Surname		Other Names	
Centre Number		Candidate Number	
Candidate Signature			

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General Certificate of Education
January 2005
Advanced Level Examination

ASSESSMENT and QUALIFICATIONS ALLIANCE

PHYSICS (SPECIFICATION B) PHB4
Unit 4 Further Physics

Wednesday 26 January 2005 Morning Session

In addition to this paper you will require:
- a calculator;
- a ruler.

Time allowed: 1 hour 30 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.
- Do all rough work in this book. Cross through any work you do not want marked.
- All working must be shown, otherwise you may lose marks.
- *Formulae Sheets* are provided on pages 3 and 4. Detach this perforated page at the start of the examination.

Information
- The maximum mark for this paper is 75.
- Mark allocations are shown in brackets.
- You are expected to use a calculator where appropriate.
- 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.

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

Answer **all** questions.

Total for this question: ***12 marks***

1 (a) The equation that describes simple harmonic motion is

$$a = -\omega^2 x.$$

State the meaning of the symbol ω in this equation and go on to explain the significance of the negative sign.

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(2 marks)

(b) **Figure 1a** shows a demonstration used in teaching simple harmonic motion. A sphere rotates in a horizontal plane on a turntable. A lamp produces a shadow of the sphere. This shadow moves with approximate simple harmonic motion on the vertical screen.

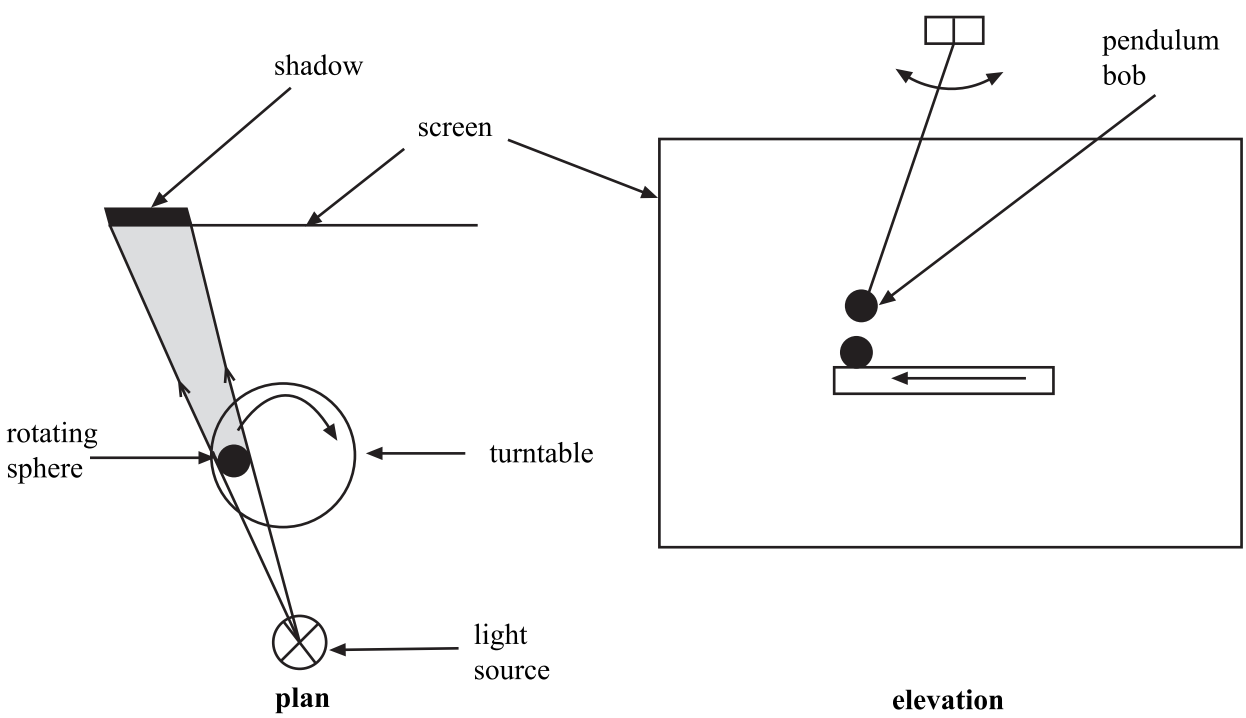


Figure 1a **Figure 1b**

Detach this perforated page at the start of the examination.

Foundation Physics Mechanics Formulae

moment of force $= Fd$

$v = u + at$

$s = ut + \frac{1}{2}at^2$

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

$s = \frac{1}{2}(u + v)t$

for a spring, $F = k\Delta l$

energy stored in a spring $= \frac{1}{2}F\Delta l = \frac{1}{2}k(\Delta l)^2$

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

Foundation Physics Electricity Formulae

$I = nAvq$

terminal p.d. $= E - Ir$

in series circuit, $R = R_1 + R_2 + R_3 + \ldots..$

in parallel circuit, $\dfrac{1}{R} = \dfrac{1}{R_1} + \dfrac{1}{R_2} + \dfrac{1}{R_3} + \ldots..$

output voltage across $R_1 = \left(\dfrac{R_1}{R_1 + R_2}\right) \times$ input voltage

Waves and Nuclear Physics Formulae

fringe spacing $= \dfrac{\lambda D}{d}$

single slit diffraction minimum $\sin\theta = \dfrac{\lambda}{b}$

diffraction grating $n\lambda = d\sin\theta$

Doppler shift $\dfrac{\Delta f}{f} = \dfrac{v}{c}$ for $v << c$

Hubble law $v = Hd$

radioactive decay $A = \lambda N$

Properties of Quarks

Type of quark	Charge	Baryon number
up u	$+\frac{2}{3}e$	$+\frac{1}{3}$
down d	$-\frac{1}{3}e$	$+\frac{1}{3}$
$\bar{u}$	$-\frac{2}{3}e$	$-\frac{1}{3}$
$\bar{d}$	$+\frac{1}{3}e$	$-\frac{1}{3}$

Lepton Numbers

Particle	Lepton number L		
	L_e	L_μ	L_τ
e^-	1		
e^+	–1		
ν_e	1		
$\bar{\nu}_e$	–1		
μ^-		1	
μ^+		–1	
ν_μ		1	
$\bar{\nu}_\mu$		–1	
τ^-			1
τ^+			–1
ν_τ			1
$\bar{\nu}_\tau$			–1

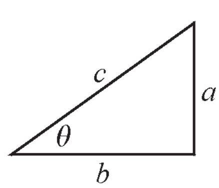
Geometrical and Trigonometrical Relationships

circumference of circle $= 2\pi r$

area of a circle $= \pi r^2$

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

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



$\sin\theta = \dfrac{a}{c}$

$\cos\theta = \dfrac{b}{c}$

$\tan\theta = \dfrac{a}{b}$

$c^2 = a^2 + b^2$

Detach this perforated page at the start of the examination.

Circular Motion and Oscillations

$$v = r\omega$$

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

$$x = A\cos 2\pi f t$$

$$\text{maximum } a = (2\pi f)^2 A$$

$$\text{maximum } v = 2\pi f A$$

$$\text{for a mass-spring system, } T = 2\pi\sqrt{\frac{m}{k}}$$

$$\text{for a simple pendulum, } T = 2\pi\sqrt{\frac{l}{g}}$$

Fields and their Applications

$$\text{uniform electric field strength, } E = \frac{V}{d} = \frac{F}{Q}$$

$$\text{for a radial field, } E = \frac{kQ}{r^2}$$

$$k = \frac{1}{4\pi\varepsilon_0}$$

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

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

$$\text{for point masses, } \Delta E_p = GM_1M_2\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$$

$$\text{for point charges, } \Delta E_p = kQ_1Q_2\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$$

$$\text{for a straight wire, } F = BIl$$

$$\text{for a moving charge, } F = BQv$$

$$\phi = BA$$

$$\text{induced emf} = \frac{\Delta(N\phi)}{t}$$

$$E = mc^2$$

Temperature and Molecular Kinetic Theory

$$T/\text{K} = \frac{(pV)_T}{(pV)_{tr}} \times 273.16$$

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

$$\text{energy of a molecule} = \tfrac{3}{2} kT$$

Heating and Working

$$\Delta U = Q + W$$

$$Q = mc\Delta\theta$$

$$Q = ml$$

$$P = Fv$$

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

$$\text{work done on gas} = p\Delta V$$

$$\text{work done on a solid} = \tfrac{1}{2} F\Delta l$$

$$\text{stress} = \frac{F}{A}$$

$$\text{strain} = \frac{\Delta l}{l}$$

$$\text{Young modulus} = \frac{\text{stress}}{\text{strain}}$$

Capacitance and Exponential Change

$$\text{in series, } \frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2}$$

$$\text{in parallel, } C = C_1 + C_2$$

$$\text{energy stored by capacitor} = \tfrac{1}{2} QV$$

$$\text{parallel plate capacitance, } C = \frac{\varepsilon_0 \varepsilon_r A}{d}$$

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

$$\text{time constant} = RC$$

$$\text{time to halve} = 0.69\,RC$$

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

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

$$\text{half-life, } t_{\frac{1}{2}} = \frac{0.69}{\lambda}$$

Momentum and Quantum Phenomena

$$Ft = \Delta(mv)$$

$$E = hf$$

$$hf = \Phi + E_{k(max)}$$

$$hf = E_2 - E_1$$

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

(i) The turntable has a radius of 0.13 m and the teacher wishes the time taken for one cycle of the motion to be 2.2 s. The mass of the sphere is 0.050 kg.

Calculate the magnitude of the horizontal force acting on the sphere.

(2 marks)

(ii) State the direction in which the force acts.

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(1 mark)

(c) **Figure 1b** shows how the demonstration might be extended. A simple pendulum is mounted above the turntable so that the shadows of the sphere and the pendulum bob can be seen to move in a similar way and with the same period.

(i) Calculate the required length of the pendulum.

acceleration due to gravity = 9.8 m s^{-2}

(1 mark)

(ii) Calculate the maximum acceleration of the pendulum bob when its motion has an amplitude of 0.13 m.

(2 marks)

QUESTION 1 CONTINUES ON THE NEXT PAGE

(d) **Figure 2** includes a graph of displacement against time for the pendulum. Sketch, on the axes below, graphs of

(i) acceleration against time for the bob, and
(ii) kinetic energy against time for the bob.

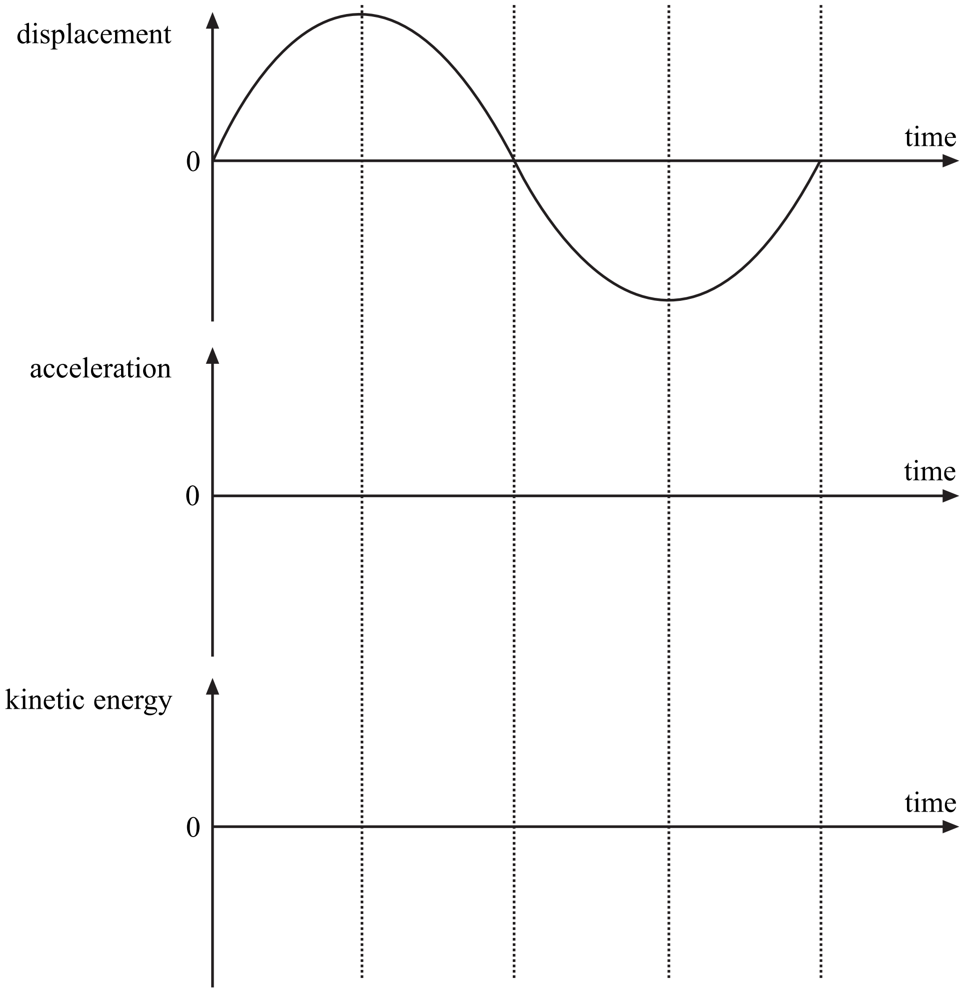

Figure 2

(4 marks)

12

Total for this question: ***9 marks***

2 (a) Explain what is meant by the *principle of conservation of momentum*.

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(2 marks)

(b) A hose pipe is used to water a garden. The supply delivers water at a rate of 0.31 kg s^{-1} to the nozzle which has a cross-sectional area of 7.3×10^{-5} m^2.

(i) Show that water leaves the nozzle at a speed of about 4 m s^{-1}.

density of water = 1000 kg m^{-3}

(2 marks)

(ii) Before it leaves the hose, the water has a speed of 0.68 m s^{-1}. Calculate the force on the hose.

(3 marks)

(iii) The water from the hose is sprayed onto a brick wall the base of which is firmly embedded in the ground. Explain why there is no overall effect on the rotation of the Earth.

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(2 marks)

9

Total for this question: ***15 marks***

3 **Figure 3** shows a capacitor microphone and its associated electrical circuit.

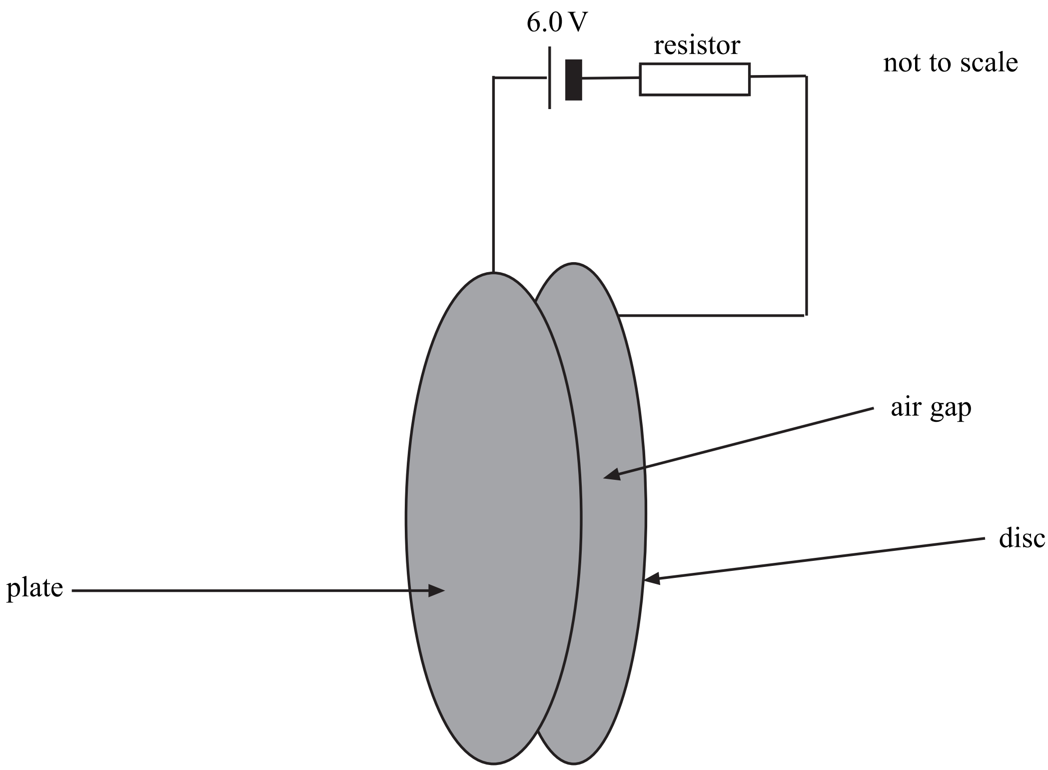

Figure 3

The microphone consists of a thin metal plate placed close to a rigid metal disc. Air-pressure variations cause the plate to move towards and away from the fixed disc when a sound wave is incident on the microphone.

(a) The metal plate has a radius of 2.5 mm and is 4.5 μm from the rigid disc. Show that the capacitance of the microphone is about 40 pF.

permittivity of free space $= 8.9 \times 10^{-12}$ F m^{-1}
relative permittivity of air $= 1.0$

(2 marks)

(b) Explain how the movements of the plate lead to electrical currents in the circuit.
Two of the 6 marks are available for the quality of your written communication.

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(6 marks)

(c) In order to reproduce sound accurately, the time constant due to the microphone capacitance and the total circuit resistance must be less than 15 μs.
Calculate the maximum value that the circuit resistance can have.

(2 marks)

(d) A sound wave causes the distance between disc and plate to increase, changing the capacitance by 0.20 pF. The potential difference across the capacitor is 6.0 V.

(i) Calculate the charge that flows through the power supply.

(2 marks)

QUESTION 3 CONTINUES ON THE NEXT PAGE

Turn over

(ii) Calculate the change in electrical energy stored by the capacitor microphone.

(2 marks)

(iii) State and explain whether energy is being supplied *by* or *to* the power supply whilst the charge in part (d)(i) is flowing.

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(1 mark)

15

Total for this question: ***16 marks***

4 **Figure 4** shows a simplified energy level diagram for the constituents of a helium-neon gas laser.

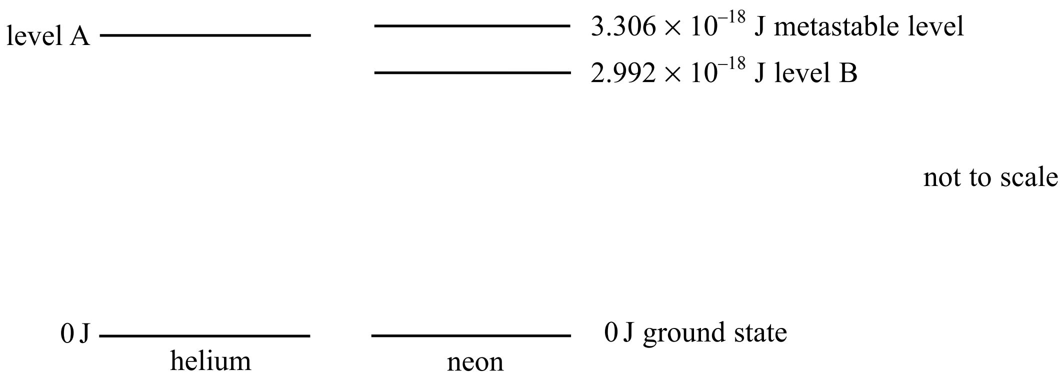

Figure 4

(a) Describe how the device produces laser light.
In your answer you should make clear

- the separate roles of the two gases,
- the meaning of the terms *metastability* and *population inversion*.

Two of the 7 marks are available for the quality of your written communication.

(7 marks)

QUESTION 4 CONTINUES ON THE NEXT PAGE

(b) Show that the frequency of the light emitted by the laser represented in **Figure 4** is about 5×10^{14} Hz.

Planck constant = 6.63×10^{-34} J s

(2 marks)

(c) This light is shone on to a specimen of potassium and a photoelectron is emitted from the metal.

(i) Calculate the maximum speed of emission that this photoelectron can have.

work function of potassium = 2.90×10^{-19} J
mass of electron = 9.11×10^{-31} kg

(3 marks)

(ii) Calculate the corresponding de Broglie wavelength for this electron.

(2 marks)

(iii) The atomic diameter of carbon is about 140 pm. Discuss whether electrons of the de Broglie wavelength you calculated in part (c)(ii) could be used to demonstrate electron diffraction using a thin carbon sheet.

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(2 marks)

16

Total for this question: ***7 marks***

5 (a) Explain the meaning of the statement *the specific heat capacity of ice is* $2100\,J\,kg^{-1}\,K^{-1}$.

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(2 marks)

(b) An engineer is designing an ice-making machine. Water will enter the device at 18°C and the ice cubes are to be cooled to –5°C before release.

(i) Show that about 0.4 MJ of energy must be removed from 1.0 kg of water at 18°C to change it into ice at –5°C.

Set out the stages in your answer clearly.

specific heat capacity of water $= 4.2 \times 10^3\ \text{J kg}^{-1}\ \text{K}^{-1}$
specific heat capacity of ice $= 2.1 \times 10^3\ \text{J kg}^{-1}\ \text{K}^{-1}$
specific latent heat of fusion of ice $= 3.3 \times 10^5\ \text{J kg}^{-1}$

(3 marks)

(ii) The design brief requires that 1.5 kg of water is frozen in 300 s. Calculate the rate at which energy must be removed by the machine.

(2 marks)

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7

Total for this question: *8 marks*

6 **Figure 5** shows a p–V graph that you are to use to illustrate the process of a gas undergoing two changes.
In its initial state, the gas has a pressure of 50 kPa and a volume of 1.5 m^3; this is plotted on the graph.
First, the gas undergoes an isothermal change from an initial volume of 1.5 m^3 to 0.85 m^3 followed by a compression at constant pressure to a volume of 0.35 m^3.

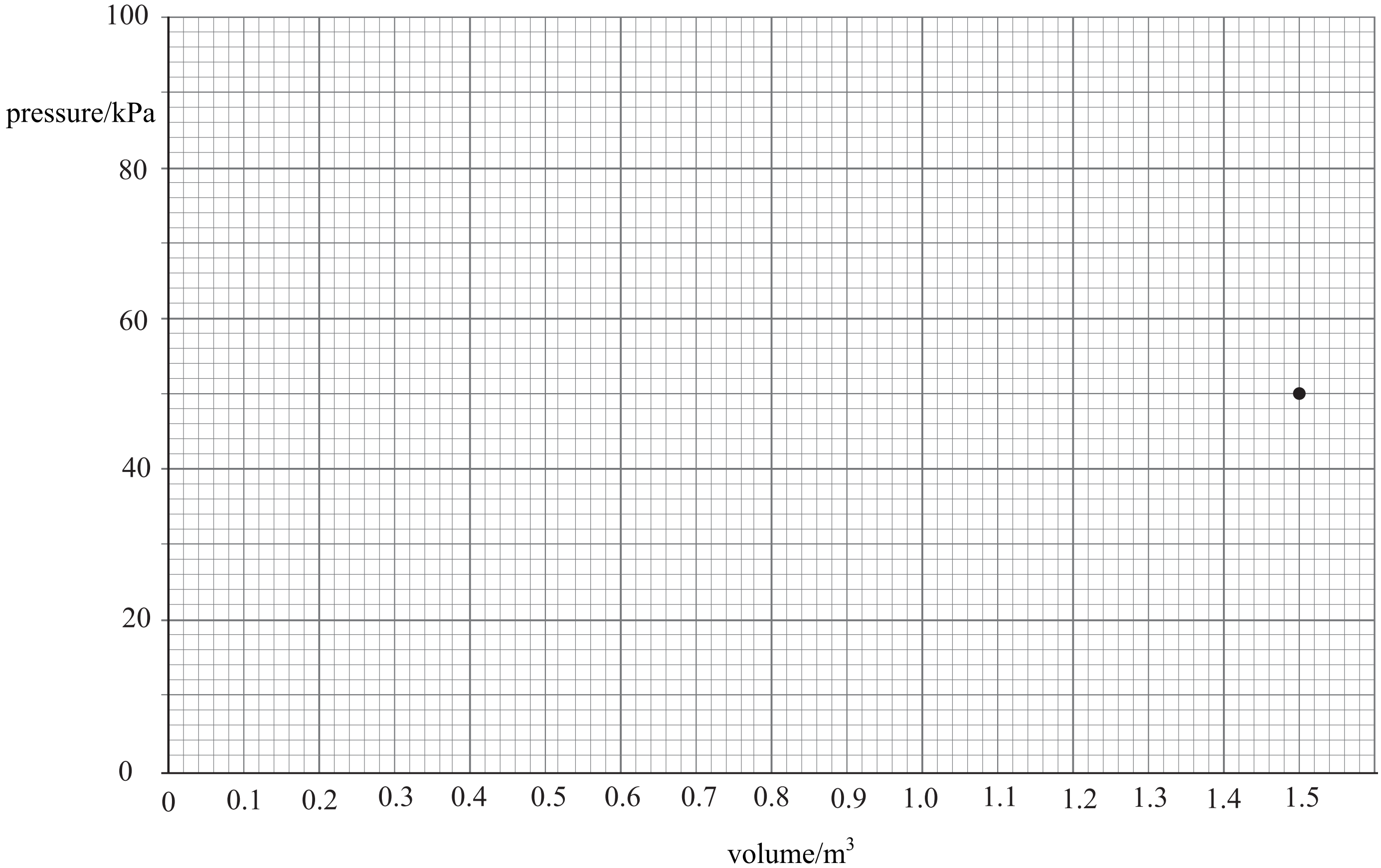

Figure 5

(a) Show that the final pressure of the gas is about 90 kPa.

(2 marks)

(b) Complete the graph in **Figure 5** to show both changes.

(2 marks)

(c) (i) Use your graph to estimate the work done during the whole process.

(3 marks)

(ii) State and explain whether the work in part (c)(i) is done *on* or *by* the gas.

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(1 mark)

8

TURN OVER FOR THE NEXT QUESTION

LEAVE MARGIN BLANK

Total for this question: *8 marks*

7 (a) State **two** assumptions of the kinetic theory of gases.

assumption 1 ....

....

assumption 2 ....

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(2 marks)

(b) Show that the mean kinetic energy of one molecule of an ideal gas at a temperature of 21°C is about 6×10^{-21} J.

Boltzmann constant $= 1.4 \times 10^{-23}$ J K^{-1}

(2 marks)

(c) Explain, in terms of the zeroth law of thermodynamics, why the nitrogen and oxygen molecules in a sample of air have the same mean kinetic energy.

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(2 marks)

(d) Assume that the air behaves as an ideal gas and that the mass of a nitrogen molecule is 5×10^{-26} kg. Estimate the mean square speed of a nitrogen molecule at 21°C.

(2 marks)

8

END OF QUESTIONS