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93103

NEW ZEALAND QUALIFICATIONS AUTHORITY
MANA TOHU MĀTAURANGA O AOTEAROA

Scholarship 2006
Physics

9.30 am Friday 1 December 2006
Time allowed: Three hours
Total marks: 48

Check that the National Student Number (NSN) on your admission slip is the same as the number at the top of this page.

Answer ALL questions.

Write all your answers in this booklet.

For all 'describe' or 'explain' questions, the answers should be written or drawn clearly with all logic fully explained.

For all numerical answers, full working must be shown and the answer must be rounded to the correct number of significant figures and given with an SI unit.

Formulae you may find useful are given on page 2.

If you need more space for any answer, use the page(s) provided at the back of this booklet and clearly number the question.

Check that this booklet has pages 2–20 in the correct order.

You are advised to spend approximately 30 minutes on each question.

YOU MUST HAND THIS BOOKLET TO THE SUPERVISOR AT THE END OF THE EXAMINATION.

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The formulae below may be of use to you.

$F_g = \frac{GMm}{r^2}$ $F_c = \frac{mv^2}{r}$ $\Delta p = F\Delta t$ $\omega = 2\pi f$ $d = r\theta$ $v = r\omega$ $a = r\alpha$ $W = Fd$ $F_{net} = ma$ $p = mv$ $\omega = \frac{\Delta\theta}{\Delta t}$ $\alpha = \frac{\Delta\omega}{\Delta t}$ $L = I\omega$ $L = mvr$ $\tau = I\alpha$ $\tau = Fr$ $E_{K(ROT)} = \frac{1}{2}I\omega^2$ $E_{K(LIN)} = \frac{1}{2}mv^2$ $\Delta E_p = mgh$ $\omega_f = \omega_i + \alpha t$ $\omega_f^2 = \omega_i^2 + 2\alpha\theta$ $\theta = \frac{(\omega_i + \omega_f)t}{2}$ $\theta = \omega_i t + \frac{1}{2}\alpha t^2$	$T = 2\pi\sqrt{\frac{l}{g}}$ $T = 2\pi\sqrt{\frac{m}{k}}$ $E_p = \frac{1}{2}ky^2$ $F = -ky$ $a = -\omega^2 y$ $y = A\sin\omega t$ $y = A\cos\omega t$ $v = A\omega\cos\omega t$ $v = -A\omega\sin\omega t$ $a = -A\omega^2\sin\omega t$ $a = -A\omega^2\cos\omega t$ $\Delta E = Vq$ $P = VI$ $V = Ed$ $Q = CV$ $C_T = C_1 + C_2$ $\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2}$ $E = \frac{1}{2}QV$ $C = \frac{\varepsilon_o \varepsilon_r A}{d}$ $\tau = RC$ $\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2}$ $R_T = R_1 + R_2$ $V = IR$ $F = BIL$	$\phi = BA$ $\varepsilon = -\frac{\Delta\phi}{\Delta t}$ $\varepsilon = -L\frac{\Delta I}{\Delta t}$ $\varepsilon = -M\frac{\Delta I}{\Delta t}$ $\frac{N_p}{N_s} = \frac{V_p}{V_s}$ $E = \frac{1}{2}LI^2$ $\tau = \frac{L}{R}$ $I = I_{MAX}\sin\omega t$ $V = V_{MAX}\sin\omega t$ $I_{MAX} = \sqrt{2}\,I_{rms}$ $V_{MAX} = \sqrt{2}\,V_{rms}$ $X_C = \frac{1}{\omega C}$ $X_L = \omega L$ $V = IZ$ $n\lambda = \frac{dx}{L}$ $n\lambda = d\sin\theta$ $f' = f\frac{V_W}{V_W \pm V_S}$ $E = hf$ $hf = \phi + E_K$ $E = \Delta mc^2$ $\frac{1}{\lambda} = R\left(\frac{1}{S^2} - \frac{1}{L^2}\right)$ $E_n = -\frac{hcR}{n^2}$ $v = f\lambda$ $f = \frac{1}{T}$

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QUESTION ONE: NUCLEAR AND QUANTUM PHYSICS (8 marks)

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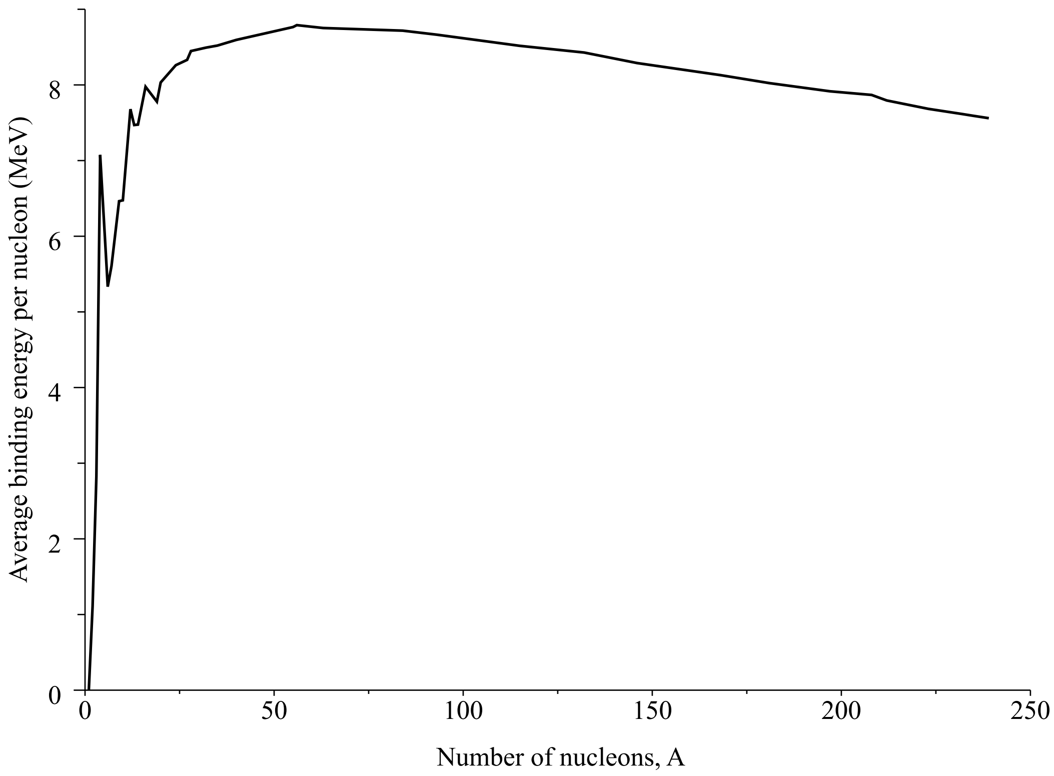
Planck's constant = 6.63×10^{-34} J s
Speed of light = 3.00×10^{8} m s^{-1}
Mass of the electron = 9.11×10^{-31} kg
Charge on the electron = -1.60×10^{-19} C



(a) By considering the above graph, discuss the relative stability of nuclei. Reference should be made to physical processes such as fission and fusion, and how the binding energy relates to Albert Einstein's equation $E = \triangle mc^2$.

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In 1923, Louis de Broglie stated that, "Because photons have wave and particle characteristics, perhaps all forms of matter have wave as well as particle properties." De Broglie suggested that particles of momentum p should also have wave properties and a wavelength of $\lambda = \frac{h}{p}$ where λ is the de Broglie wavelength and h is Planck's constant.

(b) Experiments involving electron diffraction show that the de Broglie hypothesis is correct. In one particular experiment a beam of electrons, accelerated by a potential difference $V = 1.00 \times 10^4$ V, is incident on a two-slit barrier with a slit separation of $d = 50.0$ nm.

(i) Find the distance between two adjacent maxima of the diffraction pattern on the screen, which is 1.00 m from the two-slit barrier.

Einstein's special theory of relativity states that the momentum of a particle with velocity, v, changes by the factor $\frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$.

(ii) Does relativity have a measurable effect on the diffraction result, given that the experimental uncertainty in the distance between maxima is $\pm 5\%$? Explain.

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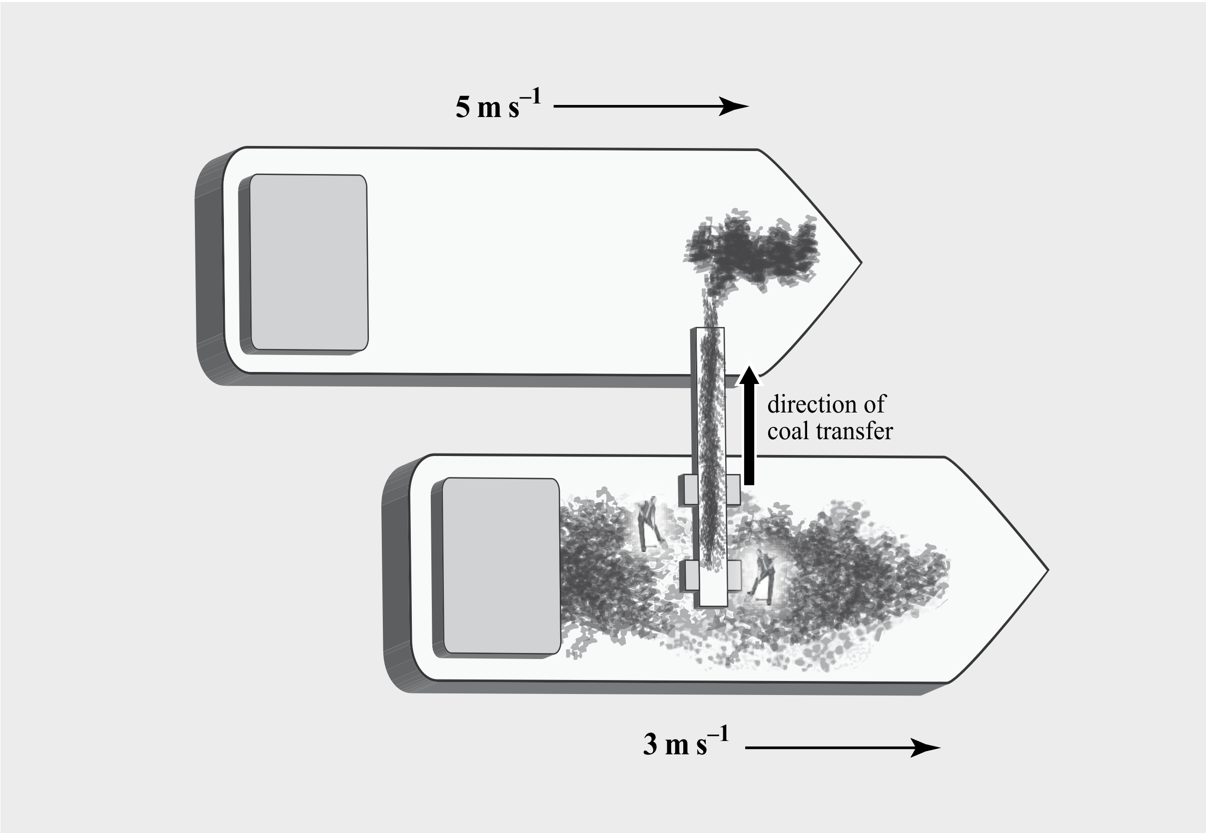
QUESTION TWO: MECHANICS (8 marks)

Acceleration due to gravity = 9.80 m s^{-2}

(a) Two long barges are moving in the same direction in still water, one with a speed of 3 m s^{-1}, and the other with a speed of 5 m s^{-1}. While they are passing each other, coal is transferred from the slower barge to the faster one at a rate of 20 kg s^{-1}.

How much additional force, if any, must be provided by the engines of each of the barges if neither barge is to change speed?

Assume that the transfer is always **perfectly sideways** and that the frictional forces remain constant.



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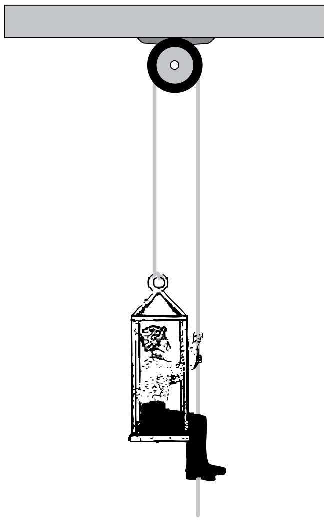
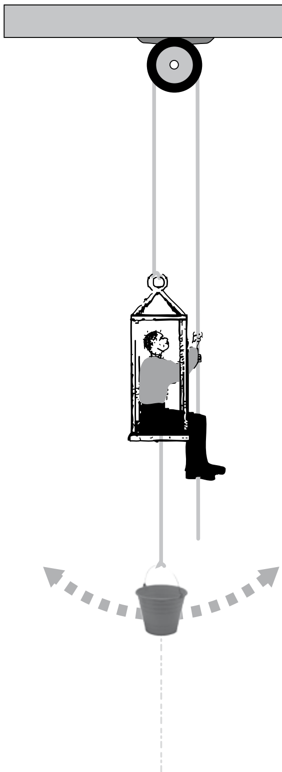
(b) A window cleaner sitting in a cage is supported by a rope and pulley system. The combined mass of the window cleaner and cage is 115 kg.

Calculate the magnitude of the force required to be exerted by the window cleaner on the rope in order for the cage to rise with constant velocity. Ignore friction and the mass of the pulley and rope.



(c) Another window cleaner has a bucket full of water, which is suspended from his cage by a rope. The bucket is set in motion and swings as a pendulum. However, there is a hole in the bottom of the bucket, and the water slowly drains away.

Describe how the period of the swinging motion changes as the bucket goes from full to empty.



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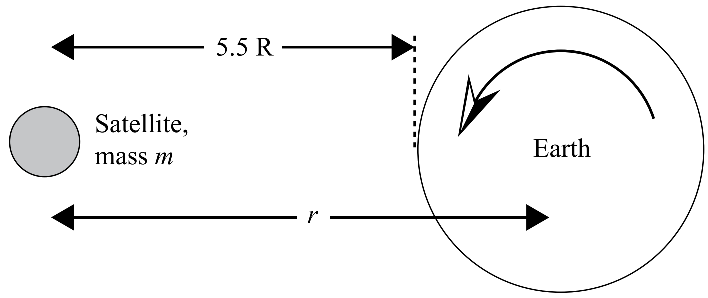
QUESTION THREE: ROTATION (8 marks)

Radius of the Earth = 6.37×10^{6} m

Mass of the Earth = 5.98×10^{24} kg

Universal gravitational constant = 6.67×10^{-11} N m^2 kg^{-2}

(a) Geosynchronous satellites have an orbital period equal to the period of the Earth's rotation about its axis. They are positioned approximately 5.5 × radius of the Earth (R) above the surface of the Earth.
The following is an attempt to prove this using the laws of mechanics.



For the satellite

$$m\omega^2 r = mg$$

$$therefore\ \ \omega = \sqrt{\frac{g}{r}}$$

$$hence\ \ T = \frac{2\pi}{\omega} = 2\pi\sqrt{\frac{r}{g}} = 2\pi\sqrt{\frac{6.5\,R}{g}}$$

$$\approx 2\pi\sqrt{\frac{6.5 \times 6.4 \times 10^6}{9.8}} \approx 1.3 \times 10^4\,s$$

Find the mistake in the working above, and calculate the correct answer with the correct working.

(b) Satellite TV uses geosynchronous satellites as transmitters.

Explain why satellite TV dishes on people's homes all point towards the same place in the sky.

(c) Imagine that the Earth-satellite system were shrunk so that the distance between the centre of the Earth and the satellite were 1 m. However, even though the sizes of the Earth and the satellite have been reduced, their densities (mass / volume) remain unchanged.

How would the period of the satellite's orbit be affected?

Assume that the Earth and the satellite are spheres of uniform densities.

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

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QUESTION FOUR: INTERFERENCE (8 marks)

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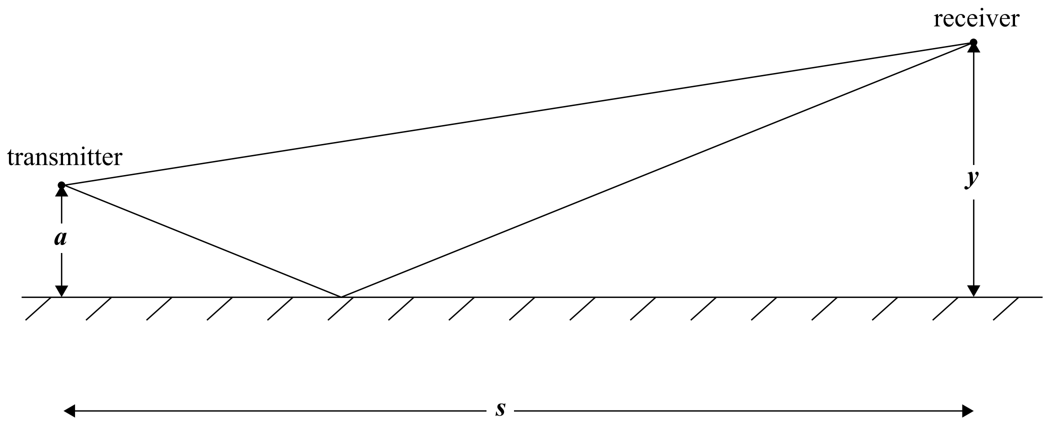
Kate and Tim are using a small ultrasound transmitter to investigate reflection from various surfaces. When the ultrasound beam is at a grazing incidence to the bench, they measure points of lower and higher intensity as the detector is moved vertically upwards. The transmitter is 5.00 cm above the bench. The transmitted ultrasound has a wavelength of 8.50 mm and the horizontal distance between the transmitter and detector is 1.00 m.

In analysing their experiment Kate and Tim assume the following:

- That two beams can be drawn – one directly from the transmitter and one originating from the transmitter but reflected from the bench top.
- That the beam reflected from the bench top experiences no change in phase as it is reflected from the bench top.

A diagram showing the setup Kate and Tim used is shown below.



(a) Explain why fluctuations in sound intensity occur as the detector is moved upwards from the bench surface.

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(b) Explain why you would expect a local maximum to be observed at the surface of the bench top.

(c) Derive a relationship between the variables ***y***, ***s*** and ***a***, for points of constructive interference. (Hint: Construct a model similar to that of Young's two-slit experiment.)

(d) If the ultrasound transmitter is replaced by a suitable light source, the interference pattern changes with a minimum being observed when a detector is very close to the table surface.

Suggest a reason for this.

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QUESTION FIVE: CAPACITANCE (8 marks)

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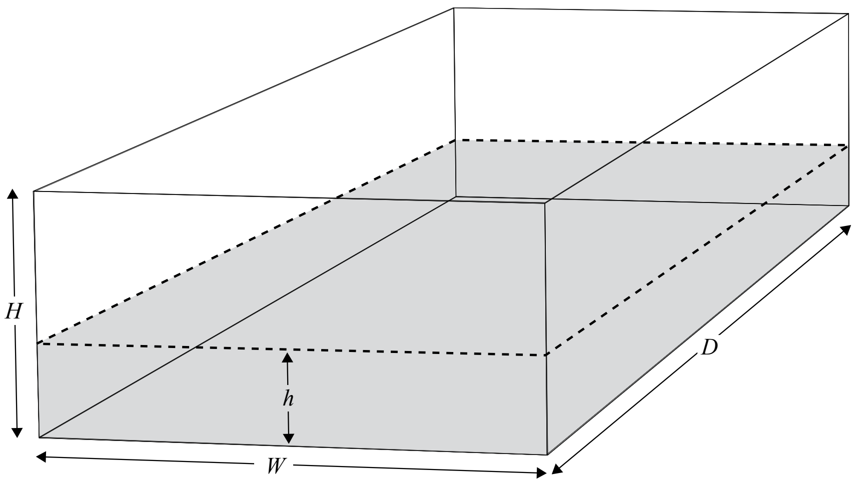
Permittivity of free space = 8.85×10^{-12} F m^{-1}

The liquid level in a tank can be measured without the need for direct observation.



(a) The liquid in the tank has a dielectric constant of $\varepsilon_r = 95$. Show that for a liquid depth, h, the capacitance between the front and rear of the tank is

$$C = \frac{\varepsilon_0 W}{D}(94h + H)$$

(b) Calculate the capacitance of the tank when empty **and** when completely full, given that $W = 1.80\,\text{m}$, $D = 2.90\,\text{m}$ and $H = 0.860\,\text{m}$.

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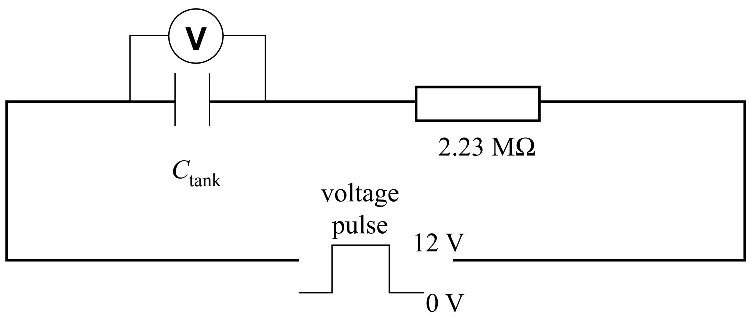
One method to monitor the level of the tank uses a radio transmitter. The transmitted frequency is the resonant frequency of an RLC circuit, where C is the capacitance of the tank, and L is the inductance added to the circuit.

(c) Show that the range of resonant frequencies for an inductance of 2.03 μH lies between 5.27 MHz and 51.4 MHz.

A second method for measuring the fluid depth is based on an RC circuit, to which a voltage pulse of 30 μs duration is applied.



(d) Describe how this circuit allows the fluid depth to be determined.

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QUESTION SIX: FARADAY'S LAW (8 marks)

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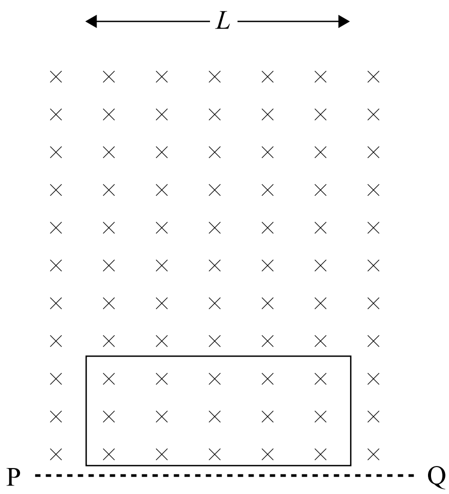
(a) Faraday's law can be written as $\varepsilon = -\frac{\Delta \phi}{\Delta t}$.

Explain the meaning of all the terms (including the negative sign) in this equation.

A long rectangular conducting loop, of length *L*, resistance *R* and mass *m*, is hung vertically in a horizontal, uniform magnetic field *B*, as shown. The magnetic field exists only above line PQ.



(b) When this loop is dropped, it initially accelerates, then reaches a constant velocity, and finally falls freely under the influence of gravity. Explain.

(c) By considering the forces on the loop, show that the constant velocity reached by the loop is

$$v = \frac{mgR}{B^2 L^2}$$

(d) When the loop is falling at constant velocity, show that the power expended by the force due to gravity equals the rate of electrical heat generation in the loop.

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(8)

Extra paper for continuation of answers if required.
Clearly number the question.

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Question Number	Marks
Q1	(8)
Q2	(8)
Q3	(8)
Q4	(8)
Q5	(8)
Q6	(8)
TOTAL	(48)

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