For Supervisor's use only

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NEW ZEALAND QUALIFICATIONS AUTHORITY
MANA TOHU MĀTAURANGA O AOTEAROA

New Zealand Scholarship
Physics, 2004

9.30 am Friday 19 November 2004

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

You should answer ALL the questions 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 pages provided at the back of this booklet and clearly number the question.

Check that this booklet has pages 2–28 in the correct order and that none of these pages is blank.

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

For Assessor's use only **Outcome Description**

The student will abstract relevant information from physical situations in order to solve complex problems and give clear explanations or analyses.

Scholarship Criteria

The student will:

- give concise explanations or analyses in terms of phenomena, concepts, principles and/or relationships that show clear understanding.
- abstract the relevant concepts and/or principles from physical situations and integrate these in the solution of complex problems.

Scholarship with Outstanding Performance Criteria

In addition to meeting the criteria for Scholarship, the student will:

- demonstrate explanations, analyses and problem solutions that consistently reflect exceptionally clear thinking together with depth and breadth of conceptual understanding.

Overall Level of Performance

The formulae below may be of use to you:

$F_g = \dfrac{GMm}{r^2}$

$F_c = \dfrac{mv^2}{r}$

$\Delta p = F\Delta t$

$\omega = 2\pi f$

$d = r\theta$

$v = r\omega$

$a = r\alpha$

$W = Fd$

$F_{net} = ma$

$p = mv$

$\omega = \dfrac{\Delta\theta}{\Delta t}$

$\alpha = \dfrac{\Delta\omega}{\Delta t}$

$L = I\omega$

$L = mvr$

$\tau = I\alpha$

$\tau = Fr$

$E_{K(ROT)} = \frac{1}{2}I\omega^2$

$E_{K(LIN)} = \frac{1}{2}mv^2$

$\Delta E_p = mgh$

$\omega_f = \omega_i + \alpha t$

$\omega_f^2 = \omega_i^2 + 2\alpha\theta$

$\theta = \dfrac{(\omega_i + \omega_f)t}{2}$

$\theta = \omega_i t + \frac{1}{2}\alpha t^2$

$T = 2\pi\sqrt{\dfrac{l}{g}}$

$T = 2\pi\sqrt{\dfrac{m}{k}}$

$E_p = \frac{1}{2}ky^2$

$F = -ky$

$a = -\omega^2 y$

$y = A\sin\omega t$ $\quad$ $y = A\cos\omega t$

$v = A\omega\cos\omega t$ $\quad$ $v = -A\omega\sin\omega t$

$a = -A\omega^2\sin\omega t$ $\quad$ $a = -A\omega^2\cos\omega t$

$\Delta E = Vq$

$P = VI$

$V = Ed$

$Q = CV$

$C_T = C_1 + C_2$

$\dfrac{1}{C_T} = \dfrac{1}{C_1} + \dfrac{1}{C_2}$

$E = \frac{1}{2}QV$

$C = \dfrac{\varepsilon_o\varepsilon_r A}{d}$

$\tau = RC$

$\dfrac{1}{R_T} = \dfrac{1}{R_1} + \dfrac{1}{R_2}$

$R_T = R_1 + R_2$

$V = IR$

$\phi = BA$

$\varepsilon = -\dfrac{\Delta\phi}{\Delta t}$

$\varepsilon = -L\dfrac{\Delta I}{\Delta t}$

$\varepsilon = -M\dfrac{\Delta I}{\Delta t}$

$\dfrac{N_p}{N_s} = \dfrac{V_p}{V_s}$

$E = \frac{1}{2}LI^2$

$\tau = \dfrac{L}{R}$

$I = I_{MAX}\sin\omega t$

$V = V_{MAX}\sin\omega t$

$I_{MAX} = \sqrt{2}\,I_{rms}$

$V_{MAX} = \sqrt{2}\,V_{rms}$

$X_C = \dfrac{1}{\omega C}$

$X_L = \omega L$

$V = IZ$

$n\lambda = \dfrac{dx}{L}$

$n\lambda = d\sin\theta$

$f' = f\dfrac{V_W}{V_W \pm V_S}$

$E = hf$

$hf = \phi + E_K$

$E = \Delta mc^2$

$\dfrac{1}{\lambda} = R\left(\dfrac{1}{S^2} - \dfrac{1}{L^2}\right)$

$E_n = -\dfrac{hcR}{n^2}$

$\upsilon = f\lambda$

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

You have three hours to answer the questions in this booklet.

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SECTION A – SHORT QUESTIONS

You are advised to spend no more than 10 minutes on any one question in this section, or a maximum of 60 minutes on Section A.

QUESTION ONE

Speed of light	$= 3.00 \times 10^{8}$ m s^{-1}
1 amu	$= 1.661 \times 10^{-27}$ kg
Mass of $^{210}_{84}Po$	= 209.983 amu
Mass of $^{206}_{82}Pb$	= 205.974 amu
Mass of an alpha particle	= 4.003 amu

Polonium 210 decays to lead 206 by emitting an alpha particle.

(i) Using the data supplied above calculate the energy change associated with this decay.

energy change = ____________________

(ii) Assuming that the polonium atom was at rest before decaying, calculate what fraction of the energy available from the decay process is gained by the alpha particle.

fraction = ____________________

QUESTION TWO

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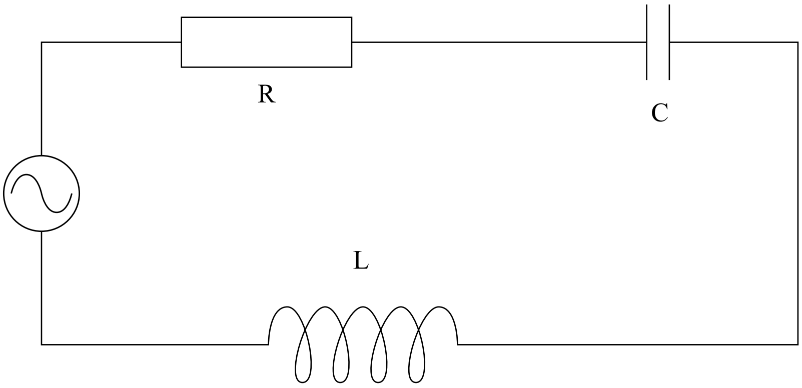
Explain what is meant by the term **wave–particle duality**, provide a description of experimental evidence supporting the wave nature of light, and a further description supporting the particle nature of light.

QUESTION THREE

An LCR series circuit is connected to an AC voltage source as shown below:



The voltages across all the components in the circuit above are measured and the following data is obtained:

Circuit component:	**AC source**	**Inductor**	**Resistor**	**Capacitor**
Voltage (V_{RMS})	12.0	15.0	7.2	5.4

On reviewing the data it was argued that the voltmeter was faulty because the inductor voltage was larger than the source voltage.

Is the voltmeter faulty? Defend your point of view.

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QUESTION FOUR

A hammer thrower launches a heavy ball on the end of a fixed length of wire by rotating his body about a vertical axis as shown in the illustration below:

(i) Assuming the ball is moving at a constant speed in a horizontal circle, explain why the wire from the thrower's hands to the ball cannot be parallel to the ground.

(ii) Explain how the hammer thrower is able to increase the speed of the ball as he winds up for the throw.

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QUESTION FIVE

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A student is sitting on a spinning stool with her arms crossed across her chest and holding a heavy mass in each hand. Explain carefully what changes (if any) will occur to her angular velocity in each of the following situations:

(i) Still holding the masses, the student extends her arms slowly.

(ii) With her arms extended, the student drops one of the masses.

QUESTION SIX

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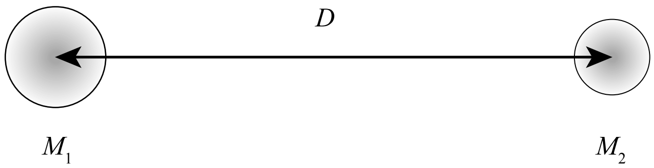
A binary star consists of two stars of masses M_1 and M_2 separated by a distance D and both rotate about their stationary centre of mass.



(i) Express the distance, r, of the star of mass M_1 from the centre of mass in terms of M_1, M_2 and D.

(ii) By equating the gravitational force between the stars with the magnitude of the centripetal force on one of them, show that the orbital period of the binary system, T, is related to the distance between the stars, D, by the relationship:

$$\frac{T^2}{D^3} = \frac{4\pi^2}{G(M_1 + M_2)}$$

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SECTION B – LONG QUESTIONS

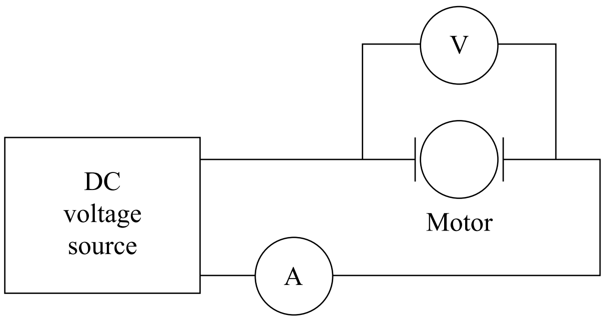
You are advised to spend no more than 30 minutes on any one question in this section, or a maximum of 120 minutes on Section B.

QUESTION ONE: ELECTRIC MOTOR

Shahril has an electric motor. He is intrigued by the similarity between an electric motor and a generator and wonders if his motor generates an emf as well as motion. Shahril devises an experiment to answer this question. His method and results are shown below. Answer the questions to complete his analysis and to reach a conclusion.

Theory
An electric motor consists of a coil of wire rotating in a magnetic field. When the motor is running, the current in the wire interacts with the magnetic field, producing a torque and causing rotation of the coil. If an electric motor is inducing an emf as well as producing motion, then it can be represented by an emf in series with a resistor. Faraday's law states that the induced emf depends on the rate of change of flux.

Method

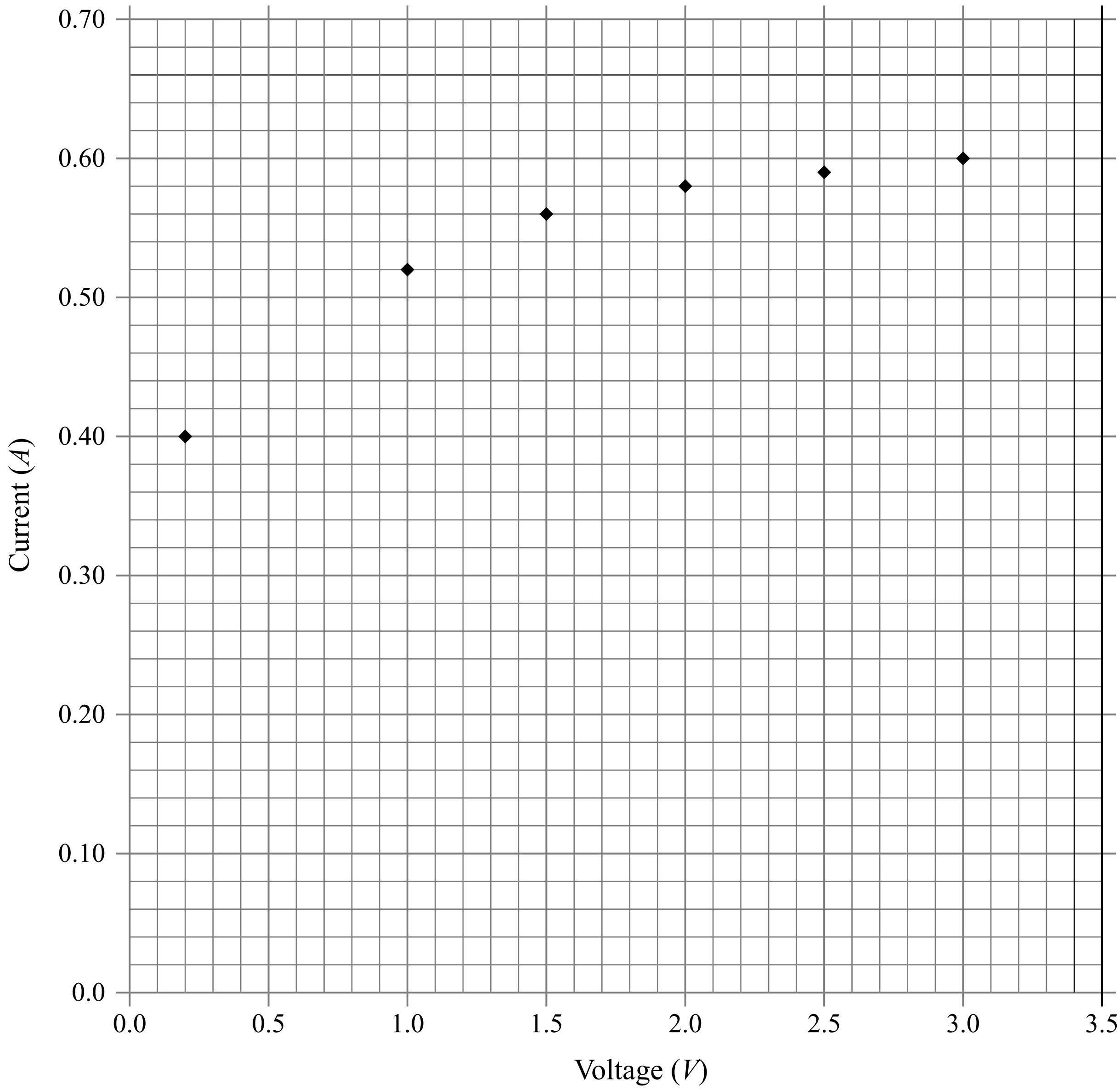


The motor was connected to a variable DC source as shown above. The voltage and current were measured when the coil was stationary and then five values of voltage and current were obtained with the motor turning. The rotation rate was measured using a strobe technique.

Results

Voltage (V)	Current (A)	Rotation rate (rev s^{-1})		
0.2	0.40	0		
1.0	0.52	9		
1.5	0.56	15		
2.0	0.58	21		
2.5	0.59	27		
3.0	0.60	34		

The graph of current plotted against voltage is shown below.



(i) Calculate the resistance, R, of the coil when stationary and graph (on the above grid) the relationship that normally exists between I and V for a conductor of resistance, R.

resistance = ____________________

(ii) Give an explanation why the voltage and current measurements obtained for the motor are different from the results you would normally expect for a conductor of resistance, *R*.

(iii) Devise a graphical method that would verify your explanation in part (ii). (*Hint: Are there any variables you would expect to be linearly related?*) Your answer should include a drawn graph.

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If you need to redraw this graph, use the spare grid provided on page 28.

(iv) Write a conclusion to summarise and explain your findings.

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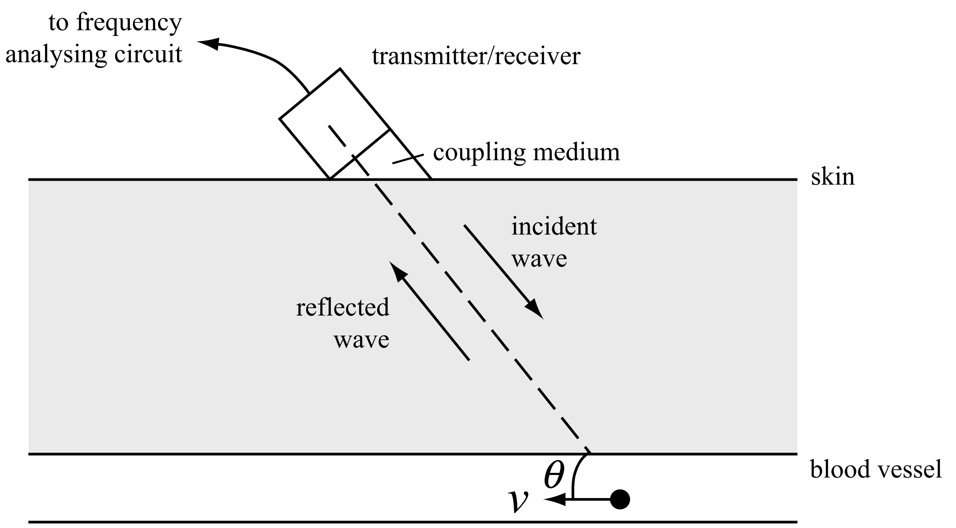
QUESTION TWO: DOPPLER AND BLOOD FLOW

The velocity of blood flowing round the body can be determined using an ultrasonic transmitter/receiver and measuring the Doppler shift of the reflected wave. The diagram below shows the essential details of this process.



Reflected ultrasound from the moving blood is subsequently detected by the stationary transmitter/receiver probe shown in the diagram.

(i) Does the reflected ultrasound have a lower, higher or the same frequency as the transmitted wave? Explain.

(ii) Three students derived the following possible equations for the total frequency change recorded by the detector. Only one equation is correct.

Identify the correct equation, giving reasons to justify your choice (a derivation of the correct equation is not required).

Student 1: $\Delta f = \frac{2fv}{c}\cos\theta$

Student 2: $\Delta f = \frac{2fc}{v}\cos\theta$

Student 3: $\Delta f = \frac{2fv}{c}(1-\cos\theta)$

Where f is the transmitted frequency, Δf is the shift in frequency of the reflected waves, v is the blood velocity, c is the wave velocity and θ is the angle between the blood velocity and wave velocity.

(iii) The velocity of ultrasound in human tissue and blood is 1.5×10^3 m s^{-1} and in the application described at the beginning of Question Two, a typical frequency of 5.0 MHz is used for the transmitted ultrasound. In one particular measurement a Doppler shift of 3.1 kHz was observed with the probe inclined at an angle of 30° to the direction of the blood flow.

Calculate the speed of the blood.

speed = ____________________

(iv) Blood flow through adjacent arteries and veins is in opposite directions.

Suggest a difficulty in determining the direction of blood flow using the above technique.

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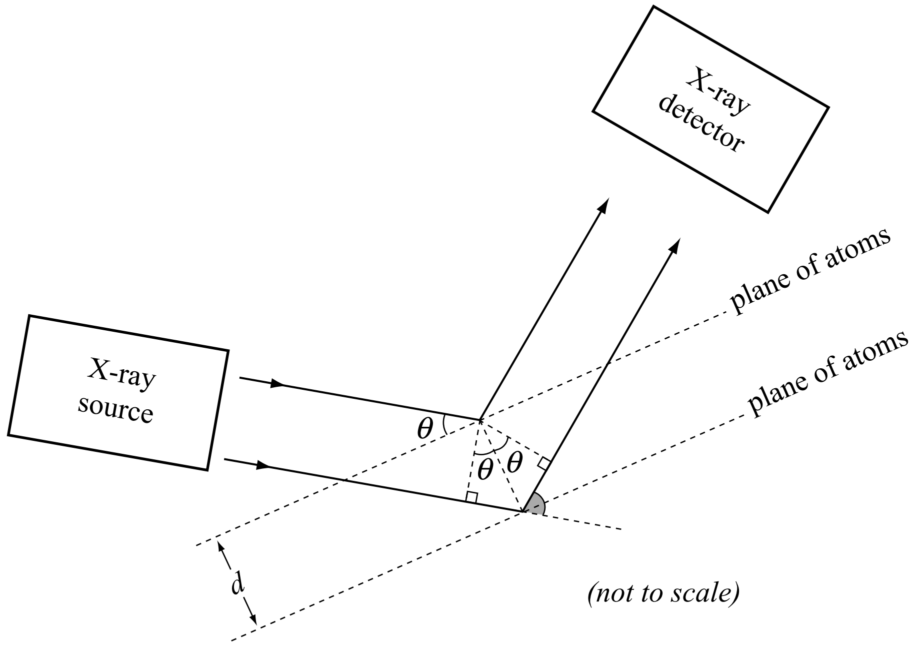
QUESTION THREE: BRAGG'S LAW

(i) State the necessary conditions for interference fringes to be produced by two sources of light at a distance *d* apart.

The regularly spaced atoms in a crystalline solid can be used to produce interference effects. The diagram shows how incident X-rays are reflected such that there is a path difference between the reflections from adjacent planes of atoms. The distance between each plane is *d*.



(ii) Using your knowledge of the necessary conditions for constructive interference of the rays, derive Bragg's Law:

$$m\lambda = 2d\sin\theta \qquad m = 1, 2, 3, \ldots$$

(iii) In one particular crystalline solid, a third order X-ray diffraction maximum is observed when the shaded angle equals 29.2°. The wavelength of the X-rays is 1.27×10^{-10} m.

Calculate the interplanar distance d.

interplanar distance = ________________

(iv) Given the value of d calculated above, comment on why X-rays rather than visible light are used for diffraction experiments with crystals.

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QUESTION FOUR: A MAGLEV TRAIN

Theory

A current-carrying wire produces a magnetic field of magnitude B at a distance r from the wire. The direction of B is given by a right-hand rule and the magnitude of B is given by the equation below where I is the current in the wire and $\mu_0 = 4\pi \times 10^{-7}\,\text{N A}^{-2}$.

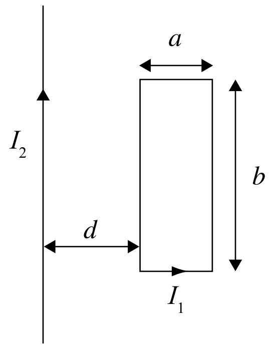
$$B = \frac{\mu_0 I}{2\pi r}$$

A wire carrying a current I in a magnetic field B experiences a force F. The direction of the force is given by an appropriate right-hand rule and the magnitude of F is calculated using the equation below, where l is the length of the wire.

$$F = BIl$$

Situation

A long wire with current I_2 lies in the plane of a rigid rectangular loop carrying current I_1. The rectangle has sides a and b and is a distance d from the long wire, as shown below.



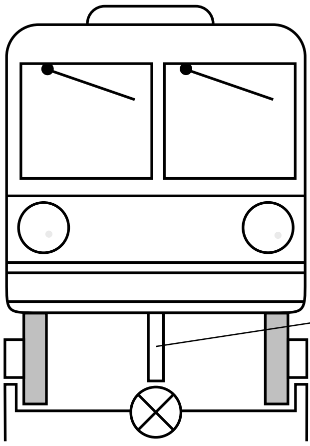
(i) Explain why there is a force acting on the loop.

(ii) Explain why the force on the loop acts to move the loop away from I_2.

(iii) Derive an expression for the magnitude of the force acting on the loop.

(iv) From your expression given above, it can be seen that the relative size of the variables *a* and *d* will have a strong influence on the size of the force. Discuss what would happen to the force in the limiting cases where $a << d$ and $d << a$.

Front view of Maglev train.



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It is suggested that the force between a loop and a long current-carrying wire could be used in the design of a magnetically levitated train (Maglev). Many loops (a coil) are placed vertically in each carriage directly above a cable fixed to the track bed. If the dimensions are chosen so that $a>>d$ and N is the number of loops in a coil then the force produced will be given by:

$$F = \frac{\mu_0 N I_1 I_2 b}{2\pi d}$$

where $\mu_0 = 4\pi \times 10^{-7}\,\text{N A}^{-2}$ and the acceleration due to gravity = 9.80 m s^{-2}.

(v) A carriage used to investigate this concept is 20 m long with a mass of 2×10^4 kg and a maximum allowed current in the cable and coil of 100 A. The coil has 5000 loops.

Calculate the distance d between the lower side of the coil and the cable.

distance =

(vi) One of the designers is concerned that the distance d will change considerably when people get on the train. Estimate the value of d for a full carriage holding 70 people.

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(vii) Discuss at least one advantage and at least one disadvantage with the design of this type of train. Your discussion should be relevant and linked to the physics of the situation.

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

Assessor's use only

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If you wish to redraw a graph, use the grid below.

Assessor's use only