Surname		Other Names	
Centre Number		Candidate Number	
Candidate Signature			

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General Certificate of Education
June 2006
Advanced Level Examination

PHYSICS (SPECIFICATION A) **PA10**
Unit 10 The Synoptic Unit

Thursday 22 June 2006 1.30 pm to 3.30 pm

For this paper you must have:
- a calculator
- a pencil and a ruler

Time allowed: 2 hours

Instructions
- Use blue or black ink or ball-point pen.
- Fill in the boxes at the top of this page.
- Answer **all** questions.
- Answer the questions in the spaces provided.
- Show all your working.
- Do all rough work in this book. Cross through any work you do not want marked.

Information
- The maximum mark for this paper is 80. This includes up to 2 marks for the Quality of Written Communication.
- The marks for questions are shown in brackets.
- A *Data Sheet* is provided on pages 3 and 4. You may wish to detach this perforated sheet at the start of the examination.
- You are expected to use a calculator where appropriate.
- You are reminded of the need for good English and clear presentation in your answers. Questions 1(b) and 2(b) should be answered in continuous prose. Quality of Written Communication will be assessed in these answers.

For Examiner's Use			
Number	Mark	Number	Mark
1			
2			
3			
4			
5			
6			
7			
8			
Total (Column 1) →			
Total (Column 2) →			
Quality of Written Communication			
TOTAL			
Examiner's Initials			

Data Sheet

- A perforated *Data Sheet* is provided as pages 3 and 4 of this question paper.
- This sheet may be useful for answering some of the questions in the examination.
- You may wish to detach this sheet before you begin work.

Fundamental constants and values

Quantity	Symbol	Value	Units
speed of light in vacuo	c	3.00×10^{8}	$\mathrm{m\ s^{-1}}$
permeability of free space	μ_0	$4\pi \times 10^{-7}$	$\mathrm{H\ m^{-1}}$
permittivity of free space	ε_0	8.85×10^{-12}	$\mathrm{F\ m^{-1}}$
charge of electron	e	1.60×10^{-19}	C
the Planck constant	h	6.63×10^{-34}	J s
gravitational constant	G	6.67×10^{-11}	$\mathrm{N\ m^2\ kg^{-2}}$
the Avogadro constant	N_A	6.02×10^{23}	$\mathrm{mol^{-1}}$
molar gas constant	R	8.31	$\mathrm{J\ K^{-1}\ mol^{-1}}$
the Boltzmann constant	k	1.38×10^{-23}	$\mathrm{J\ K^{-1}}$
the Stefan constant	σ	5.67×10^{-8}	$\mathrm{W\ m^{-2}\ K^{-4}}$
the Wien constant	α	2.90×10^{-3}	m K
electron rest mass (equivalent to 5.5×10^{-4}u)	m_e	9.11×10^{-31}	kg
electron charge/mass ratio	e/m_e	1.76×10^{11}	$\mathrm{C\ kg^{-1}}$
proton rest mass (equivalent to 1.00728u)	m_p	1.67×10^{-27}	kg
proton charge/mass ratio	e/m_p	9.58×10^{7}	$\mathrm{C\ kg^{-1}}$
neutron rest mass (equivalent to 1.00867u)	m_n	1.67×10^{-27}	kg
gravitational field strength	g	9.81	$\mathrm{N\ kg^{-1}}$
acceleration due to gravity	g	9.81	$\mathrm{m\ s^{-2}}$
atomic mass unit (1u is equivalent to 931.3 MeV)	u	1.661×10^{-27}	kg

Fundamental particles

Class	Name	Symbol	Rest energy /MeV
photon	photon	γ	0
lepton	neutrino	ν_e	0
		ν_μ	0
	electron	$e^{\pm}$	0.510999
	muon	$\mu^{\pm}$	105.659
mesons	pion	$\pi^{\pm}$	139.576
		π^{0}	134.972
	kaon	$K^{\pm}$	493.821
		K^{0}	497.762
baryons	proton	p	938.257
	neutron	n	939.551

Properties of quarks

Type	Charge	Baryon number	Strangeness
u	$+\frac{2}{3}$	$+\frac{1}{3}$	0
d	$-\frac{1}{3}$	$+\frac{1}{3}$	0
s	$-\frac{1}{3}$	$+\frac{1}{3}$	–1

Geometrical equations

arc length $= r\theta$

circumference of circle $= 2\pi r$

area of circle $= \pi r^2$

area of cylinder $= 2\pi rh$

volume of cylinder $= \pi r^2 h$

area of sphere $= 4\pi r^2$

volume of sphere $= \frac{4}{3}\pi r^3$

Mechanics and Applied Physics

$v = u + at$

$s = \left(\frac{u+v}{2}\right)t$

$s = ut + \frac{at^2}{2}$

$v^2 = u^2 + 2as$

$F = \frac{\Delta(mv)}{\Delta t}$

$P = Fv$

$efficiency = \frac{power\ output}{power\ input}$

$\omega = \frac{v}{r} = 2\pi f$

$a = \frac{v^2}{r} = r\omega^2$

$I = \sum mr^2$

$E_k = \frac{1}{2} I\omega^2$

$\omega_2 = \omega_1 + \alpha t$

$\theta = \omega_1 t + \frac{1}{2}\alpha t^2$

$\omega_2^2 = \omega_1^2 + 2\alpha\theta$

$\theta = \frac{1}{2}(\omega_1 + \omega_2)t$

$T = I\alpha$

angular momentum $= I\omega$

$W = T\theta$

$P = T\omega$

angular impulse = change of angular momentum $= Tt$

$\Delta Q = \Delta U + \Delta W$

$\Delta W = p\Delta V$

$pV^{\gamma} =$ constant

work done per cycle = area of loop

input power = calorific value × fuel flow rate

indicated power as (area of p – V loop) × (no. of cycles/s) × (no. of cylinders)

friction power = indicated power – brake power

$efficiency = \frac{W}{Q_{in}} = \frac{Q_{in} - Q_{out}}{Q_{in}}$

maximum possible efficiency $= \frac{T_H - T_C}{T_H}$

Fields, Waves, Quantum Phenomena

$g = \frac{F}{m}$

$g = -\frac{GM}{r^2}$

$g = -\frac{\Delta V}{\Delta x}$

$V = -\frac{GM}{r}$

$a = -(2\pi f)^2 x$

$v = \pm 2\pi f\sqrt{A^2 - x^2}$

$x = A\cos 2\pi ft$

$T = 2\pi\sqrt{\frac{m}{k}}$

$T = 2\pi\sqrt{\frac{l}{g}}$

$\lambda = \frac{\omega s}{D}$

$d\sin\theta = n\lambda$

$\theta \approx \frac{\lambda}{D}$

${}_1n_2 = \frac{\sin\theta_1}{\sin\theta_2} = \frac{c_1}{c_2}$

${}_1n_2 = \frac{n_2}{n_1}$

$\sin\theta_c = \frac{1}{n}$

$E = hf$

$hf = \phi + E_k$

$hf = E_1 - E_2$

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

$c = \frac{1}{\sqrt{\mu_0\varepsilon_0}}$

Electricity

$\epsilon = \frac{E}{Q}$

$\epsilon = I(R + r)$

$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots$

$R_T = R_1 + R_2 + R_3 + \cdots$

$P = I^2 R$

$E = \frac{F}{Q} = \frac{V}{d}$

$E = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}$

$E = \frac{1}{2}QV$

$F = BIl$

$F = BQv$

$Q = Q_0 e^{-t/RC}$

$\Phi = BA$

Turn over ▶

$$\textit{magnitude of induced e.m.f.} = N\frac{\Delta\Phi}{\Delta t}$$

$$I_{\text{rms}} = \frac{I_0}{\sqrt{2}}$$

$$V_{\text{rms}} = \frac{V_0}{\sqrt{2}}$$

Mechanical and Thermal Properties

$$\textit{the Young modulus} = \frac{\textit{tensile stress}}{\textit{tensile strain}} = \frac{F}{A}\frac{l}{e}$$

$$\textit{energy stored} = \tfrac{1}{2}Fe$$

$$\Delta Q = mc\,\Delta\theta$$

$$\Delta Q = ml$$

$$pV = \tfrac{1}{3}Nm\overline{c^2}$$

$$\tfrac{1}{2}m\overline{c^2} = \tfrac{3}{2}kT = \frac{3RT}{2N_A}$$

Nuclear Physics and Turning Points in Physics

$$\textit{force} = \frac{eV_p}{d}$$

$$\textit{force} = Bev$$

$$\textit{radius of curvature} = \frac{mv}{Be}$$

$$\frac{eV}{d} = mg$$

$$\textit{work done} = eV$$

$$F = 6\pi\eta rv$$

$$I = k\frac{I_0}{x^2}$$

$$\frac{\Delta N}{\Delta t} = -\lambda N$$

$$\lambda = \frac{h}{\sqrt{2meV}}$$

$$N = N_0 e^{-\lambda t}$$

$$T_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$$

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

$$E = mc^2 = \frac{m_0c^2}{\left(1-\frac{v^2}{c^2}\right)^{\frac{1}{2}}}$$

$$l = l_0\left(1-\frac{v^2}{c^2}\right)^{\frac{1}{2}}$$

$$t = \frac{t_0}{\left(1-\frac{v^2}{c^2}\right)^{\frac{1}{2}}}$$

Astrophysics and Medical Physics

Body	*Mass*/kg	*Mean radius*/m
Sun	2.00×10^{30}	7.00×10^{8}
Earth	6.00×10^{24}	6.40×10^{6}

1 astronomical unit = 1.50×10^{11} m

1 parsec = 206265 AU = 3.08×10^{16} m = 3.26 ly

1 light year = 9.45×10^{15} m

Hubble constant (H) = 65 km s^{-1} Mpc^{-1}

$$M = \frac{\text{angle subtended by image at eye}}{\text{angle subtended by object at unaided eye}}$$

$$M = \frac{f_o}{f_e}$$

$$m - M = 5\log\frac{d}{10}$$

$\lambda_{\max}T$ = constant = 0.0029 m K

$$v = Hd$$

$$P = \sigma AT^4$$

$$\frac{\Delta f}{f} = \frac{v}{c}$$

$$\frac{\Delta\lambda}{\lambda} = -\frac{v}{c}$$

$$R_s \approx \frac{2GM}{c^2}$$

Medical Physics

$$\textit{power} = \frac{1}{f}$$

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f} \quad \text{and} \quad m = \frac{v}{u}$$

$$\textit{intensity level} = 10\log\frac{I}{I_0}$$

$$I = I_0 e^{-\mu x}$$

$$\mu_m = \frac{\mu}{\rho}$$

Electronics

Resistors

Preferred values for resistors (E24)
Series: 1.0 1.1 1.2 1.3 1.5 1.6 1.8 2.0 2.2 2.4 2.7 3.0 3.3 3.6 3.9 4.3 4.7 5.1 5.6 6.2 6.8 7.5 8.2 9.1 ohms
and multiples that are ten times greater

$$Z = \frac{V_{\text{rms}}}{I_{\text{rms}}}$$

$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \cdots$$

$$C_T = C_1 + C_2 + C_3 + \cdots$$

$$X_C = \frac{1}{2\pi fC}$$

Alternating Currents

$$f = \frac{1}{T}$$

Operational amplifier

$G = \dfrac{V_{\text{out}}}{V_{\text{in}}}$ voltage gain

$G = -\dfrac{R_f}{R_1}$ inverting

$G = 1 + \dfrac{R_f}{R_1}$ non-inverting

$V_{\text{out}} = -R_f\left(\dfrac{V_1}{R_1} + \dfrac{V_2}{R_2} + \dfrac{V_3}{R_3}\right)$ summing

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Answer **all** questions.

1 (a) (i) Calculate the electrostatic force of repulsion between two protons at a separation of 1.5×10^{-15} m.

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(ii) The strong nuclear force has a range of about 3×10^{-15} m. Explain, in terms of the electrostatic force and the strong nuclear force, why two protons must be separated by less than this distance in order to fuse together.

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(3 marks)

(b) Discuss the role of the electrostatic force, the gravitational force and the strong nuclear force in maintaining the equilibrium separation of the neutrons in a neutron star.

You may be awarded additional marks to those shown in brackets for the quality of written communication in your answer.

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(3 marks)

6

Turn over ▶

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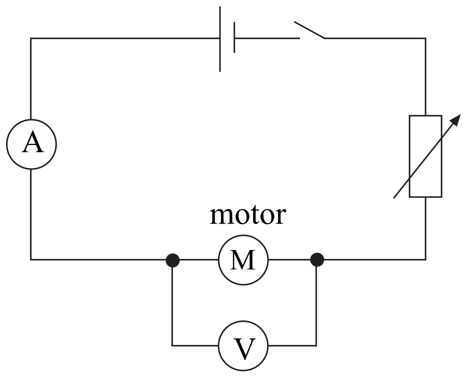
2 The circuit shown in **Figure 1** was used to investigate the efficiency of an electric motor. The motor was used to raise an object of weight 2.6 N from the ground at constant speed.

Figure 1



The following measurements were made:

current	=	1.3 A
pd across the motor	=	5.8 V
height gain of object	=	1.8 m
time taken to raise object through 1.8 m	=	6.2 s

(a) (i) Use these measurements to calculate the percentage efficiency of the motor when raising the object.

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(ii) State **two** reasons why the motor is not 100% efficient.

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(5 marks)

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(b) When a heavier object was used, the motor failed to turn. Consider the forces and their turning effects on the motor coil and hence explain why the motor was unable to turn in this situation.

You may be awarded additional marks to those shown in brackets for the quality of written communication in your answer.

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(4 marks)

9

Turn over for the next question

3 When the pump of a central heating system reaches a certain speed after being switched on, a straight section of a pipe vibrates strongly.

(a) (i) Explain why the pipe vibrates strongly at a certain pump speed.

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(ii) State and explain **one** way to reduce these vibrations of the pipe.

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(5 marks)

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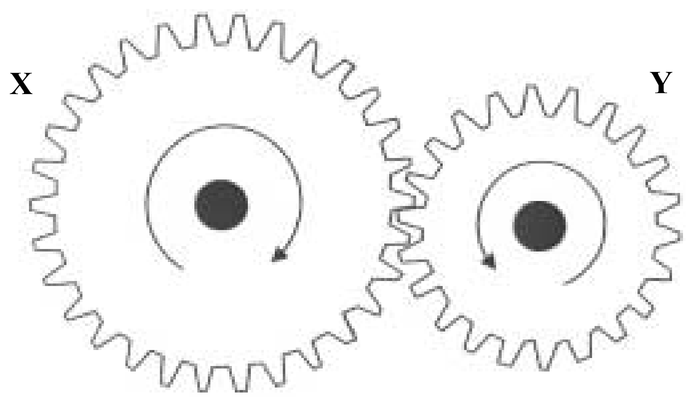
(b) **Figure 2** shows two gear wheels **X** and **Y** in a pump. An electric motor drives gear wheel **X** which is in contact with the smaller gear wheel **Y** which in turn drives the rotor of the pump.

Figure 2



(i) Explain why **Y** rotates faster than **X**.

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(ii) The teeth of the two gear wheels exert equal and opposite forces on each other when they are rotating. Explain why the torque exerted by **Y** on **X** is less than the torque exerted by **X** on **Y**.

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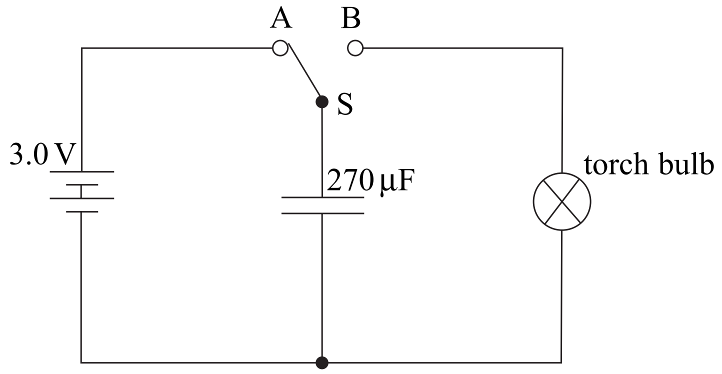
(4 marks)

9

Turn over for the next question

4 A torch bulb produces a flash of light when a 270 μF capacitor is discharged across it.

Figure 3



(a) The capacitor is charged to a pd of 3.0 V from the battery, as shown in **Figure 3**.

Calculate

(i) the energy stored in the capacitor,

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(ii) the work done by the battery.

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(3 marks)

(b) The capacitor is discharged by moving switch S in **Figure 3** from A to B. The discharge circuit has a total resistance of 1.5 Ω.

(i) Show that almost all of the energy stored in the capacitor is released when the capacitor pd has decreased from 3.0 V to 0.3 V.

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(ii) Emission of light from the torch bulb ceases when the pd falls below 2.0 V. Calculate the duration of the light flash.

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(iii) Assuming that the torch bulb produces photons of average wavelength 500 nm, estimate the number of photons released during the light flash.

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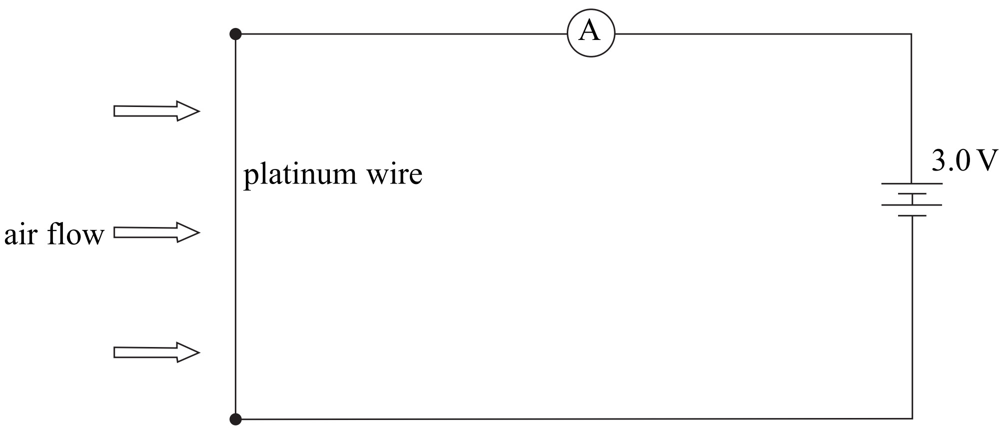
(8 marks)

11

Turn over for the next question

5 A hot-wire anemometer is a device used to measure the air-flow speed. The device consists of a thin platinum wire in series with an ammeter and a 3.0 V battery of negligible internal resistance, as shown in **Figure 4**.

Figure 4



(a) The wire is heated by the current passing through it. The flow of air over the surface of the wire reduces the temperature of the wire. Explain why the current increases when the air speed is increased.

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(2 marks)

(b) The table shows how the current I through the wire varies with the speed v of the air flow.

v/ mm s^{-1}	I/ A	ln (v/ mm s^{-1})	ln (I/ A)
2.00	0.357		
4.00	0.448		
6.00	0.508		
8.00	0.556		
10.0	0.602		

(i) Complete the table and plot a graph of ln I against ln v.

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(ii) Explain why your graph shows that the current I varies with speed v according to

$$I = kv^n,$$

where k and n are constants.

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(iii) Use your graph to determine the values of k and n.

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(12 marks)

(c) Discuss how the sensitivity of the instrument varies with air-flow speed.

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(2 marks)

16

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6 (a) (i) State the quark composition of a π^+ meson.

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(ii) The equation below represents the production of a π^+ meson when two protons collide.

$$p + p \rightarrow p + \pi^+ + X$$

Identify particle X and state its quark composition.

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(3 marks)

(b) π^+ mesons at rest decay into μ^+ mesons which are always emitted at a certain speed.

(i) Explain, in terms of momentum, why another particle Y must be emitted when a π^+ meson at rest decays into a μ^+ meson.

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(ii) The equation below represents the decay of a π^+ meson into a μ^+ meson and another particle Y.

$$\pi^+ \rightarrow \mu^+ + Y$$

Identify particle Y and state **one** of its properties.

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(4 marks)

7

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7 In a geothermal power station, water is pumped through pipes into an underground region of hot rocks. The thermal energy of the rocks heats the water and turns it to steam at high pressure. The steam then drives a turbine at the surface to produce electricity.

(a) Water at 21 °C is pumped into the hot rocks and steam at 100 °C is produced at a rate of 190 kg s^{-1}.

(i) Show that the energy per second transferred from the hot rocks to the power station in this process is at least 500 MW.

specific heat capacity of water = 4200 J kg^{-1} K^{-1}
specific latent heat of steam = 2.3×10^6 J kg^{-1}

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(ii) The hot rocks are estimated to have a volume of 4.0×10^6 m^3. Estimate the fall of temperature of these rocks in one day if thermal energy is removed from them at the rate calculated in part (i) without any thermal energy gain from deeper underground.

specific heat capacity of the rocks = 850 J kg^{-1} K^{-1}
density of the rocks = 3200 kg m^{-3}

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(7 marks)

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(b) Geothermal energy originates as energy released in the radioactive decay of the uranium isotope $^{238}_{92}U$ deep inside the Earth. Each nucleus that decays releases 4.2 MeV. Calculate the mass of $^{238}_{92}U$ that would release energy at a rate of 500 MW.

half-life of $^{238}_{92}U$ = 4.5×10^9 years
molar mass of $^{238}_{92}U$ = $0.238\,kg\,mol^{-1}$

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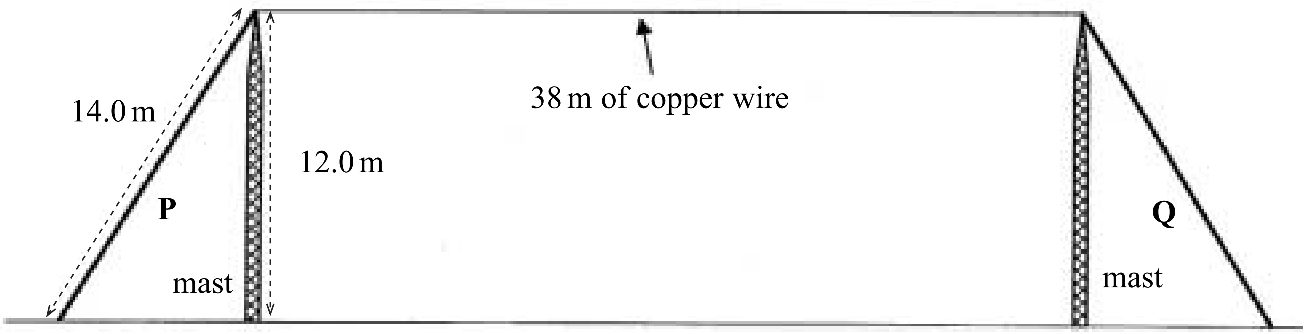
(5 marks)

12

Turn over for the next question

8 An aerial system consists of a horizontal copper wire of length 38 m supported between two masts, as shown in **Figure 5**. The wire transmits electromagnetic waves when an alternating potential is applied to it at one end.

Figure 5



(a) The wavelength of the radiation transmitted from the wire is twice the length of the copper wire. Calculate the frequency of the transmitted radiation.

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(1 mark)

(b) The ends of the copper wire are fixed to masts of height 12.0 m. The masts are held in a vertical position by cables, labelled **P** and **Q**, as shown in **Figure 5**.

(i) **P** has a length of 14.0 m and the tension in it is 110 N. Calculate the tension in the copper wire.

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(ii) The copper wire has a diameter of 4.0 mm. Calculate the stress in the copper wire.

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(iii) Discuss whether the wire is in danger of breaking if it is stretched further due to movement of the top of the masts in strong winds.

breaking stress of copper = 3.0×10^8 Pa

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(7 marks)

8

Quality of Written Communication *(2 marks)*

2

END OF QUESTIONS

There are no questions printed on this page