Cambridge Pre-U

UNIVERSITY OF CAMBRIDGE INTERNATIONAL EXAMINATIONS
Cambridge International Level 3 Pre-U Certificate
Principal Subject

CANDIDATE NAME

CENTRE NUMBER

CANDIDATE NUMBER

8166669961

PHYSICS **9792/03**

Paper 3 Part B Written Paper **May/June 2011**

3 hours

Candidates answer on the Question Paper.

No Additional Materials are required.

READ THESE INSTRUCTIONS FIRST

Write your Centre number, candidate number and name on all the work you hand in.
Write in dark blue or black pen.
You may use a soft pencil for any diagrams, graphs or rough working.
Do not use staples, paper clips, highlighters, glue or correction fluid.
DO **NOT** WRITE IN ANY BARCODES.

Section A
Answer **all** questions.
You are advised to spend about 1 hour 30 minutes on this section.

Section B
Answer any **three** questions. All six questions carry equal marks.
You are advised to spend about 1 hour 30 minutes on this section.

You may lose marks if you do not show your working or if you do not use appropriate units.

At the end of the examination, fasten all your work securely together.
The number of marks is given in brackets [ ] at the end of each question or part question.

For Examiner's Use	
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	
13	
14	
Total	

This document consists of **39** printed pages and **1** blank page.

DC (NF/CGW) 34086/7

UNIVERSITY *of* CAMBRIDGE
International Examinations

[Turn over

Data

gravitational field strength close to Earth's surface	$g = 9.81\,\mathrm{N\,kg^{-1}}$
elementary charge	$e = 1.60 \times 10^{-19}\,\mathrm{C}$
speed of light in vacuum	$c = 3.00 \times 10^{8}\,\mathrm{m\,s^{-1}}$
Planck constant	$h = 6.63 \times 10^{-34}\,\mathrm{J\,s}$
permittivity of free space	$\varepsilon_0 = 8.85 \times 10^{-12}\,\mathrm{F\,m^{-1}}$
gravitational constant	$G = 6.67 \times 10^{-11}\,\mathrm{N\,m^{2}\,kg^{-2}}$
electron mass	$m_e = 9.11 \times 10^{-31}\,\mathrm{kg}$
proton mass	$m_p = 1.67 \times 10^{-27}\,\mathrm{kg}$
unified atomic mass constant	$u = 1.66 \times 10^{-27}\,\mathrm{kg}$
molar gas constant	$R = 8.31\,\mathrm{J\,K^{-1}\,mol^{-1}}$
Avogadro constant	$N_A = 6.02 \times 10^{23}\,\mathrm{mol^{-1}}$
Boltzmann constant	$k = 1.38 \times 10^{-23}\,\mathrm{J\,K^{-1}}$
Stefan-Boltzmann constant	$\sigma = 5.67 \times 10^{-8}\,\mathrm{W\,m^{-2}\,K^{-4}}$

Formulae

uniformly accelerated motion	$s = ut + \frac{1}{2}at^2$	magnetic force	$F = BIl\sin\theta$
	$v^2 = u^2 + 2as$		$F = BQv\sin\theta$
	$s = \left(\frac{u+v}{2}\right)t$	electromagnetic induction	$E = \frac{-\mathrm{d}(N\Phi)}{\mathrm{d}t}$
heating	$\Delta E = mc\Delta\theta$	Hall effect	$V = Bvd$
change of state	$\Delta E = mL$	time dilation	$t' = \frac{t}{\sqrt{1-\frac{v^2}{c^2}}}$
refraction	$n = \frac{\sin\theta_1}{\sin\theta_2}$	kinetic theory	$\frac{1}{2}m\langle c^2\rangle = \frac{3}{2}kT$
	$n = \frac{v_1}{v_2}$	work done on/by a gas	$W = p\Delta V$
photon energy	$E = hf$	radioactive decay	$\frac{\mathrm{d}N}{\mathrm{d}t} = -\lambda N$
de Broglie wavelength	$\lambda = \frac{h}{p}$		$N = N_0\mathrm{e}^{-\lambda t}$
simple harmonic motion	$x = A\cos\omega t$		$t_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$
	$v = -A\omega\sin\omega t$	attenuation losses	$I = I_0\mathrm{e}^{-\mu x}$
	$a = -A\omega^2\cos\omega t$	mass-energy equivalence	$\Delta E = c^2\Delta m$
	$F = -m\omega^2 x$	hydrogen energy levels	$E_\mathrm{n} = \frac{-13.6\,\mathrm{eV}}{n^2}$
	$E = \frac{1}{2}mA^2\omega^2$		
energy stored in a capacitor	$W = \frac{1}{2}QV$	Heisenberg uncertainty principle	$\Delta p\Delta x \geqslant \frac{h}{2\pi}$
electric force	$F = \frac{Q_1Q_2}{4\pi\varepsilon_0 r^2}$		$\Delta E\Delta t \geqslant \frac{h}{2\pi}$
electrostatic potential energy	$W = \frac{Q_1Q_2}{4\pi\varepsilon_0 r}$	Wien's law	$\lambda_{\max} \propto \frac{1}{T}$
gravitational force	$F = \frac{-Gm_1m_2}{r^2}$	Stefan's law	$L = 4\pi\sigma r^2T^4$
gravitational potential energy	$E = \frac{-Gm_1m_2}{r}$	electromagnetic radiation from a moving source	$\frac{\Delta\lambda}{\lambda} \approx \frac{\Delta f}{f} \approx \frac{v}{c}$

Section A

Answer **all** questions in this section.
You are advised to spend about 1 hour 30 minutes on this section.

For Examiner's Use

1 **(a)** A body is travelling in a circular orbit of radius r with constant speed v as shown in Fig. 1.1.

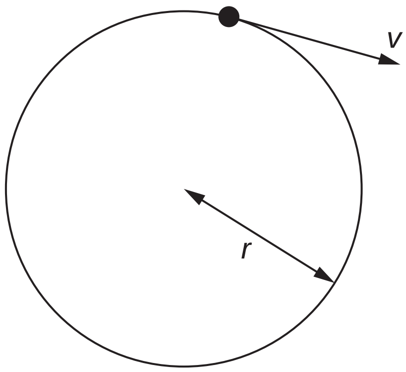

Fig. 1.1

Use a vector diagram to show that the acceleration a of the body is given by

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

towards the centre of the circle.

[4]

(b) The drum of a spin drier has a rate of rotation of 4.0 revolutions per second. An object in the drum has a mass of 0.20 kg and rotates in a vertical circle of radius 0.16 m.

(i) Calculate the magnitude of the acceleration of the object.

acceleration = ... m s^{-2} [2]

(ii) Calculate the magnitude of the resultant force on the object.

resultant force = ... N [1]

(iii) For each of the three positions shown in Fig. 1.2 draw arrows to represent the weight *W* of the object and the force *D* that the drum exerts on the object. Indicate how these two forces always add to produce the resultant force of constant magnitude calculated in **(ii)**.

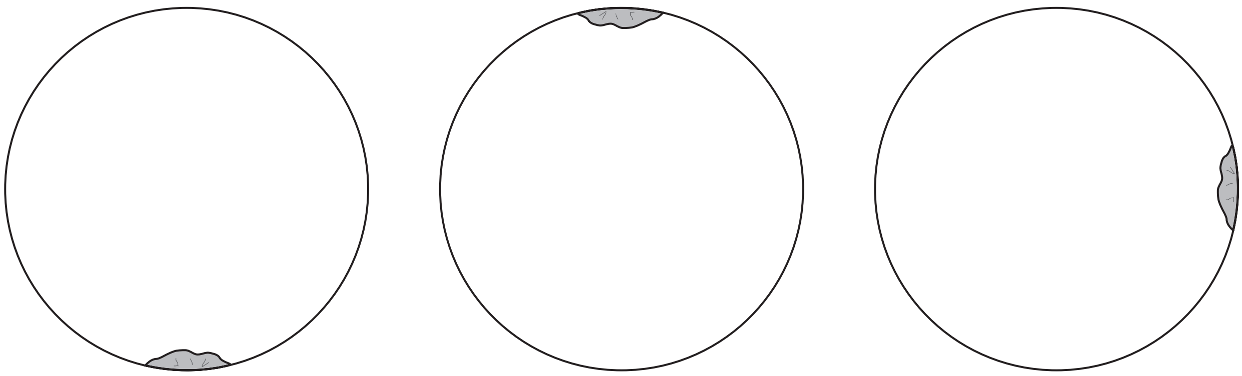

Fig. 1.2

[6]

[Total: 13]

[Turn over

For Examiner's Use

2 **(a)** **(i)** Define *electric field strength*.

....

.... [1]

(ii) A charge q is moved through a potential difference V. State the expression for the work W done on the charge.

[1]

(iii) Show that for a uniform electric field the electric field strength is equal to the potential gradient.

[2]

(b) Two metal plates of a capacitor are separated by a distance of 0.50 mm. The charges on the plates are +5.2 nC on one plate and –5.2 nC on the other. The potential difference between the plates is 24 V.

Calculate the values of

(i) the uniform electric field strength between the plates,

field strength = ... unit .... [2]

(ii) the capacitance of the capacitor,

capacitance = ... unit .... [2]

(iii) the energy stored in the capacitor.

energy = ... J [2]

(c) It is possible to have unequal charges on two parallel plates. Draw a field diagram around the two separated parallel plates shown in Fig. 2.1 where the positive charge on one of the plates has twice the numerical value of the negative charge on the other.

For Examiner's Use

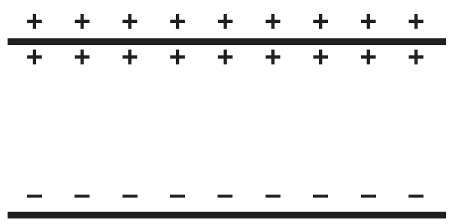

Fig. 2.1 [3]

[Total: 13]

For Examiner's Use

3 **(a)** The Moon has a mass of 7.35×10^{22} kg and can be considered to travel around the Earth in a circular orbit of radius 3.84×10^{8} m. The time to complete one orbit is 2.36×10^{6} s.

Calculate

(i) the speed of the Moon in this orbit,

speed of the Moon = ... m s^{-1} [1]

(ii) the kinetic energy of the Moon in this orbit,

kinetic energy of the Moon = ... J [2]

(iii) the gravitational potential energy of the Moon in this orbit.

The mass of the Earth is 5.98×10^{24} kg.

potential energy of the Moon = ... J [2]

For Examiner's Use

(b) In fact, the Moon's orbit is not a circle but an ellipse. At its closest, the Moon is 3.56×10^8 m from the Earth, and at its furthest, it is 4.07×10^8 m from the Earth.

Given that the total energy of the Moon is constant during one orbit, complete the following table to show how the gravitational and kinetic energies of the Moon change during an orbit.

distance from Earth / 10^8 m	gravitational potential energy / 10^{28} J	total energy / 10^{28} J	kinetic energy / 10^{28} J
3.56	–8.24		
3.84	Answer from **(a)(iii)**		Answer from **(a)(ii)**
4.07			

[4]

(c) Calculate the maximum speed of the Moon.

maximum speed = ... $m\,s^{-1}$ [2]

[Total: 11]

For Examiner's Use

4 **(a)** Explain, with the aid of a diagram, how electric and magnetic fields can be used as a velocity selector in a mass spectrometer.

....

....

....

....

....

....

.... [4]

(b) Different terms may be applied to the magnetic field in a coil.

State the meanings of the three terms *magnetic flux density*, *magnetic flux* and *magnetic flux* linkage.

magnetic flux density ....

....

magnetic flux ....

....

magnetic flux linkage ....

....
[3]

For Examiner's Use

(c) The magnetic flux density B in a coil is given by the equation

$$B = \frac{\mu_0 N I}{l}$$

where μ_0 is a constant with the value $1.26 \times 10^{-6}\,\mathrm{Wb\,A^{-1}\,m^{-1}}$, N is the number of turns in the coil, l is the length of the coil and I is the current.

Determine the current required in the wires of a 2000 turn coil of length 0.22 m to produce a magnetic flux density of 1.2 T within the coil.

current = ... A [2]

(d) Fig. 4.1 shows a patient entering a Magnetic Resonance Imaging (MRI) scanner.

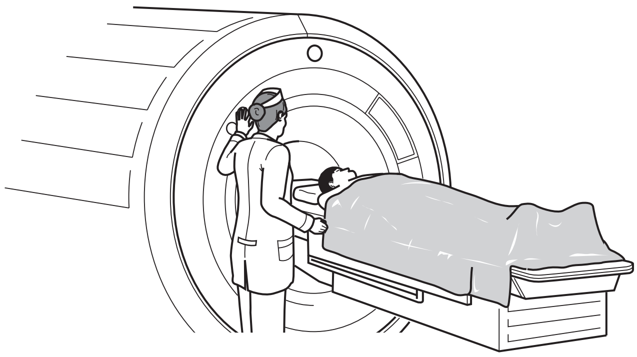

Fig. 4.1

The magnetic field in **(c)** has the magnitude required for an MRI scanner.

(i) Suggest why the coil in **(c)** would be impracticable for the current required by an MRI scanner.

....

.... [1]

(ii) Suggest two ways in which this problem could be avoided.

1. ....

....

.... [1]

2. ....

....

.... [1]

[Total: 12]

5 **(a)** State three main assumptions made in developing the kinetic theory model for a gas.

For Examiner's Use

1 ....

....

2 ....

....

3 ....

.... [3]

(b) **(i)** Calculate the root mean square (rms) speed for oxygen molecules in the atmosphere when the temperature is 23 °C. The mass of an oxygen molecule is 5.3×10^{-26} kg.

rms speed = ... $m\,s^{-1}$ [3]

(ii) Explain why the rms speed of argon atoms in the atmosphere at 23 °C will be different from that of the oxygen molecules given in **(i)**.

....

.... [1]

(c) The rms speed of hydrogen molecules at 23 °C is $1920\,m\,s^{-1}$. The escape velocity from the Earth is $11\,000\,m\,s^{-1}$.

Explain why almost all the molecules of hydrogen that have ever been in the Earth's atmosphere have escaped into space but many oxygen molecules have remained in the atmosphere.

....

....

....

....

....

.... [3]

[Total: 10]

For Examiner's Use

6 **(a)** State and explain the difference between the activity of a radioactive source and the count rate from a counter placed near to that source.

....

....

.... [1]

(b) A count rate from a counter near a radioactive source is $7.6 \times 10^{8}\,\text{s}^{-1}$. The decay constant of the source is $4.6 \times 10^{-3}\,\text{s}^{-1}$.

Calculate

(i) the half-life of the source,

half-life = ... s [1]

(ii) the time taken for the count rate to fall to $8.3 \times 10^{3}\,\text{s}^{-1}$.

time = ... s [3]

(c) At a distance *x* from a radioactive source, a counter records an average rate of 234 counts per minute.

Assuming that the source is radiating uniformly in all directions, deduce the average count rate when the counter is at a distance 3*x* from the source.

average count rate = ... counts per minute [2]

[Total: 7]

For Examiner's Use

7 **(a)** Distinguish between *free*, *forced* and *damped* oscillations.

free oscillations ....

....

....

....

....

forced oscillations ....

....

....

....

....

damped oscillations ....

....

....

....

.... [3]

(b) Earthquake waves can produce forced oscillations in tall buildings. The buildings may collapse because resonance occurs.

Explain what is meant by the term *resonance* in this situation.

....

....

....

.... [2]

For Examiner's Use

(c) Fig. 7.1 shows a tall building designed to prevent collapse during an earthquake. The building has a solid base which rests on a rubber bearing.

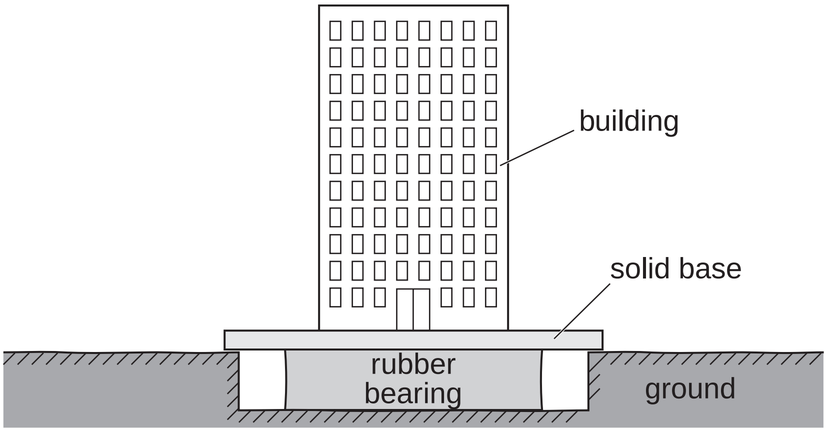

Fig. 7.1

Suggest why this design helps to prevent the building from collapse.

....

....

....

.... [2]

[Total: 7]

For Examiner's Use

8 **(a)** The Sun has a surface temperature of 5700 K. Its radius is 6.96×10^8 m.

Use Stefan's law to find the luminosity of the Sun. Give the unit for luminosity.

luminosity = ... unit .... [2]

(b) **(i)** Use Wien's law to calculate the peak wavelength of visible emission from the Sun. The constant in Wien's equation is 2.9×10^{-3} m K.

wavelength = ... m [2]

(ii) State the colour of this peak wavelength.

colour .... [1]

(c) Use the relationship between mass and energy to calculate the rate of decrease of the Sun's mass.

rate of decrease = ... kg s^{-1} [2]

[Total: 7]

End of Section A

Section B

Answer any **three** questions in this section.
You are advised to spend about 1 hour 30 minutes on this section.

For Examiner's Use

9 Bats emit high frequency sound waves and receive reflected echoes. They use the echoes to locate their position. This process is called echolocation.

Fig. 9.1 illustrates this process.

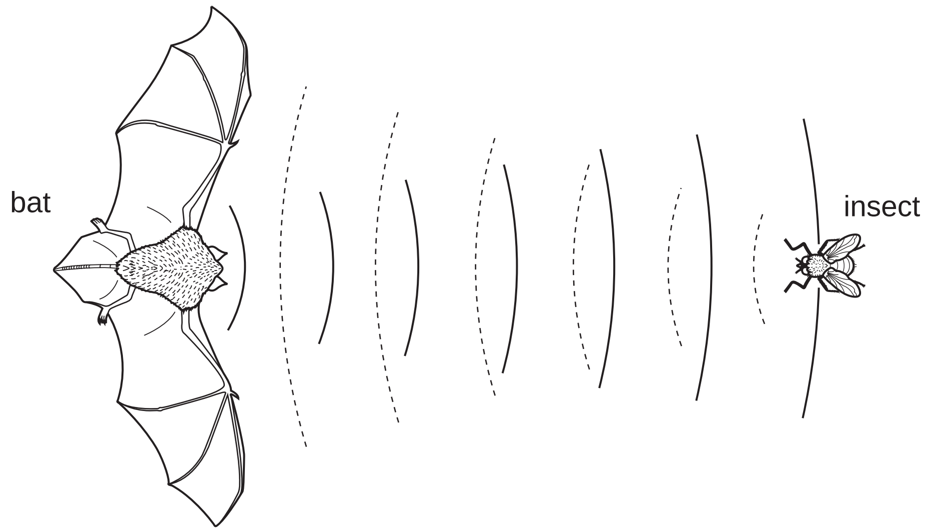

Fig. 9.1

(a) Sound waves are longitudinal waves.

Explain in terms of molecular movement what is meant by a *longitudinal wave*. You may use the space below to draw an annotated diagram to help illustrate your answer.

....

....

.... [3]

(b) Sound waves emitted by the bat travel at 340 ms^{-1}. Their typical frequency range is 20 kHz to 80 kHz.

Calculate the range of wavelengths for this frequency range.

range of wavelengths = ... [2]

(c) Bats emit two waveforms, wave B and wave P, which superpose to form wave E.

- Wave B (shown in Fig. 9.2) gives information about the surrounding background.
- Wave P (not shown in Fig. 9.2) enables the bat to detect insect prey.
- Wave E (shown in Fig. 9.2) is the superposition of wave B and wave P.

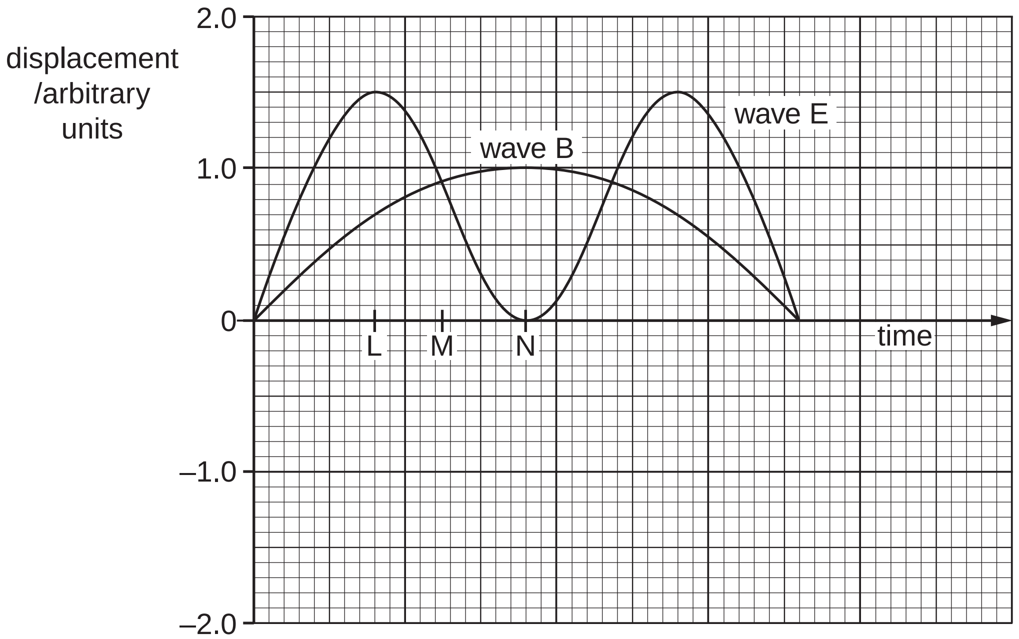

Fig. 9.2

For Examiner's Use

(i) Use the principle of superposition to determine the displacement of wave P at times corresponding to points L, M and N on the time axis.

Write the displacement values in the spaces provided.

displacement of wave P at L = ... units

displacement of wave P at M = ... units

displacement of wave P at N = ... units
[2]

(ii) Hence draw the waveform for wave P on Fig. 9.2. [2]

(d) An effect known as the Doppler effect uses changes in frequency to determine speeds. The change in frequency, Δf, shown by wave P when it is reflected by an insect travelling with speed v is given approximately by the formula

$$\frac{\Delta f}{f} = \frac{2v}{c}$$

where c represents the speed, $340\,\mathrm{m\,s^{-1}}$, of sound waves emitted by the bat.

(i) Wave P has a frequency of 50.80 kHz. Its apparent frequency after reflection is 51.25 kHz.

Calculate the speed of the insect.

insect's speed = ... $\mathrm{m\,s^{-1}}$ [2]

(ii) The bat best discriminates small insect prey when the wavelength of the reflected wave P is similar in size to the insect.

State the wave property that is being demonstrated in this situation.

.... [1]

For Examiner's Use

(e) The bat's high frequency waves are strongly attenuated in air. Fig. 9.3 is a graph of intensity I against range in air x for the high frequency waves. The attenuation coefficient is α.

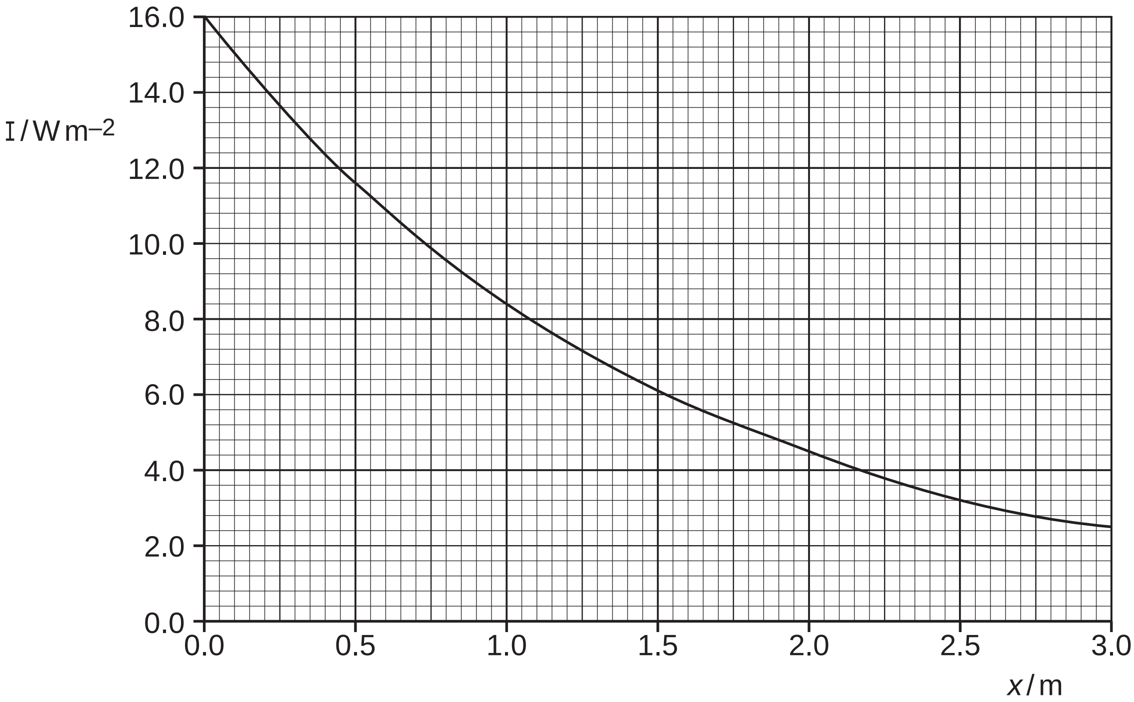

Fig. 9.3

(i) Use the graph and the differential equation $\frac{dI}{dx} = -\alpha I$ to show that a value for the attenuation coefficient, when $I = 8.4\,W\,m^{-2}$, is about 0.7 units.

Explain your working.

α = ... [3]

(ii) State the units of α.

.... [1]

For Examiner's Use

(iii) State the solution to the differential equation $\frac{\mathrm{d}I}{\mathrm{d}x} = -\alpha I$.

[1]

(iv) Verify, by substitution, that the approximate value of 0.7 for α is an acceptable solution to the differential equation when $x = 0.4\,\mathrm{m}$.

[3]

[Total: 20]

10 Fig. 10.1 shows part of an array of wind turbines on farmland.

Fig. 10.1

(a) Each turbine converts the kinetic energy of the wind into electrical energy.
1.16×10^7 kg of air, travelling at a speed of $20\,\text{m}\,\text{s}^{-1}$, pass through the turbine each minute.

Calculate the maximum power of the turbine in MW assuming all of the kinetic energy of the wind is transferred to the turbine.

maximum power = ... MW [2]

(b) Blades of length l sweep out area A with each rotation.

When air of density ρ and wind speed v passes the blades then the maximum power P transferred to the turbine is also given by the expression:

$$P = \tfrac{1}{2}A\rho v^3$$

Fig. 10.2 is a graph of ln$P$ against ln$v$ for different wind speeds. The gradient of the line is 3.

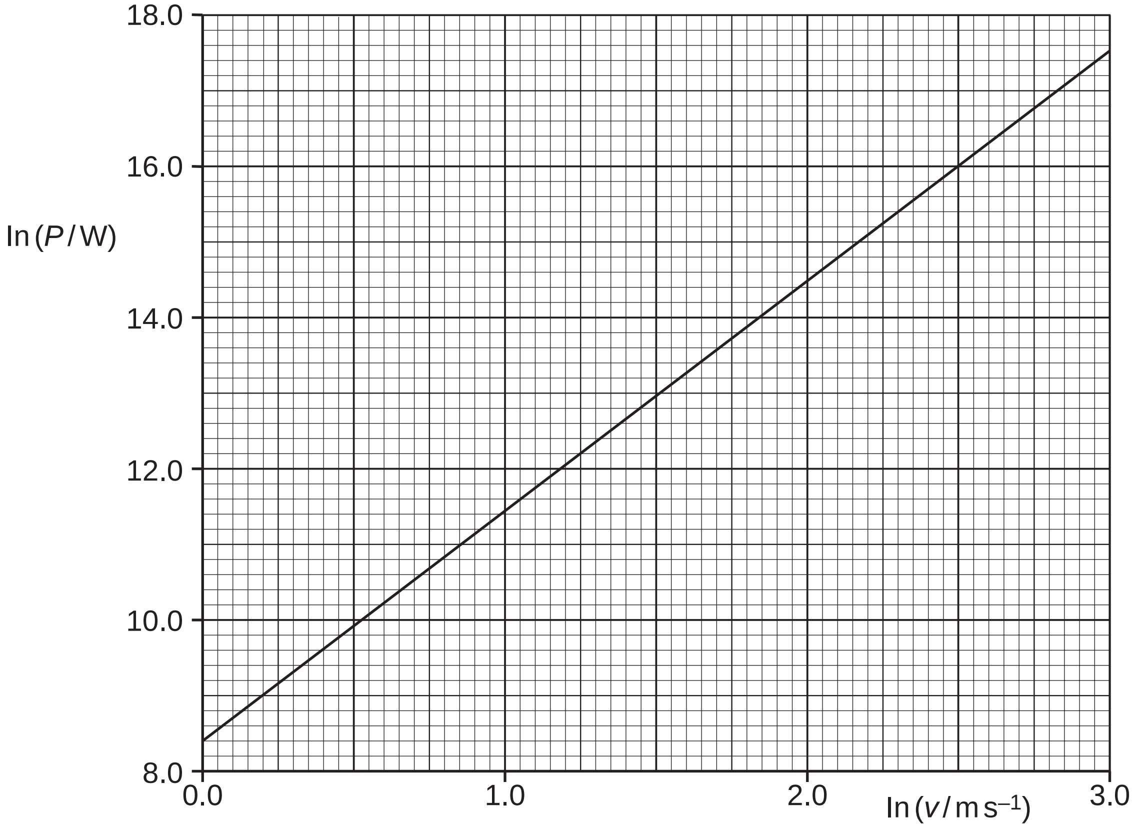

Fig. 10.2

(i) State the expression for the intercept on the ln$P$ axis in terms of A and ρ.

....

.... [1]

(ii) State the value of this intercept.

.... [1]

(iii) Use the value of the intercept stated in **(ii)** to determine the blade length l.
The density of air ρ is 1.23 kg m^{-3}.

blade length = ... m [2]

(c) As the wind passes each blade a torque is exerted on it causing it to rotate about its horizontal axis. The blade has a moment of inertia.

State, in words, the equation that relates torque to moment of inertia.

....

.... [2]

(d) Fig. 10.3 shows a typical waterwheel used in a mill to generate rotational kinetic energy. Water exerts a torque on the wheel as it pours from above into the buckets built into the rim of the wheel.

Fig. 10.3

Assume the wheel is a large ring of dense oak wood, of mass M. Fig. 10.4 is a diagram of the wheel.

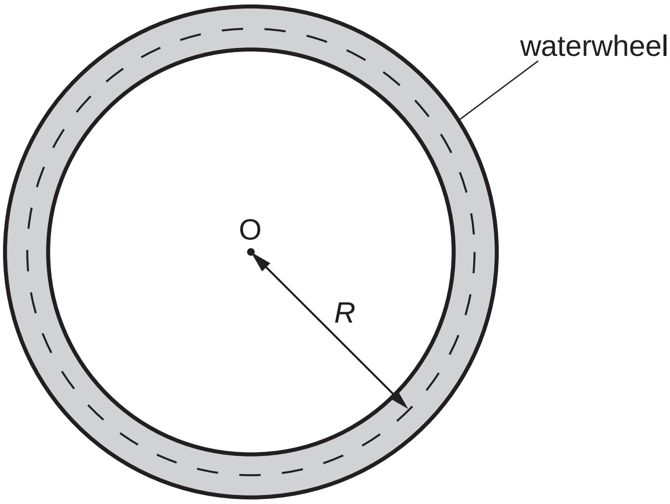

Fig. 10.4

For Examiner's Use

(i) Show that the moment of inertia of the waterwheel can be taken to be

$$I = MR^2$$

as long as the waterwheel is treated as a thin ring of average radius R.

[2]

(ii) The waterwheel rotates at 4 revolutions per minute.

Calculate its angular speed in rad s^{-1}.

angular speed = ... rad s^{-1} [1]

(iii) The maximum power of the waterwheel is 6.5 kW. The wheel comes to rest in 30 minutes once the water stops flowing. As it slows down its average output power is 3.25 kW.

1. Show that the loss in rotational kinetic energy of the wheel as it comes to rest is approximately 6 MJ.

[2]

2. State an assumption made in the calculation in **1**.

....

.... [1]

(iv) Using information given in **(ii)** and **(iii)**, determine the moment of inertia of the wheel. Give the unit with your answer.

moment of inertia = ... unit .... [4]

(v) The radius of the wheel is 5.5 m.

Determine the mass M of the waterwheel.

mass of waterwheel = ... kg [2]

[Total: 20]

For Examiner's Use

11 Hydrogen is the simplest atom, consisting of a nucleus of one proton orbited by a single electron.

(a) **(i)** State the quark content of the proton.

.... [1]

(ii) State the force carrier between the proton and the electron.

.... [1]

(iii) The magnitude of the force of attraction between the proton and the electron is 8.23×10^{-8} N. Calculate the radius of the electron orbit in nm.

radius of orbit = ... nm [4]

(b) Hydrogen line spectra are formed when the electron falls between discrete energy levels and photons of electromagnetic radiation are emitted.

(i) Calculate, in eV, the energy difference corresponding to a transition from the second excited state (n=3) to the first excited state (n=2).

energy difference = ... eV [2]

(ii) Hence, determine the wavelength of the emitted photon.

wavelength = ... m [3]

[Turn over

For Examiner's Use

(c) Quantum theory uses the model of standing waves to explain the existence of energy levels in atoms.

Outline the main points of this explanation. Bullet points are acceptable.

You may wish to draw a simple annotated diagram in the space below to illustrate your answer.

....

....

....

....

....

....

.... [4]

(d) Quantum theory is said to be indeterministic.

Briefly explain what is meant by the term *indeterministic* in the context of the hydrogen atom.

....

....

....

.... [2]

For Examiner's Use

(e) Energy released by the Sun is due to the fusion of hydrogen. The star Betelgeuse is older than the Sun and is a red supergiant.

The table in Fig. 11.1 gives approximations for the relative sizes of the radii and surface temperatures of the Sun and Betelgeuse.

	Sun	Betelgeuse
Radius	R_S	$R_B = 400\ R_S$
Surface Temperature	$T_S = 2T_B$	T_B

Fig. 11.1

Use the information in the table to determine a value for the ratio of the luminosities of the Sun and Betelgeuse, $\frac{L_S}{L_B}$.

$\frac{L_S}{L_B}$ = ... [3]

[Total: 20]

For Examiner's Use

12 The principle of relativity states that the laws of physics are the same for all uniformly moving observers.

(a) State what is meant by *uniformly moving*.

....

.... [1]

(b) State what this implies about *c*, the speed of light in a vacuum.

....

.... [1]

(c) Explain what is meant by *time dilation* (do not derive any formulae).

....

....

....

....

....

.... [3]

(d) An unstable particle has a lifetime of 10 ns when it is at rest in a laboratory. When these particles are created in collisions inside a particle accelerator they have large velocities relative to the laboratory.

Sketch a graph to show how the lifetime observed from the laboratory varies with the particle's velocity through the laboratory.

Include any significant values on the axes and draw attention to any important characteristics of the graph.

[4]

For Examiner's Use

(e) In 1911 Einstein pointed out one of the consequences of special relativity:

"*If we placed a living organism in a box, one could arrange that the organism, after any arbitrary lengthy flight, could be returned to its original spot in a scarcely altered condition, while corresponding organisms which had remained in their original positions had already long since given way to new generations. For the moving organism the lengthy time of the journey was a mere instant, provided the motion took place with approximately the speed of light*."

Albert Einstein 1911

(i) Explain why, for the moving organism, '*the lengthy time of the journey was a mere instant, provided the motion took place with approximately the speed of light*'.

....

....

....

....

....

.... [3]

(ii) Assume that total distance travelled on the round trip is 20 light years and that the travelling organism has an almost constant speed of 0.95 *c*.

1. Calculate how much time has passed during the journey for the organisms remaining on Earth.

time = ... years [1]

2. Calculate how much time has passed for the travelling organisms during their journey.

time = ... years [3]

(iv) Explain why this could be considered to be an example of *time travel*.

....

....

....

.... [2]

(v) The arguments and calculations in parts **(i)** to **(iv)** are all from the reference frame of the *stay-at-home* organisms.

Explain why it would not be justified to carry out the same analysis in the same way from the reference frame of the travelling organism.

....

....

....

.... [2]

[Total: 20]

For Examiner's Use

For Examiner's Use

13 **(a)** State the first law of thermodynamics, defining any terms that you use.

....

....

....

.... [2]

(b) State how the first law of thermodynamics is related to the law of conservation of energy.

....

....

.... [1]

(c) Here is a statement of the second law of thermodynamics:

The total entropy in the universe can never decrease.

Explain what is meant by the term *entropy*.

....

....

....

.... [2]

(d) Most cars are driven by an internal combustion engine. These engines work by compressing a fuel-air mixture inside the engine cylinder and igniting it with a spark. The explosion of the mixture results in rapid heating of the compressed gas and a great increase in temperature and pressure. The force exerted on a moveable piston does useful work that is used (ultimately) to drive the car. The hot gaseous reaction products are expelled in the exhaust. Engines designed to extract useful work from heat are called *heat engines*.

(i) State, in terms of particles, how energy is conserved when the fuel-air mixture explodes.

....

.... [1]

(ii) Explain why entropy increases when the fuel-air mixture explodes and expands.

....

....

....

.... [2]

(iii) Explain, in terms of energy transfers, why the internal combustion engine cannot be 100% efficient.

....

....

....

.... [2]

For Examiner's Use

(e) The diagram in Fig. 13.1 represents the flow of heat in a heat engine (e.g. an internal combustion engine).

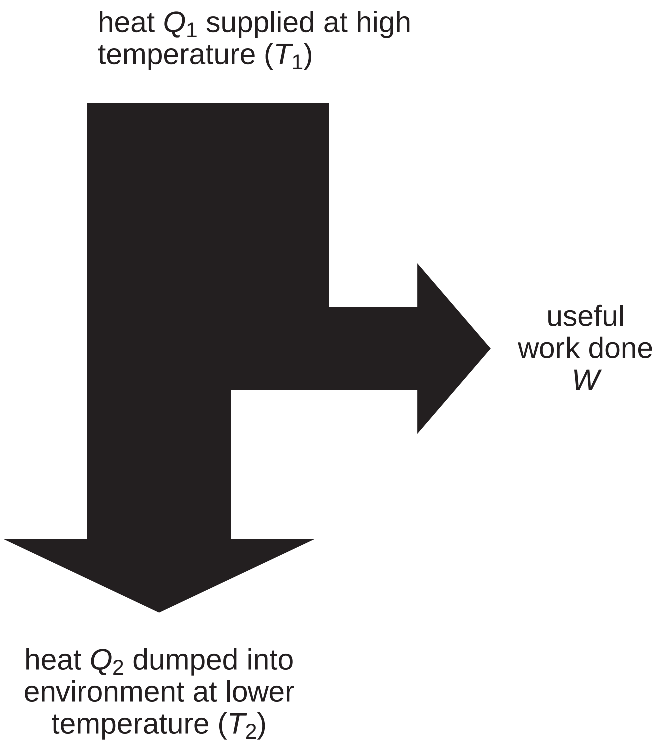

Fig. 13.1

(i) State an expression for the efficiency of the engine in terms of Q_1 and W.

[1]

(ii) For an ideal heat engine the entropy change ΔS of the surroundings at temperature T is given by the expression:

$$\Delta S = \pm \frac{Q}{T} \qquad \text{(positive if heat } Q \text{ flows into the surroundings)}$$

Use this expression, your answer to part **(e)(i)** and the second law of thermodynamics to show that the efficiency of a heat engine (such as an internal combustion engine) is limited by the relationship:

$$efficiency \leq (1 - \frac{T_2}{T_1})$$

[6]

(iii) Estimate the maximum theoretical efficiency of an internal combustion engine stating any numerical values used in the calculation.

maximum efficiency = ... [3]

[Total: 20]

For Examiner's Use

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14 Albert Einstein and Niels Bohr made many contributions to the early development of quantum theory. Einstein's explanation of the photoelectric effect in terms of photon theory and Bohr's explanation of atomic spectra in terms of quantised energy levels are just two important examples. However, these two great physicists argued about the interpretation of quantum theory.

One of Einstein's arguments was that quantum theory could not be a complete description of physical reality because it did not allow particles, such as electrons, to have well defined properties of *both* position *and* momentum at any moment.

Bohr, on the other hand, thought that quantum theory contains all that can be known about reality, a view he developed in the *Copenhagen Interpretation* of quantum theory.

(a) Explain how Einstein's photon model of light differs from the classical description of light as an electromagnetic wave in the way it explains

(i) light intensity,

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(ii) the absorption of light energy by a metal surface.

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(b) Explain how the quantum model of the atom (Bohr's model) differed from the pre-quantum nuclear model (Rutherford's model) in the way electrons orbit the nucleus.

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(c) Explain, using a diagram, how Bohr's quantised atom and Einstein's photon theory can be used to explain why atoms of a cold gas absorb characteristic frequencies of electromagnetic radiation.

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(d) The Heisenberg Uncertainty principle for position and momentum can be written in the form:

$$\Delta p \Delta x \geq \frac{h}{2\pi}$$

where Δp is the uncertainty in momentum, Δx is the uncertainty in the position of a particle and h is the Planck constant.

(i) Use the uncertainty principle to explain Einstein's belief that quantum theory gives an **incomplete** description of the electron compared to the description given by Newtonian mechanics.

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(ii) Calculate the uncertainty in momentum when an electron of mass 9.11×10^{-31} kg travelling at 3.00×10^{7} m s^{-1} passes through a narrow slit of width 1.00×10^{-10} m (comparable to the spacing of atoms in a crystal).

For Examiner's Use

uncertainty in momentum = ... [2]

(iii) Compare this uncertainty in momentum to the original momentum of the electron and state its significance.

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(e) The diagrams in Fig. 14.1 show what happens to two successive photons from a laser as they pass through a narrow slit and strike a light-sensitive screen.

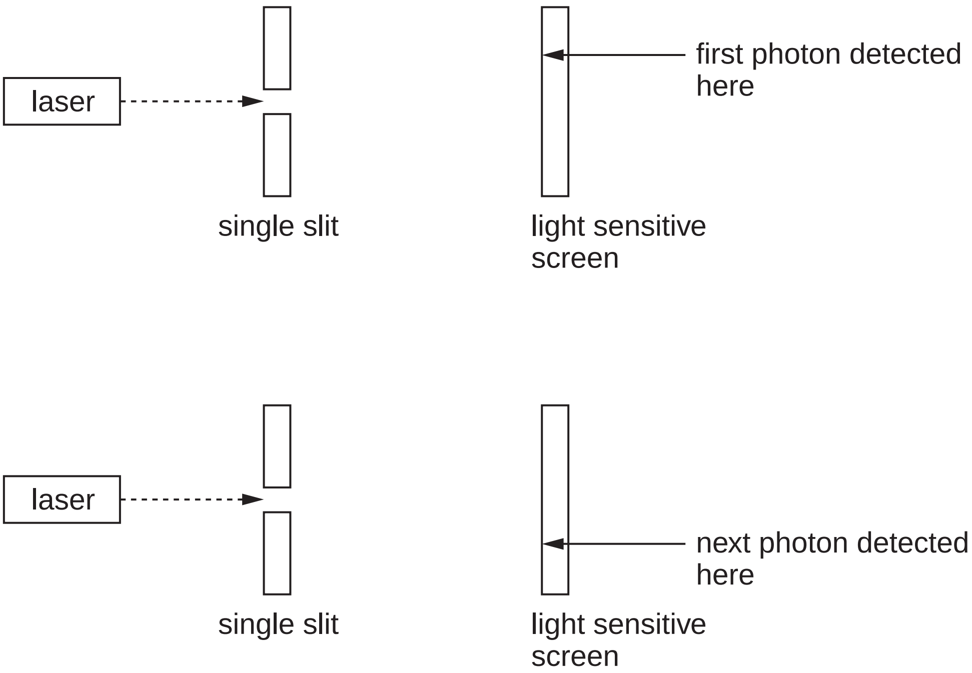

Fig. 14.1

Use the Copenhagen interpretation of quantum theory to explain how two identical photons approaching the slit in the same way can end up striking the screen in two very different places.

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