + 1/12 = 0.142\text{ k}\Omega^{-1}$$

$$R_T = 7.06\text{ k}\Omega \approx 7\text{ k}\Omega$$

$$I = V / R = 12 / 7.06 \times 10^3$$

$$I = 1.7 \times 10^{-3}\text{ A}$$

Current = 1.7×10^{-3} A

[4]



- (ii) Use the axes of **Fig. 6.3** to sketch a graph to show how the discharge current will vary with time.

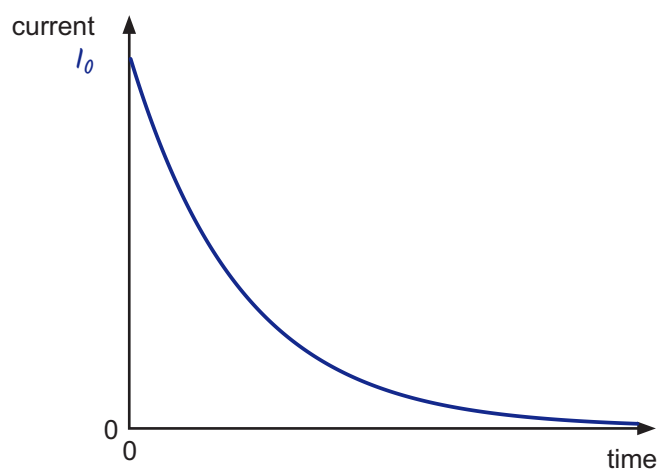


Fig. 6.3

[2]

[Turn over]



7 Quality of written communication will be assessed in part (a) of this question.

In an electric guitar, the energy of the vibrations of the steel guitar string are converted into an electrical signal by a device called a pick-up. A picture and a simplified diagram of a pick-up are shown in **Fig. 7.1(a)** and **(b)**.

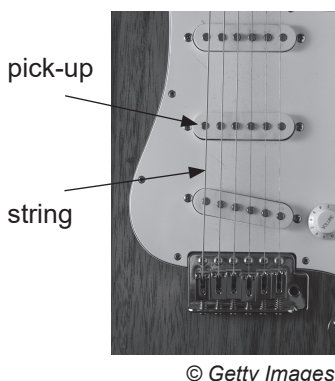


Fig. 7.1(a)

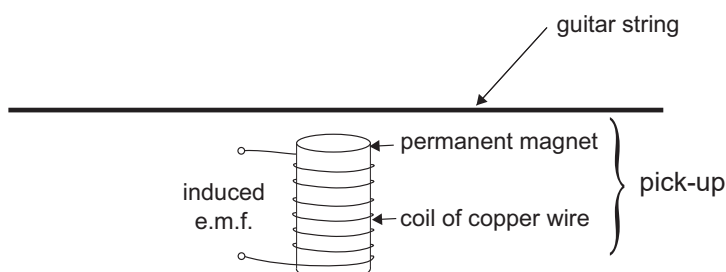


Fig. 7.1(b)

- (a) Explain how, when the string vibrates in a direction perpendicular to the plane of the page, it causes an e.m.f. to be induced across the coil of wire.

State Faraday's law and use it to explain how plucking the string with greater force increases the e.m.f.

The vibrating string oscillates through the fixed magnetic field of the magnet, so a changing current is induced in the string.

This sets up a changing magnetic field around the string, which interacts with the copper coil, so an e.m.f. is induced across the coil.

Faraday's law: the induced e.m.f. is proportional to the rate of change of magnetic flux linkage.

Plucking harder gives a greater amplitude, so the string moves faster: the rate of change of flux linkage increases, so the e.m.f. increases.

[6]



- (b) (i) The length of a guitar string is 0.73 m and it is plucked at the centre, setting up a standing wave in the first mode of vibration. Draw the standing wave on the string shown in Fig. 7.2.

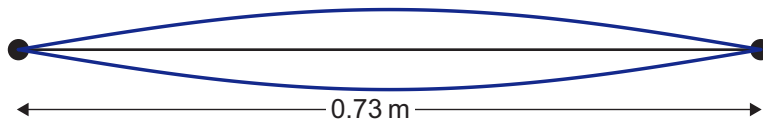


Fig. 7.2

[1]

- (ii) The speed of the wave is 286 m s^{-1} . Calculate the frequency of the note produced by the string.

$$\text{First mode: } L = \lambda / 2, \text{ so } \lambda = 2 \times 0.73 = 1.46 \text{ m}$$

$$v = f\lambda \text{ so } f = v / \lambda$$

$$f = 286 / 1.46$$

$$f = 196 \text{ Hz}$$

Frequency 196 Hz

[3]

- (iii) State how, and explain why, the frequency changes when the length of the string that vibrates is effectively shortened by holding it down along its length.

The frequency increases. The wave speed stays constant (same
string and tension), but the shorter length means a shorter
wavelength, so $f = v/\lambda$ increases.

[3]

[Turn over]



8 Fig. 8.1 shows how the output e.m.f. E of an a.c. generator varies with time.

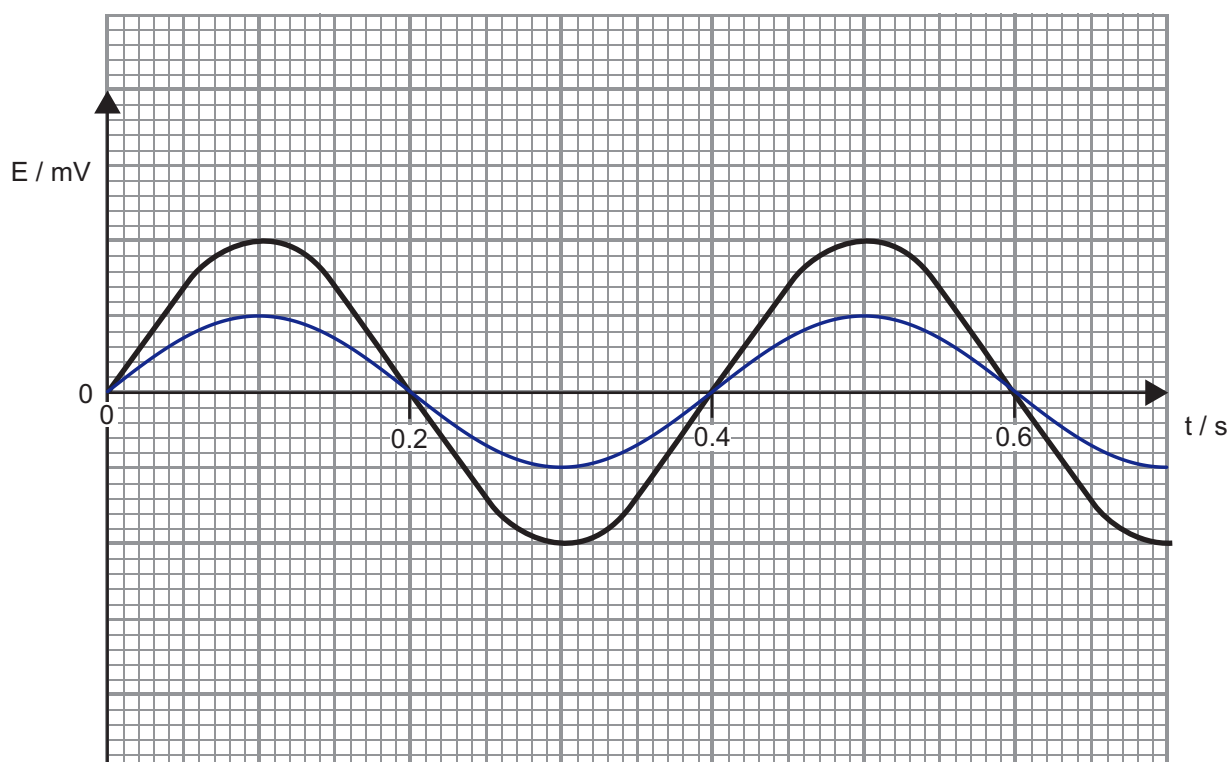


Fig. 8.1

- (a) Use data from Fig. 8.1 to determine the value of the constant ω in Equation 8.1. State the unit of ω .

$$E = BAN\omega \sin\omega t \quad \text{Equation 8.1}$$

From Fig. 8.1, period $T = 0.4 \text{ s}$

$$\omega = 2\pi / T$$

$$\omega = 2\pi / 0.4 = 15.7$$

$$\omega = \underline{15.7}$$

$$\text{Unit of } \omega = \underline{\text{rad s}^{-1}}$$

[4]



- (b) The coil in a second a.c. generator has the same area as the first and twice the number of turns. It is rotated in a magnetic field of one quarter of the strength of the first generator. The coils in both generators are rotated at the same speed.

On **Fig. 8.1**, draw a line to show the output of the second generator. [2]

- (c) On the axis drawn in **Fig. 8.2**, sketch a graph to show how the e.m.f. E generated would change over time t if a generator gradually slowed down.

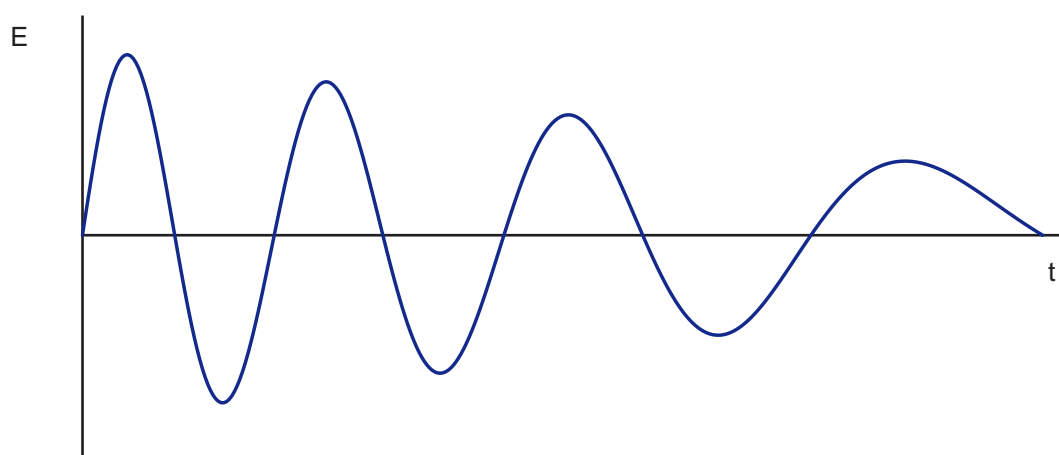


Fig. 8.2

[2]

[Turn over]



- 9 Particle physicists use the unit GeV/c^2 as an appropriate unit of mass, where c is the speed of light.

- (a) (i) Use the base units of GeV and the base units for c , the speed of light, to show that the unit GeV/c^2 is equivalent to the unit of mass, the kilogram.

GeV is a unit of energy: $1 \text{ J} = 1 \text{ N m} = 1 \text{ kg m s}^{-2} \times \text{m}$

so the base units of GeV are $\text{kg m}^2 \text{ s}^{-2}$

c is a speed, units m s^{-1} , so c^2 has units $\text{m}^2 \text{ s}^{-2}$

GeV/c^2 : $\text{kg m}^2 \text{ s}^{-2} \div \text{m}^2 \text{ s}^{-2} = \text{kg}$

so GeV/c^2 is equivalent to the kilogram, a unit of mass

[3]

- (ii) A kaon K^+ is a positively charged meson with a rest mass of $0.494 \text{ GeV}/c^2$. Calculate the rest mass of a kaon in kg.

$0.494 \text{ GeV} = 0.494 \times 10^9 \text{ eV}$ ($1 \text{ GeV} = 1 \times 10^9 \text{ eV}$)

$E = 0.494 \times 10^9 \times 1.60 \times 10^{-19} = 7.9 \times 10^{-11} \text{ J}$

$E = mc^2$ so $m = E / c^2$

$m = 7.904 \times 10^{-11} / (3.00 \times 10^8)^2$

$m = 8.78 \times 10^{-28} \text{ kg}$

Rest mass = 8.78×10^{-28} kg

[4]



- (b) (i) In particle physics, particles are classified according to their composition. Describe the composition of a kaon.

A kaon is a meson, which is a hadron composed of quarks: it is made of one quark and one antiquark (K^+ is an up quark and an anti-strange quark).

[2]

- (ii) The four fundamental forces are shown below. Tick the box beside each force that is experienced by the K^+ particle.

Gravitational force



Electromagnetic force



Strong nuclear force



Weak nuclear force



[2]

[Turn over]



- (iii) A moving kaon decays at point X into two particles with the same magnitude of charge and velocity.

Fig. 9.1 shows the paths followed by the two particles due to a magnetic field which acts perpendicular to the plane of the page.

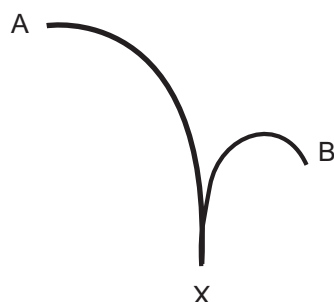


Fig. 9.1

From **Fig. 9.1**, what conclusions can be made about the two particles which follow paths A and B?

They curve in opposite directions, so they have opposite charges.

A has a larger radius and $r = mv/Bq$, so they have different

masses: A has a greater mass than B.

[3]



- (c) (i) Explain what is meant by annihilation.

*A particle and its antiparticle collide and their mass is converted
into energy, as electromagnetic radiation (photons).*

[2]

- (ii) Calculate the frequency of the electromagnetic radiation produced when an electron and positron annihilate.

Two photons are produced, each with energy $E = mc^2$

$$m = 9.11 \times 10^{-31} \text{ kg}$$

$$E = 9.11 \times 10^{-31} \times (3.00 \times 10^8)^2 = 8.2 \times 10^{-14} \text{ J}$$

$$E = hf \quad \text{so} \quad f = E / h = 8.2 \times 10^{-14} / 6.63 \times 10^{-34}$$

$$f = 1.24 \times 10^{20} \text{ Hz}$$

Frequency = 1.24×10^{20} Hz

[3]

THIS IS THE END OF THE QUESTION PAPER



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Question Number	Marks
1	
2	
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Total Marks	
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Examiner Number

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Rewarding Learning

ADVANCED
General Certificate of Education

Physics

Assessment Units A2 1 and A2 2

[APH11/APH21]

DATA AND FORMULAE SHEET

Data and Formulae Sheet for A2 1 and A2 2

Values of constants

speed of light in a vacuum	$c = 3.00 \times 10^8 \text{ m s}^{-1}$
permittivity of a vacuum	$\epsilon_0 = 8.85 \times 10^{-12} \text{ F m}^{-1}$ $\left(\frac{1}{4\pi\epsilon_0} = 8.99 \times 10^9 \text{ F}^{-1} \text{ m} \right)$
elementary charge	$e = 1.60 \times 10^{-19} \text{ C}$
the Planck constant	$h = 6.63 \times 10^{-34} \text{ J s}$
(unified) atomic mass unit	$1 \text{ u} = 1.66 \times 10^{-27} \text{ kg}$
mass of electron	$m_e = 9.11 \times 10^{-31} \text{ kg}$
mass of proton	$m_p = 1.67 \times 10^{-27} \text{ kg}$
molar gas constant	$R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$
the Avogadro constant	$N_A = 6.02 \times 10^{23} \text{ mol}^{-1}$
the Boltzmann constant	$k = 1.38 \times 10^{-23} \text{ J K}^{-1}$
gravitational constant	$G = 6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$
acceleration of free fall on the Earth's surface	$g = 9.81 \text{ m s}^{-2}$
electron volt	$1 \text{ eV} = 1.60 \times 10^{-19} \text{ J}$
the Hubble constant	$H_0 \approx 2.4 \times 10^{-18} \text{ s}^{-1}$

Useful formulae

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

Mechanics

conservation of energy $\frac{1}{2}mv^2 - \frac{1}{2}mu^2 = Fs$
for a constant force

Hooke's Law $F = kx$ (spring constant k)
strain energy $E = \frac{1}{2}Fx = \frac{1}{2}kx^2$

Uniform circular motion

centripetal Force $F = \frac{mv^2}{r}$

Simple harmonic motion

displacement $x = A \cos \omega t$
simple pendulum $T = 2\pi \sqrt{\frac{l}{g}}$
loaded spiral spring $T = 2\pi \sqrt{\frac{m}{k}}$

Waves

two-source interference $\lambda = \frac{ay}{d}$
diffraction grating $d \sin \theta = n \lambda$

Thermal physics

average kinetic energy of
a molecule

$$\frac{1}{2} m \langle c^2 \rangle = \frac{3}{2} kT$$

kinetic theory

$$pV = \frac{1}{3} Nm \langle c^2 \rangle$$

thermal energy

$$Q = mc\Delta\theta$$

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

$$\tau = RC$$

capacitor discharge

$$Q = Q_0 e^{\frac{-t}{CR}}$$

$$\text{or } V = V_0 e^{\frac{-t}{CR}}$$

$$\text{or } I = I_0 e^{\frac{-t}{CR}}$$

Light

lens formula

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$$

Electricity

terminal potential difference

$$V = E - Ir$$

(e.m.f., E ; Internal Resistance, r)

potential divider

$$V_{\text{out}} = \frac{R_1 V_{\text{in}}}{R_1 + R_2}$$

a.c. generator

$$E = BAN\omega \sin\omega t$$

Nuclear Physics

nuclear radius

$$r = r_0 A^{\frac{1}{3}}$$

radioactive decay

$$A = -\lambda N, \quad A = A_0 e^{-\lambda t}$$

half-life

$$t_{\frac{1}{2}} = \frac{0.693}{\lambda}$$

Particles and photons

Einstein's equation

$$\frac{1}{2} m v_{\max}^2 = hf - hf_0$$

de Broglie equation

$$\lambda = \frac{h}{p}$$

Astronomy

red shift

$$z = \frac{\Delta \lambda}{\lambda}$$

recession speed

$$z = \frac{v}{c}$$

Hubble's law

$$v = H_0 d$$

