

Surname						Other Names					
Centre Number						Candidate Number					
Candidate Signature											

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General Certificate of Education  
June 2005  
Advanced Level Examination



**PHYSICS (SPECIFICATION A)**  
**Unit 5 Nuclear Instability: Astrophysics Option**

**PHA5/W**

Thursday 16 June 2005 Morning Session

**In addition to this paper you will require:**

- a calculator;
- a pencil and a ruler.

For Examiner's Use			
Number	Mark	Number	Mark
1			
2			
3			
4			
5			
Total (Column 1)		→	
Total (Column 2)		→	
TOTAL			
Examiner's Initials			

Time allowed: 1 hour 15 minutes

**Instructions**


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

**Information**

- The maximum mark for this paper is 40.
- Mark allocations are shown in brackets.
- The paper carries 10% of the total marks for Physics Advanced.
- 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.
- In questions requiring description and explanation you will be assessed on your ability to use an appropriate form and style of writing, to organise relevant information clearly and coherently, and to use specialist vocabulary where appropriate. The degree of legibility of your handwriting and the level of accuracy of your spelling, punctuation and grammar will also be taken into account.

**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				Mechanics and Applied Physics		Fields, Waves, Quantum Phenomena	
Quantity	Symbol	Value	Units				
speed of light in vacuo	$c$	$3.00 \times 10^8$	$\text{m s}^{-1}$	$v = u + at$	$g = \frac{F}{m}$		
permeability of free space	$\mu_0$	$4\pi \times 10^{-7}$	$\text{H m}^{-1}$	$s = \left(\frac{u+v}{2}\right)t$	$g = -\frac{GM}{r^2}$		
permittivity of free space	$\epsilon_0$	$8.85 \times 10^{-12}$	$\text{F m}^{-1}$	$s = ut + \frac{at^2}{2}$	$g = -\frac{\Delta V}{\Delta x}$		
charge of electron	$e$	$1.60 \times 10^{-19}$	C	$v^2 = u^2 + 2as$	$V = -\frac{GM}{r}$		
the Planck constant	$h$	$6.63 \times 10^{-34}$	J s	$F = \frac{\Delta(mv)}{\Delta t}$	$a = -(2\pi f)^2 x$		
gravitational constant	$G$	$6.67 \times 10^{-11}$	$\text{N m}^2 \text{kg}^{-2}$	$P = Fv$	$v = \pm 2\pi f \sqrt{A^2 - x^2}$		
the Avogadro constant	$N_A$	$6.02 \times 10^{23}$	$\text{mol}^{-1}$	$\text{efficiency} = \frac{\text{power output}}{\text{power input}}$	$x = A \cos 2\pi ft$		
molar gas constant	$R$	8.31	$\text{J K}^{-1} \text{mol}^{-1}$	$\omega = \frac{v}{r} = 2\pi f$	$T = 2\pi\sqrt{\frac{m}{k}}$		
the Boltzmann constant	$k$	$1.38 \times 10^{-23}$	$\text{J K}^{-1}$	$a = \frac{v^2}{r} = r\omega^2$	$T = 2\pi\sqrt{\frac{l}{g}}$		
the Stefan constant	$\sigma$	$5.67 \times 10^{-8}$	$\text{W m}^{-2} \text{K}^{-4}$	$I = \sum mv^2$	$\lambda = \frac{\omega s}{D}$		
the Wien constant	$\alpha$	$2.90 \times 10^{-3}$	m K	$E_k = \frac{1}{2} I\omega^2$	$d \sin \theta = n\lambda$		
electron rest mass	$m_e$	$9.11 \times 10^{-31}$	kg	$\omega_2 = \omega_1 + at$	$\theta \approx \frac{\lambda}{D}$		
(equivalent to $5.5 \times 10^{-4}u$ )				$\theta = \omega_1 t + \frac{1}{2} at^2$	$n_2 = \frac{\sin \theta_1}{\sin \theta_2} = \frac{c_1}{c_2}$		
electron charge/mass ratio	$e/m_e$	$1.76 \times 10^{11}$	$\text{C kg}^{-1}$	$\omega_2^2 = \omega_1^2 + 2\alpha\theta$	$n_2 = \frac{n_2}{n_1}$		
proton rest mass	$m_p$	$1.67 \times 10^{-27}$	kg	$\theta = \frac{1}{2} (\omega_1 + \omega_2)t$	$\sin \theta_c = \frac{1}{n}$		
(equivalent to 1.00728u)				$T = I\alpha$	$E = hf$		
proton charge/mass ratio	$e/m_p$	$9.58 \times 10^7$	$\text{C kg}^{-1}$	$\text{angular momentum} = I\omega$	$hf = \phi + E_k$		
neutron rest mass	$m_n$	$1.67 \times 10^{-27}$	kg	$W = T\theta$	$hf = E_1 - E_2$		
(equivalent to 1.00867u)				$P = T\omega$	$\lambda = \frac{h}{p} = \frac{h}{mv}$		
gravitational field strength	$g$	9.81	$\text{N kg}^{-1}$	$\text{angular impulse} = \text{change of angular momentum} = Tt$	$c = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$		
acceleration due to gravity	$g$	9.81	$\text{m s}^{-2}$	$\Delta Q = \Delta U + \Delta W$	<b>Electricity</b>		
atomic mass unit	$u$	$1.661 \times 10^{-27}$	kg	$\Delta W = p\Delta V$	$\epsilon = \frac{E}{Q}$		
(1u is equivalent to 931.3 MeV)				$pV^\gamma = \text{constant}$	$\epsilon = I(R + r)$		
				$\text{work done per cycle} = \text{area of loop}$	$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots$		
				$\text{input power} = \text{calorific value} \times \text{fuel flow rate}$	$R_T = R_1 + R_2 + R_3 + \dots$		
				$\text{indicated power as (area of } p-V \text{ loop)} \times (\text{no. of cycles/s}) \times (\text{no. of cylinders})$	$P = I^2 R$		
				$\text{friction power} = \text{indicated power} - \text{brake power}$	$E = \frac{F}{Q} = \frac{V}{d}$		
				$\text{efficiency} = \frac{W}{Q_{in}} = \frac{Q_{in} - Q_{out}}{Q_{in}}$	$E = \frac{1}{4\pi\epsilon_0} \frac{Q}{r^2}$		
				$\text{maximum possible efficiency} = \frac{T_H - T_C}{T_H}$	$E = \frac{1}{2} QV$		
					$F = BIl$		
					$F = BQv$		
					$Q = Q_0 e^{-t/RC}$		
					$\Phi = BA$		
					<b>Turn over</b> 		

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

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

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

**Mechanical and Thermal Properties**

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

$$\text{energy stored} = \frac{1}{2} Fe$$

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

$$\Delta Q = ml$$

$$pV = \frac{1}{3} Nmc^2$$

$$\frac{1}{2} mc^2 = \frac{3}{2} kT = \frac{3RT}{2N_A}$$

**Nuclear Physics and Turning Points in Physics**

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

$$\text{force} = Bev$$

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

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

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

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

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

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

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

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

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

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

$$E = mc^2 = \frac{m_0 c^2}{\left(1 - \frac{v^2}{c^2}\right)^{\frac{1}{2}}}$$

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

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

**Astrophysics and Medical Physics**

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

$$1 \text{ astronomical unit} = 1.50 \times 10^{11} \text{ m}$$

$$1 \text{ parsec} = 206265 \text{ AU} = 3.08 \times 10^{16} \text{ m} = 3.26 \text{ ly}$$

$$1 \text{ light year} = 9.45 \times 10^{15} \text{ m}$$

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

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

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

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

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

$$v = Hd$$

$$P = \sigma AT^4$$

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

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

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

**Medical Physics**

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

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

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

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

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

**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

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

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

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

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

**Alternating Currents**

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

**Operational amplifier**

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

$$G = -\frac{R_f}{R_1} \quad \text{inverting}$$

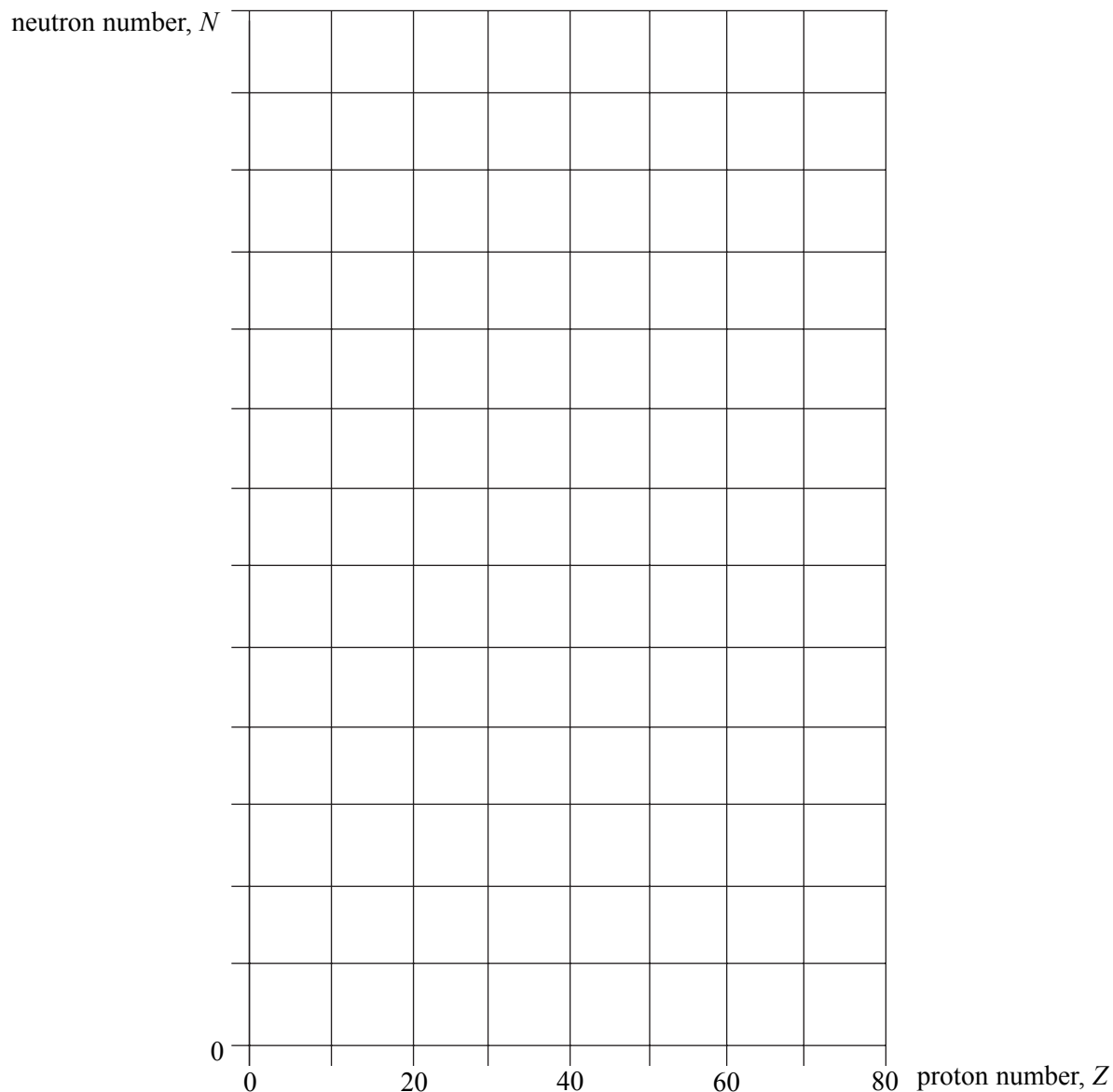
$$G = 1 + \frac{R_f}{R_1} \quad \text{non-inverting}$$

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

**TURN OVER FOR THE FIRST QUESTION**

**SECTION A: NUCLEAR INSTABILITY**Answer **all** parts of the question.

- 1 (a) Sketch, using the axes provided, a graph of neutron number,  $N$ , against proton number,  $Z$ , for stable nuclei over the range  $Z = 0$  to  $Z = 80$ . Show suitable numerical values on the  $N$  axis.

*(2 marks)*

- (b) On the graph indicate, for each of the following, a possible position of a nuclide that may decay by
- $\alpha$  emission, labelling the position with **W**,
  - $\beta^-$  emission, labelling the position with **X**,
  - $\beta^+$  emission, labelling the position with **Y**.

*(3 marks)*

- (c) The isotope  ${}^{222}_{86}\text{Rn}$  decays sequentially by emitting  $\alpha$  particles and  $\beta^-$  particles, eventually forming the isotope  ${}^{206}_{82}\text{Pb}$ . Four  $\alpha$  particles are emitted in the sequence.

Calculate the number of  $\beta^-$  particles in the sequence.

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(2 marks)

- (d) A particular nuclide is described as proton-rich. Discuss **two** ways in which the nuclide may decay.

You may be awarded marks for the quality of written communication in your answer.

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(3 marks)

10

**TURN OVER FOR SECTION B**

**Turn over ▶**

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**SECTION B: ASTROPHYSICS**

Answer **all** questions.

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- 2 A converging lens can be used to produce both a magnified real image and a magnified virtual image of an object.
- (a) Draw ray diagrams to show how each image is formed. Label the principal foci of the lens in each case.

*(4 marks)*



(b) Calculate the object distance required to produce a magnified image 0.25 m from a lens of power +10 D when the image is

(i) real,

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(ii) virtual.

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(4 marks)

8

**TURN OVER FOR THE NEXT QUESTION**

**Turn over ▶**

- 3 (a) The table summarises the properties of five of the stars in the constellation of Cassiopeia.

name	absolute magnitude	apparent magnitude	spectral class
Achird	4.6	3.5	G
Chaph	1.9	2.3	F
Ruchbah	0.24	2.7	A
Segin	-2.4	3.4	B
Shedir	-0.9	2.2	K

Explaining your answer in each case, state which star

- (i) is the hottest,

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- (ii) is likely to appear orange in colour,

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- (iii) appears the brightest from Earth,

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- (iv) is less than 10 pc away from the Earth.

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(4 marks)

(b) The constellation Cassiopeia contains another star with an apparent magnitude of 2.2, absolute magnitude of  $-4.6$  and a surface temperature of  $12\,000\text{ K}$ . Calculate, for this star,

(i) its distance from the Earth,

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(ii) the peak wavelength in its black body radiation curve.

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(3 marks)

7

**TURN OVER FOR THE NEXT QUESTION**

**Turn over ▶**

4 The red shift of a galaxy's spectrum can be used to determine its velocity, relative to the Earth.

- (a) The wavelength of the hydrogen alpha line in the spectrum of the galaxy NGC 1357 is 660.86 nm. The wavelength of the same line from a laboratory based source is 656.28 nm. Calculate the velocity of galaxy NGC 1357.

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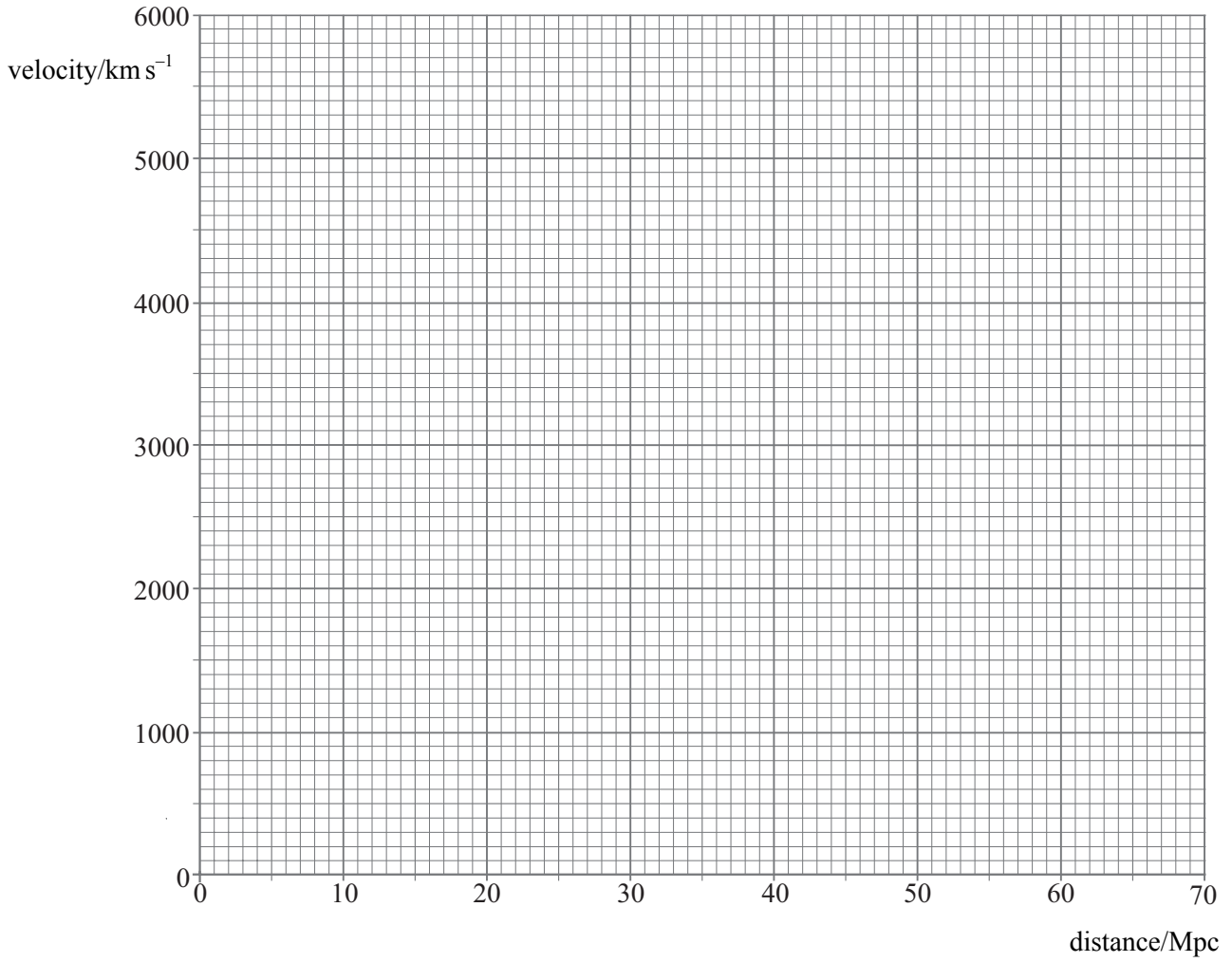
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(2 marks)

- (b) Use the value obtained in part (a) to complete the table. Plot a graph of the data in the table below and use the graph to determine a value for the Hubble constant.

galaxy	velocity/km s <sup>-1</sup>	distance/Mpc
NGC 1357		28
NGC 1832	2000	31
NGC 5548	5270	67
NGC 7469	4470	65



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(3 marks)

5

Turn over ▶

- 5 (a) Describe what is meant by an Airy disc and explain its significance in determining the resolving power of a telescope.

You may be awarded marks for the quality of written communication in your answer.

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(3 marks)

- (b) The Arecibo telescope is the largest radio telescope in the world. It can be used to investigate distant galaxies by detecting the 1.4 GHz radio signal produced by molecular hydrogen.

- (i) When the telescope was being built, any surface irregularities had to be less than 0.01 m in order for it to detect the molecular hydrogen signal. Verify this value using an appropriate calculation.

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- (ii) The diameter of the Arecibo telescope is 305 m. Calculate its resolving power when detecting the molecular hydrogen signal.

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(3 marks)

- (c) Describe a problem associated with spherical reflecting telescopes and state how telescopes are designed to prevent it.

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(2 marks)

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8

**QUALITY OF WRITTEN COMMUNICATION** (2 marks)

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2

**END OF QUESTIONS**

**THERE ARE NO QUESTIONS PRINTED ON THIS PAGE**