General Certificate of Education
January 2008
Advanced Level Examination

PHYSICS (SPECIFICATION B)   **PHB4**
Unit 4 Further Physics

Monday 21 January 2008   9.00 am to 10.30 am

For this paper you must have:
- a ruler
- a calculator.

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.
- 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 to be marked.
- *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.
- The marks for questions are shown in brackets.
- You are expected to use a calculator where appropriate.
- Questions 1(c) and 4(c) should be answered in continuous prose.
  In these questions you will be marked on your ability to use good English, to organise information clearly and to use specialist vocabulary where appropriate.

PHB4

Answer **all** questions.

1 A rear-view mirror is mounted on the side of a lorry cab. The mirror and its support act as a mass–spring system with the mass m of the mirror attached to a spring of spring constant k.

(a) (i) State and explain the conditions necessary for an object to oscillate with simple harmonic motion.

....

....

....

....

(ii) Show that the mirror will oscillate at an approximate frequency f given by

$$f = 0.16 \sqrt{\frac{k}{m}}$$

(iii) The mirror is displaced from its equilibrium position.
Show that the frequency of oscillation is about 5 Hz.

$m = 2.2\,\text{kg}$
$k = 2.4\,\text{kN}\,\text{m}^{-1}$

(5 marks)

Detach this perforated page at the start of the examination.

<div style="display: flex;">

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 $= \frac{1}{2}F\Delta l = \frac{1}{2}k(\Delta l)^2$

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

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 $\quad n\lambda = d\sin\theta$

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

Hubble law $\quad v = Hd$

radioactive decay $\quad A = \lambda N$

Properties of Quarks

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

Lepton Numbers

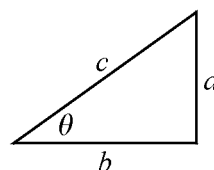| Particle	Lepton number L		
	L_e	L_μ	L_τ
e^-	1		
e^+	-1		
v_e	1		
$\overline{v}_e$	-1		
μ^-		1	
μ^+		-1	
v_μ		1	
$\overline{v}_\mu$		-1	
τ^-			1
τ^+			-1
v_τ			1
$\overline{v}_\tau$			-1

</div>

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 $= \frac{4}{3}\pi r^3$

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

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

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

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

Turn over ▶

Detach this perforated page at the start of the examination.

Circular Motion and Oscillations

$$v = r\omega$$

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

$$x = A\cos 2\pi ft$$

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

$$\text{maximum } v = 2\pi fA$$

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

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

Fields and their Applications

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

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

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

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

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

$$\text{for point masses, } \Delta E_p = GM_1 M_2\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$$

$$\text{for point charges, } \Delta E_p = kQ_1 Q_2\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$$

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

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

$$\phi = BA$$

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

$$E = mc^2$$

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

$$Ft = \Delta(mv)$$

$$E = hf$$

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

$$hf = E_2 - E_1$$

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

(b) The mirror oscillates vertically with simple harmonic motion of amplitude 12 mm.

(i) Calculate the acceleration of the mirror when it is at its maximum vertical displacement.

(ii) State and explain what happens to a small object resting on the upper edge of the mirror when undergoing this maximum vertical displacement.

acceleration due to gravity = $9.8\,\mathrm{m\,s^{-2}}$

....

....

....

....

(5 marks)

Question 1 continues on the next page

Turn over ▶

(c) At low engine speeds, the driver finds that the amplitude of oscillation of the mirror is too great to allow a clear view behind. However, at higher engine speeds the mirror and its image are steady.

Explain how this difference arises and suggest how the designer of the mirror system might minimize this problem. Include a sketch graph of amplitude of mirror vibration against frequency to illustrate your answer.
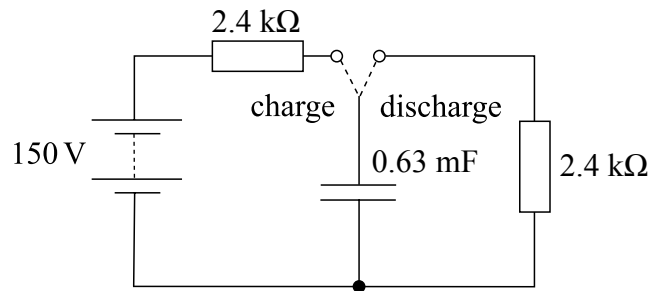
Two of the 6 marks are for the quality of your written communication.

....

....

....

....

....

....

....

....

....

....

....

(6 marks)

16

2 **Figure 1** shows a circuit containing a capacitor that can be charged and discharged.

Figure 1

(a) The capacitor has a capacitance of $0.63\,\text{mF}$ and the resistance in the discharge circuit is $2.4\,\text{k}\Omega$.

(i) Calculate the time constant of the discharge circuit.

(ii) Show that it takes about $3\,\text{s}$ to discharge the capacitor from $120\,\text{V}$ to $15\,\text{V}$.

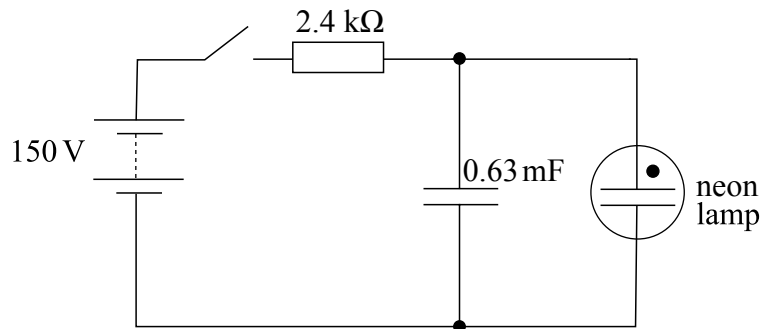*(4 marks)*

Question 2 continues on the next page

Turn over ▶

(b) **Figure 2** shows a neon lamp connected across the capacitor. The circuit is designed to make the lamp flash on and off.

Figure 2

When the switch is closed, the capacitor charges through the $2.4\,\text{k}\Omega$ resistor.
The lamp only conducts and emits light when the potential difference across it reaches $120\,\text{V}$. The lamp then continues to conduct and emit light until the potential difference across it drops to $15\,\text{V}$.

(i) Calculate the energy stored by the capacitor at the instant before the lamp begins to conduct.

(ii) When the lamp is lit it transfers energy at the average rate of $40\,\text{W}$. Calculate the time for which the lamp is alight.

(4 marks)

(c)   Sketch on the axes below the graph of potential difference across the lamp against time for **one** charge-discharge cycle for the circuit. Include on the axes any numerical values that you can deduce about the charge-discharge cycle.

You may assume that whilst it is lit the neon lamp behaves as a resistor of constant value. The time to charge the capacitor from 15 V to 120 V through a 2.4 kΩ resistor is the same as the time to discharge it from 120 V to 15 V through a resistor of the same value.
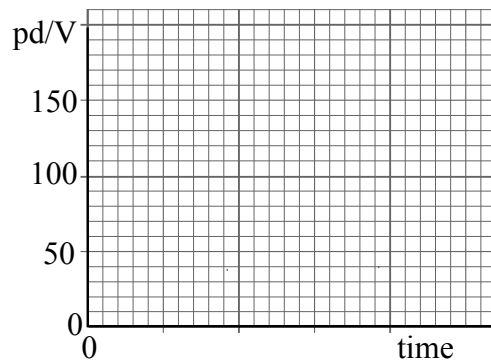
(3 marks)

11

Turn over for the next question

Turn over ▸

3 (a) One form of Newton's second law of motion is

$$Ft = \Delta(mv)$$

(i) State the name given to the product *Ft*.

....

(ii) What does the term $\Delta(mv)$ represent?

....

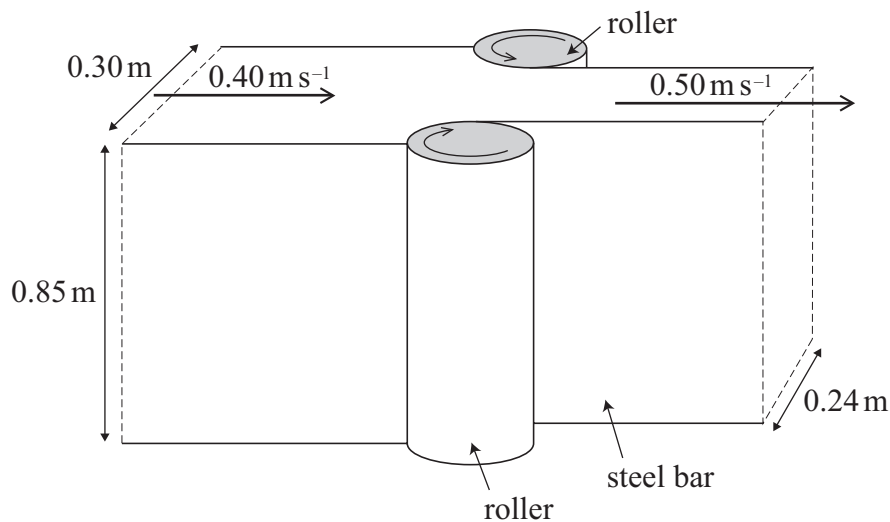..

(2 marks)

(b) **Figure 3** shows a steel bar being reduced in thickness as it moves between two rollers.

Figure 3

The steel is fed into the rollers at a speed of $0.40\,\mathrm{m\,s^{-1}}$ and emerges at $0.50\,\mathrm{m\,s^{-1}}$. The thickness of the metal is reduced from $0.30\,\mathrm{m}$ to $0.24\,\mathrm{m}$ and the width of the metal remains constant at $0.85\,\mathrm{m}$.

(i) Show that about $800\,\mathrm{kg}$ of steel moves through the rollers in each second.

density of steel $= 8200\,\mathrm{kg\,m^{-3}}$

(ii)   Calculate the change in momentum of the steel that passes through the rollers in each second.

(iii)   State the magnitude of the force that acts on the rollers due to the change in momentum of the steel and state the direction in which this force acts.

(5 marks)

(c)   The rolling of an 800 kg steel bar is carried out at a high temperature. Before rolling it is heated in a furnace for 3.0 hours to raise its temperature from 20 °C to 1210 °C.

Calculate the average rate at which the furnace must supply energy to the metal.

specific heat capacity of steel $= 440 \, \mathrm{J\,kg^{-1}K^{-1}}$
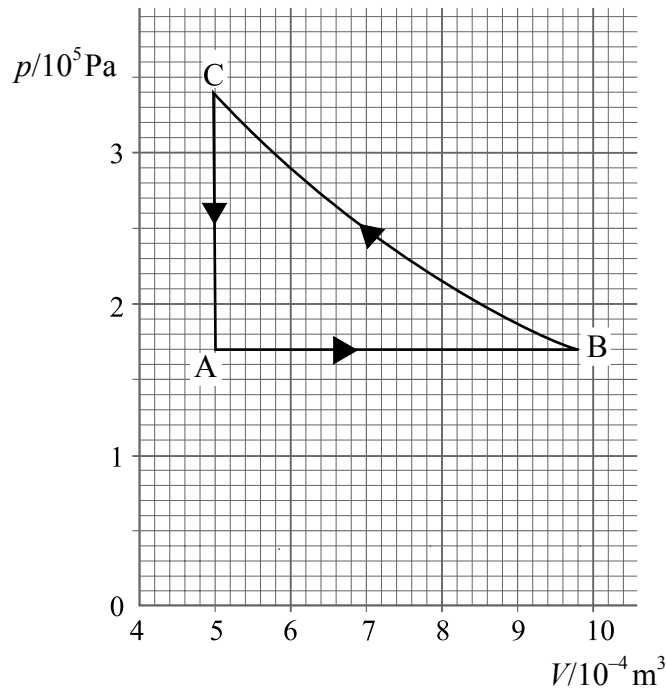
(3 marks)

10

Turn over ▶

4 A fixed mass of an ideal gas is subject to a cycle of changes **ABCA**. **Figure 4** shows a graph of pressure p against volume V for one cycle of changes for the gas.

Figure 4

(a) (i) Use data from the graph to confirm that change **BC** is isothermal. Make your working clear.

(ii) State and explain how you would attempt to ensure experimentally that the change **BC** is isothermal.

....

....

....

....

(5 marks)

(b) The temperature of the gas at point **C** is 385 K.
Calculate the temperature of the gas in ºC at point **A**.

(3 marks)

(c) Discuss how the first law of thermodynamics applies to the gas during the change **CA**.

Two of the 5 marks are for the quality of your written communication.

....

....

....

....

....

....

....

....

....

....
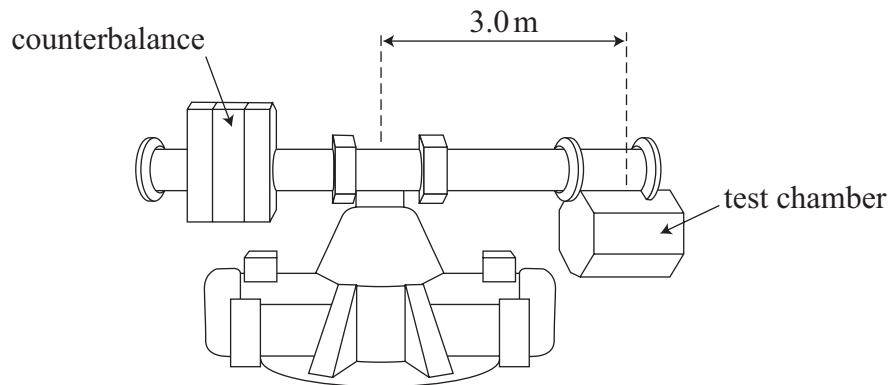
(5 marks)

(d) During the change AB, 420 J of energy is supplied by heating the gas.
Calculate the change in internal energy of the gas.

(3 marks)

16

Turn over ▶

5 A centrifuge is a machine that can spin at high speed to help study how large forces affect objects.

Figure 5

Figure 5 shows a centrifuge used for carrying out tests on models of buildings. The models are placed in a test chamber mounted at the end of one arm of the centrifuge.

(a) (i) The maximum rotational speed of the centrifuge is 260 revolutions per minute. Show that the maximum angular speed of the centrifuge is about $30 \, \text{rad s}^{-1}$.

(ii) The centre of the test chamber is $3.0 \, \text{m}$ from the axis of rotation. Calculate the acceleration of an object placed at the centre of the test chamber when the centrifuge is rotating at its maximum angular speed.

(iii) The total mass of the test chamber and sample is 140 kg. You may assume that the chamber and sample act as a single point mass located 3.0 m from the axis of rotation.

Show that, when the centrifuge is rotating at its maximum angular speed, the force acting on this total mass is about 300 kN.

(5 marks)

(b) The test chamber of total mass 140 kg is connected to the central motor of the centrifuge by a steel rod. The rod has a length of 2.8 m and a cross-sectional area of 0.21 m^2.

(i) Calculate the change in length of the steel rod when the centrifuge is rotating at its maximum speed.
Young modulus of steel = 1.6×10^{11} Pa

(ii) Calculate the elastic strain energy stored in the metal rod under these conditions.

(4 marks)

(c) **Figure 5** shows that a counterbalance is attached to the arm of the centrifuge opposite to the test chamber. Explain why a counterbalance is necessary for the safe operation of the machine.
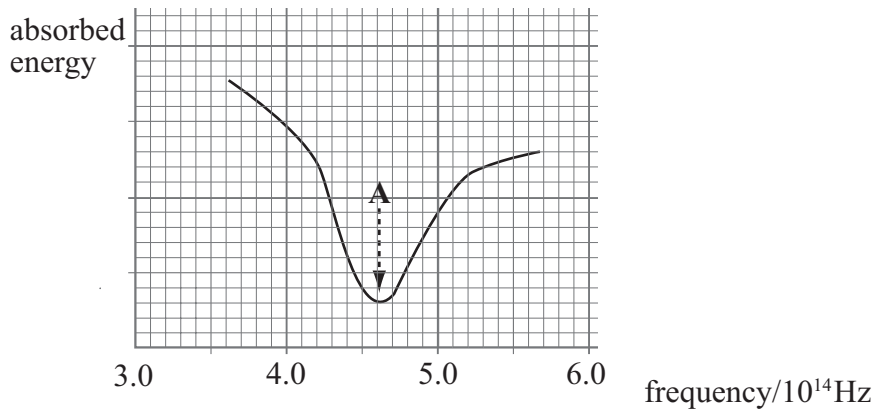
....

....

....

....

....

....

(3 marks)

12

Turn over ▶

6 When electromagnetic radiation passes through hydrogen gas, some of the frequencies of the radiation are absorbed. **Figure 6** shows part of the absorption spectrum with a pronounced absorption shown at point **A**.
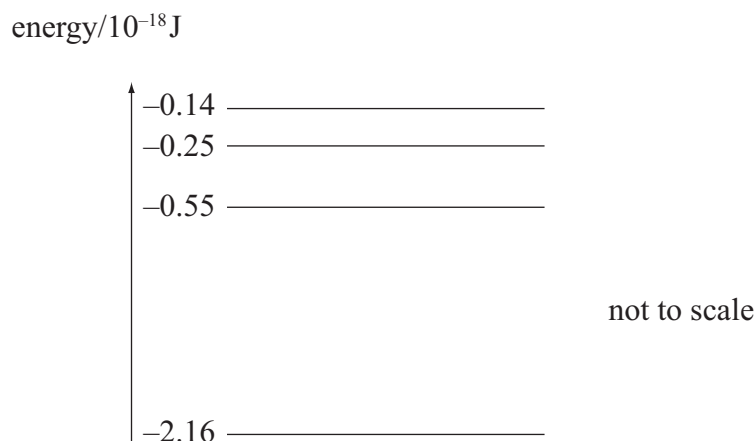
Figure 6

(a) Show that an absorbed photon with a frequency corresponding to point **A** on the graph has an energy of about $3 \times 10^{-19}\,\text{J}$.

Planck constant $= 6.6 \times 10^{-34}\,\text{J s}$

(2 marks)

(b) **Figure 7** shows part of the electron energy level diagram for a hydrogen atom.

Figure 7

energy/$10^{-18}\,\text{J}$

not to scale

−0.14
−0.25
−0.55

−2.16

On the diagram, draw a line to show the transition that occurs when an atom absorbs a photon of about $3 \times 10^{-19}\,\text{J}$. *(1 mark)*

(c) In a simple model for the hydrogen atom, the electron must exist between the proton and the edge of the atom. The electron is effectively trapped in a box of length r where r is the radius of the atom. The model suggests that the de Broglie stationary wave for the electron in the lowest energy level may be drawn as shown in **Figure 8**.

Figure 8
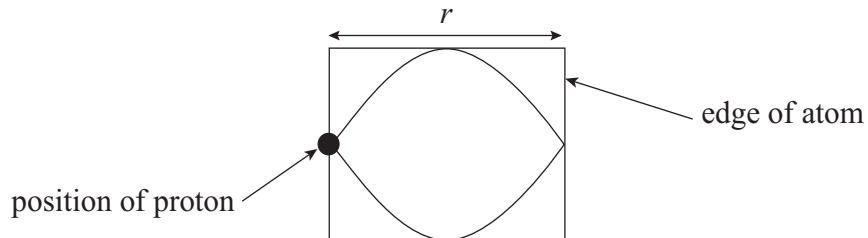
 (i) Draw the stationary wave pattern that corresponds to an energy one level higher than the lowest energy level shown in **Figure 8**.

 (ii) Explain the significance of the amplitude of the wave in these stationary wave diagrams.

....

....

....

....

(3 marks)

Question 6 continues on the next page

Turn over ▶

(d) The kinetic energy, E_k, of the electron can be written as

$$E_k = \frac{p^2}{2m}$$

where m is the mass of the electron and p is its momentum.

(i) Calculate the de Broglie wavelength of an electron with a kinetic energy of 2.16×10^{-18} J.

mass of the electron $= 9.1 \times 10^{-31}$ kg
Planck constant $= 6.6 \times 10^{-34}$ J s

(ii) Assume that the electron in the lowest energy state has a kinetic energy of 2.16×10^{-18} J and that this kinetic energy does not vary with electron position.

Use the de Broglie wavelength from part (d)(i) to estimate the radius of the atom, r, in the lowest energy state.

Planck constant $= 6.6 \times 10^{-34}$ J s

(4 marks)

10

END OF QUESTIONS

There are no questions printed on this page

There are no questions printed on this page