1.List of data, formulae and relationships

Data

Gravitational constant	$G = 6.67 \times 10^{-11}\, Nm^2 kg^{-2}$	
Acceleration of free fall	$g = 9.81\, m\, s^{-2}$	(close to the Earth)
Gravitational field strength	$g - 9.81\, N\ kg^{-1}$	(close to the Earth)
Electronic charge	$e = -1.60 \times 10^{-19}\, C$	
Electronic mass	$m_e = 9.11 \times 10^{-31}\, kg$	
Unified mass unit	$u = 1.66 \times 10^{-27}\, kg$	
Planck constant	$h = 6.63 \times 10^{-34}\, J\ s$	
Speed of light in vacuum	$c = 3.00 \times 10^{8}\ m\, s^{-1}$	
Molar gas constant	$R = 8.31\, J\ K^{-1}\ mol^{-1}$	
Boltzmann constant	$k = 1.38 \times 10^{-23}\, J\ K^{-1}$	
Avogadro constant	$N_a = 6.02 \times 10^{23}\ mol^{-1}$	
Permittivity of free space	$\varepsilon_0 = 8.85 \times 10^{-12}\, Fm^{-1}$	
Permeability of free space	$\mu_0 = 4\pi \times 10^{-7}\, N\ A^{-2}$	

Experimental physics

Percentage uncertainty $= \dfrac{\text{Estimated uncertainty}}{\text{Average value}} \times 100\%$

Mechanics

Force $F = \dfrac{\Delta p}{\Delta t}$

For uniformly accelerated motion:

$v = u + at$

$x = ut + ½ at^2$

$v^2 = + 2ax$

Work done or energy transferred $\Delta W = \Delta E = p\Delta V$ (Presssure p; Volume V)

Power P = Fv

Angular speed $\omega = \dfrac{\Delta\theta}{\Delta t} = \dfrac{v}{r}$ (Radius of circular path r)

Period $T = \dfrac{1}{f} = \dfrac{2\pi}{\omega}$ (Frequency f)

Radial acceleration $a = r\omega^2 = \dfrac{v^2}{r}$

Couple (due to a pair of forces F and $-F$)

$= F \times$ (Perpendicular distance from F to $-F$)

Electricity

Electric current	$I = nAQv$(Number of charge carriers per unit volume n)	
Electric power	$P = I^2R$	
Resistors in series	$R = R_1 + R_2 + R_3$	
Resistors in parallel	$R_\theta = R_0(1+\alpha\theta)$	(Temperature coefficient α)
Resistance at temperature θ	$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$	
Capacitance of parallel plates	$C = \frac{\varepsilon_0 \varepsilon_1 A}{d}$	
Capacitors in parallel	$C = C_1 + C_2 + C_3$	
Capacitors in series	$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$	
Energy stored	$W = \frac{1}{2}CV^2$	

Nuclear physics

Mass-energy	$\Delta E = c^2 \Delta m$	
Radioactive decay rate	$\frac{dN}{dt} = -\lambda N$	(Decay constant λ)
	$N = N_0 e^{-\lambda t}$	
Half-life	$T_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$	
Photon model	$E = hf$	
Energy levels	$hf = E_1 - E_2$	
de Broglie wavelength	$\lambda = \frac{h}{p}$	

Matter and materials

Density	$\rho = \frac{m}{V}$	
Hooke's law	$F = k\Delta x$	
Stress	$\sigma = \frac{F}{A}$	
Strain	$\varepsilon = \frac{\Delta l}{l}$	
Young modules	$E = \frac{Stress}{Strain}$	
Work done in stretching	$\Delta W = ½F\Delta x$	(provided Hooke's law holds)

Oscillations and waves

For a simple pendulum $T = 2\pi\sqrt{\frac{l}{g}}$

For a mass on a spring $T = 2\pi\sqrt{\frac{m}{k}}$

At distance r from a point source of power P, intensity $I = \frac{P}{4\pi r^2}$

For Young's slits, of slit seperation s, wavelength $\lambda = \frac{xs}{D}$

(Fringe width x; slits to screen distance D)

Refraction $\frac{\sin\theta_1}{\sin\theta_2} = \frac{\lambda_1}{\lambda_2} = \frac{c_1}{c_2} = \frac{n_2}{n_1}$ (Refractive index n)

$\sin\theta_c = \frac{c_1}{c_2}$ (Critical angle θ_c)

$n_1 = \frac{c}{c_1}$

Quantum phenomena

Maximum energy temperature $= hf - \varphi$ (Work function φ)

Thermal physics

Celcius temperature $\theta/^\circ C = T/K - 273.15$

Practical Celsius scale $\theta = \frac{X_\theta - X_0}{X_{100} - X_0} \times 100\,^\circ C$

Thermal energy transfer $\Delta Q = mc\Delta T$ (Specific heat capacity c; temperature change ΔT)

Change of internal energy $\Delta U = \Delta Q + \Delta W$ (Work done on body ΔW)

Thermal energy transferred on change of state $= l\Delta m$

(Specific latent heat or specific enthalpy change l)

Rate of thermal energy transfer by conduction $= kA\dfrac{\Delta T}{\Delta x}$

(Thermal conductivity k; temperature gradient $\dfrac{\Delta T}{\Delta x}$)

Kinetic theory $pV = \frac{1}{3}Nm(c^2)$

$T \propto$ *Average kinetic energy of molecules*

Mean kinetic energy of molecules $= 3/2\, kT$ (Boltzmann constant k)

Molar gas constant $R = kN_A$ (Avogadro constant N_A)

Upthrust U = Weight of displaced fluid

Pressure difference in fluid $\Delta p = \rho g \Delta h$

Fields

Electric field strength

uniform field $E = F/Q = V/d$

radial field $E = kQ/r^2$ (Where for free space or air $k = 1/4\pi\varepsilon_0$)

Electric potential

radial field $V = kQ/r$

For an electron in a vacuum tube $e\Delta V = \Delta(1/2\, mv^2)$

Gravitational field strength

radial field $g = GM/r^2$

Gravitational potential

radial field $V = -GM/r$, numerically

Time constant for capacitor charge or discharge = RC

Force on a wire $F = BIl$

Force on a moving charge $F = BQv$

Field inside a long solenoid $= \mu_0 nI$ (Number of turns per metre n)

Field near a long straight wire $= \dfrac{\mu_0 I}{2\pi r}$

E.m.f. induced in a moving conductor $= Blv$

Flux $\Phi = BA$

E.m.f. induced in a coil $= \dfrac{Nd\Phi}{dt}$ (Number of turns N)

For $I = I_0 \sin 2\pi ft$ *and* $V = V_0 \sin 2\pi ft$:

$$I_{\text{rms}} = \frac{I_0}{\sqrt{2}} \text{ and } V_{\text{rms}} = \frac{V_0}{\sqrt{2}}$$

$$\text{Mean power} = I_{\text{rms}} \times V_{\text{rms}} = \frac{I_0 V_0}{2}$$

Mathematics

$\sin(90° - \theta) = \cos\theta$

$\text{In}(x^n) = n \ln x$

$\text{In}(e^{kx}) = kx$

Equation of a straight line $y = mx + c$

Surface area cylinder $= 2\pi rh + 2\pi r^2$

sphere $= 4\pi r^2$

Volume cylinder $= \pi r^2 h$

sphere $= {}^4/_3\, \pi r^3$

For small angles: $\sin\theta \approx \tan\theta \approx \theta$ (in radians)

$\cos\theta \approx 1$

2. The list gives some quantities and units. *Underline* those which are base quantities of the International (SI) System of units.

coulomb force length mole newton temperature interval

(2)

Define the volt.

....

....

(2)

Use your definition to express the volt in terms of base units.

....

....

....

(3)

Explain the difference between scalar and vector quantities.

....

....

....

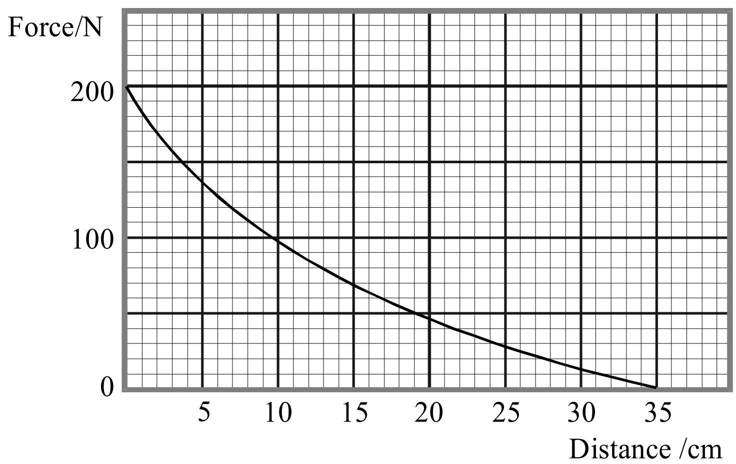
(2)

Is potential difference a scalar or vector quantity?

....

(1)
(Total 10 marks)

3. A catapult fires an 80 g stone horizontally. The graph shows how the force on the stone varies with distance through which the stone is being accelerated horizontally from rest.



Use the graph to estimate the work done on the stone by the catapult.

....

....

Work done = ...

(4)

Calculate the speed with which the stone leaves the catapult.

....

....

Speed = ...

(2)
(Total 6 marks)

4. Define capacitance.

....

.... **(2)**

An uncharged capacitor of 200 μF is connected in series with a 470 kΩ resistor, a 1.50 V cell and a switch. Draw a circuit diagram of this arrangement.

(1)

Calculate the maximum current that flows.

....

....

Current .... **(2)**

Sketch a graph of voltage against charge for your capacitor as it charges. Indicate on the graph the energy stored when the capacitor is fully charged.

(4)

Calculate the energy stored in the fully-charged capacitor.

....

....

Energy = ... **(2)**

(Total 11 marks)

5. Derive a formula for the equivalent capacitance of two capacitors in series.

....

....

....

....

....

....

(4)

A 200 μF capacitor is connected in series with a 1000 μF capacitor and a battery of e.m.f. 9V. Calculate

(i) the total capacitance

....

....

Capacitance = ...

(2)

(ii) the charge that flows from the battery

....

....

Charge = ...

(2)

(iii) the final potential difference across each capacitor.

....

....

....

P.d. across 1000 μF = ...

P.d. across 200 μF = ...

(3)
(Total 11 marks)

6. A toroid is a conducting wire wound in the shape of a torus (a doughnut). A toroid could be made by bending a slinky spring into a torus. Figure 1 shows such a toroid. Figure 2 shows a plan view of this toroid with one magnetic field line added.

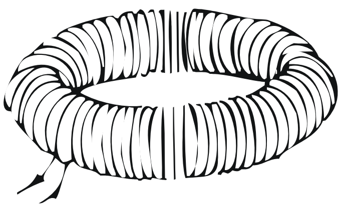


Figure 1

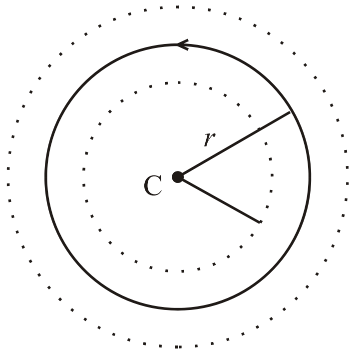


Figure 2

Theory suggests that for a toroid of N turns, the magnetic flux density B within the coils of the toroid at a distance r from the centre C of the toroid is given by

$$B = \frac{\mu_o NI}{2\pi\, r}$$

Describe how you would verify this relationship using a precalibrated Hall probe.

....

....

....

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....

(6)

For distances $r < r_o$, suggest how B might vary with r. Give a reason for your answer.

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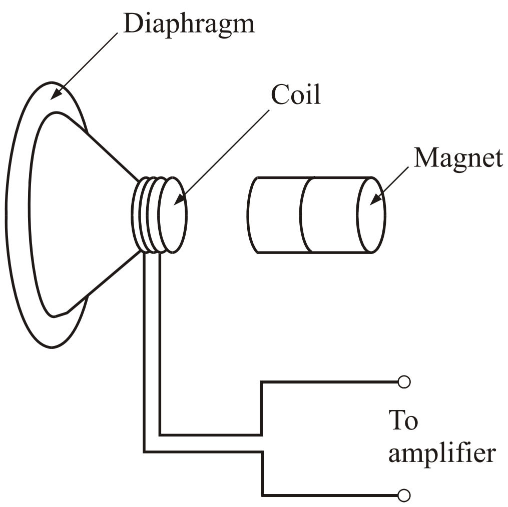
....

....

(2)
(Total 8 marks)

7. An induction microphone converts sound waves into electrical signals which can be amplified.



Describe the stages by which the sound waves are converted into electrical signals.
State whether the signals are a.c. or d.c.

....

....

....

....

(6)

If the alternating output from a signal generator were fed into the microphone, describe and explain what would happen to the diaphragm.

....

....

....

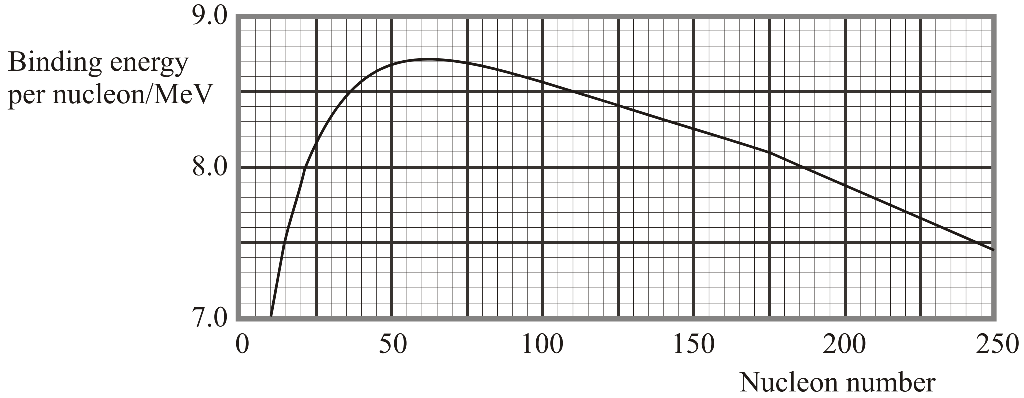
....

(3)
(Total 9 marks)

8. Read the passage* carefully and then answer the questions at the end.

Nuclear Matter

The list of atomic nuclei that exist is extremely long. All but the smallest nuclei have approximately the same density, and all but the lightest have approximately the same binding energy per nucleon. Nuclear binding energies are accurately known from the masses of the nuclei and of the individual nucleons, using Einstein's relationship $\Delta E = c^2 \Delta m$. The graph below shows the binding energy per nucleon against the nucleon number (mass number).



Nuclei are limited in size because, as they become larger, their electrical charge increases. The mutual repulsion of like charges causes a tendency to fission. The largest nuclei contain some 250 nucleons. This looks like a large number but the diameter of a sphere of 250 balls packed closely together is only about six times the diameter of a single ball. The best evidence for the size of nuclear radii comes from experiments on the scattering of fast electrons by nuclei. The electrons are fast enough to be deflected only slightly from their original direction by passage through, or close by, a nucleus. The de Broglie wavelength associated with these electrons is small compared to the dimensions of the nucleus. The angular distribution of the scattered electrons gives a diffraction pattern from which the distribution of charged nucleons in the nucleus can be determined.

We may think of nuclei as small amounts of nuclear matter, in the same sense as a raindrop is a small amount of water. Nuclear matter has many of the properties with which we are familiar from other forms of matter, such as density and specific heat capacity. The measured density of nuclear matter has been found to be about 3.3×10^{17} kg m^{-3}. When a nucleus is struck by an energetic nucleon, the nucleus may be left with excess energy which is then shared between its nucleons. The motion of the nucleons is then exactly like thermal agitation. If the excitation is high enough to produce emission (evaporation) of nucleons, these will possess only a small fraction of the available energy, just as the energy of a water molecule evaporating from a drop of water is only a small fraction of the thermal energy of the whole drop.

[*The passage is taken from "Nuclear Matter" by R E Peierls: *Endeavour, Vol XX11 (1963),* Pergamon Press. Reproduced by permission.]

(a) Distinguish between *a nucleus, a nucleon* and *nuclear matter*.

What other states of matter exist?

(4)

(b) Estimate the nucleon number (mass number) and the proton number (atomic number) of the most stable nucleus. Explain how you made your estimates.

By how much does the mass of a nucleus of nucleon number 180 differ from the sum of the masses of its nucleons? (1 MeV = 1.6×10^{-13} J.)

(7)

(c) Justify the statement that *the diameter of a sphere of 250 balls packed closely together is only about six times the diameter of a single ball* (paragraph 2). Explain why any calculations you make are only approximate.

(4)

(d) Describe the ways in which small amounts of nuclear matter behave like drops of water.

(3)

(e) Consider a nucleus which divides into two parts. If one part contains 55 protons and the other part contains 37 protons, calculate the electrostatic force between them when their centres are 3.0×10^{-14} m apart.

The electrical potential energy of the two parts of the dividing nucleus is about 2×10^{-11} J, i.e. over 100 MeV. Comment on this value.

(5)

The earliest experiments which identified the atomic nucleus involved the scattering of alpha particles by gold foil. Draw a sketch to illustrate the paths of the alpha-particles in such an experiment.

How do the paths of fast electrons, as described in the passage (paragraph 2), differ from those of the alpha particles?

(5)

(g) Calculate the de Broglie wavelength for an electron having a momentum of 2.0×10^{-18} N s.

Sketch the diffraction pattern produced when a beam of low-energy electrons passes through a thin slice of graphite.

(4)
(Total 32 marks)

9. (a) Two capacitors are connected in series as shown.

A charge of 50 μC is transferred to terminal A and an equal charge is removed from terminal B.

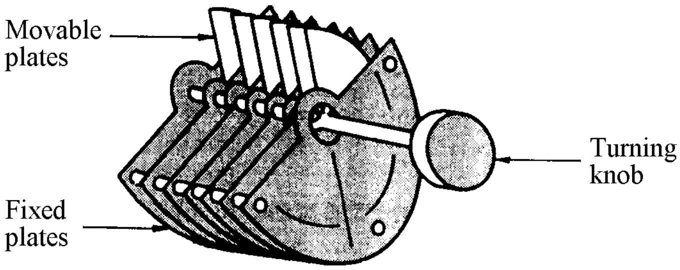
(i) Calculate the potential difference across each capacitor. Hence show that the potential difference between A and B is 3.3 V to two significant figures.

(ii) What single capacitor connected between A and B would store 50 μC when a potential difference of 3.3 V is connected across it?

(iii) What is the combined capacitance of a 22 μF capacitor and a 47 μF capacitor connected in parallel?

(6)

(b)



The diagram shows a variable capacitor drawn full size. It consists of a set of fixed and a set of movable semicircular metal plates. These are insulated from one another.

(i) How would you make a similar variable capacitor which had a larger capacitance?

(ii) When the plates are in the position shown they are charged and disconnected from the voltage source. The potential difference between the plates is then V. Explain how the potential difference between the plates will vary as the area of overlap between the semicircular plates is reduced by turning the knob anticlockwise.

(5)

(c) Outline briefly how you would demonstrate that, for a capacitor of capacitance about 500 μF, the charge stored is proportional to the potential difference, i.e. that $Q \propto V$. Your answer should contain a circuit diagram.

(5)
(Total 16 marks)

10. The energy for a pendulum (long case) clock is stored as gravitational potential energy in a heavy brass cylinder. As the cylinder descends its energy is gradually transferred to a steel pendulum to keep it swinging with a constant amplitude.

(a) In one clock the brass cylinder has a mass of 5.6 kg.

(i) The cylinder descends 1.4 m in seven days. What is the power transfer during its descent?

(ii) In an accident the brass cylinder suddenly fell 1.4 m to the ground. Estimate by how much its temperature would rise. State any assumption you make.

(Take the specific heat capacity of brass to be 360 J kg^{-1} K^{-1}.)

(6)

(b) The pendulum swings in an East-West plane with a time period of 2.00 s.

(i) Explain why a potential difference will be induced between the top and the bottom of the steel pendulum.

(ii) Sketch a graph to show the variation of this induced p.d. with time. Add a scale to your time axis.

(6)

(c) It is suggested that the induced p.d. described in (b) could be used to energise an electromagnet. This could then be placed so as to attract the steel pendulum during part of each swing and thus do away with the need for the brass cylinder.

Discuss this suggestion, concentrating on the physical principles involved.

(4)
(Total 16 marks)

11. With the aid of an example, explain the statement "The magnitude of a physical quantity is written as the product of a number and a unit".

....

....

....

....

(2)

Explain why an equation must be homogeneous with respect to the units if it is to be correct.

....

....

....

....

....

(1)

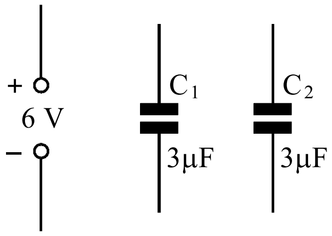
Write down an equation which is homogeneous, but still incorrect.

....

....

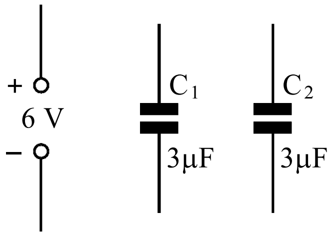
(2)

12. complete the circuit below to show the capacitors connected in parallel.



(1)

Complete the circuit below to show the capacitors connected in series.



(1)

Use the information in the diagrams to complete the following table.

Capacitors in parallel	Charge on C_1	
	Energy stored in C_1 when fully charge	
Capacitors in series	Charge on C_2	
	Work done by power supply in charging both capacitors	

(4)
(Total 6 marks)

13. State Coulomb's law for the electric force between two charged particles in free space.

....

....

....

....

(2)

What are the base units of ε_0 (the permittivity of free space)?

....

....

....

....

(2)
(Total 4 marks)

14. Read the passage carefully and then answer the questions at the end.

What is Lightning?

Lightning has been a source of wonder to all generations. Its origins, in the processes of the electrification of thunderstorms, are being studied by means of laboratory experiments, together with observational and theoretical studies.

Summer airmass storms and winter-time cold frontal storms can become electrified and produce lightning and thunder. The high currents in the lightning strokes (typically 20 000 A) heat the air sufficiently to cause rapid expansion; the resulting shock wave is heard as thunder. Travelling at the speed of sound, 340 m/s', the noise arrives after the flash is seen and so the distance to the storm may be estimated. The flash is seen as a result of the effect of the electrical discharge on the gases through which the discharge travels. The lightning may occur completely within the cloud as a cloud stroke, often called sheet lightning, or it may reach the Earth as a ground stroke.

In the production of a ground stroke, the lightning channel first makes its way towards the ground as a weakly luminous negative leader which attracts positive charge from sharp objects on the ground. This leader is a column of negatively charged ions which flow from the charged lower regions of the cloud in a stepwise fashion to form a conducting channel between the cloud and the ground. When a conducting channel is completed the negative charge flows to ground. The brightest part of the channel appears to move upwards at about 30% of the speed of light. Often there is sufficient charge available to allow several strokes to occur along the same lightning channel within a very short time. The resulting flickering can be observed by the eye and the whole series of strokes is called a flash. The peak electrical power is typically 1×10^8 W per metre of channel, most of which is dissipated in heating the channel to around 30 000 °C.

In London the average number of days per year on which thunder is heard is 17, the peak thunderstorm activity being in the late afternoon and evening during Summer. When a person is struck by lightning, heart action and breathing stop immediately. Heart action usually starts again spontaneously but breathing may not and, on average, four people are killed by lightning each year in Britain.

(a) Explain how the distance from an observer to a lightning flash may be estimated. Illustrate this for the case where the distance is 1.5 km.

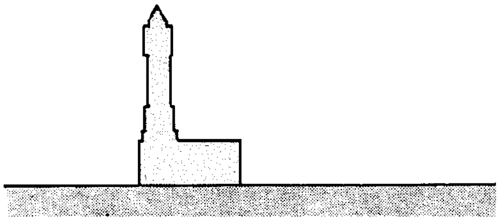
(3)

(b) Explain the meaning of the phrase *sheet lightning* (paragraph 2).

Use the passage to explain how thunder is produced.

(5)

(c) The diagram represents a storm cloud over a building with a high clock tower.



Copy the diagram. Explain, with the aid of additions to your diagram, what is meant by a *negative leader* (paragraph 3).

(4)

(d) Describe the process by which a lightning stroke produces visible light.

Explain why, when you see a lightning flash, it may seem to flicker.

(5)

(e) Suppose lightning strikes from a cloud to the Earth along a channel 400 m long.

Calculate

(i) a typical potential difference between cloud and Earth,

(ii) the average electric field strength along such a lightning channel.

(6)

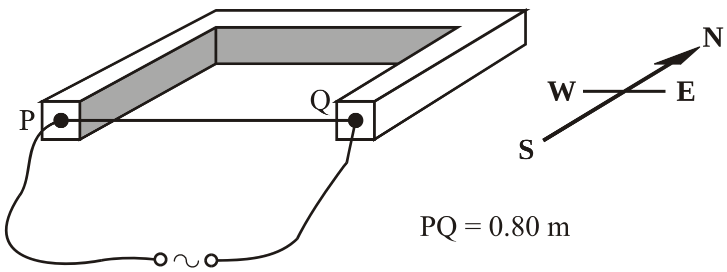
(f) Describe how you would attempt to demonstrate in the laboratory that the electric field strength needed to produce a spark in air is about 3000 V mm^{-1} (3×10^6 V m^{-1}). Suggest why this value differs from that which you calculated in (*e*).

(4)

(g) Estimate the pressure of the air within a lightning channel immediately after a lightning flash. Take the atmospheric pressure to be 100 kPa. State any assumptions you make.

(5)
(Total 32 marks)

15. A thin copper wire PQ, 0.80 m long, is fixed at its ends. It is connected as shown to a variable frequency alternating current supply and set perpendicular to the Earth's magnetic field.



(a) When there is a current from P to Q the wire experiences a force. Draw a diagram showing the resultant magnetic field lines near the wire as viewed from the West. (You should represent the wire PQ as ⊗.)

Explain what is meant by a neutral point.

(4)

(b) The wire PQ experiences a maximum force of 0.10×10^{-3} N at a place where the Earth's magnetic field is 50×10^{-6} T. Calculate the maximum value of the current and its r.m.s. value.

(4)

(c) A strong U-shaped (horseshoe) magnet is now placed so that the mid-point of the wire PQ lies between its poles. The frequency of the a.c. supply is varied from a low value up to 50 Hz, keeping the current constant in amplitude. The wire PQ is seen to vibrate slightly at all frequencies and to vibrate violently at 40 Hz.

(i) Explain carefully why the wire vibrates and why the amplitude of the vibrations varies as the frequency changes.

(3)

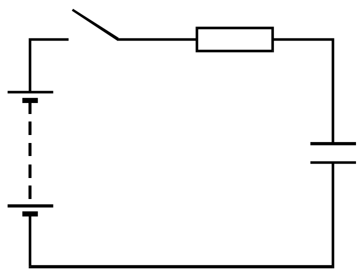
(ii) Calculate the speed of transverse mechanical waves along the wire PQ.

(3)

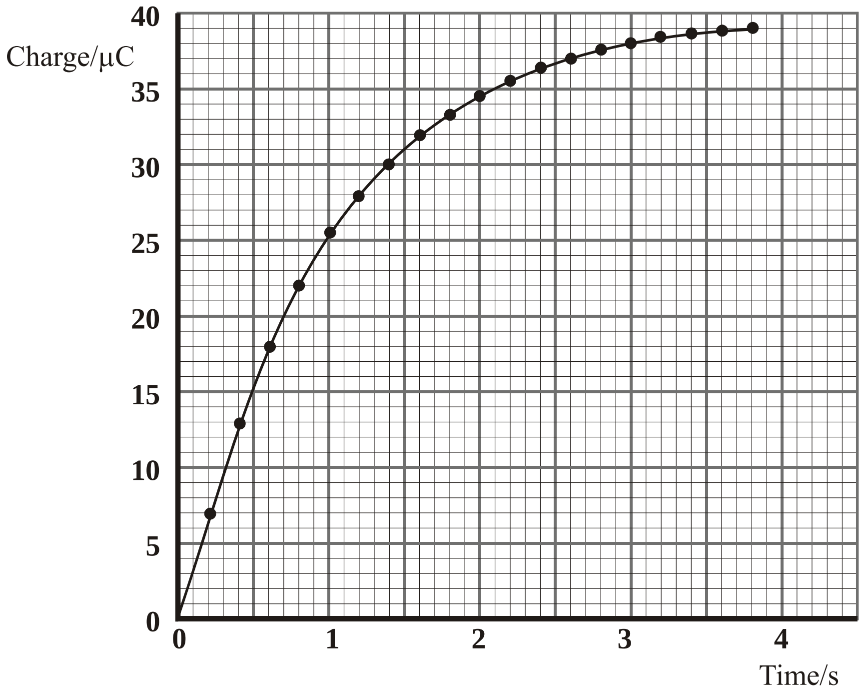
(iii) Describe the effect on the wire of gradually increasing the frequency of the a.c. supply up to 150 Hz.

(2)
(Total 16 marks)

16. The circuit shown is used to charge a capacitor.



The graph shows the charge stored on the capacitor whilst it is being charged.



On the same axes, sketch as accurately as you can a graph of current against time.
Label the current axis with an appropriate scale.

(4)

The power supply is 3 V. Calculate the resistance of the charging circuit.

....

....

Resistance = ...

(2)
(Total 6 marks)

17. Using the usual symbols write down an equation for

(i) Newton's law of gravitation

....

(ii) Coulomb's law

....

(2)

State one difference and one similarity between gravitational and electric fields.

Difference ....

....

Similarity ....

(2)

A speck of dust has a mass of 1.0×10^{-18} kg and carries a charge equal to that of one electron. Near to the Earth's surface it experiences a uniform downward electric field of strength 100 N C^{-1} and a uniform gravitational field of strength 9.8 N kg^{-1}.

Draw a free-body force diagram for the speck of dust. Label the forces clearly.

Calculate the magnitude and direction of the resultant force on the speck of dust.

....

....

....

....

....

Force = ...

(6)

(Total 10 marks)

18. The permittivity of free space ε_0 has units F m^{-1}. The permeability of free space μ_0 has units N A^{-2}

Show that the units of $\dfrac{1}{\sqrt{\varepsilon_0 \mu_0}}$ are m s^{-1}

....

....

....

....

....

....

(3)

Calculate the magnitude of $\dfrac{1}{\sqrt{\varepsilon_0 \mu_0}}$.

....

....

Magnitude = ...

(1)

Comment on your answers.

....

....

(1)
(Total 5 marks)

19. A child sleeps at an average distance of 30 cm from household wiring. The mains supply is 240 V r.m.s. Calculate the maximum possible magnetic flux density in the region of the child when the wire is transmitting 3.6 kW of power.

....

....

....

....

Magnetic flux density = ...

(4)

Why might the magnetic field due to the current in the wire pose more of a health risk to the child than the Earth's magnetic field, given that they are of similar magnitudes?

....

....

....

....

(2)
[6]

20. Read the passage carefully and then answer the questions at the end.

Atmospheric Electricity

Lightning was probably the cause of the first fire observed by humans and today it still leads to danger and costly damage. It is now known that most lightning strokes bring negative charge to ground and that thunderstorm electric fields cause positive charges to be released from pointed objects near the ground.

Worldwide thunderstorm activity is responsible for maintaining a small negative charge on the surface of the Earth. An equal quantity of positive charge in the atmosphere leads to a typical potential difference of 300 kV between the Earth's surface and a conducting ionospheric layer at about 60 km. The resulting, fair-weather, electric field decreases with height because of the increasing conductivity of the air. Across the lowest metre there is a voltage difference of about 100 V.

Early estimates of global activity have still to be improved upon by satellite surveillance. The 2000 thunderstorms estimated to be active at any one time each produce an average current of 1 A bringing negative charge to ground. The resulting fair-weather field thus causes a leakage current of around 2000 A in the reverse direction, so the charge flows are in equilibrium. The charge on the Earth and the fair-weather field are too small to cause us problems in everyday life. With an average current per storm of only 1 A, there is no scope for tapping into thunderstorms as an energy source.

The long range sensing of lightning depends on detecting the radio waves which lightning produces. Different frequency bands are chosen for different distances. The very high frequency (VHF) band at 30-300 MHz can only be used up to about 100 km because the Earth's curvature defines a radio horizon. Greater ranges, of several thousand kilometres, are achieved in the very low frequency (VLF) band at frequencies of 10-16 kHz. These signals bounce with little attenuation within the radio duct formed between the Earth and ionospheric layers at heights of 50-70 km.

A further system senses radio waves in the extremely low frequency (ELF) band around 1 kHz. ELF waves are diffracted in the region between the Earth's surface and the ionosphere and propagate up to several hundred kilometres. Horizontally polarised ELF waves do not propagate to any significant extent, hence this system avoids the polarisation error of conventional direction-finding systems.

(a) Explain the meaning of the following terms as used in the passage:

(i) to ground (paragraph 1),

(ii) leakage current (paragraph 3),

(iii) horizontally polarised (paragraph 5).

(5)

(b) What is the electric field strength at the Earth's surface?

Calculate the average electric field strength between the Earth's surface and the conducting ionospheric layer.

Sketch a graph to show the variation of the Earth's fair-weather electric field with distance above the Earth's surface to a height of 60 km.

(7)

(c) The power associated with a lightning stroke is extremely large. Explain why *there is no scope for tapping into thunderstorms as an energy source* (paragraph 3).

(3)

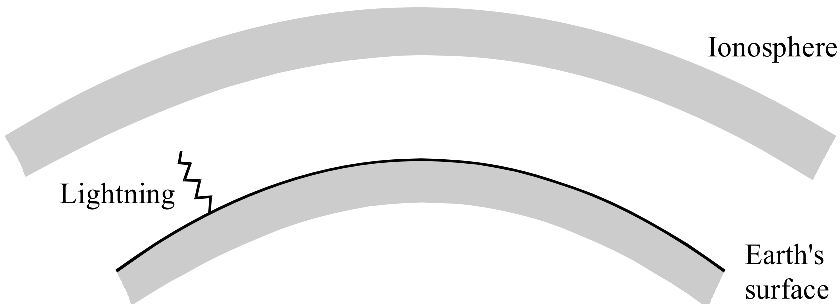
(d) Show that a total charge of 5×10^5 C spread uniformly over the Earth will produce an electric field of just over 100 V m^{-1} at the Earth's surface. Take the radius of the Earth to be 6400 km.

Draw a diagram to show the direction of this fair-weather field.

Suggest a problem which might arise if the charge on the Earth were very much larger.

(6)

(e) The diagram shows a lightning stroke close to the surface of the Earth.



Copy the diagram and add rays to it to illustrate the propagation of radio waves in the VLF band.

On a second copy of the diagram add wavefronts to illustrate the propagation of radio waves in the ELF band.

Explain with the aid of a diagram the meaning of the term *radio horizon* used in paragraph 4 with reference to VHF radio waves.

(7)

(f) List the frequency ranges of VHF, VLF and ELF radio waves.

Calculate the wavelength of

(i) a typical VHF signal,

(ii) an ELF signal.

(4)
(Total 32 marks)

21. For each of the four concepts listed in the left hand column, place a tick by the correct example of that concept in the appropriate box.

A base quantity	mole	☐	length	☐	kilogram	☐
A base unit	coulomb	☐	ampere	☐	volt	☐
A scalar quantity	torque	☐	velocity	☐	kinetic energy	☐
A vector quantity	mass	☐	weight	☐	density	☐

(Total 4 marks)

22. A 100 μF capacitor is connected to a 12V supply. Calculate the charge stored.

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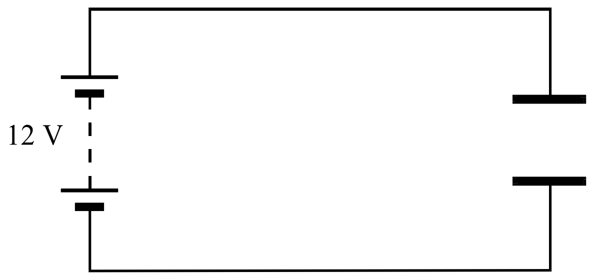
Charge stored = ...

Show on the diagram the arrangement and magnitude of charge on the capacitor.



(3)

This 100 μF charged capacitor is disconnected from the battery and is then connected across a 300 μF uncharged capacitor. What happens to the charge initially stored on the 100 μF capacitor?

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Calculate the new voltage across the pair of capacitors.

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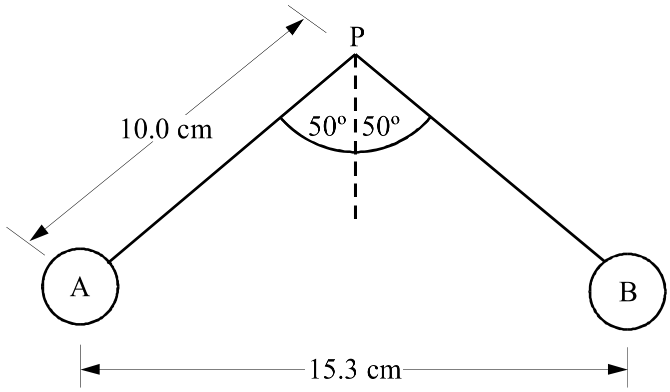
Voltage = ...

(4)
(Total 7 marks)

23. Two identical table tennis balls, A and B, each of mass 1.5g, are attached to non-conducting threads. The balls are charged to the same positive value. When the threads are fastened to a point P the balls hang as shown in the diagram. The distance from P to the centre of A or B is 10.0 cm.



Draw a labelled free-body force diagram for ball A.

(3)

Calculate the tension in one of the threads.

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Tension = ...

(3)

Show that the electrostatic force between the two balls is 1.8×10^{-2} N.

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(1)

Calculate the charge on each ball.

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Charge = ...

(3)

How does the gravitational force between the two balls compare with the electrostatic force given above?

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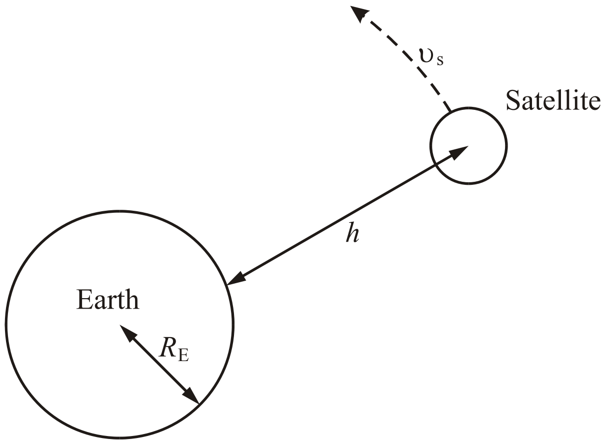
(2)
(Total 12 marks)

24. The diagram (not to scale) shows a satellite of mass m_s in circular orbit at speed υ_s around the Earth, mass M_E. The satellite is at a height h above the Earth's surface and the radius of the Earth is R_E.



Using the symbols above write down an expression for the centripetal force needed to maintain the satellite in this orbit.

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(2)

Write down an expression for the gravitational field strength in the region of the satellite.

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State an appropriate unit for this quantity.

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(3)

Use your two expressions to show that the greater the height of the satellite above the Earth, the smaller will be its orbital speed.

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(3)

Explain why, if a satellite slows down in its orbit, it nevertheless gradually spirals in towards the Earth's surface.

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(2)
(Total 10 marks)

25. The magnitude of the force on a current-carrying conductor in a magnetic field is directly proportional to the magnitude of the current in the conductor. With the aid of a diagram describe how you could demonstrate this in a school laboratory.

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(4)

At a certain point on the Earth's surface the horizontal component of the Earth's magnetic field is 1.8×10^{-5} T. A straight piece of conducting wire 2.0m long, of mass 1.5g lies on a horizontal wooden bench in an east-west direction. When a very large current flows momentarily in the wire it is just sufficient to cause the wire to lift up off the surface of the bench.

State the direction of the current in the wire.

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Calculate the current.

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Current = ...

What other noticeable effect will this current produce?

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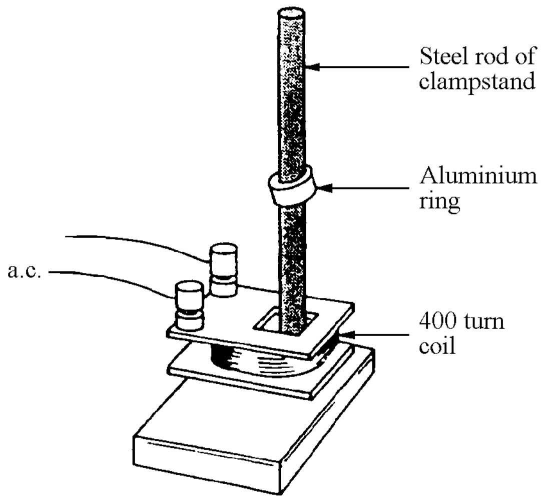
(4)

(Total 8 marks)

26. Apparatus to demonstrate electromagnetic levitation is shown in the diagram.



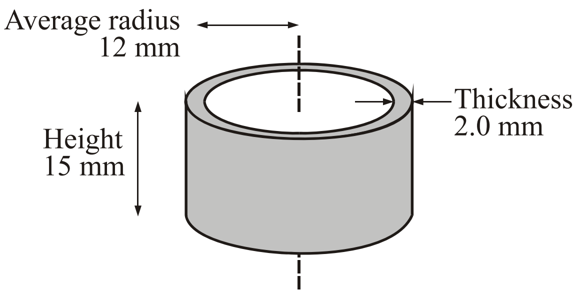
When there is an alternating current in the 400-turn coil the aluminium ring rises to a few centimetres above the coil. Changes in the size of the alternating current make the ring rise to different heights.

(a) (i) Explain why. When there is a varying current in the coil, there is an induced current in the aluminium ring. Suggest why the ring then experiences an upward force.

(5)

(ii) In one experiment the power transfer to the aluminium ring is 1.6 W. The induced current is then 140 A. Calculate the resistance of the aluminium ring.

The dimensions of the aluminium ring are given on the diagram below. Use your value for its resistance to find a value for the resistivity of aluminium.



(5)

(b) The aluminium ring becomes hot if the alternating current is left on for a few minutes. In order to try to measure its temperature it is removed from the steel rod and then dropped into a small plastic cup containing cold water.

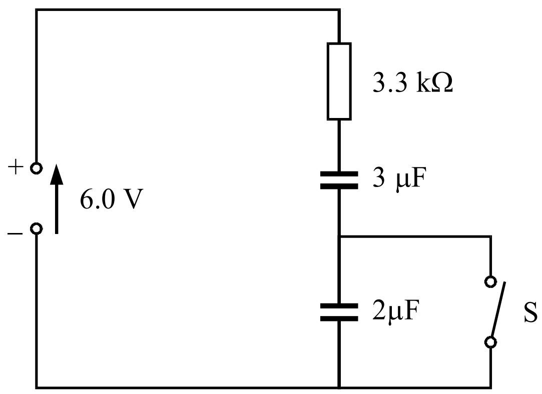
(i) State what measurements you would take and what physical properties of water and aluminium you would need to look up in order to calculate the initial temperature of the hot aluminium ring.

(3)

(ii) Explain whether experimental errors would make your value for the initial temperature of the aluminium ring too big or too small.

(3)
(Total 16 marks)

27.



Calculate the maximum energy stored in the 3 μ**F** capacitor in the circuit above

(i) with the switch S closed,

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Maximum energy = ……………………..

(2)

(ii) with the switch S open.

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Maximum energy = ………………………..

(4)
(Total 6 marks)

28. Explain what is meant by a neutral point in field.

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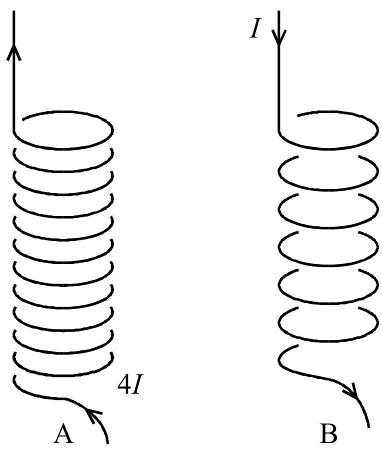
(2)

The diagram shows two similar solenoids A and B. Solenoid A has twice the number of turns per metre. Solenoid A carries four times the current as B.



Draw the magnetic field lines in, around and between the two solenoids.

(4)

If the distance between the centres of A and B is 1 m, estimate the position of the neutral point. Ignore the effect of the Earth's magnetic field.

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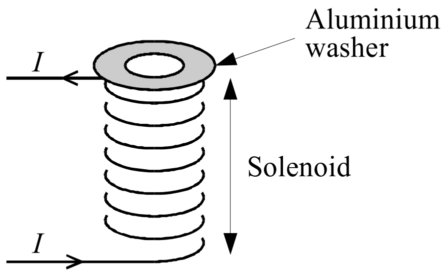
(3)
(Total 9 marks)

29. A light aluminium washer rests on the end of a solenoid as shown in the diagram.



A large direct current is switched on in the solenoid. Explain why the washer jumps and immediately falls back.

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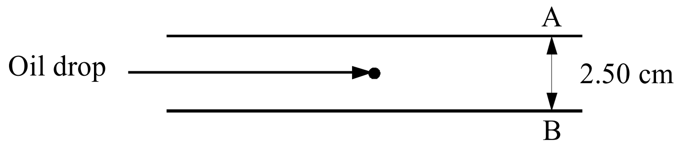
(Total 5 marks)

30. Classify each of the terms in the left-hand column by placing a tick in the relevant box.

	Base unit	**Derived unit**	**Base quantity**	**Derived quantity**
Length				
Kilogram				
Current				
Power				
Coulomb				
Joule				

(Total 6 marks)

31. The diagram shows a positively charged oil drop held at rest between two parallel conducting plates A and B.



The oil drop has a mass 9.79 x 10^{-15} kg. The potential difference between the plates is 5000 V and plate B is at a potential of 0 V. Is plate A positive or negative?

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Draw a labelled free-body force diagram which shows the forces acting on the oil drop. (You may ignore upthrust).

(3)

Calculate the electric field strength between the plates.

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Electric field strength =…………………………………

(2)

Calculate the magnitude of the charge Q on the oil drop.

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Charge =……………………………………

How many electrons would have to be removed from a neutral oil drop for it to acquire this charge?

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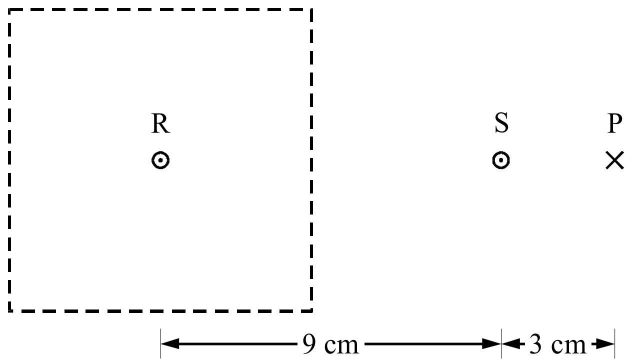
(3)
(Total 8 marks)

32. Two long parallel wires R and S carry steady currents I_1 and I_2 respectively in the same direction. The diagram is a plan view of this arrangement. The directions of the currents are out of the page.



In the region enclosed by the dotted lines, draw the magnetic field pattern due to the current in wire R alone.

(2)

The current I_1 is 4 A and I_2 is 2 A. Mark on the diagram a point N where the magnetic flux density due to the currents in the wires is zero.

(2)

Show on the diagram the direction of the magnetic field at P.

(1)

Calculate the magnitude of the magnetic flux density at P due to the currents in the wires.

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Flux density = ……………………………………………

(3)
(Total 8 marks)

33. What is meant by the term *electromagnetic induction*?

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(3)

Describe an experiment you could perform in a school laboratory to demonstrate Faraday's law of electromagnetic induction.

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(5)

An aircraft has a wing span of 54 m. It is flying horizontally at 860 km h^{-1} in a region where the vertical component of the Earth's magnetic field is 6.0×10^{-5} T. Calculate the potential difference induced between one wing tip and the other.

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Potential difference = ……………………………………

What extra information is necessary to establish which wing is positive and which negative?

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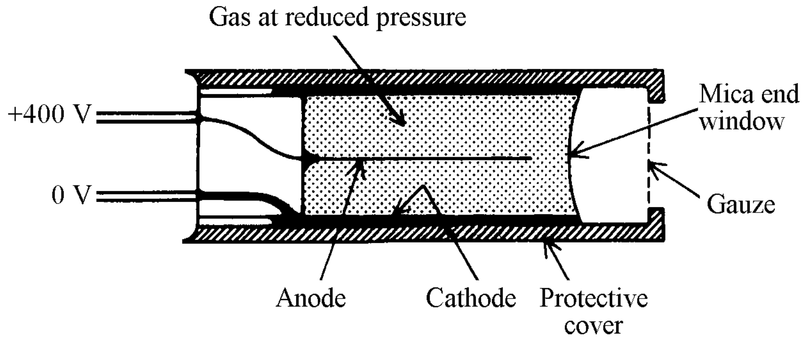
(3)
(Total 11 marks)

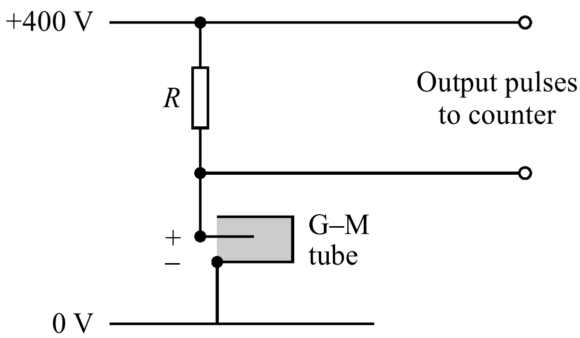
34. Read the passage and then answer the questions at the end.

The Geiger-Müller Tube

This instrument is probably the most versatile and useful of the devices available for detecting radiations from radioactive substances. It is activated by the ionization of the gas it contains and is essentially a form of discharge tube, containing gas at a pressure of about 11 kPa. The voltage at which it operates is just less than that which would produce a continuous discharge in it. Because of the extreme delicacy of the window that must be provided for the particles to enter, it is difficult to design a G–M tube to detect α-particles. A thickness equivalent to a mass per unit area of about 2.0×10^{-2} kg m^{-2} is all that can be allowed. To detect β-particles, a rather thicker window can be used; 30×10^{-2} kg m^{-2} is a common figure.



A typical design is shown in the diagram. The anode consists of a thin wire which runs along the axis of the cylindrical cathode. A large electric field is therefore produced in the immediate vicinity of the anode. In this region any free electrons are sufficiently accelerated to cause further ionization. The process is cumulative, and a small amount of initial ionization can give rise to a considerable "avalanche" of electrons. The electrons, being very light, are collected almost at once by the anode, leaving behind a space-charge formed by the more massive and slow-moving positive ions. In a short time ($\approx 10^{-6}$s) the space-charge becomes sufficiently dense to cancel the electric field round the anode; the ionization process then ceases, and the positive ions are drawn away by the field to the cathode. Thus any ionization of the gas in the tube triggers off an appreciable pulse of current. A single ion pair may be sufficient to initiate a detectable pulse.



The G–M tube is connected in the circuit shown. When an ionizing particle enters the tube, the resulting pulse of current causes a corresponding pulse of p.d. across the resistance R in series with it. This is amplified and registered by a suitable device, e.g. a counter.

It is obviously important that only one pulse should be registered for each ionizing particle entering the tube. One method of achieving this is to include a small quantity of a halogen vapour in the tube as a quenching agent. The interval during which these tubes are insensitive to the arrival of further particles is about 10^{-4} a quantity known as the dead time of the counter.

(a) What is meant in the passage by the phrases

(i) *ion pair* (paragraph 2),

(ii) *space-charge* (paragraph 2),

(iii) *dead time* (paragraph 4)?

Explain in your own words what is meant by an "avalanche” of electrons (paragraph 2).

(8)

(b) The mica end window of a G–M tube has a diameter of 24 mm. Calculate the force on the end window when atmospheric pressure is 101 kPa.

Explain why it is difficult to design a G–M tube to detect α-particles.

(6)

(c) (i) The density of mica in the end window of an α-particle detecting G–M tube is 2.8 × 10^3 kg m^{-3}. The average diameter of a mica molecule is 8.4 × 10^{-9}m. Calculate the thickness of the end window and hence estimate how many mica molecules make up this thickness.

(ii) Assume that α-particles and β-particles have about the same energy when they are emitted from a nucleus. Suggest why the values of the window thicknesses differ by a factor of 15.

(6)

(d) Sketch the electric field pattern between the anode and the cathode of a G–M tube.

Calculate the acceleration of an electron near to the anode at a place where the electric field strength is 1.2 × 10^5 V m^{-1}.

(7)

(e) The G–M tube acts as a capacitor of capacitance *C*, typically 10pF, given by

$$C = \frac{2\pi\varepsilon_0 h}{\ln(r_c / r_a)}$$

where r_c and r_a are the radii of the cathode and anode respectively and *h* is the length of the G–M tube.

(i) Show that the expression for *C* is homogeneous with respect to units.

(ii) Calculate a typical time constant for the detecting circuit opposite when R = 1 × 10^5Ω.

(5)
(Total 32 marks)

35. Define the term *capacitance*.

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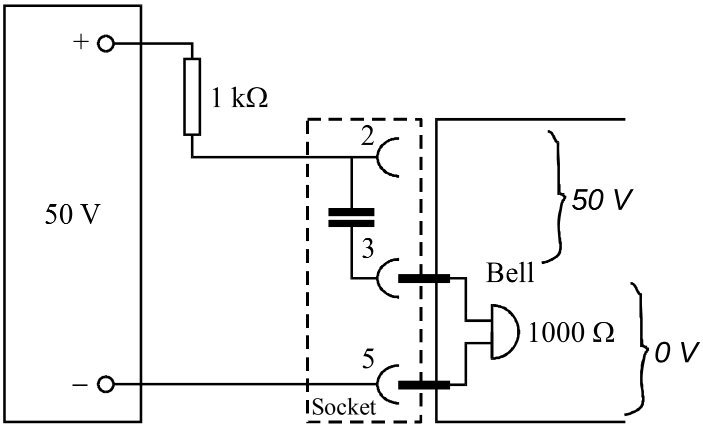
(2)

The sockets of modern telephones have six pins. A power supply of 50 V in series with a resistance of about 1000 ? is connected to pins 2 and 5.



A capacitor of 2 ?F is connected between pins 2 and 3. In one installation, a bell of resistance 1000 ? is connected to pins 3 and 5.

Explain why there is a pulse of current through the bell when the circuit is first connected, but not after the bell has been connected for some time.

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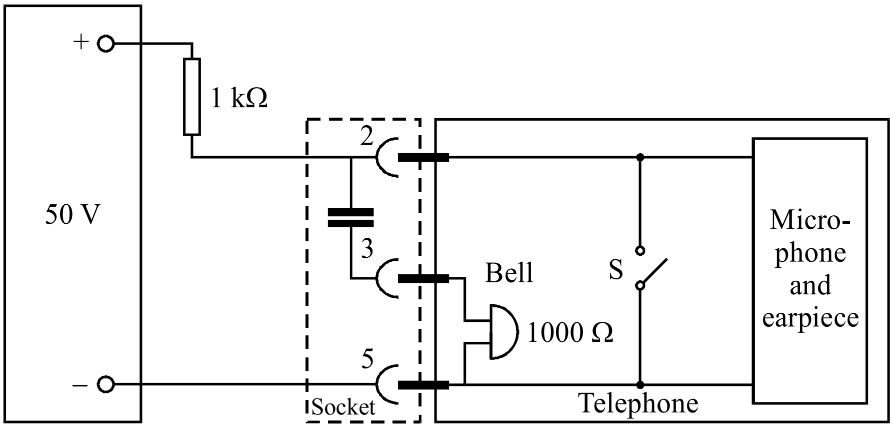
(2)

On the circuit diagram above, label the values of the voltages across the capacitor and across the bell when the circuit has been connected for some time.

(2)

To dial a number, e.g 7, switch S must be closed that number of times.



Explain why the bell sounds softly (tinkles) when the switch is closed and then opened again.

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(2)

To avoid this tinkling, an "anti-tinkling switch is connected to short-circuit the bell during dialling. Draw this switch on the diagram.

(1)

Explain the operation of the anti-tinkling switch.

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....

(1)
(Total 10 marks)

36. Draw diagrams to represent

(i) the gravitational field near the surface of the Earth,

(ii) the electric field in the region of an isolated negative. point charge.

(4)

How does the electric field strength E vary with distance r from the point charge?

....

(1)

Give an example of a region in which you would expect to find a uniform electric field.

....

....

(1)
(Total 6 marks)

37. State Lenz's law of electromagnetic induction

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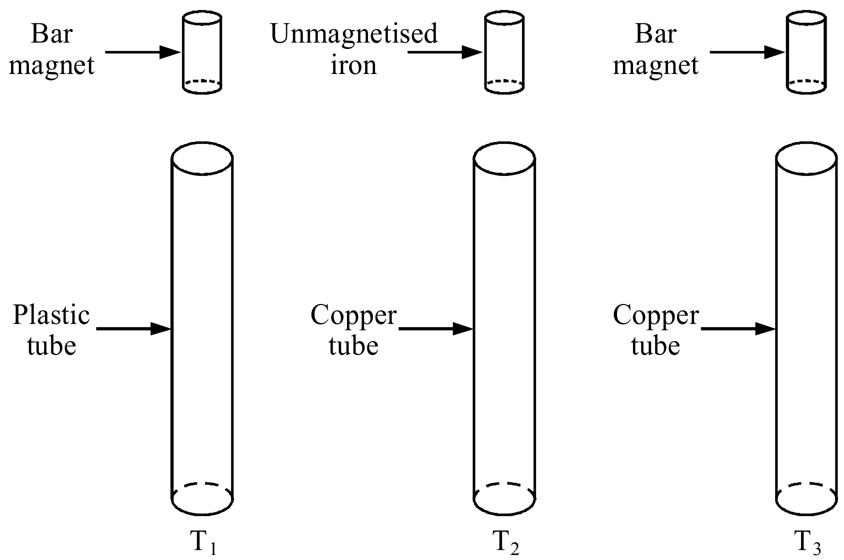
(2)

An exhibit at a science centre consists of three apparently identical vertical tubes, T_1, T_2 and T_3, each about 2 m long. With the tubes are three apparently identical small cylinders, one to each tube.



When the cylinders are dropped down the tubes those in ~T, and ~T2 reach the bottom in less than I second, while that in ~T3 takes a few seconds.

Explain why the cylinder in T_3 takes longer to reach the bottom of the tube than the cylinder in T_1

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....

(5)

Explain why the cylinder in T_2 takes the same time to reach the bottom as the cylinder in T_1

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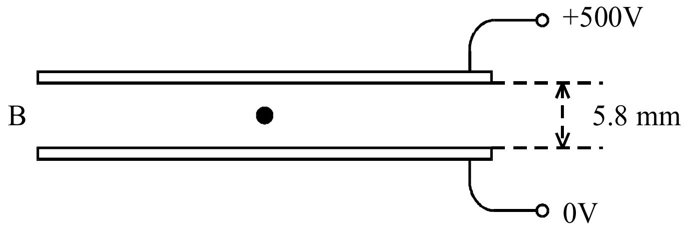
(2)
(Total 9 marks)

38. Lots of tiny plastic spheres are sprayed into the space between two horizontal plates which are electrically charged. After a time one sphere of mass 1.4×10^{-11}g is seen to be suspended at rest as shown.



(a) Explain how the sphere can be in equilibrium and calculate the charge on it.

Why must the plates be horizontal for the plastic spere to be at rest?

(6)

(b) A radioactive β-source is now placed at B for a short time and then removed. The plastic sphere is seen to move down at a steady speed.

Explain how the presence of the β-source has altered the charge on the sphere.

Draw a free-body force diagram of the sphere as it falls.

(3)

(c) Experiments of this kind confirm that *electric charge is quantised*.

Explain the meaning of the phrase in italics.

Name one other physical quantity which is quantised. Describe one situation where this quantum property is significant.

(4)

(d) The experiment above is repeated with plastic spheres which have a much smaller mass and using a lower potential difference between the plates. At no stage does any sphere appear to be completely at rest or to move steadily up or down. This agitated motion of the spheres is less noticeable when the temperature is considerably lowered.

Explain these observations.

(3)
(Total 16)

39. (a) In an oscilloscope, *N* electrons each of charge *e* hit the screen each second. Each electron is accelerated by a potential difference *V*.

(i) Write down an expression for the total energy of the electrons reaching the screen each second.

(ii) The power of the elctron beam is 2.4W. When the oscilloscope is first switched on the spot on the glass screen is found to rise in temperature by 85 K during the first 20 s.

The specific heat capacity of glass is 730 J kg $^{-1}$K^{-1}. Calculate the mass of glass heated by the electron beam. State two assumptions you have made in your calculation.

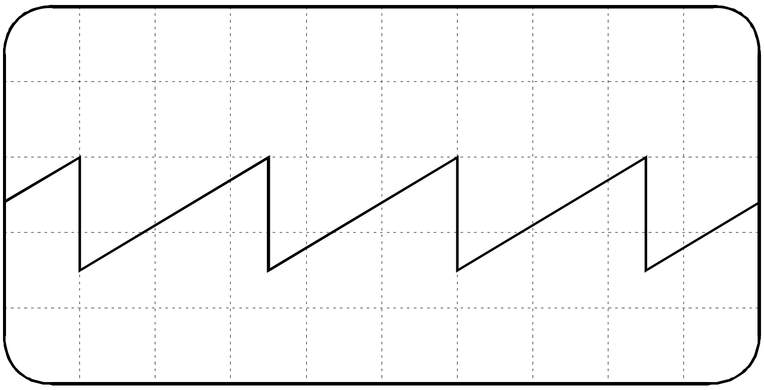
(7)

(b) Outline how, in principle, you would measure the specific heat capacity of glass. You may use a lump of glass of any convenient shape in your experiment.

What difficulties might lead to errors?

(5)

(c) The oscilloscope is now used to investigate the 'saw-toothed' signal from a signal generator. The trace show is obtained.



The Y-gain control is set at 0.2 volts per division and the time-based control at 100 microseconds per division.

(i) Calculate the frequency of the saw-toothed signal.

(ii) What is the rate of rise of the signal voltage during each cycle?

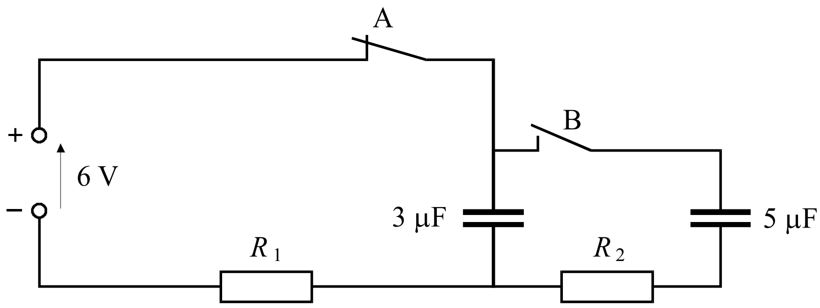
(4)
(Total 16)

40. Each row in the following table starts with a term in the left hand column. Indicate with a tick which of the three expressions in the same row relates to the first term.

Joule	kg m s^{-2}		kg m s^{-2}		kg $m^2 s^{-3}$	
Coulomb	Base Unit		Derived unit		Base quantity	
Time	Scalar quantity		Vector quantity		Neither vector nor scalar	
Volt	A × W		A × W^{-1}	×	W × A^{-1}	

(Total 4 marks)

41. In the circuit below, switch A is initially closed and switch B is open. Calculate the energy stored in the 3 μF capacitor when it is fully charged.



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Energy =..............................

(3)

Switch A is now opened and switch B is closed. Calculate the final value of the total energy stored in the two capacitors when the 5 μF capacitor is fully charged.

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....

....

....

....

Total energy =..........................

(4)

State briefly how you would account for the decrease in stored energy.

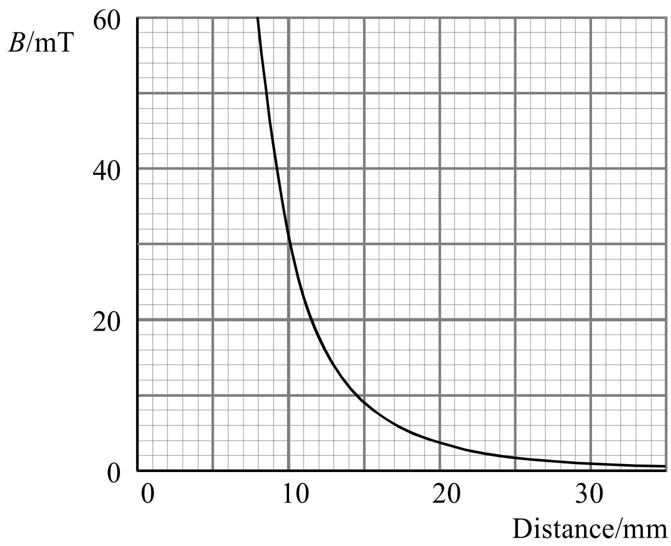
.............................…..

.............................…..

.............................…..

(1)
(Total 8 marks)

42. Magnetic flux density B varies with distance beyond one end of a large bar magnet as shown on the graph below.



A circular loop of wire of cross–sectional area 16 cm^2 is placed a few centimetres beyond the end of the bar magnet. The axis of the loop is aligned with the axis of the magnet.

Calculate the total magnetic flux through the loop when it is 30 mm from the end of the magnet.

.............................…..

.............................…..

.............................…..

Magnetic flux =...

Calculate the total magnetic flux through the loop when it is 10 mm from the end of the magnet.

.............................…..

.............................…..

.............................…..

Magnetic flux =...

(3)

The loop of wire is moved towards the magnet from the 30 mm position to the 10 mm position so that a steady e.m.f. of 15 μV is induced in it. Calculate the average speed of movement of the loop.

....

....

....

....

....

....

Speed =.......................

(3)

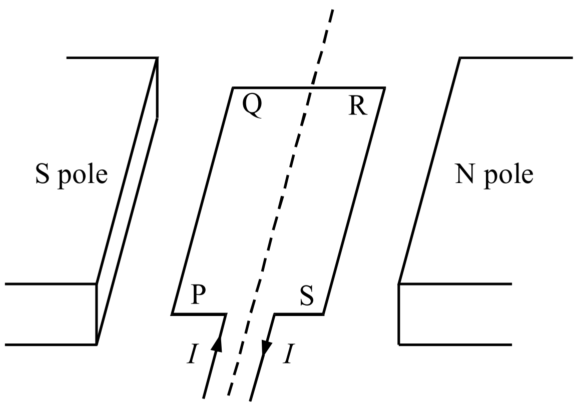
In what way would the speed of the loop have to be changed while moving towards the magnet between these two positions in order to maintain a steady e.m.f.?

....

(1)

(Total 7 marks)

43. The diagram shows a rectangular coil PQRS which can rotate about an axis which is perpendicular to the magnetic field between two magnetic poles.



Explain why the coil begins to rotate when the direct current *I* is switched on.

....

....

....

....

Add to the diagram an arrow showing the direction of the force on PQ.

State *three* factors which would affect the magnitude of this force.

(1) ....

(2) ....

(3) ....

(7)

A student notices that as the coil rotates faster the current in it reduces. Explain this observation.

....

....

....

....

....

(2)
(Total 9 marks)

44. Express the ohm and the farad in terms of SI *base* units.

Ohm ……………………………………………………………………….……………………..

....

Farad ………………..……………………………………………………………..……..

....

Hence show that ohm x farad = second.

....

....

....

....

(4)

Most d.c. power supplies include a smoothing capacitor to minimise the variation in the output voltage by storing charge. In a particular power supply, a capacitor of 40 000 μF is used. It charges up quickly to 12.0 V, then discharges to 10.5 V over the next 10.0 ms, and then charges again to 12.0 V. The process then repeats continually.

Calculate the charge on the capacitor at the beginning and at the end of the 10.0 ms discharge period.

Beginning ……...………………………………………………………………………..

....

....

Charge ……………………………

....

....

End ………………………………………………..…………………………………

....

....

Charge ……………………………

(3)

What is the average current during the discharge?

....

....

....

Average current = ……………….…………

(3)

The discharge times for the smoothing capacitors in modern computer power supplies are reduced to a minimum. Explain one advantage of this reduced discharge time.

....

....

....

(2)
(Total 12 marks)

45. A large solenoid is 45 cm long and has 72 turns. Calculate the magnetic flux density inside the solenoid when a current of 2.5 A flows in it.

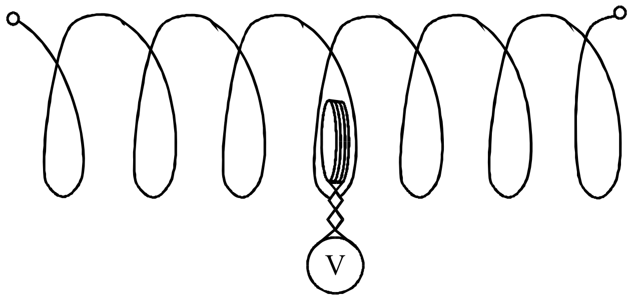
…………………………………………………………………………………………

…………………………………………………………………………………………

Flux density =……….......……..............

(2)

A small solenoid is placed at the centre of the large solenoid as shown. The small solenoid is connected to a digital voltmeter.



State what would be observed on the *voltmeter* when each of the following operations is carried out consecutively.

(a) A battery is connected across the large solenoid.

....

....

(b) The battery is disconnected.

....

(c) A very low frequency alternating supply is connected across the large solenoid.

....

....

(5)
(Total 7 marks)

46. **Figure 1** shows a simple moving coil loudspeaker. **Figure 2** is an end on view showing the position of the coil between the poles of the magnet.

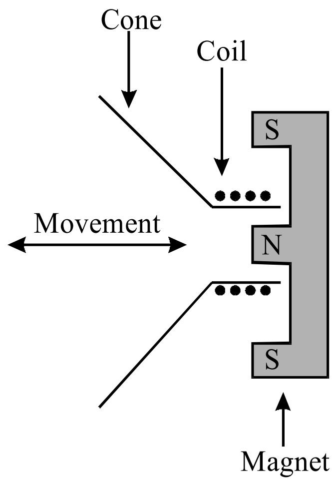


Figure 1

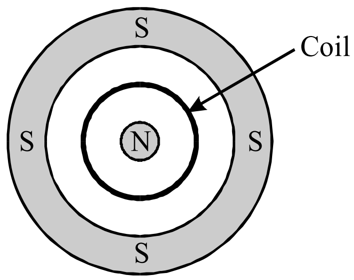


Figure 2

Explain how an alternating current in the coil causes the cone of the loudspeaker to move in and out as shown.

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

(2)

On **Figure 2** draw six magnetic field lines in the gap which contains the coil.

What is the advantage of having such an unusually shaped magnet?

……………………………………………………………………………………………

……………………………………………………………………………………………

Show on **Figure 2** the direction of the current in the coil that would cause the cone to move towards you out of the plane of the paper.

(3)

The magnetic flux density in the gap is 0.6 T. The coil has 300 turns of diameter 40 mm. What is the force on the coil when it carries a current of 20 mA?

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

Force =………..........……................

(3)
(Total 8 marks)

47. State what is meant by "an equation is homogeneous with respect to its units".

....

....

(1)

Show that the equation $x = ut + 1/2at^2$ is homogeneous with respect to its units.

....

....

....

....

....

(3)

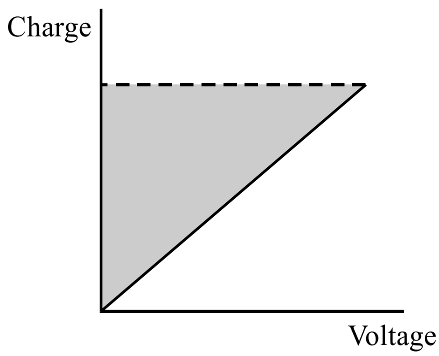
Explain why an equation may be homogeneous with respect to its units but still be incorrect.

....

....

(1)
(Total 5 marks)

48. The diagram shows a graph of charge against voltage for a capacitor.



What quantity is represented by the slope of the graph?

....

What quantity is represented by the shaded area?

....

(2)

An electronic camera flash gun contains a capacitor of 100 μF which is charged to a voltage of 250 V. Show that the energy stored is 3.1 J.

....

....

....

....

....

(2)

The capacitor is charged by an electronic circuit that is powered by a 1.5 V cell. The current drawn from the cell is 0.20 A. Calculate the power from the cell and from this the minimum time for the cell to recharge the capacitor.

....

....

....

....

Minimum time = ...

(3)
(Total 7 marks)

49. A solenoid is formed by winding 250 turns of wire on to a hollow plastic tube of length 0.14m.

Show that when a current of 0.08 A flows in the solenoid the magnetic flux density at its centre is 0.0018 T.

....

....

....

....

(2)

The solenoid has a cross-sectional area of $6.0 \times 10^{-3} m^2$. The magnetic flux emerging from one end of the solenoid is 5.4×10^{-6} Wb(Tm^2)

Calculate the magnetic flux density at the *end* of the solenoid.

....

....

....

Magnetic flux density = ...

(2)

Why is the flux density at the end of the solenoid not equal to the flux density at the centre?

....

....

(1)
(Total 5 marks)

50. The joule is the SI unit of energy. Express the joule in the base units of the SI system.

....

....

(1)

A candidate in a physics examination has worked out a formula for the kinetic energy E of a solid sphere spinning about its axis. His formula is

$$E = \frac{1}{2} \rho r^5 f^2,$$

where ρ is the density of the sphere, r is its radius and f is the rotation frequency. Show that this formula is homogeneous with respect to base units.

....

....

....

....

....

....

(3)

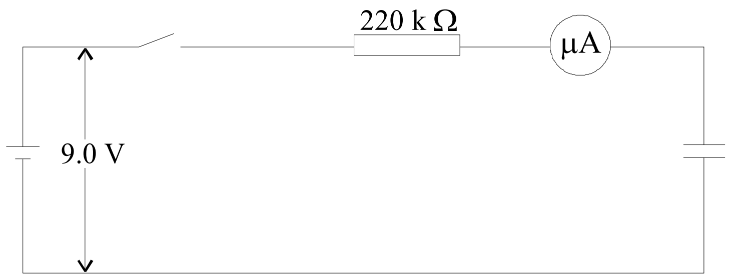
Why might the formula still be incorrect?

....

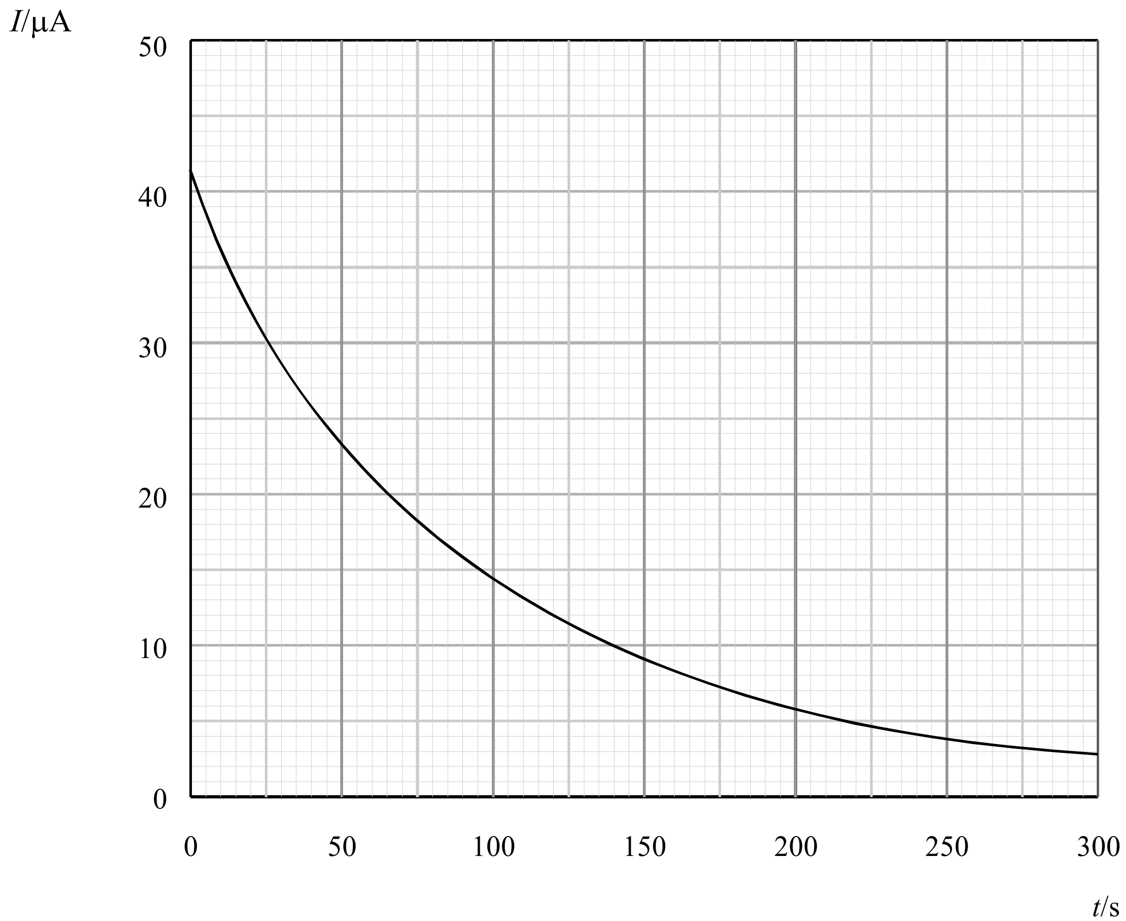
....

(1)
(Total 5 marks)

51. A student assembles the circuit shown in which the switch is initially open and the capacitor uncharged.



He closes the switch and reads the microammeter at regular intervals of time. The battery maintains a steady p.d. of 9.0 V throughout. The graph shows how the current I varies with the time t since the switch was closed.



Use the graph to estimate the total charge delivered to the capacitor.

....

....

....

Charge =..

(3)

Estimate its capacitance.

....

....

Capacitance =..

(2)
(Total 5 marks)

52. Calculate the magnitude of the electric field strength at the surface of a nucleus $^{238}_{92}U$. Assume that the radius of this nucleus is 7.4×10^{-15} m.

....

....

....

Magnitude of electric field strength =..

State the direction of this electric field.

....

(4)

State one similarity and one difference between the electric field and the gravitational field produced by the nucleus.

Similarity ....

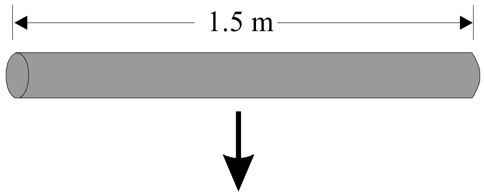
....

Difference ....

....

(2)
(Total 6 marks)

53. A horizontal metal rod, 1.5 m long, is aligned in an E $\leftrightarrow$ W direction and dropped from rest from the top of a high building.



Calculate the e.m.f. induced across the falling rod 2.5 s after release. The horizontal component of the Earth's magnetic field = 2.0×10^{-5} T.

....

....

....

....

e.m.f. =.....................................

(3)

Explain briefly why the magnitude of the vertical component of the Earth's magnetic field is not required in this calculation.

....

....

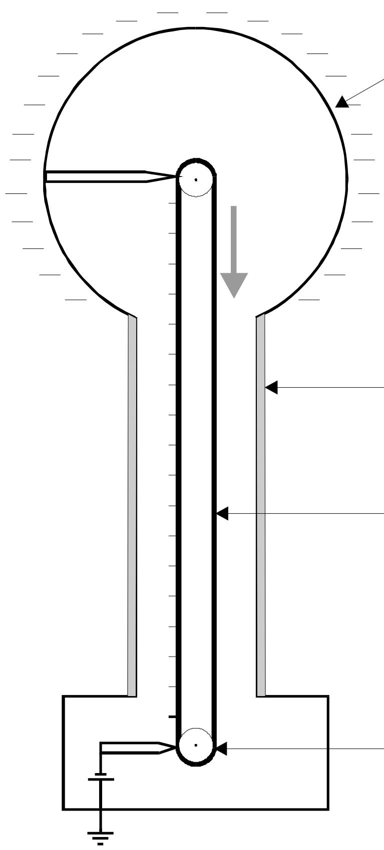
....

....

....

(2)
(Total 5 marks)

54. The diagram shows the principle of a Van de Graaff machine for producing high voltages. A spherical hollow conductor is supported by an insulating column. A moving belt collects electrons at the bottom and these are deposited on to the sphere.



(a) Describe how you would use a negatively charged Van de Graaff machine plus other common laboratory materials to show that like charges repel.

(2)

(b) For a belt of width w moving at a speed v, the current I carried to the sphere is given by

$$I = wvX$$

By considering units, deduce what X represents in this equation.

(3)

(c) (i) Draw a small negatively charged sphere. Add lines showing the electric field in the region around the sphere.

(ii) The electric field close to the surface of a charged sphere of radius 15 cm is found to be 3.6×10^5 N C^{-1}.

Show that the charge on the sphere is a little under 1 μC and calculate the potential of the sphere.

(6)

(d) The sphere of the Van de Graaff is raised to a voltage *V* and the motor driving the belt is switched off. Charge then leaks through the insulating column reducing the voltage to *V*/2 in 30 s.

(i) How does the motion of the electrons in this leakage current differ from that of the electrons carried by the belt?

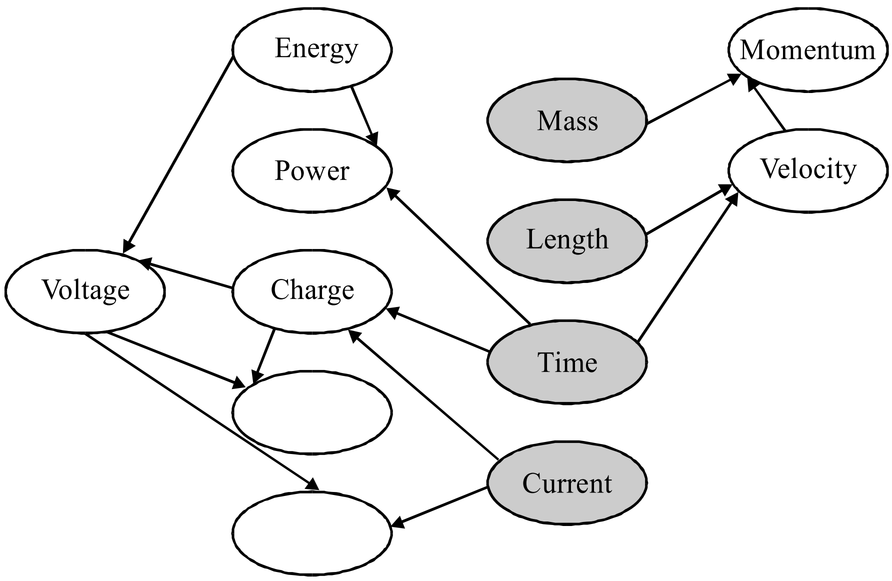
(ii) Sketch a graph showing how the voltage will vary with time for two minutes after the belt ceases to move.

(5)
(Total 16 marks)

55. Many physical quantities are defined from two other physical quantities.

The diagram shows how a number of different quantities are defined by either multiplying or dividing two other quantities.

Write correct quantities in the two blank ellipses below.



(2)

Explain what is special about the physical quantities in the shaded ellipses.

....

....

....

(2)
(Total 4 marks)

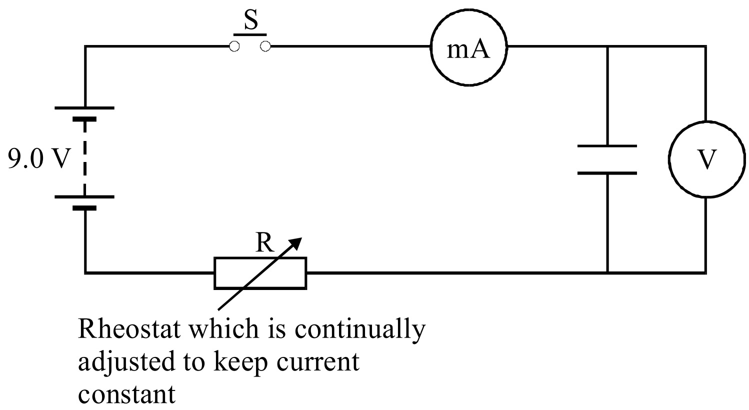
56. State the relationship between current and charge

....

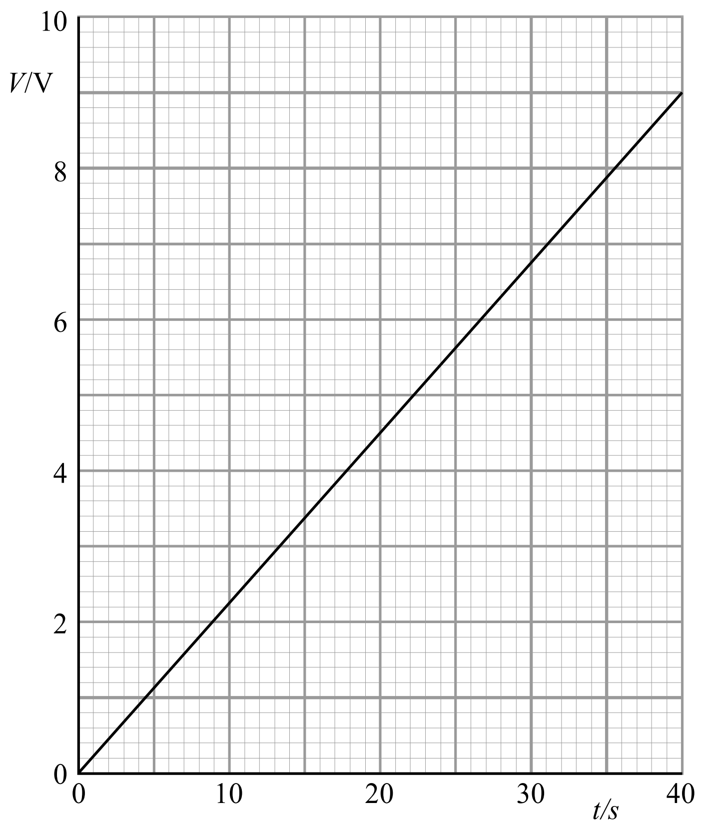
....

(1)

Two students are studying the charging of a capacitor using the circuit shown. The voltmeter has a very high resistance.



The capacitor is initially uncharged. At time zero, one student closes switch S. She watches the milliammeter and continually adjusts the rheostat R so that there is a constant current in the circuit. Her partner records the voltage across the capacitor at regular intervals of time. The graph below shows how this voltage changes with time.



Explain why the graph is a straight line.

....

....

....

....

....

....

(2)

The capacitance used was 4700 μF. Use the graph to determine the charging current.

....

....

....

....

Current =...

(3)

In order to keep the current constant, did the student have to increase or decrease the resistance of the rheostat as time passed? Explain your answer.

....

....

....

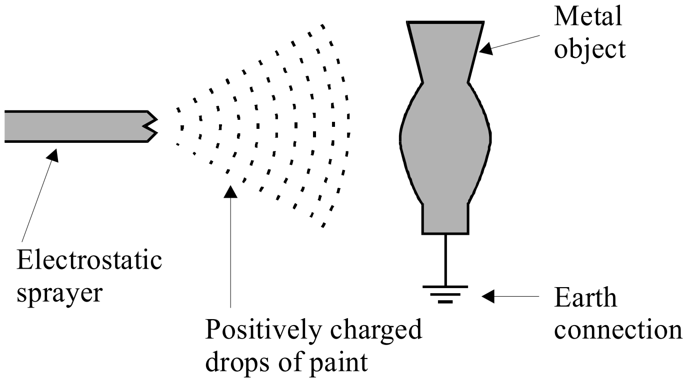
....

(3)

The students repeat the experiment, with the capacitor initially uncharged. The initial current is the same as before, but this time the first student forgets to adjust the rheostat and leaves it at a fixed value. Draw a second graph on the same axes to show qualitatively how the voltage across the capacitor will now change with time.

(2)
(Total 11 marks)

57. The diagram shows an electrostatic paint sprayer, used to obtain a uniform coat of paint on a metal object. The paint drops are charged positively by the sprayer. The metal object is connected to Earth.



Why does using identically charged paint drops help produce an evenly distributed spray of paint?

....

....

(1)

Explain why the positive paint drops are attracted to the metal object.

....

....

....

....

....

(3)

Why does the coat of paint become very patchy if the Earth connection is accidentally broken?

....

....

....

....

(2)

(Total 6 marks)

58. A beam of electrons is directed at a target. They are accelerated from rest through 12 cm in a uniform electric field of strength 7.5×10^5 N C^{-1}.

Calculate the potential difference through which the electrons are accelerated.

....

....

Potential difference = ...

Calculate the maximum kinetic energy in joules of one of these electrons.

....

....

Maximum kinetic energy = ...

(4)

Calculate the maximum speed of one of these electrons.

....

....

....

Maximum speed = ...

(2)

Draw a diagram to represent the electric field close to an isolated electron.

(2)
(Total 8 marks)

59. Write a word equation which states Newton's law of gravitation.

....

....

....

(2)

Mars may be assumed to be a spherical planet with the following properties:

Mass m_M of Mars = 6.42×10^{23} kg

Radius r_M of Mars = 3.40×10^{6} m

Calculate the force exerted on a body of mass 1.00 kg on the surface of Mars.

....

....

....

Force =..

(3)

For any planet the relationship between g (the free fall acceleration at the surface) the planet's density ρ and its radius R is

$$g = \frac{4}{3}\pi\rho GR$$

Has Mars a larger, smaller or similar radius to the Earth?

....

Explain your reasoning.

....

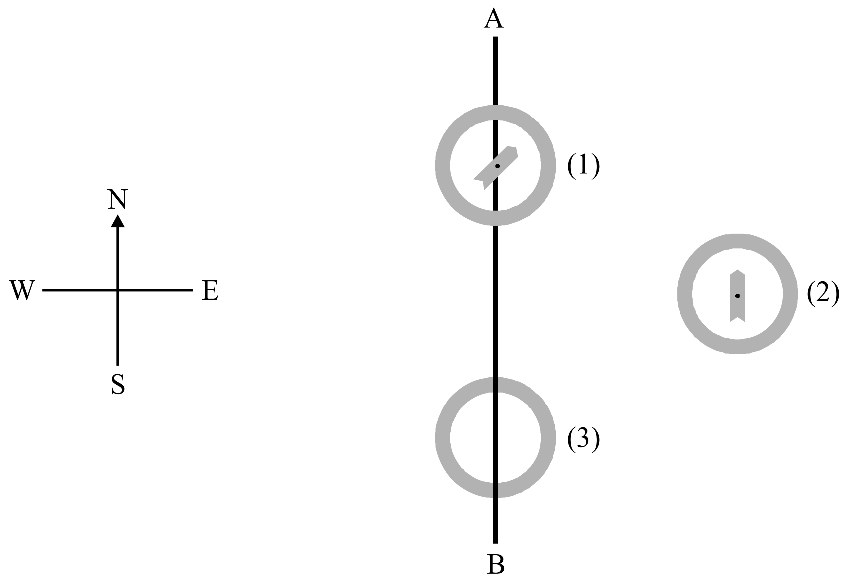
....

....

....

(2)
(Total 7 marks)

60. The diagram shows part of a long straight copper wire through which there is a direct current. Three plotting compasses are positioned as shown: (1) just above the wire, (2) alongside the wire, (3) just below the wire.



Deduce the direction of the current in the wire.

Direction of current ....

(1)

Complete the diagram by adding the pointer to compass (3).

(2)

Explain why the pointer in compass (2) settles in the direction shown.

....

....

....

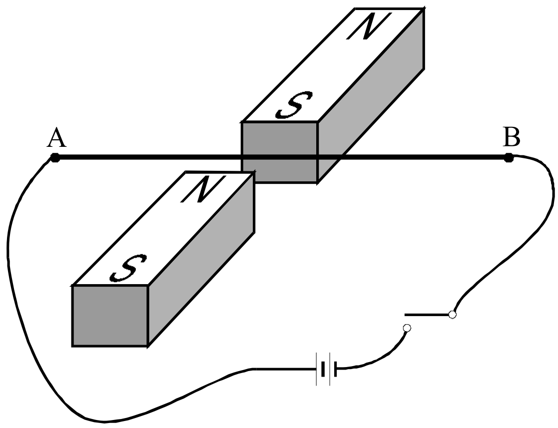
....

....

....

(2)
(Total 5 marks)

61. A stretched wire AB is held horizontally between the poles of two magnets and is connected to a battery as shown in the diagram.



Show on the diagram the direction of the force on the wire when the switch is closed.

(1)

The battery is replaced by a variable frequency a.c. supply. The wire AB has a natural frequency of 20 Hz.

Describe what is seen when

(i) a very low frequency (less than 1 Hz) is selected,

....

....

(1)

(ii) the frequency is **gradually** increased to 50 Hz.

....

....

....

....

....

....

(5)

(Total 7 marks)

62. A metal framed window is 1.3 m high and 0.7 m wide. It pivots about a vertical edge and faces due south.

Calculate the magnetic flux through the closed window. (Horizontal component of the Earth's magnetic field = 20 μT. Vertical component of the Earth's magnetic field = 50 μT.)

....

....

....

Flux =......................................

(2)

The window is opened through an angle of 90° in a time of 0.80 s. Calculate the average e.m.f. induced.

....

....

....

e.m.f. =...

(2)

State and explain the effect on the induced e.m.f. of converting the window to a sliding mechanism for opening.

....

....

....

....

....

(2)
(Total 6 marks)

63. (a) The shaded square in the diagrams represents a piece of resistance paper. The surface of the paper is coated with a conducting material. In the figure below two metal electrodes E_1 and E_2 are placed on the resistance paper and connected to a battery.

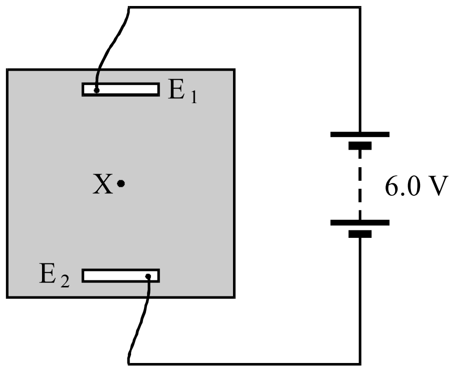


Figure 1

(i) Sketch the electric field in the region between E_1 and E_2.

(ii) E_1 and E_2 are 15 cm apart. What is the strength of the electric field at X, a point half-way between them?

(iii) Add and label three equipotential lines in the region between E_1 and E_2.

(7)

(b) Figure 2 shows two 470 Ω resistors and a milliammeter connected to the initial arrangement. The other side of the milliammeter is connected to a metal probe which makes contact with the surface of the resistance paper.

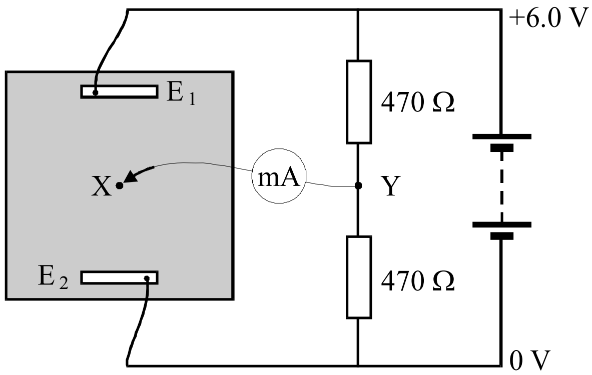


Figure 2

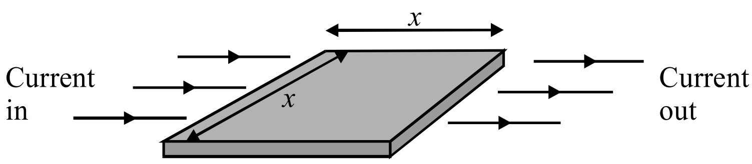
(i) The metal probe is moved over the resistance paper surface. When the probe is at X the milliammeter registers zero. State the potential at X and explain why the milliammeter registers zero.

(ii) Describe how you would adapt the apparatus to find the potentials at other points on the resistance paper.

(5)

(c) The resistance of a square piece - a tile - of the resistance paper is given by $R = \rho/t$, where ρ is the resistivity and t the thickness of the material forming the conducting layer.

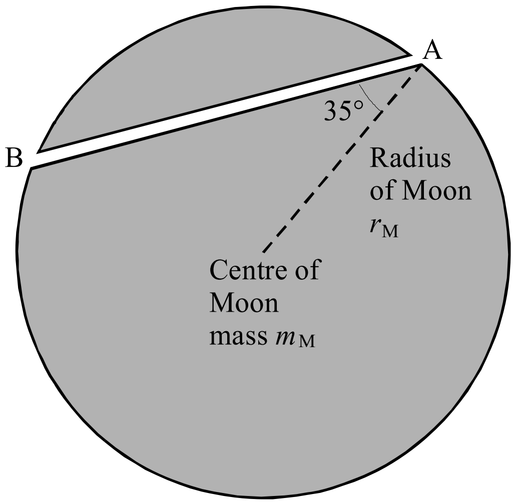
(i) By considering a square of side x as shown, prove that $R = \rho/t$, i.e. that the resistance of the tile is independent of the size of the square.



(ii) Calculate the resistivity of a material of thickness 0. 14 mm which has a resistance of 1000 ohms for a square of any size.

(4)
(Total 16 marks)

64. A futuristic postal system on a colonised Moon might use tunnels bored through the Moon, such as that shown between A and B. There is no air in the tunnels and their sides are frictionless.



It can be shown that a parcel released at A would oscillate with simple harmonic motion between A and B unless it was "collected" at B.

(a) (i) Explain what is meant by *simple harmonic motion.*

(ii) Sketch a graph to show how the velocity of the parcel varies at it moves through the tunnel from A to B.

(4)

(b) The time taken by a parcel to reach B from A is given by

$$t_{AB} = \left(\frac{3\pi}{4\rho_M G}\right)^{\frac{1}{2}}$$

where ρ_M is the mean density of the Moon.

(i) Show that the units of $\rho_M G$ reduce to s^{-2}.

(ii) Calculate t_{AB} to the nearest minute.

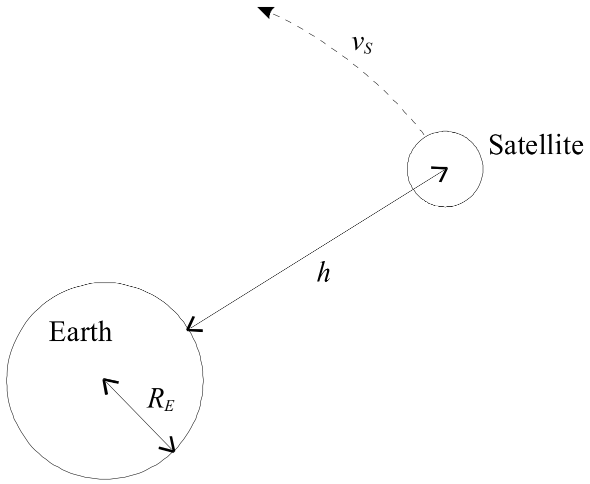
Take the radius of the Moon to be 1.64×10^6 m and its mass to be 7.34×10^{22} kg.

(iii) The equation shows that t_{AB} does not depend on the length of the tunnel.

Explain qualitatively why this appears to be reasonable.

(8)
(Total 12 marks)

65. The diagram (not to scale) shows a satellite of mass m_s in circular orbit at speed υ_s around the Earth, mass M_E. The satellite is at a height h above the Earth's surface and the radius of the Earth is R_E.



Explain why, although the speed of the satellite is constant, its velocity varies.

....

....

(1)

Using the symbols above, write down an expression for the centripetal force needed to maintain the satellite in this orbit.

....

....

....

(2)

Write down an expression for the Earth's gravitational field strength in the region of the satellite.

....

....

State an appropriate unit for this quantity.

....

(3)

Use your two expressions to show that the greater the height of the satellite above the Earth, the smaller will be its orbital speed.

....

....

....

....

....

....

(3)
(Total 9 marks)

66. Write down an equation for the force between two point charges, Q_1 and Q_2 , separated by a distance *r*

....

(1)

A speck of dust has a mass of 1.0×10^{-18} kg and carries a charge equal to that of one electron. Near to the Earth's surface it experiences a uniform downward electric field of strength 100 N C^{-1} and a uniform gravitational field of strength 9.8 N kg^{-1}.

Draw a free-body force diagram for the speck of dust. Label the forces clearly.

Calculate the magnitude and direction of the resultant force on the speck of dust.

....

....

....

....

Magnitude of force =…………………..

Direction of force =…………………….

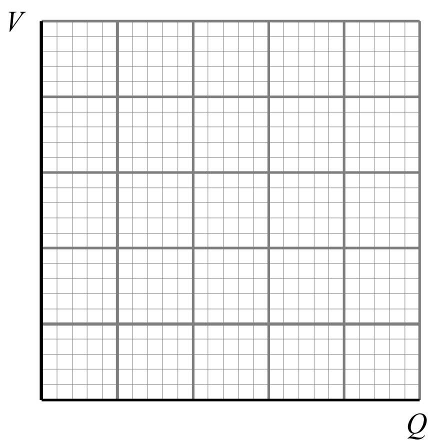
(6)
(Total 7 marks)

67. A 200 μF capacitor is connected in series with a 470 kΩ resistor, a switch and a 4.5 V battery.

Draw a circuit diagram of this arrangement.

(1)

On the axes below, draw a graph showing how the potential difference V across the capacitor varies as the charge Q stored in it increases. Add a scale to both axes.



(3)

Calculate the energy stored by the fully charged capacitor.

....

....

Energy =……………………………….

(2)
(Total 6 marks)

68. The magnitude of the force on a current-carrying conductor in a magnetic field is directly proportional to the magnitude of the current in the conductor. Draw a fully labelled diagram of the apparatus you would use to verify this relationship.

State what measurements you would make and how you would use your results. You may be awarded a mark for the clarity of your answer.

....

....

....

....

....

....

(6)

At a certain point on the Earth's surface the horizontal component of the Earth's magnetic field is 1.8×10^{-5} T. A straight piece of conducting wire 2.0 m long, of mass 1.5 g , lies on a horizontal wooden bench in an East-West direction. When a very large current flows momentarily in the wire it is just sufficient to cause the wire to lift up off the surface of the bench.

Calculate the current.

....

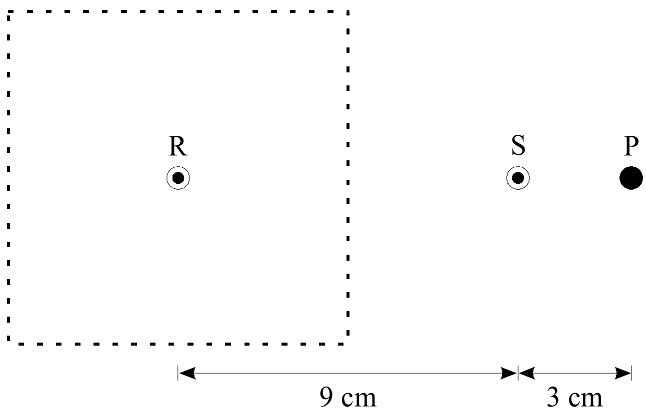
....

....

Current =.....................................

(2)
(Total 8 marks)

69. Two long parallel wires R and S carry steady currents I_1 and I_2 respectively in the same direction. The diagram is a plan view of this arrangement. The directions of the currents are out of the page.



In the region enclosed by the dotted lines, draw the magnetic field pattern due to the current in wire R alone. Show at least three field lines.

(2)

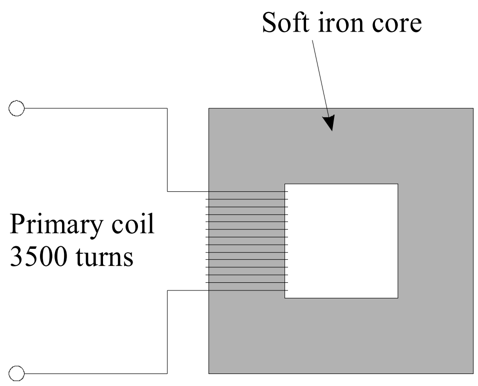
The current I_1 is 4 A and I_2 is 2 A. Mark on the diagram a point N where the magnetic flux density due to the currents in the wires is zero.

(1)

Show on the diagram the direction of the magnetic field at P.

(1)
(Total 4 marks)

70. Complete the diagram below of a transformer designed to step down a potential difference of 11 kV to 415 V.



(2)

Explain why the transformer could not be used to step down the potential difference of a d.c. supply.

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(1)

Show that for an ideal transformer (100% efficient)

$$\frac{I_{primary}}{I_{secondary}} = \frac{\text{number of secondary turns}}{\text{number of primary turns}}$$

....

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(2)

Transformers are not 100%efficient. State one cause of energy loss in a transformer.

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(1)
(Total 6 marks)

71. Instructions

Part 1

1 Microammeter capable of measuring currents up to 100 μA to a precision of 1 μA.

2 D.c. power supply set at 4.5 V d.c. (3, 1.5 V cells in a cell holder are suitable.).

3 470 μF electrolytic capacitor with the positive terminal clearly marked.

4 47 kΩ resistor.

5 Connecting leads.

Part 2

1 12 V, 24 W lamp, with a suitable power supply. The coiled lamp filament should be straight.

2 Diffraction grating having 300 line mm^{-1} (7500 line $inch^{-1}$)(e.g. Philip Harris P39462/8 or Griffin XFY-530-B).

3 Stand, at least 80 cm high, with two bosses and clamps.

4 Piece of white paper, about A4 size (210 mm × 297 mm), fresh for each candidate.

Items 1 - 4 should be assembled above the bench, with the lamp filament horizontal. The grating should be clamped a few centimetres below the lamp with its rulings parallel to the filament. The paper should be placed on the bench with its shorter sides parallel to the filament.

In the experiment the candidate will be required to place the lens, 5, on top of the grating and then to move the grating so that a sharp image of the filament is formed on the paper. The Supervisor should check that this will be possible but should remove the lens and change the position of the grating after doing so.

5 Converging lens, focal length 10 cm.

6 Petri dish containing a very dilute solution of potassium manganate (VII) (potassium permanganate) supported on a tripod with balls of Plasticene wedged in the corners to hold the dish. The strength of the solution should be such that when the dish is placed below the grating so as to interrupt the beam of light, the candidate is clearly able to see the presence of an absorption band in the spectra. A few crystals in 100 cm^3 of water should suffice.

7 Metre rule.

The experiment should be performed in a part of the laboratory where there is subdued light.

Part 1

You are to determine the time taken for the charging current in an RC circuit to halve.

(a) Draw a diagram of the circuit you would use to charge a capacitor in series with a resistor from a d.c. power supply.

Explain why it is necessary to connect the capacitor into the circuit **with the correct polarity.**

....

....

Discharge the capacitor. How did you do this?

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....

Set up the circuit and determine the time taken for the current to halve. Show all your results below and explain the precautions you took to make your readings as accurate as possible. You are *not* expected to draw a graph.

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(8)

Part 2

This experiment is concerned with the use of a diffraction grating to observe spectra.

Place the converging lens on top of the diffraction grating and adjust the height of the grating so that a sharp image of the filament of the lamp is focused on the paper on the bench. Record the distance D from the diffraction grating to the bench.

D = ...

Mark on the piece of paper the limits of the first order visible spectrum on either side of the image of the filament.

Sketch the spectra in the space below and record on the sketch the distance X_R between the two red limits and the distance X_V between the two violet limits.

Find the angle θ_R between the first order red limit of the spectrum and the image of the filament using

$$\tan\theta_R = \frac{X_R}{2D}$$

Hence find $\sin\theta_R$.

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Carefully insert the tripod and dish containing the purple solution so that the light to one of the first order spectra passes through the solution. Describe any change in the appearance of the spectrum. You may use the space below to sketch what is observed.

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Explain briefly why the spectrum changes.

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(8)
(Total 16 marks)

72. Instructions

1 Wooden metre rule labelled A.

2 Two 100g slotted masses.

3 Rubber band to secure the masses to the rule, 1. The candidate will be required to secure the masses either side of the rule at the 95.0 cm mark.

4. Small block of wood to provide a well-defined edge.

5 G-clamp.

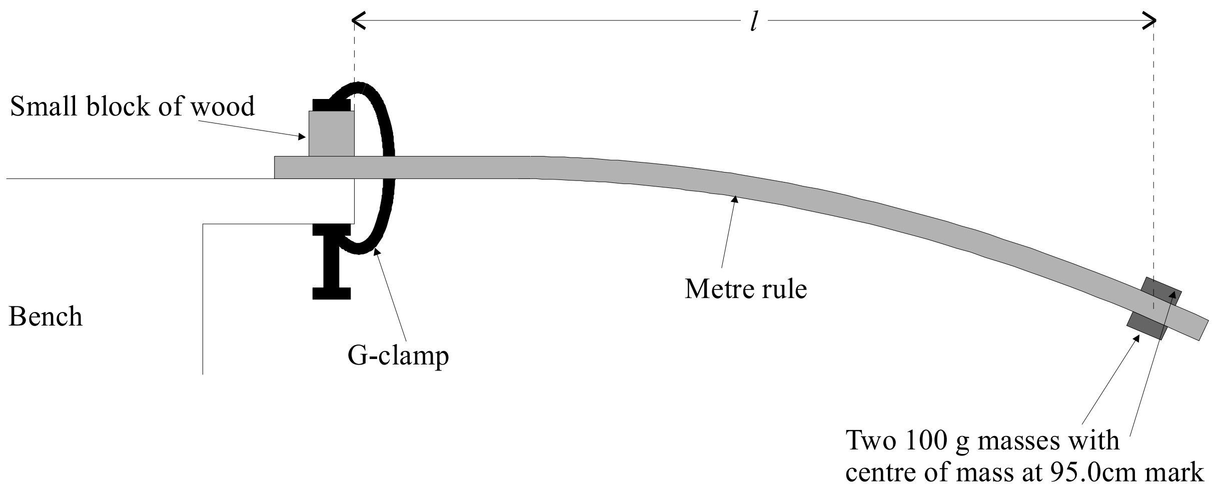
6. Second metre rule.

7 Stand, clamp and boss to support the second metre rule.

8 Vernier calipers.

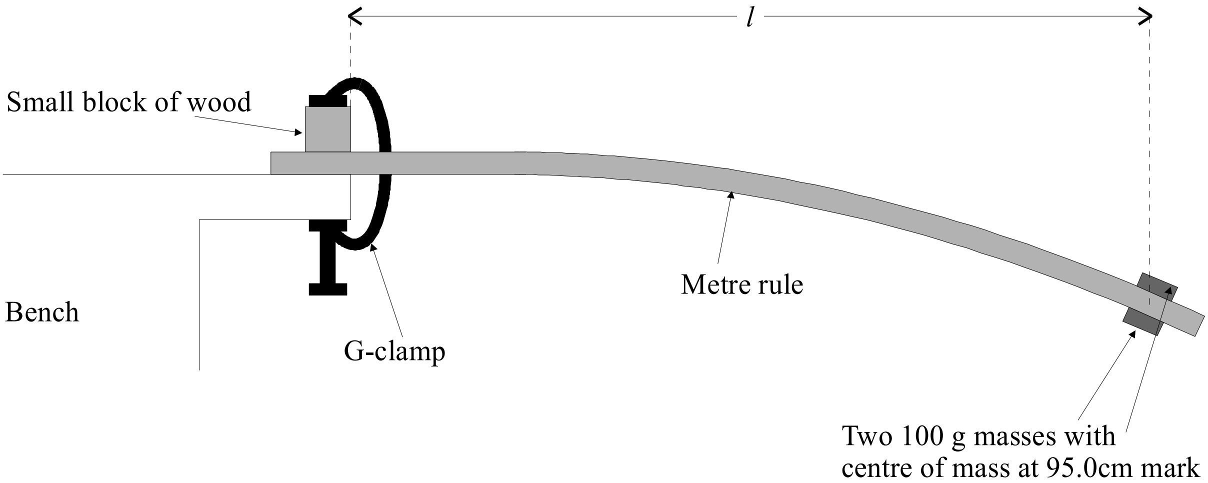
9 Digital stopwatch.

Items 1 - 5 are to be assembled by the candidates as shown in the diagram below.
The distance *l* is to be set initially at 0.900 m.



You are to investigate how the periodic time of a vibrating cantilever is dependent on the length of the cantilever.

(a) Set up the apparatus as shown in the diagram below using the metre rule labelled A. The length l should be set to 0.900 m.



Explain carefully how you ensured that the length l was set to 0.900 m. You may add to the diagram if you wish.

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....

(2)

(b) Displace the end of the rule vertically and determine the period T of the vertical oscillations.

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(3)

(c) Measure the width b and the thickness d of the clamped rule. Estimate the percentage uncertainty in each of these quantities.

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(5)

(d) The Young modulus E of the material of the rule is given by $E = \dfrac{16\pi^2 Ml^3}{bd^3T^2}$

where M = total mass attached to the rule.

Use your results to calculate a value for E.

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(2)

(e) Explain why d would contribute far more than b to the uncertainty in your value for E.

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(2)

(f) What additional apparatus would you use to improve the precision in your measurement of d? Estimate the factor by which this would reduce your percentage uncertainty in d.

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(2)
(Total 16 marks)

73. Instructions

1 250 ml beaker filled to within approximately1 cm from the top with dry sand.

2 Table tennis ball.

You are to plan an investigation of how the diameter of a crater formed in soft sand by a polystyrene sphere is dependent on the impact velocity of the sphere. You are then to analyse a set of data from such an experiment.

You may use the sphere and sand provided to observe the crater formation, but you are not required to take any measurements. In addition to the apparatus provided, you may assume that a metre rule, a pair of dividers, a set square and a stand and clamp would be available.

(a) (i) Which quantity would you vary in order to vary the impact velocity of the sphere?

....

Draw a diagram of your experimental arrangement. Indicate any measurements to be taken on the diagram.

Explain how the impact velocity could be found from your measurements.

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....

(4)

(ii) State an assumption which you have to make to determine the impact velocity. How might this assumption affect the range of velocities which you use?

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(2)

(iii) The diameter *d* of the crater is expected to be related to the impact velocity υ by an equation of the form

$$d = k\upsilon^n$$

where *k* and *n* are constants.

Describe briefly how you would investigate this relationship experimentally. Your description should include an indication of the graph you would plot to investigate the equation.

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(3)

(b) The following data was obtained in such an investigation.

υ/m s^{-1}	d/m		
0.44	0.0118		
0.77	0.0168		
1.17	0.0218		
1.47	0.0234		
1.72	0.0275		
2.12	0.0308		

Use the columns provided for your processed data, and then plot a suitable graph to test the equation on the grid below.

(5)

(c) Use your graph to determine a value for *n*

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(2)
(Total 16 marks)

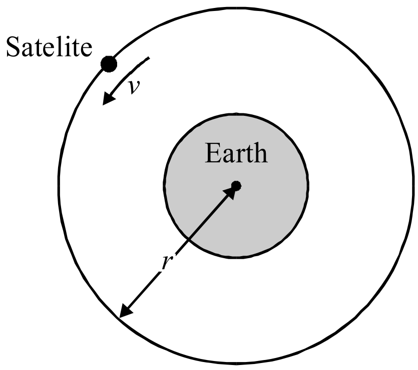
74. The value of *G,* the gravitational constant, is 6.67×10^{-11} N m^2 kg^{-2}. What are the base units of *G*?

....

....

(1)

A satellite orbits the Earth, mass *M*, in a circular path of radius *r*, with speed *v*, as shown in the diagram.



It can be shown that the period of orbit *T* of the satellite is given by

$$T^2 = \frac{4\pi^2 r^3}{GM}$$

Show that this equation is homogeneous with respect to units.

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(2)

Personal navigation devices use the Global Positioning System (GPS). GPS satellites are in a non-equatorial orbit at a height of 20 000 km above the Earth. The time to complete one orbit is 12 hours. Given that the radius of the Earth is 6400 km, use the above relationship to find the mass *M* of the Earth.

....

....

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....

Mass of the Earth = ...

(3)
(Total 6 marks)

75. State Faraday's law of electromagnetic induction.

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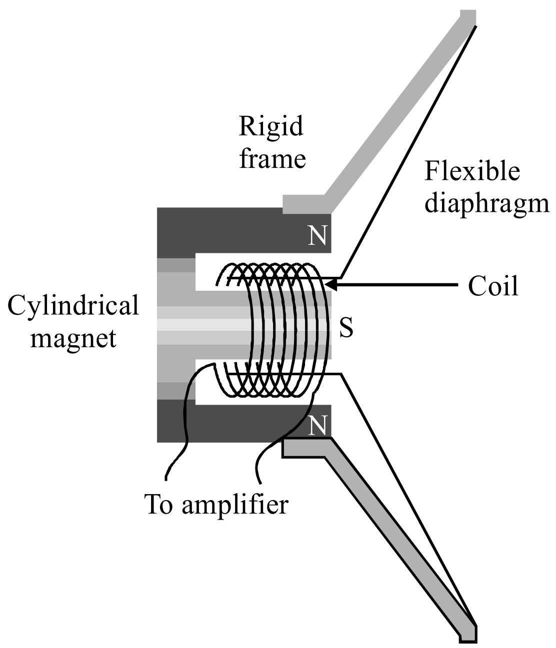
(2)

Microphones convert longitudinal sound waves into electrical signals, which can be amplified. One type of microphone consists of a flexible diaphragm connected to a coil of wire, which is near a cylindrical magnet.



Describe how sound waves are converted into electrical signals. You may be awarded a mark for the clarity of your answer.

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(4)
(Total 6 marks)

76. A defibrillator is a machine that is used to correct irregular heartbeats by passing a large current through the heart for a short time. The machine uses a 6000 V supply to charge a capacitor of capacitance 20 μF. The capacitor is then discharged through the metal electrodes (defibrillator paddles) which have been placed on the chest of the patient.

Calculate the charge on the capacitor plates when charged to 6000 V.

....

Charge = ...

(2)

Calculate the energy stored in the capacitor.

....

....

Energy = ...

(2)

When the capacitor is discharged, there is an initial current of 40 A through the patient.

Calculate the electrical resistance of the body tissue between the metal electrodes of the paddles.

....

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Resistance = ...

(1)

Assuming a constant discharge rate of 40 A, calculate how long it would take to discharge the capacitor.

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Time = ...

(2)

In practice the time for discharge is longer than this calculated time. Suggest a reason for this

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(1)
(Total 8 marks)

77. The diagram shows a straight wire Y carrying a current *I*. In the space below draw the magnetic field pattern close to the wire as seen when looking from above.

Wire Y

Magnetic field pattern
as seen from above

(3)

Calculate the current in this wire when the field strength due to the wire alone at a point 12 cm from the centre of the wire is 1.4×10^{-5} T.

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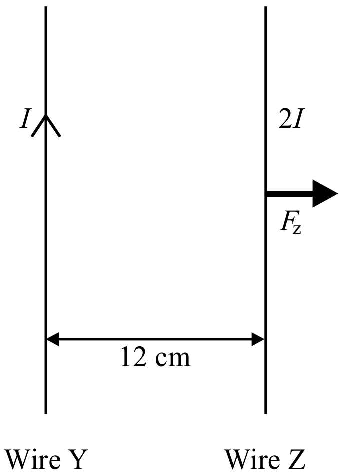
Current = ...

(2)

A second wire Z, carrying a current of 2*I*, is placed parallel and 12 cm from wire Y.



The diagram shows the direction of the force F_Z exerted on the second wire Z.

Add to the diagram an arrow showing the direction of the current 2*I* in the second wire Z.

(1)

A force F_Y is also exerted on the first wire Y.

Add to the same diagram another arrow showing the direction of this force.
Label it F_Y.

What is the ratio F_Y:F_Z of the two forces?

....

(1)

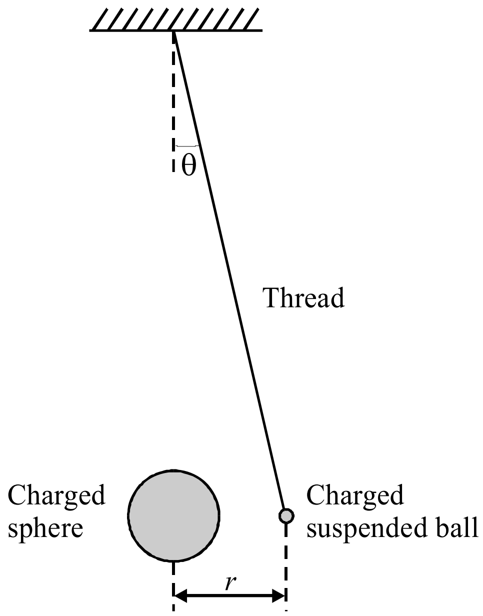
State two methods by which the magnitude of the force F_Y could be reduced.

....

....

(2)
(Total 10 marks)

78. One practical arrangement for verifying Coulomb's law is to use a lightweight, negatively-charged, freely-suspended ball. It is repelled by the negative charge on a larger sphere that is held near it, on an insulated support. The small angle of deflection θ is then measured.



Draw a free-body force diagram for the suspended ball.

(3)

The weight of the ball is W. Show that the force of repulsion F on the suspended ball is given by

$$F = W \tan \theta$$

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(2)

A student takes several sets of readings by moving the larger sphere towards the suspended ball in order to increase the mutual force of repulsion between them. He measures the angle of deflection θ and the separation distance r in each case. He then calculates the magnitude of the force F.

Here are some of his results.

Force $F/10^{-3}$ N			142	568
Distance $r/10^{-3}$ m	36.0	27.0	18.0	9.0

Calculate the values that you would expect the student to have obtained for the missing forces, assuming that Coulomb's law was obeyed.

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Write your answers in the table.

(4)

Suggest why, in practice, it was necessary for the student to take measurements quickly using this arrangement.

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(1)
(Total 10 marks)

79. (a) Secure the can to the bench with Blu-tack to prevent it from rolling. Balance the metre rule on the can and determine the period T_1 of **small** oscillations of the rule.

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....

Repeat the above to find the period T_2 of **small** oscillations of the half-metre rule.

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To what extent do your measurements confirm that the period of such oscillations is proportional to the length of the rule?

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(6)

(b) (i) Use the balance provided to find the mass M of the can and its contents.

....

Use the data given on the can to determine the mass m of the can itself. (1 litre of water has a mass of 1 kg.) Explain how you calculated m.

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Using the information on the card, estimate the volume V of material in the can itself.

....

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(3)

(ii) Measure the diameter D of the central part of the can and the length L of the can. Draw a diagram below to show how you measured D.

....

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Calculate a value for the thickness t of the can given that, to a good approximation

$$t = \frac{V}{\pi D(L + D)}$$

....

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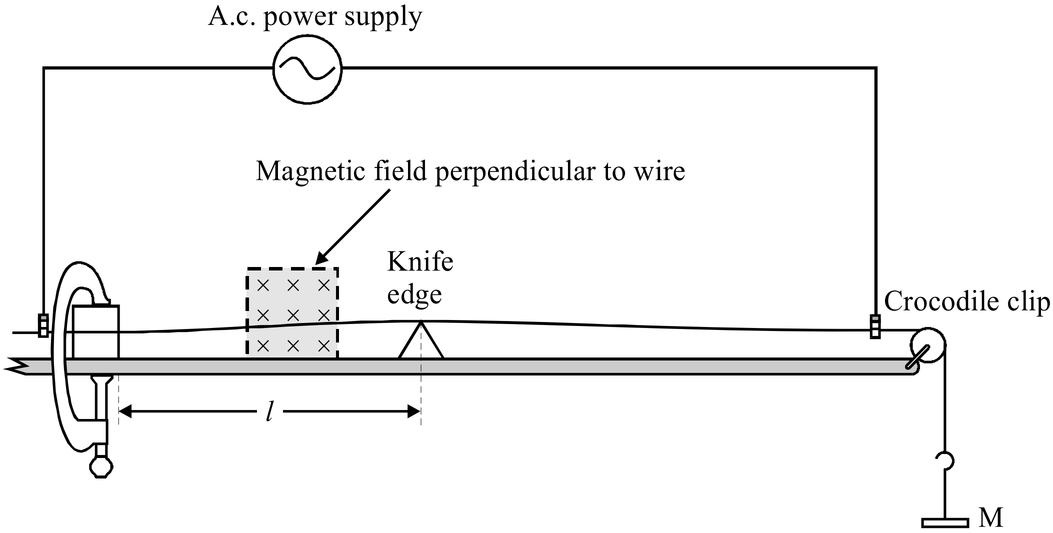
(7)
(Total 16 marks)

80. (a) The apparatus shown in the diagram below has already been set up for you with $M = 100$ g.



Switch on the power supply. Adjust the length l of the wire between the wooden blocks and the knife edge until you can see that the amplitude of vibration of the wire passing through the magnetic field is at its maximum value. Record the length l_1 at this point.

....

....

Explain carefully how you ensured that the value of l_1 was as accurate as possible.

....

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....

Estimate the percentage uncertainty in your value of l_1.

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....

Repeat the above procedure with M = 300 g to obtain a value for the new resonant length l_2.

....

....

Switch off the power supply.

(6)

(b) When a wire is forced to vibrate at its natural frequency, the tension T in the wire and the length *1* of the wire are related by an equation of the form

$$\frac{T}{l^2} = k$$

where k = a constant.

Use your results from part (a) to determine two values for k. Comment on the extent to which your results support the relationship.

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(5)

(c) Measure the diameter d of the wire. Hence determine a value for the density ρ of the material of the wire given that

$$k = \rho \pi d^2 f^2$$

where f = the frequency of the a.c. supply, which is given on the card.

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(5)

(Total 16 marks)

81. *You are to plan an investigation into the relationship between the intensity of the light passing through a pair of polaroid filters and the angle between their planes of polarisation. You are then to analyse a set of data from such an experiment.*

(a) You have been provided with a pair of polaroid filters to observe what happens when one filter is rotated with respect to the other, but you are **not** required to take any measurements.

The following additional apparatus would be available:

- light source
- LDR and ohmmeter together with a calibration curve enabling resistance measurements to be converted to light intensity in a unit called lux
- light shield
- protractor
- stands and clamps

Draw a diagram of the experimental arrangement which you would use.

Describe, with the aid of diagrams, how you would measure the angle through which one filter had been turned with respect to the other.

....

....

State a suitable starting angle between the planes of polarisation of the two filters. Explain how you would determine when the planes are at this angle from your resistance readings.

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(8)

(b) The intensity I of light passing through the two polaroids is thought to be related to the angle θ between their planes of polarisation by an equation of the form $I = k(\cos\theta)^n$ where k and n are constants.

Write this equation in a suitable format which can be used to plot a linear graph.

....

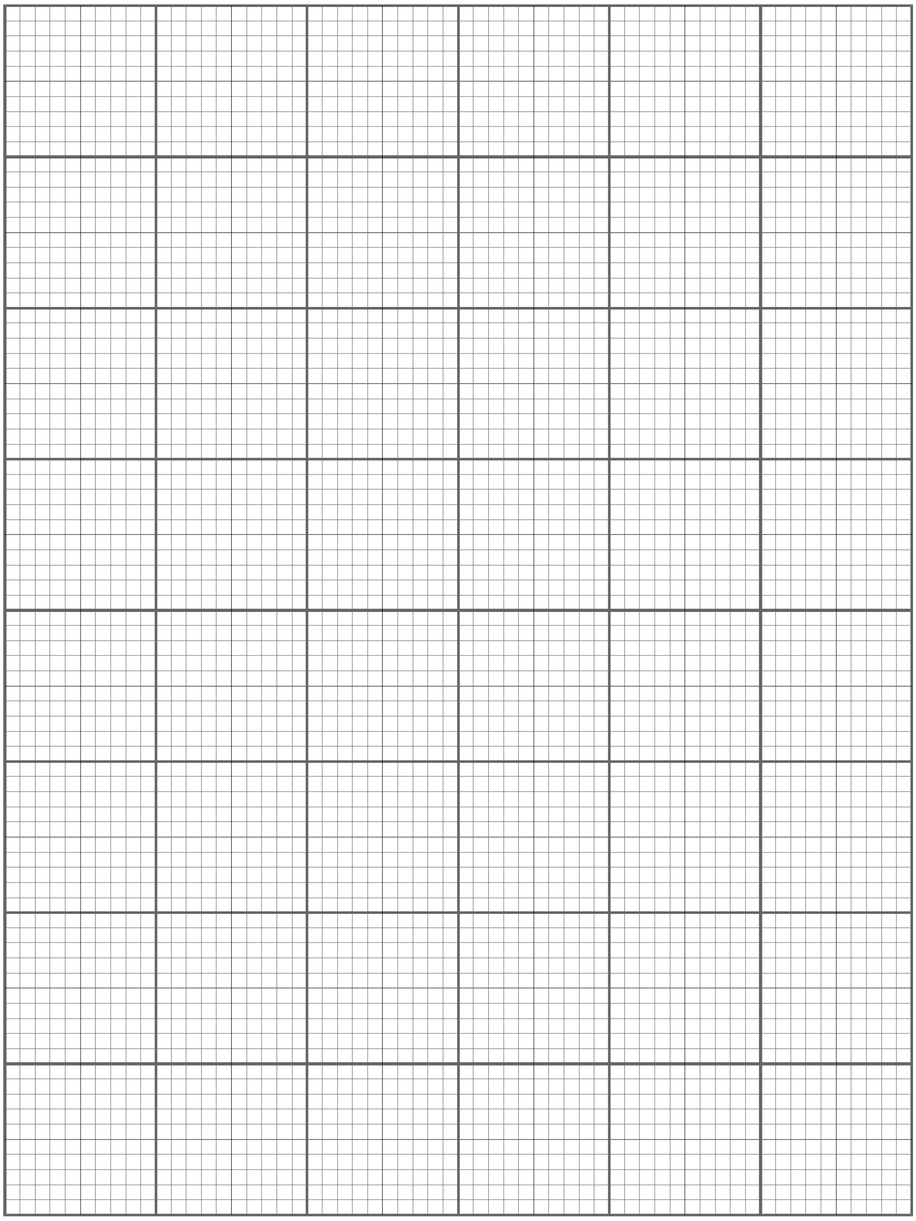
....

(1)

(c) The following data was obtained in an investigation of the above equation.

θ / °	I / lux	Cos θ		
10	481	0.985		
20	450	0.940		
30	398	0.866		
40	330	0.766		
50	256	0.643		
60	172	0.500		
70	98	0.342		
80	40	0.174		

Use the empty columns provided for your processed data, and then plot a suitable graph to test the equation on the grid below.



(5)

(d) Use your graph to determine a value for *n*.

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(2)
(Total 16 marks)

82. (a) (i) Secure the can to the bench with Blu-tack to prevent it from rolling. Balance the metre rule on the can and determine the period T_1 of **small** oscillations of the rule.

....

....

Secure the cell to the wooden block and then secure this arrangement to the bench.

Find the period T_2 of **small** oscillations of the metre rule when it is balanced on the cell.

....

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(4)

(ii) Measure the diameter D_1 of the central part of the can and the diameter D_2 of the cell. Draw a diagram to show how you made these measurements.

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To what extent do your results support the hypothesis that $T_2 \propto 1 / D$, provided the diameter is much greater than the thickness of the rule?

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(6)

(b) Use the measuring cylinder and water to find the internal volume V of the can. Briefly explain how you did this.

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Measure the length L of the can and calculate an approximate value V' for the volume of the can using

$$V' = \frac{\pi D_1^2 L}{4}$$

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Suggest why your value of V differs from the volume stated on the label of the can.

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....

Suggest why your value of V' differs from that for V.

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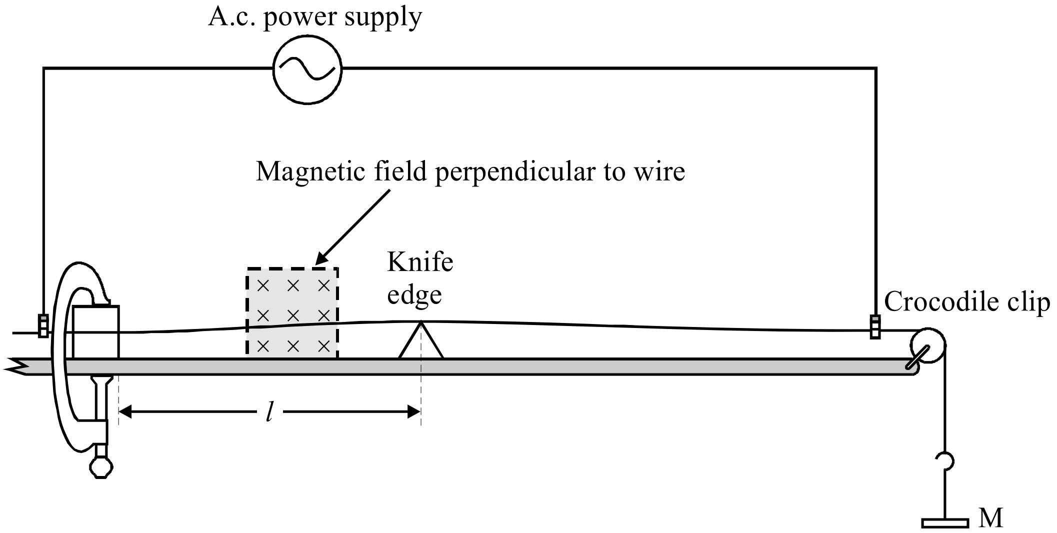
(6)
(Total 16 marks)

83. (a) The apparatus shown in the diagram below has already been set up for you with M = 200 g.



Switch on the power supply. Adjust the length of the wire between the wooden blocks and the knife edge until you can see that the amplitude of vibration of the wire passing through the magnetic field is at its maximum value. Record the length l at this point.

....

....

Explain carefully how you ensured that the value of l was as accurate as possible.

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....

Estimate the percentage uncertainty in your value of l.

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....

....

(5)

(b) Measure the diameter d of the wire and estimate the percentage uncertainty in your value.

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....

....

(3)

(c) Calculate a value for the density ρ of the material from which the wire is made given that

$$\rho = \frac{T}{\pi d^2 f^2 l^2}$$

where T = tension in the wire

and f = frequency of the a.c. supply, which is given on the card.

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(3)

(d) Using the percentage uncertainties obtained in (a) and (b) determine the percentage uncertainty in your value of the density.

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The accepted value for the density of constantan is 8880 kg m^{-3}. From the evidence of your experimental results discuss whether the wire used could be made from constantan.

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(5)
(Total 16 marks)

84. *You are to plan an investigation into the relationship between the intensity of the light from a small filament lamp and the distance from the filament. You are then to analyse a set of data from such an experiment.*

(a) You may assume that the following apparatus would be available:

- filament lamp with suitable power supply
- LDR and ohmmeter together with a calibration curve enabling resistance measurements to be converted to light intensity in a unit called lux
- metre rule
- 50 cm black paper tube to act as a light shield.

Draw a diagram of the experimental arrangement, indicating clearly the distance to be determined. Explain how you would measure this distance.

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State any special precautions you would take, other than using the light shield, to ensure that the measured light intensity was that of the lamp.

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(8)

(b) The intensity I of light from a small filament lamp varies with the distance d from the filament according to an equation of the form $I = kd^n$ where k and n are constants.

Write this equation in a suitable format which can be used to plot a linear graph.

....

....

(1)

(c) The following data was obtained in an investigation of the above equation.

d/mm	*I* /lux		
140	8.20		
160	6.05		
200	3.35		
250	1.80		
300	1.15		
350	0.79		

Use the empty columns provided for your processed data, and then plot a suitable graph to test the equation on the grid below.

(5)

(d) Use your graph to determine a value for *n*.

....

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....

....

(2)
(Total 16 marks)

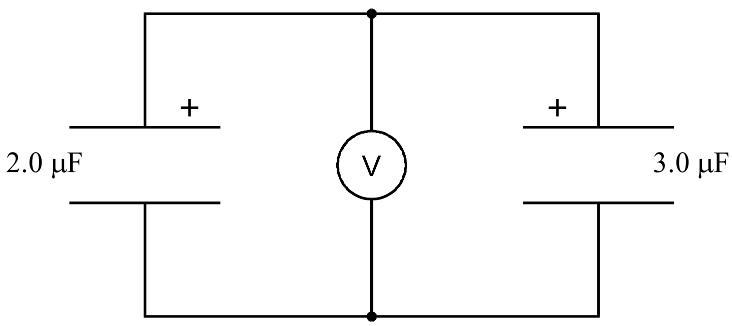
85. A 2.0 μF capacitor is charged to a potential difference (p.d.) of 50 V and a 3.0 μF capacitor is charged to a p.d. of 100 V.

Calculate the charge on the plates of each capacitor and the energy stored by each. Write your answers in the table below.

Capacitor	2.0 μF	3.0 μF
P.d.	50 V	100 V
Charge		
Energy		

(4)

The capacitors are then joined together **in parallel** with their positive plates connected together.



What is the equivalent capacitance of this combination?

....

Equivalent capacitance = ... μF

(1)

Hence calculate the total energy stored by the capacitors after connection.

....

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Total energy = ...

(3)

Suggest why there is a loss of stored energy when the capacitors are connected.

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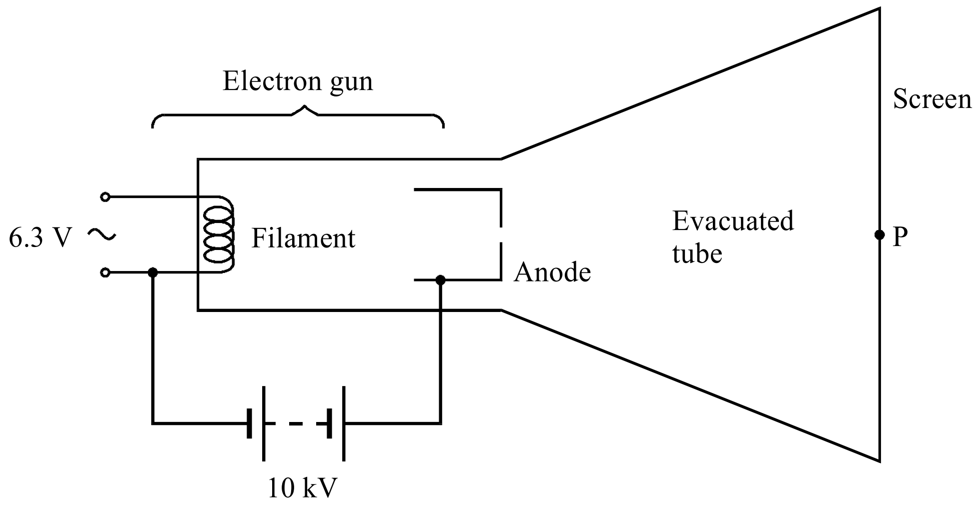
(2)
(Total 10 marks)

86. The diagram is of a simplified cathode ray tube.



An electron beam is produced by the electron gun in the tube. A beam of electrons emerges from the hole in the anode and strikes the screen at point P.

Explain why electrons are emitted from the surface of the filament.

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(2)

Explain why the electrons move from the filament towards the anode.

....

....

(1)

The potential difference between the filament and the anode is 10 kV. Calculate the energy in joules of an electron emerging from the hole in the anode.

....

....

....

Energy = ... H

(2)

The electron beam forms a current of 1.5 mA. Show that the number of electrons passing through the hole in the anode is about 9×10^{15} per second.

....

....

....

(2)

Hence calculate the rate at which energy is being delivered to the screen by the beam of electrons.

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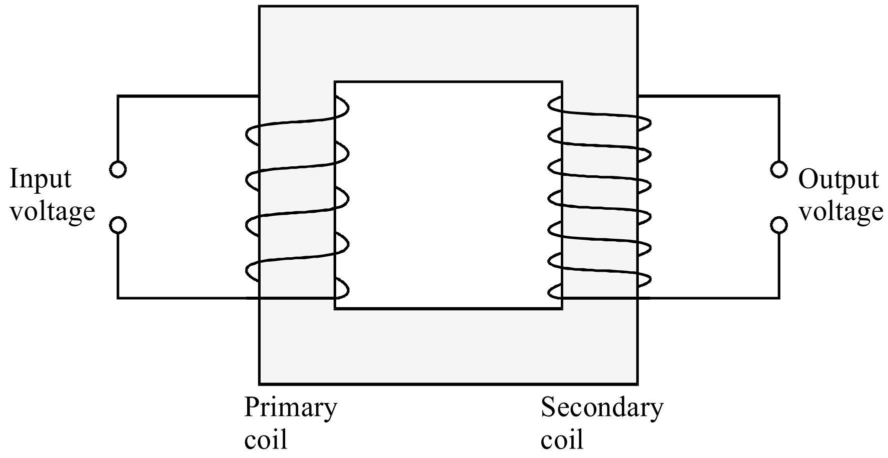
....

....

Rate = ...

(2)
(Total 9 marks)

87. Explain the action of the transformer shown below. You may be awarded a mark for the clarity of your answer.



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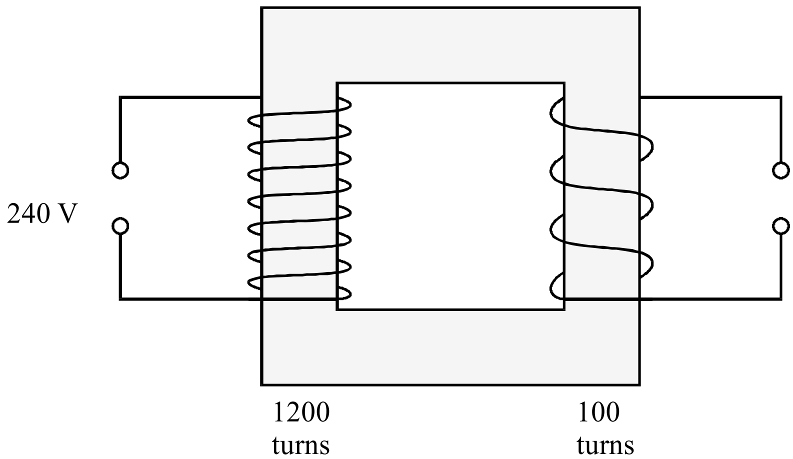
(5)

The following diagram shows an ideal step-down transformer.



The input voltage is 240 V. Calculate the output voltage of the transformer.

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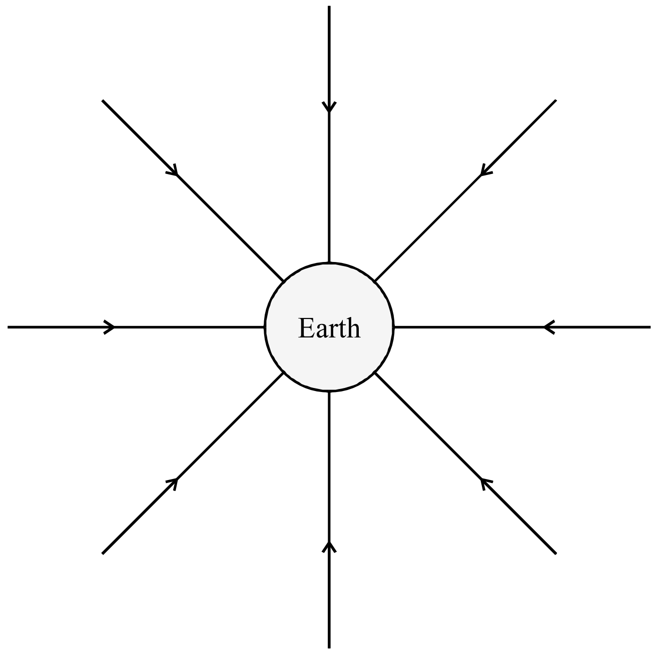
Output voltage = ...

(2)
(Total 7 marks)

88. The Earth's Gravitational field is radial.



Explain how the diagram indicates that gravitational field strength is a vector quantity.

....

(1)

Add to the diagram three successive equipotential lines.

(3)

When a satellite is placed in a circular orbit around the Earth its change in gravitational potential is 2.2×10^7 J kg^{-1}. If the satellite has a mass of 5500 kg, calculate the work done in placing the satellite in this orbit.

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(2)

Explain why the gravitational potential energy of a satellite does not chance as it orbits the Earth.

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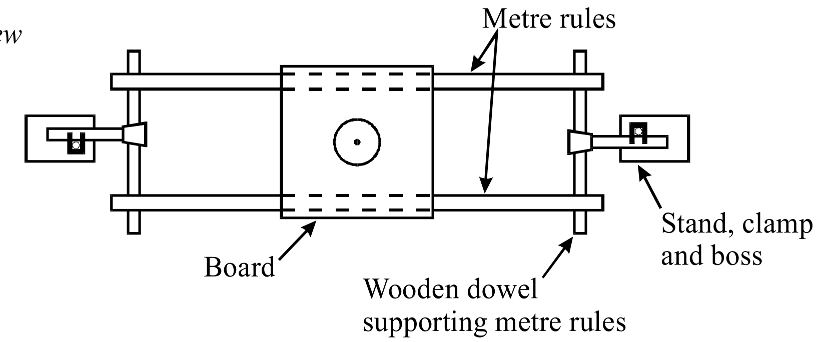
(1)
(Total 7 marks)

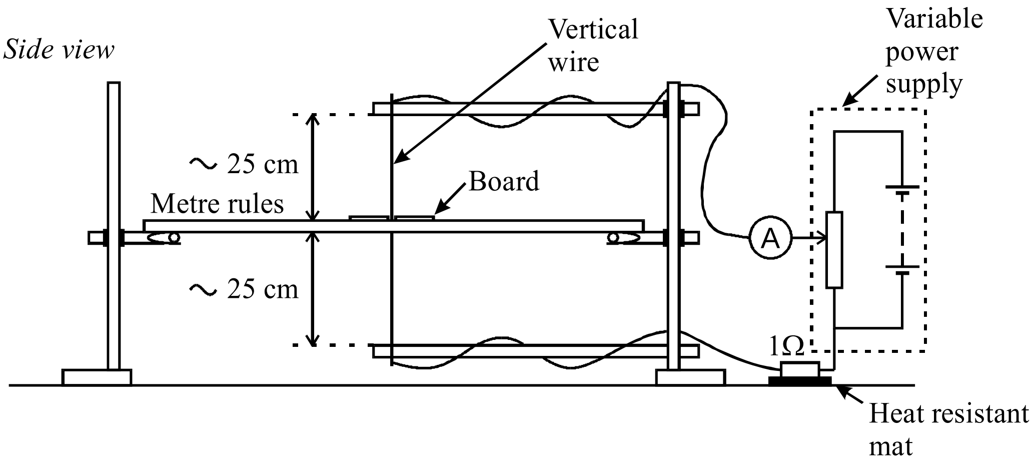
89. (a) (i) The apparatus shown in the diagram below has already been set up for you and should not be altered.

Plan view

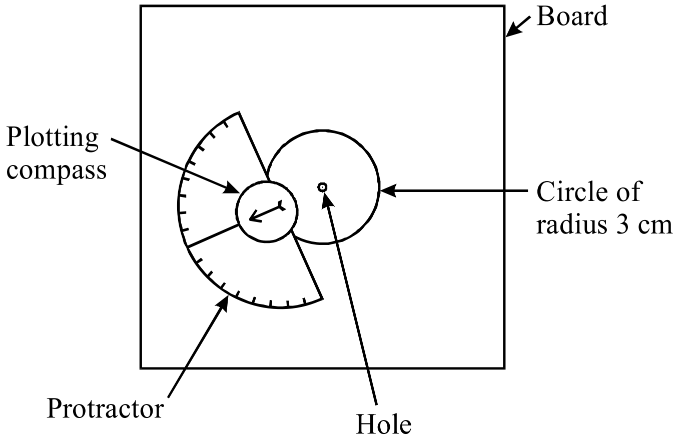


The two lengths of dowel above and below the metre rules are not shown in the plan view.

Side view



The circle drawn on the board has a radius of 3.0 cm and is centred on the point where the wire passes through the board. Before switching on the power supply place the centre of the plotting compass on the circumference of this circle at a point where the needle points directly away from the wire. Place the centre of the protractor directly below the centre of the plotting compass at this point with its zero aligned with the compass. This arrangement is shown in the diagram below. Note that your plotting compass **may not** be in the position shown in the diagram.



Ensure that the resistor is on the heat resistant mat. Switch on the power supply but DO NOT TOUCH THE RESISTOR AS IT MAY GET HOT DURING THE COURSE OF THE EXPERIMENT. Slowly increase the current and describe what happens to the compass needle. With the aid of a diagram, explain your observations, using your knowledge of the magnetic effect of an electric current.

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(3)

(ii) Determine an accurate value for the current I which causes the needle to deflect through an angle of 45° and then **switch off the power supply.** State any special precautions which you took to ensure that this was an accurate value.

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(2)

(iii) Calculate the magnetic flux density (field strength) B at a distance of 3.0 cm from the wire due to the current I.

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Explain, with the aid of a diagram, why this is equal to the horizontal component of the Earth's magnetic flux density flux density B_{hor}.

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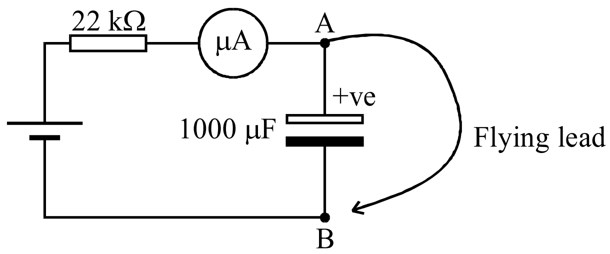
(3)

(b) (i) Set up the apparatus as shown in the diagram below with the 22k Ω resistor in the circuit.



Before you connect the cell, have your circuit checked by the Supervisor. You will be allowed a short time to correct any faults. If you are unable to set up the circuit, the Supervisor will set it up for you. You will only lose two marks for this.

(2)

(ii) Connect the cell and short-circuit the capacitor by means of the flying lead. Record the current I_1 in the circuit.

....

Disconnect the flying lead from point B to allow the capacitor to charge and measure the time t_1 taken for the current to reduce to $\frac{I_1}{2}$.

....

....

Connect the unknown resistor in series with the 22 kΩ resistor. Reconnect the flying lead across the capacitor to discharge it. Record the value of the current I_2 in the circuit.

....

Disconnect the flying lead from B to allow the capacitor to charge and measure the time t_2 taken for the current to reduce to $\frac{I_2}{2}$.

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(3)

(iii) The time taken for the current to reduce to half its initial value is directly proportional to the total resistance in the circuit. Deduce a value for the unknown resistor. Why is it reasonable to ignore the resistance of the other circuit components in this calculation?

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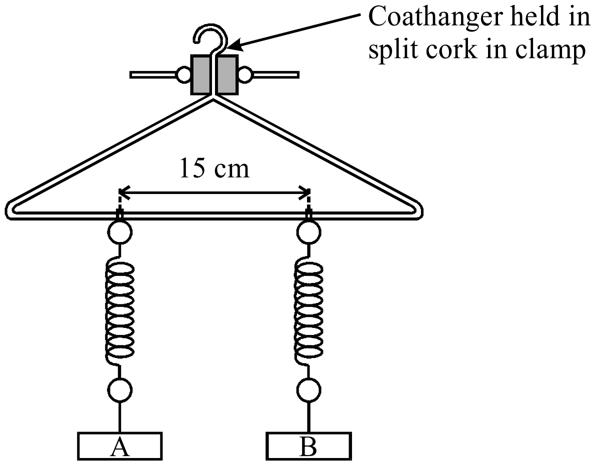
(3)
(Total 16 marks)

90. You are to investigate the oscillations of a spring system.



(a) Place two 100 g masses on mass hanger A. Do the same for mass hanger B. Give hanger A a downward vertical displacement of about 5 cm and release. Describe and explain the subsequent motion of B.

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(4)

(b) Remove B from its spring. Determine the period T_A of small vertical oscillations of A.

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Remove A from its spring. Add another 100 g mass to B and then replace it on its spring. Determine the period T_B of small vertical oscillations of B.

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....

State any precautions that you took to ensure that your timing was accurate.

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(6)

(c) Leaving B in position, replace A (i.e. hanger with two added masses) on its spring. Pull both A and B down a distance of about 5 cm and let go simultaneously. Observe the motion of A and B and determine as precisely as possible the time T that elapses between A and B being in phase and the next time that this happens.

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Discuss the extent to which your experiment supports the theory that

$$\frac{1}{T} = \frac{1}{T_A} - \frac{1}{T_B}$$

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(6)
(Total 16 marks)

91. *You are to plan an investigation into the relationship between the current in a filament lamp and the voltage across it. You are then to analyse a set of data from such an experiment.*

(a) You may assume that the following apparatus would be available:

- 6 V, 0.06 A filament lamp
- Two multimeters
- Power supply
- Rheostat

Draw a diagram of the circuit you would use to investigate how the current in the lamp was dependent on the voltage across it. Your circuit should allow the maximum range of voltage and current to be investigated.

State suitable range settings for the multimeters.

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Suggest why it is better to start with the minimum voltage across the lamp and then take reading as the voltage is increased.

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(8)

(b) The current I in the filament is thought to be related to the voltage V across the filament by an equation of the form $I = kV^n$, where k and n are constants.

Write this equation in a suitable format which can be used to plot a linear graph.

....

....

(1)

(c) The following data were obtained in an investigation of the above equation.

V/V	I/mA		
0.87	20		
1.33	25		
1.81	30		
2.51	35		
3.08	40		
4.02	45		
4.66	50		
5.66	55		
6.79	60		

Use the empty columns provided for your processed data, and then plot a suitable graph to test the equation on the grid below.

(5)

(d) Use your graph to determine a value for *n*.

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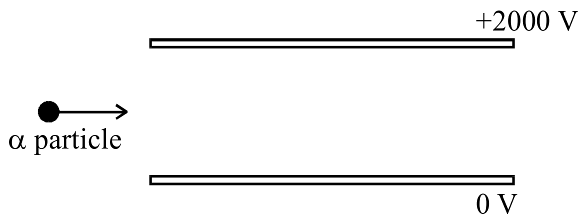
(2)
(Total 16 marks)

92. The diagram shows a high-speed alpha particle entering the space between two charged plates in a vacuum.



Add to the diagram the subsequent path of the alpha particle as it passes between the plates and well beyond them.

(3)

The gap between the plates is 10 mm. Calculate the magnitude of the electric force on the alpha particle as it passes between the plates.

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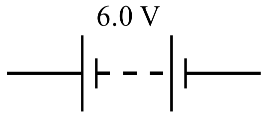
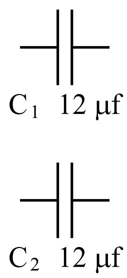
Electric force = ...

(3)
(Total 6 marks)

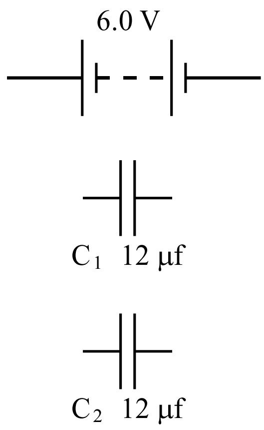
93. Complete the circuit below to show the two capacitors connected in parallel with the battery.





(1)

Complete the circuit below to show the two capacitors connected in series with the battery.



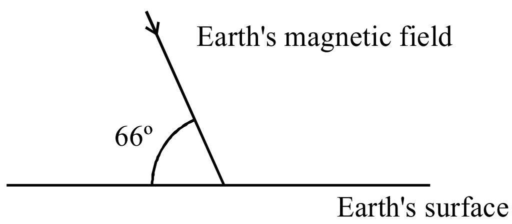
(1)

Use the values given to help you complete the table.

Capacitors in parallel	Charge on C_1	
	Energy stored on C_1 when fully charged	
Capacitors in series	Charge on C_2	
	Total energy stored on C_1 and C_2 when fully charged	

(6)
(Total 8 marks)

94. In London the Earth's magnetic field has a magnetic flux density of 4.8×10^{-5} T at 66 to the horizontal as shown in the diagram.



Calculate the magnitude of the horizontal component of the Earth's magnetic field in London.

....

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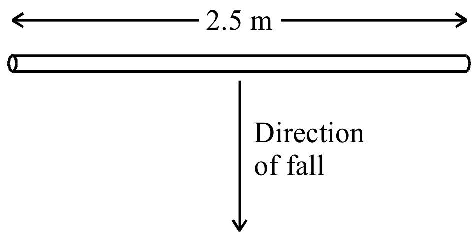
Horizontal component = ...

(2)

For a conductor of length I moving at a speed i) perpendicular to a field of flux density *B*, the induced voltage V between the ends of the conductor is given by

$$V = Bl\upsilon$$

A metal scaffolding pole falls from rest off a high building. The pole is aligned horizontally in an east-west direction. The Earth's magnetic field lines at this point lie in a north-south direction.



Calculate the induced voltage across the pole 2.0 s after it started to fall.

....

....

....

Induced voltage = ...

(3)

What would be the induced voltage after 2.0 s if the pole were aligned in a north-south direction? explain your answer.

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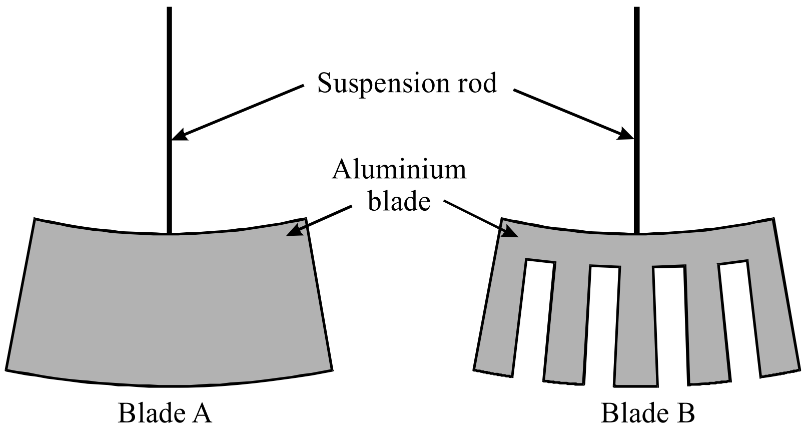
(2)
(Total 7 marks)

95. The diagram shows two blades of aluminium. Blade A is complete. Blade B has been cut to form a comb.

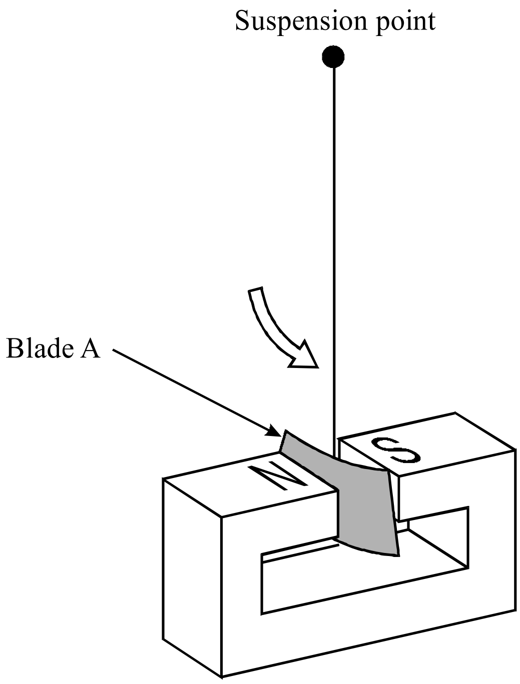


Which electrical property of the blade is increased by cutting away the aluminium?

....

(1)

Each blade is suspended in turn between the poles of a strong permanent magnet. Electromagnetic induction produces current loops in blade A as it swings between the poles.



Express Faraday's law of electromagnetic induction in words.

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(2)

The oscillations of blade A are rapidly damped. Explain why. You may be awarded a mark for the clarity of your answer.

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(4)

Suggest why the oscillations of blade B are only very lightly damped when it replaces blade A as the blade swinging between the poles.

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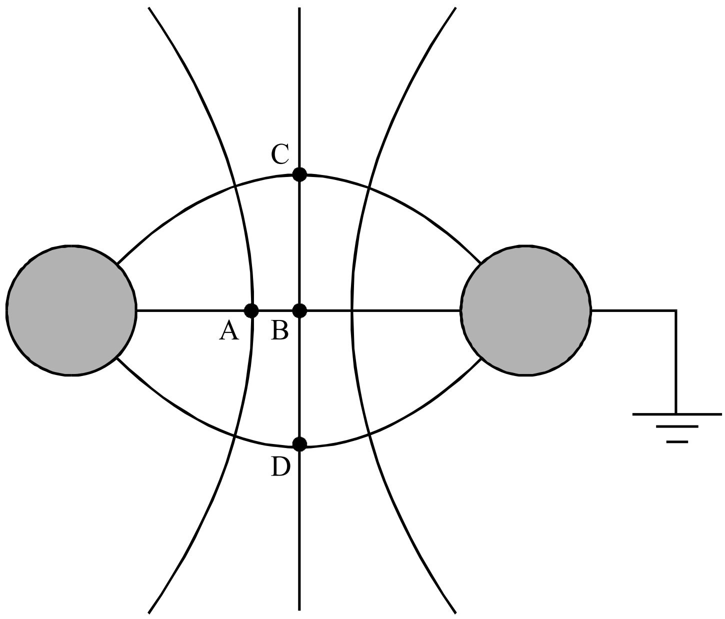
(1)
(Total 8 marks)

96. An isolated charged metallic sphere is brought close to an identical earthed sphere that initially was uncharged. Part of the resultant electric field and some of its equipotential lines are shown.



On the diagram mark the sign of the charge on each sphere.

(2)

Draw an arrow on one of the field lines to indicate its direction.

(1)

Expressing your answers in eV, state how much work is done

(i) against the field in taking an electron from C to D,

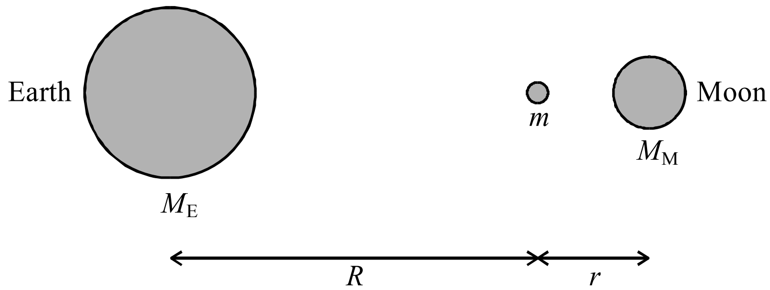
Work done = ... eV

(ii) against the field in taking an electron from C to A.

Work done = ... eV

(3)
(Total 6 marks)

97. The diagram shows a body of mass m situated at a point which is a distance R from the centre of the Earth and r from the centre of the Moon.



The masses of the Earth and Moon are M_E and M_M respectively. The gravitational constant is G.

Using the symbols given, write down an expression for

(i) the gravitational force of attraction between the body and the Earth,

....

(ii) the gravitational force of attraction between the body and the Moon.

....

(2)

The resultant gravitational force exerted upon the body at this point is zero. Calculate the distance R of the body from the centre of the Earth given that

$$r = 3.9 \times 10^7 \text{ m} \quad \text{and} \quad M_E = 81\, M_M$$

....

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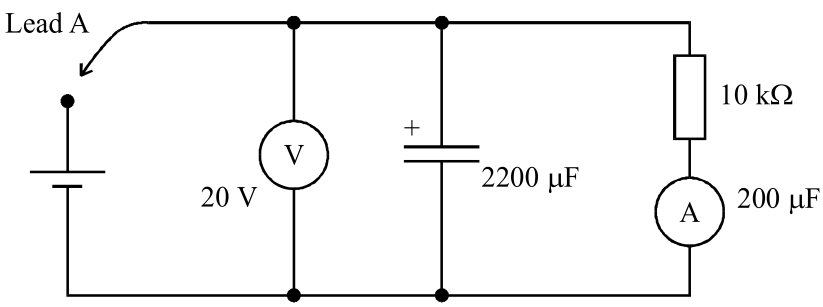
....

R = ...

(3)
(Total 5 marks)

98. (a) (i) Set up the circuit as shown in the diagram. Before you connect lead A to the cell, have your circuit checked by the Supervisor. You will be allowed a short time to correct any faults, but if you are unable to set up the circuit the Supervisor will set it up for you. You will only lose 2 marks for this.



Charge the capacitor by connecting lead A to the cell. Record the p.d. V across the capacitor.

....

Calculate the theoretical initial current $I_0 = V/R$ that will flow when the capacitor is discharged through the resistor. Give your answer in μA.

....

....

(3)

(ii) Simultaneously disconnect lead A from the cell and start the stopwatch. Determine the time t it takes for the current I to reduce to $I_0/2$, using the value of I_0 which you have calculated in (i).

....

....

Re-charge the capacitor by re-connecting lead A and then repeat the above procedure to find the time taken for I to reduce to $I_0/10$.

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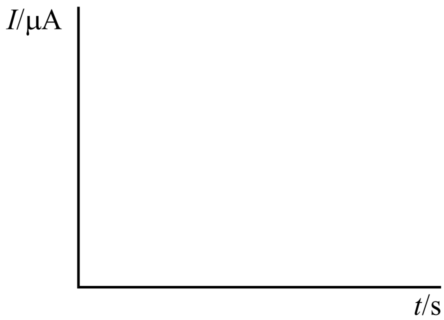
....

(3)

(iii) Sketch a graph of I against t on the axes below. Your sketch should be approximately to scale and should show your experimental values.

(2)



(b) (i) Switch on the lamp. Hold the diffraction grating close to your eye and look at the filament through the grating. The lines of the grating should be parallel to the filament.

Briefly describe what you observe, with the aid of a diagram, in the space below.

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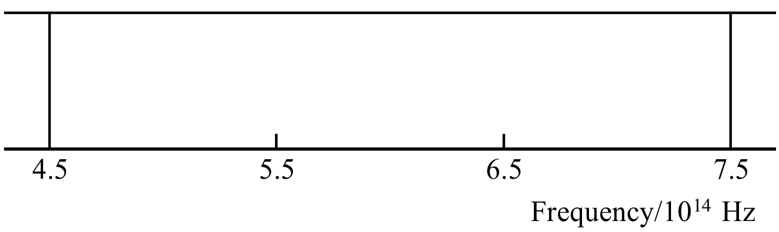
....

(3)

(ii)



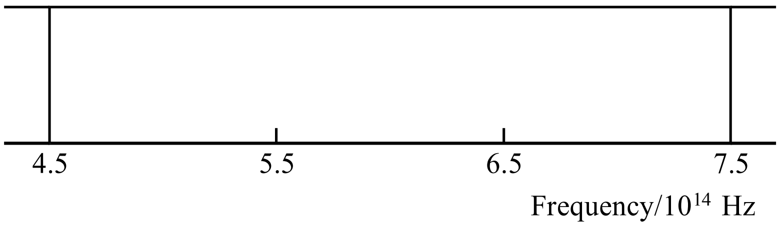
The vertical lines on the grid above, indicate the extent of the visible spectrum.

Draw on the grid one of the spectra that you observe, labelling the approximate positions of the colours.

(2)

(iii) Place the tube of orange liquid in front of the filament and view the filament through the liquid with the grating close to your eye.

On the grid below, draw what you see.

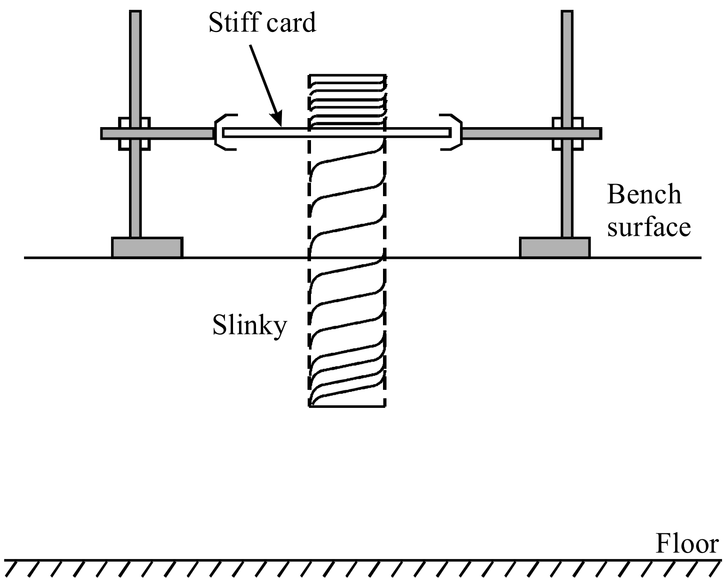


Estimate the range of visible frequencies that are transmitted by the liquid.

....

(3)
(Total 16 marks)

99. (a) Set up the apparatus as shown in the diagram below.



Ensure that there are exactly $N = 20$ turns of the spring suspended below the horizontal board. Explain how you did this.

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Determine the period T of vertical oscillations of the spring. Explain carefully how you obtained an accurate value for T and determine the percentage uncertainty in its value.

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For this system it is suggested that T is directly proportional to N. Obtain a value for the constant of proportionality s.

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(7)

(b) Obtain a second value for s using a different number of turns.

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(4)

(c) Assuming that the percentage uncertainty calculated in (a) also applies to your second value of T, comment on the extent to which your results support the suggestion that the period is directly proportional to the number of turns.

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For this system it can be shown that

$$T = 2\pi\sqrt{(ml/\lambda)}$$

where m = the mass of the suspended part of the spring,
l = the length of this part of the spring when the turns are touching,
and λ = a constant.

Explain why this suggests that T would be directly proportional to N.

....

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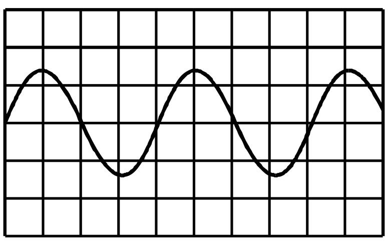
....

....

(5)
(Total 16 marks)

100. *You are to plan an experiment to determine a value for the speed of sound using stationary waves. You are then to analyse a set of data from such an experiment.*

(a) A student connects the output of a signal generator to an oscilloscope and obtains the trace shown below.



The timebase is set at 0.1 ms per division. What value does this give for the frequency *f* of the signal?

....

....

....

(2)

(b) The student proposes to determine a value for the speed of sound by finding the corresponding wavelength λ and using $c = f\lambda$. He sets up a stationary wave pattern between a loudspeaker, connected to the signal generator, and a reflecting board and determines the position of the antinodes using a microphone connected to the oscilloscope.

(i) Draw a diagram to show how the apparatus would be set up.

(ii) Explain how a value for the wavelength could be determined to a high precision.

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(5)

(c) The following data were obtained in such an experiment, in which the frequency *f* was varied and the corresponding wavelength A was measured.

f / kHz	λ / m	
2.00	0.180	
2.50	0.146	
3.00	0.123	
3.50	0.107	
4.00	0.095	
5.00	0.078	

Tabulate values of $1/f$ in the column provided and plot a graph of λ against $1/f$. Your scales should begin at the origin.

(5)

(d) Use your graph to find a value for the speed c of sound.

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Why is a graphical method clearly advantageous in this particular experiment?

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(4)
(Total 16 marks)

101. (a) You are to compare the rate at which a burette empties with the discharge of a capacitor.

(i) Determine the volume of water in the burette when it is filled to the 50 ml mark.

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Fill the burette to the zero mark. What volume of water does the burette now contain? Find the time t that it takes for half this volume of water to run out. (Do not take repeat readings.) Explain how you did this.

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....

(4)

(ii) Calculate the time constant T for the burette emptying given that $T = t/\ln 2$.

....

....

The time constant for a capacitor of capacitance C discharging through a resistor of resistance R is CR.. Given a 2200 μF capacitor, what value resistor would you use to give a time constant comparable with that of your burettes

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....

....

(4)

(b) The apparatus has been set up ready for you to use.

(i) Carefully twist the masses about a vertical axis, release and determine the period T, of rotational oscillations.

....

....

Remove the mass hanger from the spring and measure D_1, the mean of the diameters of the hanger and the slotted mass.

....

....

Repeat the above procedure to find the corresponding values of T_2 and D_2 for the 50 g mass hanger with three further 50 g slotted masses. When securing the hanger to the spring use the Blu-Tack to ensure that the hanger does not slip when it is twisted.

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(4)

(ii) Estimate the percentage uncertainty in your values of T_2 and D_2.

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Assuming a comparable percentage uncertainty in T_1 and D_1, discuss the extent to which your results show that T is proportional to D.

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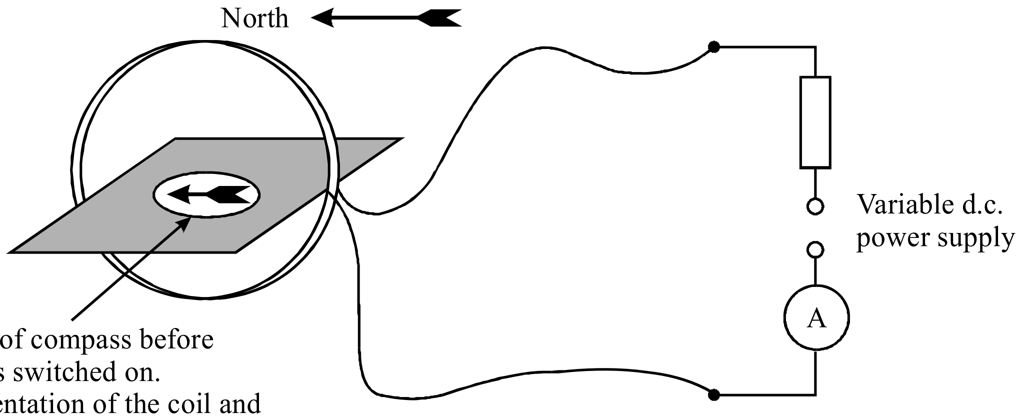
(4)
(Total 16 marks)

102. (a) Set up the circuit as shown in the diagram below without placing the compass on the hardboard. Before connecting the circuit to the power supply have your circuit checked by the Supervisor. You will be allowed a short time to correct any faults. If you are unable to set up the circuit the Supervisor will set it up for you. You will lose only two marks for this.



Position of compass before current is switched on.
(The orientation of the coil and compass is relative to where you are sitting and will depend on the N-S line in the laboratory.)

(2)

(b) Switch off the power supply and place the compass on the hardboard at the centre of the coil. You may need to rotate the hardboard and coil arrangement through a small angle in order to ensure that the compass needle lies in the plane of the coil as shown in the diagram above. Rotate the compass or the scale until the compass needle points to North (0°) on the scale.

Switch on the power supply and adjust the current I in the circuit until the deflection θ of the compass needle is approximately 30°. Record I and θ in the spaces below.

I = ...

θ = ...

For a range of currents I in the circuit measure the corresponding deflection θ of the compass needle. You should limit your maximum deflection to about 50°. Tabulate all your observations in the space below together with values of tan θ.

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(5)

(c) State any special precautions or procedures that you adopted in order to reduce the uncertainty in your measurements.

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(2)

(d) Using the grid below plot a graph of $\tan\theta$ against I. Draw the straight line of best fit through your points.

(3)

(e) The equation that applies to the deflection of the plotting compass needle is

$$\tan\theta = \frac{\mu_0 NI}{2rB_{hor}}$$

where μ_0 = permeability of free space = $4\pi \times 10^{-7}$ N A^{-2}
N = number of turns on the coil, which is given on the card
r = radius of the coil = 60 mm
B_{hor} = the horizontal component of the Earth's magnetic flux density.

Determine the gradient of your graph. Hence find a value for B_{hor}.

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(4)
(Total 16 marks)

103. *You are to plan an investigation of how the resistive property of an a.c. circuit, called its impedance, depends on the frequency of the a. c. supply. You are then to analyse a set of data from such an experiment.*

(a) (i) In a preliminary experiment a 47 Ω resistor, a capacitor of nominal value 47 μF and a laboratory power supply are connected in series, using the a.c. terminals of the power supply. An ammeter is used to measure the current I in the circuit and a voltmeter is used to measure the potential difference V across the resistor-capacitor combination. Draw a circuit diagram of this arrangement.

When the p.d. was 1.49 V the current was found to be 17.0 mA. What value does this give for the impedance Z where $Z = V/I$?

....

....

(3)

(ii) For this circuit

$$Z^2 = \frac{1}{4\pi^2 C^2 f^2} + R^2$$

where f = frequency of a.c. supply = 50 Hz
R = value of the resistor
C = value of the capacitor

Calculate the theoretical value of Z given by the formula.

....

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....

....

(2)

(iii) Describe briefly how you would investigate the equation in part (ii) experimentally for different values of f. Your description should state any changes you would need to make to the apparatus and should explain why a graph of Z^2 against $1/f^2$ should be plotted.

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(4)

(b) The following data were obtained in such an investigation.

f / Hz	*V* / V	*I* / mA	
40	1.50		
45	1.50	15.9	
50	1.49	17.0	
55	1.49	18.2	
60	1.49	19.2	
70	1.48	20.7	
90	1.48	23.3	

Add further columns for your processed data, and then plot a graph of Z^2 against $1/f^2$ on the grid above to test the equation.

(5)

(c) Use your graph to determine an experimental value for the capacitance of the capacitor.

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(2)
(Total 16 marks)

104. Explain what, in physics, is meant by a field.

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(2)

State two differences between electric and magnetic fields.

1 ....

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2 ....

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(2)
(Total 4 marks)

105. A current-carrying conductor is situated in a magnetic field. Describe how you could demonstrate that the magnitude of the force on the conductor is directly proportional to the magnitude of the current in it. You may wish to include a diagram in your answer.
You may be awarded a mark for the clarity of your answer.

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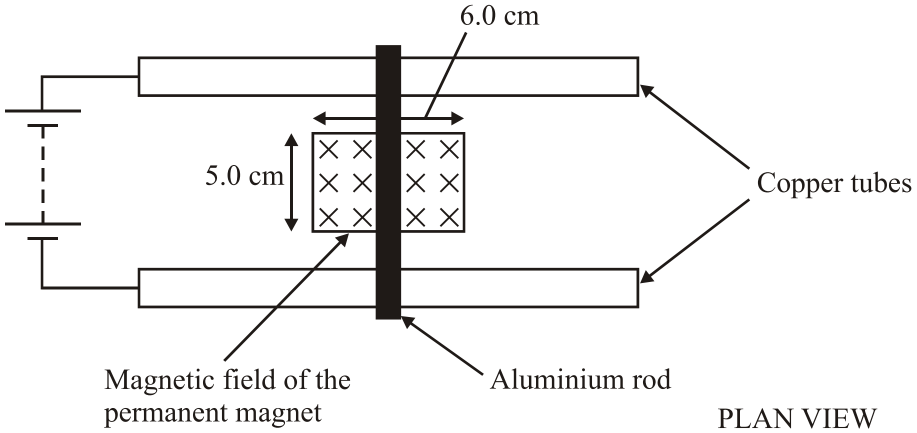
(4)

An aluminium rod of mass 50 g is placed across two parallel horizontal copper tubes which are connected to a low voltage supply. The aluminium rod lies across the centre of and perpendicular to the uniform magnetic field of a permanent magnet as shown in the diagram.

The magnetic field acts over a region measuring 6.0 cm × 5.0 cm.



PLAN VIEW
(NOT TO SCALE)

The magnetic flux density of the field between the poles is 0.20 T. Calculate the initial acceleration of the rod, assuming that it slides without rolling, when the current in the rod is 4.5 A.

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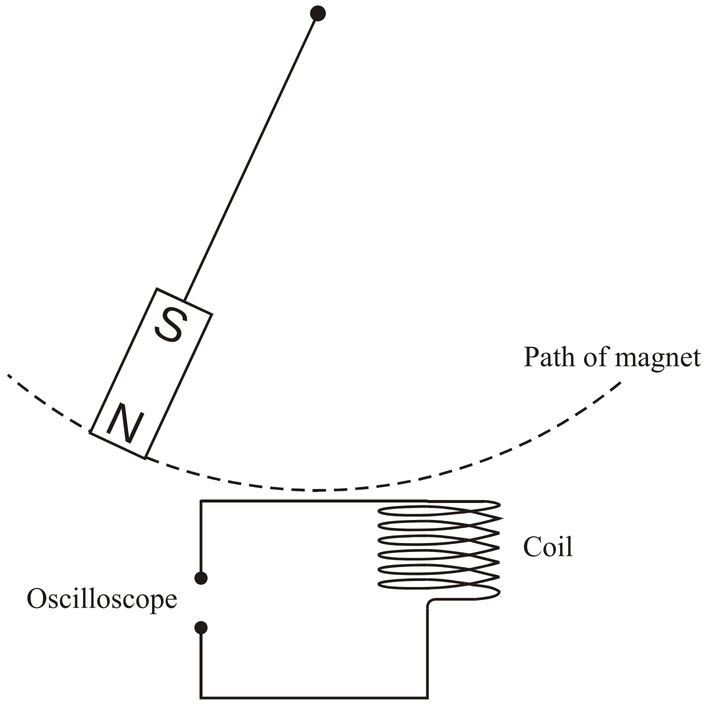
Initial acceleration = ...

(4)
(Total 8 marks)

106. A bar magnet is suspended above a vertical coil of wire. It is then displaced to one side and released such that it oscillates above the coil as shown in the diagram. The coil of wire has its ends connected to an oscilloscope.



Explain why an e.m.f. is induced across the ends of the coil.

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(2)

By considering Lenz's law, label with an X on the diagram each position of the magnet at which the induced e.m.f. changes polarity.

(2)

The maximum induced e.m.f. is 3.0 mV. Calculate the rate of change of flux needed to induce this e.m.f. in a coil of 500 turns.

....

....

....

Rate of change of flux = ...

(2)

State three changes that could be made to the apparatus in order to increase the maximum induced e.m.f.

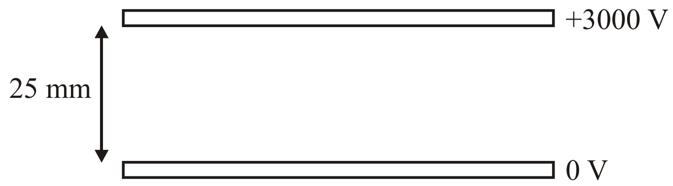
1 ....

2 ....

3 ....

(3)
(Total 9 marks)

107. The diagram shows two parallel plates with a potential difference of 3000 V applied across them. The plates are in a vacuum.



On the diagram sketch the electric field pattern in the region between the plates.

(2)

On the same diagram sketch and label two equipotential lines.

(1)

The plates are 25 mm apart. Show that the force experienced by an electron just above the bottom plate is about 2×10^{-14} N.

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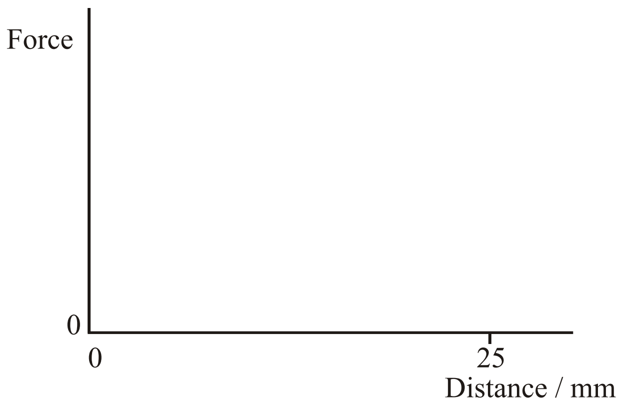
(3)

Complete the graph to show how the force on the electron varies with the distance of the electron from the bottom plate.



(2)

This force causes the electron to accelerate.

The electron is initially at rest in contact with the bottom plate when the potential difference is applied. Calculate its speed as it reaches the upper plate.

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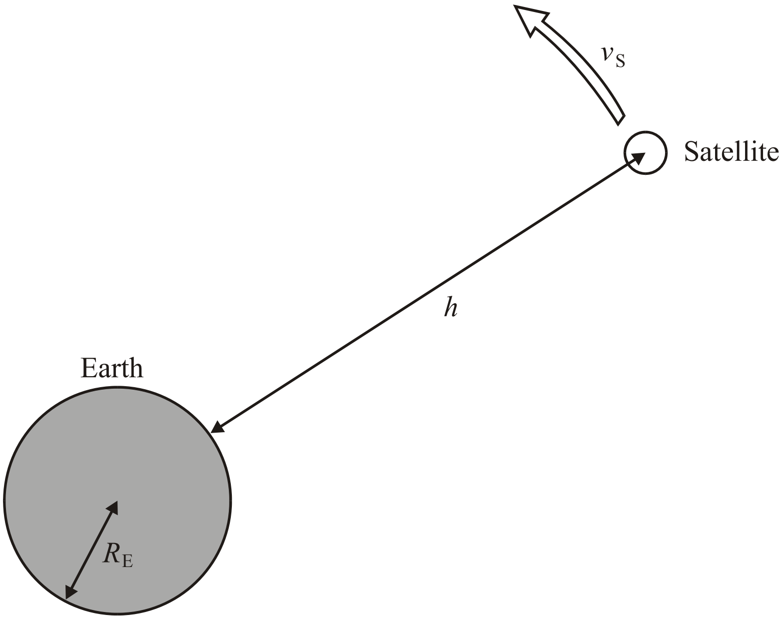
Speed = ...

(3)
(Total 11 marks)

108. A satellite of mass m_S moving at speed v_S is in a circular orbit around the Earth, mass M_E. The radius of the Earth is R_E and the satellite is at a height h above the Earth's surface. The gravitational constant is G.



Using the symbols given, write down an expression for the magnitude of

(i) the centripetal force needed to maintain the satellite in this orbit,

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(ii) the gravitational field strength in the region of the satellite.

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(3)

Show that the greater the height of the satellite above the Earth's surface, the smaller will be its orbital speed.

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(3)

A mechanic working outside an orbiting spacecraft accidentally releases his spanner. Describe the subsequent motion of the spanner.

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(2)
(Total 8 marks)

109. (a) The apparatus has been set up ready for you to use.

(i) Count the number n of paperclips in the suspended chain.

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Keeping the chain taut, give it a small sideways displacement, release and determine the period *T* of oscillation.

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Explain the precautions you took to make your value of T as accurate as possible.

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Remove 7 paperclips from the chain and repeat the above to determine the new period of oscillation.

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(4)

(ii) Estimate the percentage uncertainty in your values of T.

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Discuss the extent to which your results show that $T \propto \sqrt{n}$

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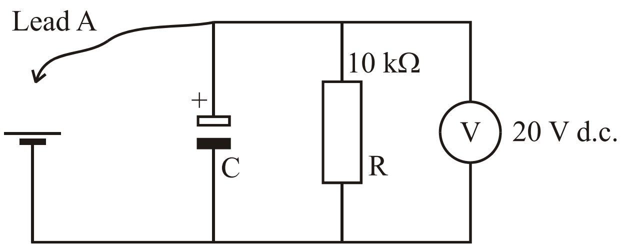
(4)

(b) (i) Set up the circuit as shown in the diagram. Before you connect lead A to the cell, have your circuit checked by the Supervisor. You will be allowed a short time to correct any faults, but if you are unable to set up the circuit, the Supervisor will set it up for you. You will lose only two marks for this.



The capacitor C is charged by connecting lead A to the cell and discharged through the resistor R when lead A is disconnected. Determine the time t for the p.d. across the resistor to fall from 1.00 V to 0.37 V.

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(4)

(ii) Use the three 10 kΩ resistors in a suitable combination to give a resistance of 15 kΩ. Sketch the arrangement of resistors in the space below. If you are unable to do this, ask the Supervisor for the card on which the arrangement is shown. You will lose only two marks for this and you need not draw the arrangement.

Connect your arrangement into the circuit and find the time for the p.d. to fall from 1.00 V to 0.37 V when the resistance *R* of the resistor is 15 kΩ.

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Given that $t = CR$, use your data to find an average value for the capacitance *C* of the capacitor.

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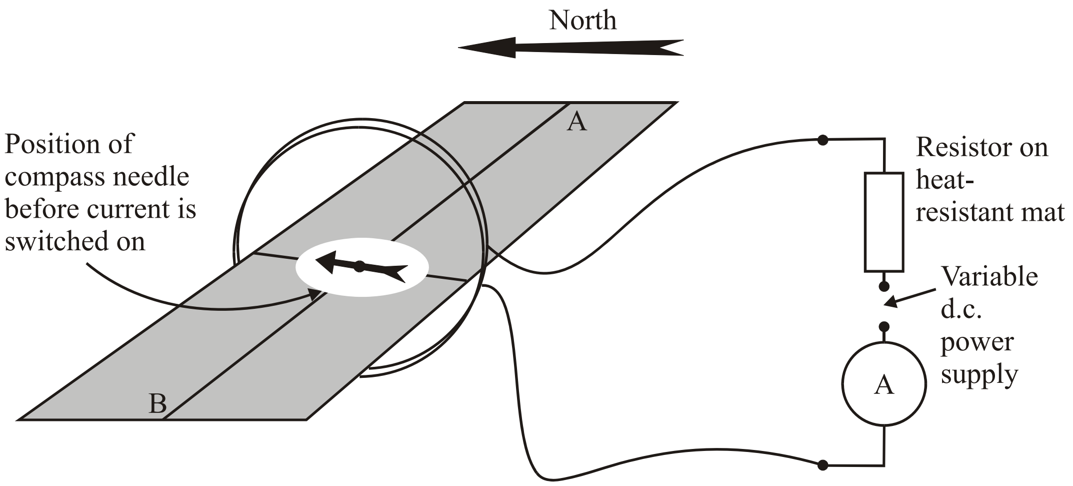
(4)

(Total 16 marks)

110. (a) Set up the circuit as shown in the diagram below with the resistor on the heat-resistant mat. **DO NOT TOUCH THE RESISTOR DURING THE EXPERIMENT AS IT MAY GET HOT**. Before connecting the circuit to the power supply have your circuit checked by the Supervisor. You will be allowed a short time to correct any faults. If you are unable to set up the circuit the Supervisor will set it up for you. You will lose only two marks for this.



(The orientation of the coil and compass is relative to where you are sitting and will depend on the N-S line in the laboratory.)

(2)

(b) Disconnect the power supply and place the compass on the board at the centre of the coil with the centre of the compass at the point of intersection of the two lines marked on the board. You may need to rotate the hardboard through a small angle in order to ensure that the compass needle lies in the plane of the coil as shown in the diagram above. Rotate the compass, or the scale around the edge of the compass, until the compass needle points to North (0°) on the scale. Reconnect the power supply and adjust the current I in the circuit until the deflection θ of the compass needle is approximately 50°. Record I and θ in the spaces below.

I = ...

θ = ...

Keeping I constant, move the centre of the compass, **without rotating it**, along the line AB and measure θ for a range of distances x from the centre of the coil. Tabulate all your observations in the space below together with values of tan θ.

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(5)

(c) State any special precautions or procedures that you adopted in order to reduce the uncertainty in your measurements.

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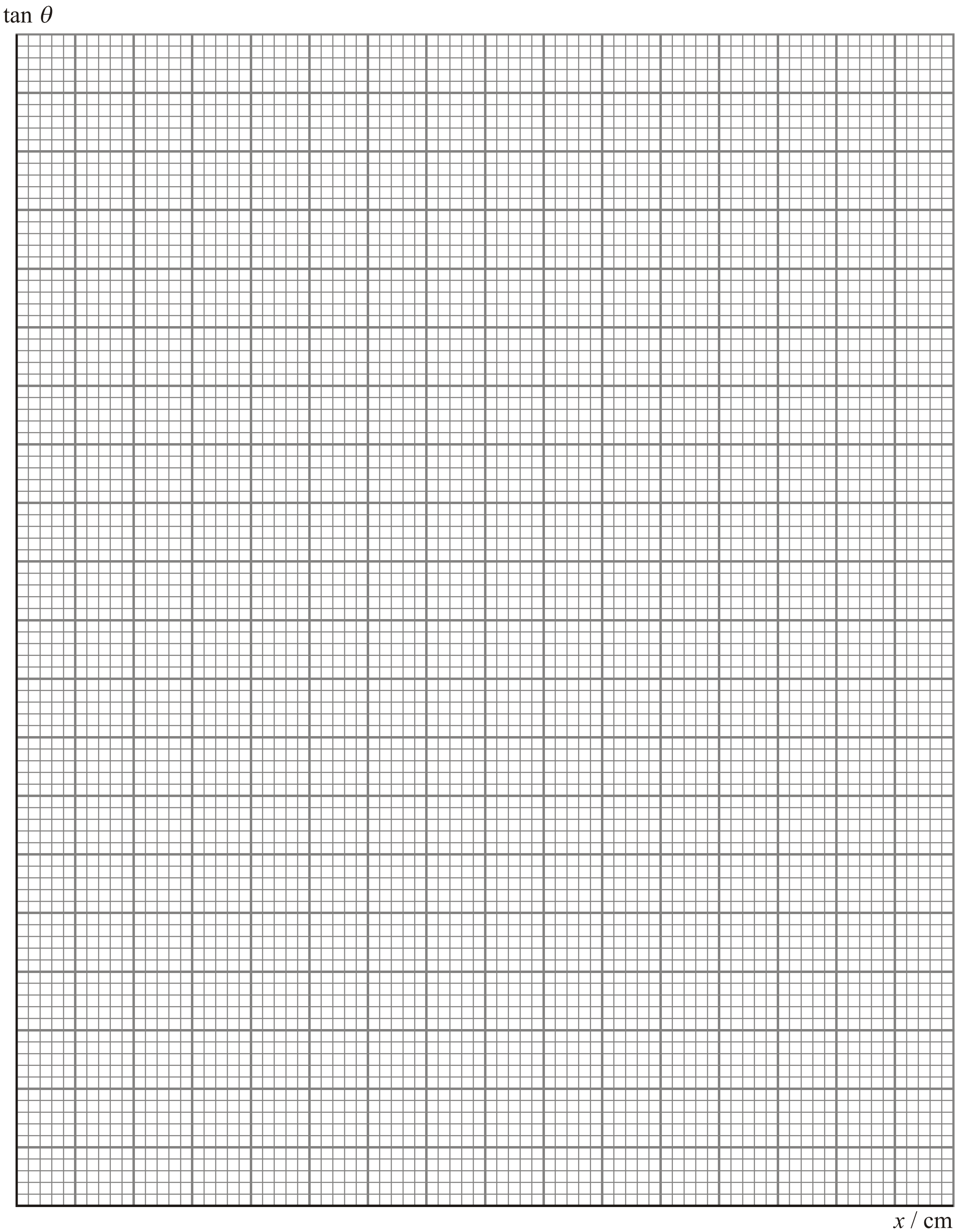
(2)

(d) Using the grid below, plot a graph of tan θ against x.



(3)

(e) Use your graph to determine the value of x at the point where tanθ is 0.71 of its value at the centre of the coil.

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Theory predicts that this value of x should be $\frac{1}{2}$ the radius of the coil. Determine the mean radius of the coil and discuss the extent to which your results support the theory.

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(4)
(Total 16 marks)

111. *You are to plan an investigation of how the frequency of vibration of air in a conical flask depends on the volume of air. You are then to analyse a set of data from such an experiment.*

(a) (i) Blow directly into the neck of the flask and listen to the sound of the air vibrating. Pour water into the flask until it is approximately half filled and blow into the flask as before. What difference do you observe in the pitch (frequency) of the vibrating air when the flask is half full of water?

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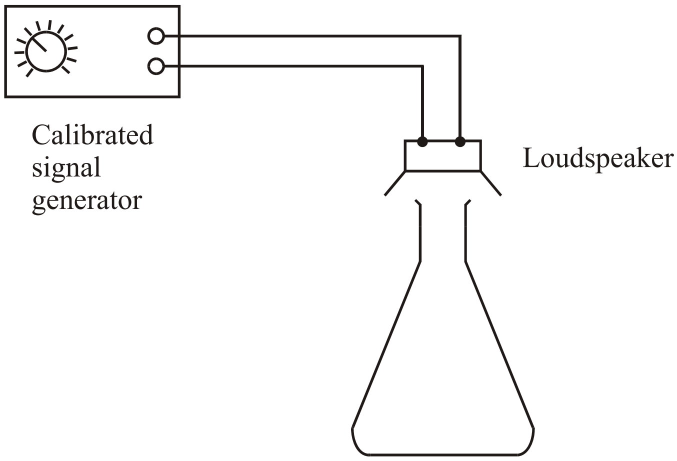
(1)

(ii) A student thinks that there might be a relationship between the natural frequency of vibrafion f of the air in the flask and the volume V of air in the flask of the form $f \propto V^n$ where n is a constant.
In order to test this relationship she sets up the following arrangement:



She increases the frequency of the signal generator until the air in the flask vibrates very loudly. Explain why this happens at the natural frequency of vibration of the air.

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(2)

(iii) Explain how she could vary, and measure, the volume of air in the flask and state a graph she could plot to test whether $f \propto V^n$.

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(4)

(b) The following data were obtained in such an investigation:

V/cm^3	f/Hz
554	219
454	242
354	274
254	324
204	361
154	415

Use the columns provided for your processed data, and then plot a suitable graph to test the relationship on the grid opposite.

(5)

(c) Use your graph to determine a value for n.

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Explain **qualitatively** whether your value for n is consistent with your initial observations in (a)(i).

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(4)
(Total 16 marks)

112. An acetate rod is rubbed with a duster. The rod becomes positively charged.

Describe what happens during this process.

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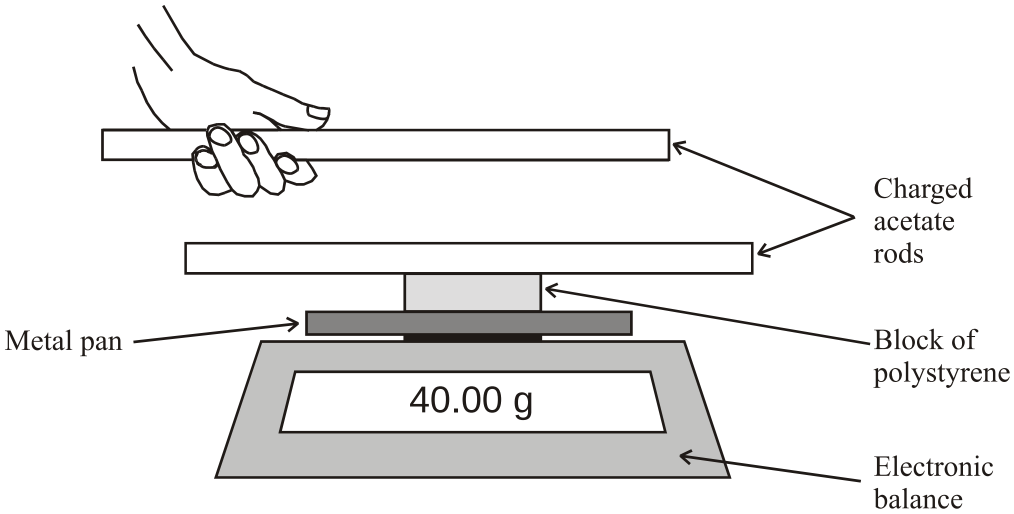
(2)

The rod is then lowered, at constant speed, towards another positively charged rod that rests on an electronic balance.



Explain why it is necessary to have the block of polystyrene beneath the bottom rod.

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(2)

Describe and explain what would happen to the reading on the balance as the top rod slowly approaches, and comes **very close** to, the bottom rod. You may be awarded a mark for the clarity of your answer.

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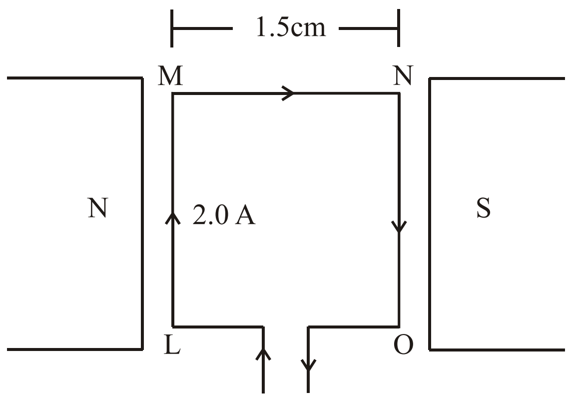
(4)
(Total 8 marks)

113. The diagram shows the top view of a square of wire of side 1.5 cm. It is in a uniform magnetic field of flux density 8.0 mT formed between magnetic north and south poles. The current in the wire is 2.0 A



What is the meaning of **uniform** in the phrase uniform magnetic field?

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(1)

Determine the sizes and directions of the electromagnetic forces that act on the sides LM and NO of the square of wire.

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Force on LM: ....   Force on NO: ....

Direction: ....   Direction: ....

(3)

Why do no electromagnetic forces act on the sides MN and OL of the square?

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(1)

What effect will the forces acting on LM and NO have on the square of wire?

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(1)

The magnetic poles are now moved further apart. Describe and explain what effect, if any, this will have on the magnitudes of the forces produced on LM and NO assuming the current of 2.0 A is unchanged.

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(2)
(Total 8 marks)

114. The potential difference between the plates of a 220 μF capacitor is 5.0 V.

Calculate the **charge** stored on the capacitor.

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……..……..…………………………………………………………………………………..

Charge = ...

(2)

Calculate the **energy** stored by the capacitor.

……..……..…………………………………………………………………………………..

……..……..…………………………………………………………………………………..

Energy = ...

(2)

Describe how you would show experimentally that the charge stored on a 220 μF capacitor is proportional to the potential difference across the capacitor for a range of potential differences between 0 and 15 V. Your answer should include a circuit diagram.

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(5)
(Total 9 marks)

115. State Lenz's law of electromagnetic induction.

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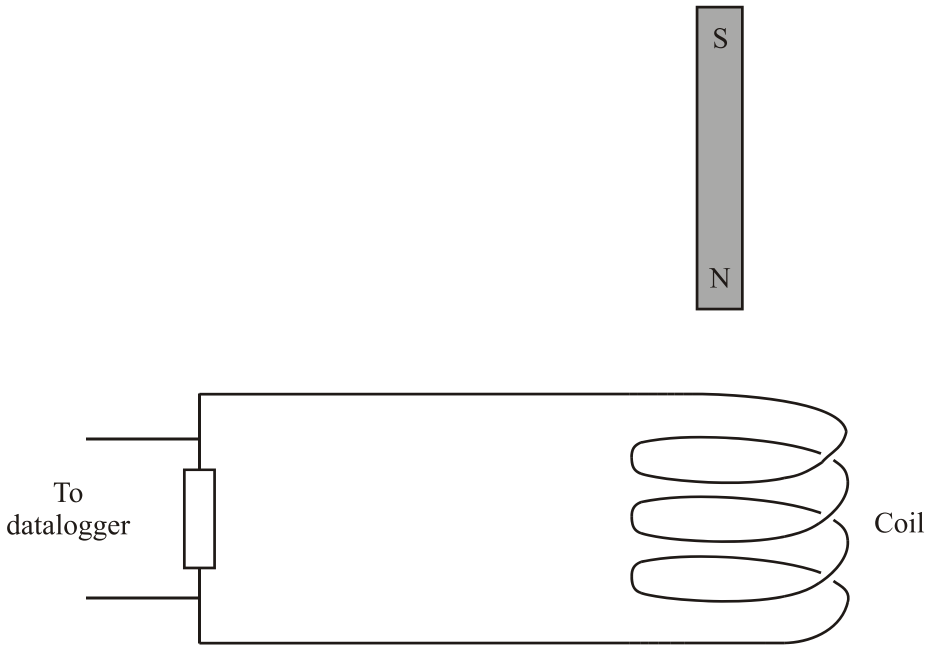
(2)

A bar magnet is dropped from rest through the centre of a coil of wire which is connected to a resistor and datalogger.



State the induced magnetic polarity on the top side of the coil as the magnet falls towards it.

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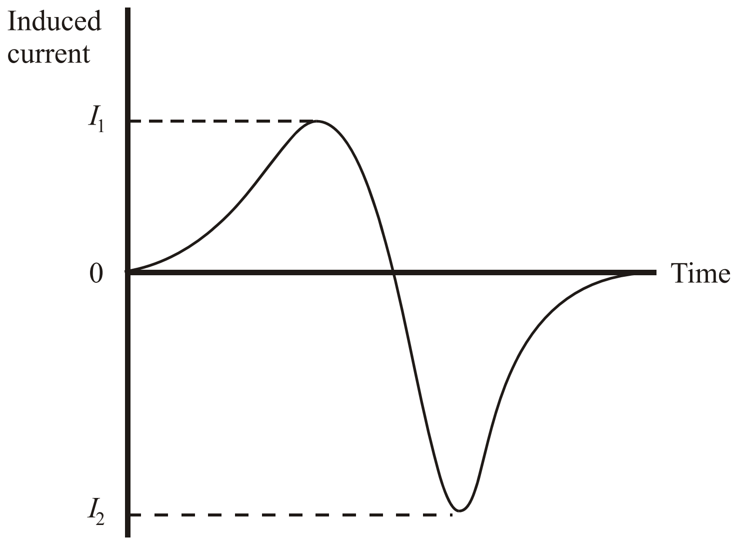
Add an arrow to the wire to show the direction of the induced current as the magnet falls towards the coil.

(2)

The graph shows the variation of induced current in the resistor with time as the magnet falls.



Explain why the magnitude of I_2 is greater than I_1.

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(2)

(Total 6 marks)

116. The orbit of the Moon, which has a mass *m*, is a circle of approximate radius 60*R*, where *R* is the radius of the Earth. Show that the gravitational attraction between the Earth, mass *M*, and the Moon is given by

$$\frac{GMm}{3600R^2}$$

……..……..………………………………………………………………………………………..

……..……..………………………………………………………………………………………..

(1)

The mass of the Earth is 6.0×10^{24} kg and its radius is 6.4×10^{6} m. Show that the orbital speed of the Moon around the Earth is approximately 1 km s^{-1}.

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(4)

Hence confirm that it takes the Moon about 30 days to orbit the Earth.

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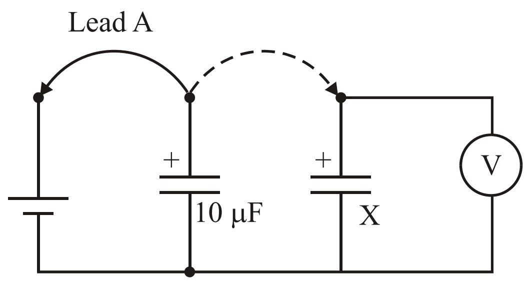
(4)
(Total 9 marks)

117. (a) (i) Use the voltmeter to measure the p.d. V_0 across the cell.

V_0 = ...

Now set up the circuit as shown in the diagram. If you do not have an auto-ranging voltmeter, change the range of the voltmeter to 200 mV d.c. Before you connect lead A to the cell, have your circuit checked by the Supervisor who will allow you a short time to correct any faults. If you are unable to set up the circuit, the Supervisor will set it up for you. You will lose only 2 marks for this.



(2)

(ii) Connect lead A to the cell in order to charge the 10 μF capacitor to the p.d. V_0 of the cell. Calculate the charge Q stored on the 10 μF capacitor.

....

....

Use the spare lead to short circuit the capacitor X to make sure it is fully discharged.

Disconnect this lead, then disconnect lead A from the cell and connect it to the capacitor X. Record the p.d. V across X.

Repeat the above procedure to find an average value for V, remembering to discharge X each time.

....

....

(3)

(iii) Assuming that all the charge Q originally stored on the 10 μF capacitor is transferred to X, calculate a value for the capacitance C of X.

....

....

With reference to your value for C, discuss the validity of assuming that all the charge stored on the 10 μF capacitor is transferred to X.

....

....

(3)

(b) (i) Take suitable measurements to determine the average depth *d* of water in the tray. Explain how you did this and record all your data below.

....

....

....

....

....

....

(2)

(ii) Measure the internal width of the tray. Record your value below.

....

Tilt the tray by lifting one of its long sides about 1 cm above the bench. Drop the side of the tray onto the bench to set up a wave, which you should be able to observe reflecting back and forth 3 or 4 times.

Find the time *t* that it takes for the wave to travel the width of the tray and hence calculate the speed υ of the wave. Show all your data and calculations below.

....

....

....

....

....

....

(3)

(iii) Theory suggests that $\upsilon^2 = kd$, where k is a constant.

Use your data from (i) and (ii) to calculate a value for k.

....

....

Estimate the percentage uncertainty in your value for d and hence discuss whether k could be equal to the gravitational field strength g.

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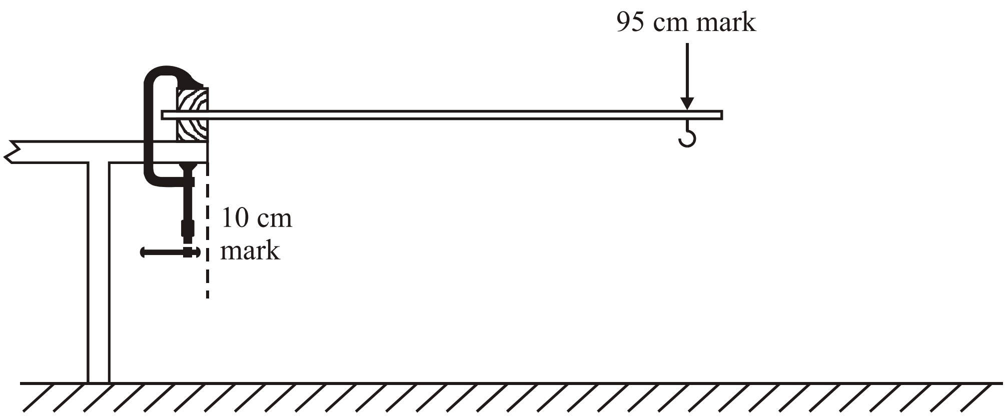
(3)
(Total 16 marks)

118. (a) Determine the depression y_1 of the end of the clamped metre rule when the mass hanger (i.e. a mass of 100 g) is hung from the hook at the 95 cm mark. Record your readings in the table below.

Add to the diagram below to show how you did this.



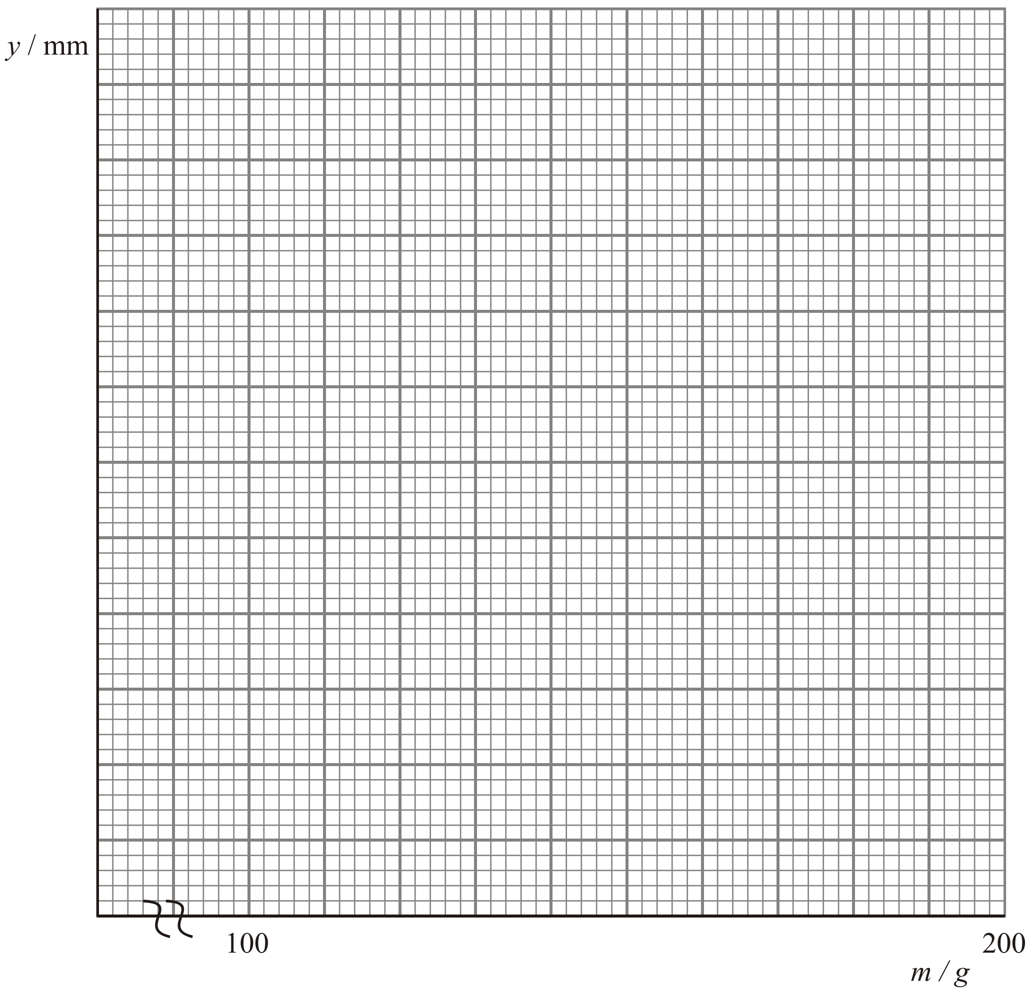
Find the depression y_2 when a total mass of 200 g is hung from the hook and the depression y_b when the block of wood is hung from the hook.

Record all your readings in the table below.

100 g			
200 g			
Block			

Plot your values of y_1 and y_2 on the grid below. Assuming a linear relationship between y and the suspended mass, determine a value for the mass m of the wooden block and its hook.

m = ...



(7)

(b) (i) Remove the block and tape a 100 g mass with its centre at the 95 cm mark of the clamped rule. Determine the period T_1 of small vertical oscillations of the mass.

....

....

Tape a second 100 g mass on top of the first and determine the period T_2 for 200 g.

....

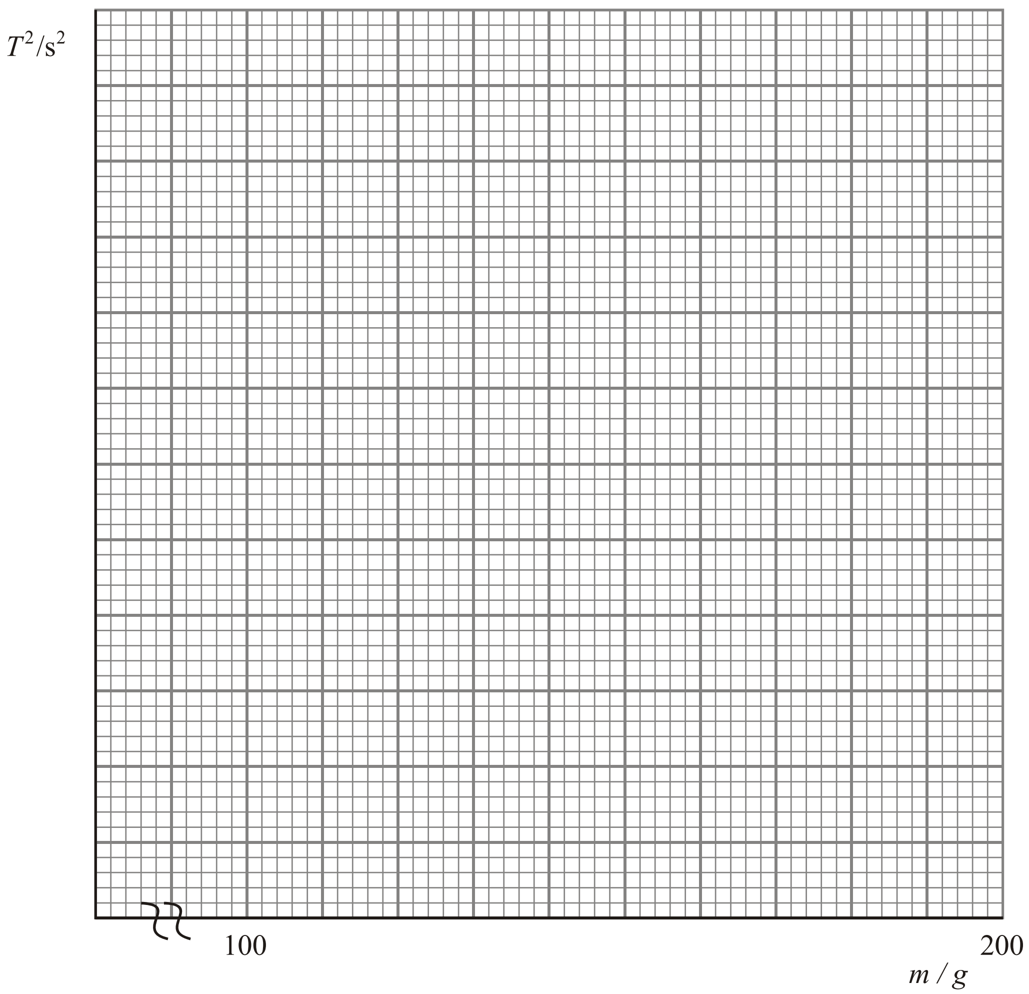
....

Calculate values for T_1^2 and T_2^2.

T_1^2 = ...

T_2^2 = ...

Plot your values of T_1^2 and T_2^2 on the grid below.



(3)

(ii) Assuming a linear relationship between T^2 and the suspended mass, use your graph to predict a value for the period T_b when using the wooden block as the suspended mass.

....

....

....

(3)

(c) Estimate the percentage uncertainty in your value for y_b in part (a) and your value for T_2^2 in part (b).

....

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....

....

....

....

(3)
(Total 16 marks)

119. *You are to plan an investigation of how the magnetic flux density due to a current-carrying wire depends on the distance r from the wire. You are then to analyse a set of data from such an investigation*.

(a) In order to plan the investigation you may assume that the following apparatus is available:

- a Hall probe with its power supply
- a meter to measure the output of the Hall probe
- a long straight wire
- a 0–12 V variable d.c. power supply for the wire
- an ammeter to measure the current in the wire
- a 2.2 Ω resistor connected in series with the wire
- a half-metre rule

(i) Draw a diagram of the experimental arrangement of both the wire and the Hall probe. Show clearly on your diagram the orientation of the sensor at the end of the probe with respect to the wire and the distance *r*.

(ii) Explain the purpose of the resistor in the circuit containing the wire.

....

....

(iii) Suggest a suitable range for the ammeter that measures the current in the wire.

....

(iv) Your friend suggests that a single current-carrying wire will produce only a small magnetic flux density that is difficult to detect by means of the Hall probe. Suggest a modification to the apparatus that would enable a much larger flux density to be produced.

....

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....

(8)

(b) In such an investigation it is expected that

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

where B is the magnetic flux density due to the current-carrying wire, I is the current in the wire, and r is the distance from the wire at which the flux density is measured.

State the graph you would plot to test the relationship between B and r.

....

....

The following data were obtained.

B/μT	r/m	
93	0.020	
74	0.025	
54	0.035	
38	0.050	
19	0.100	

Add your processed data to the third column and then plot your graph on the grid below.

(5)

(c) Determine the gradient of your graph. Hence determine a value for the current I in the wire.

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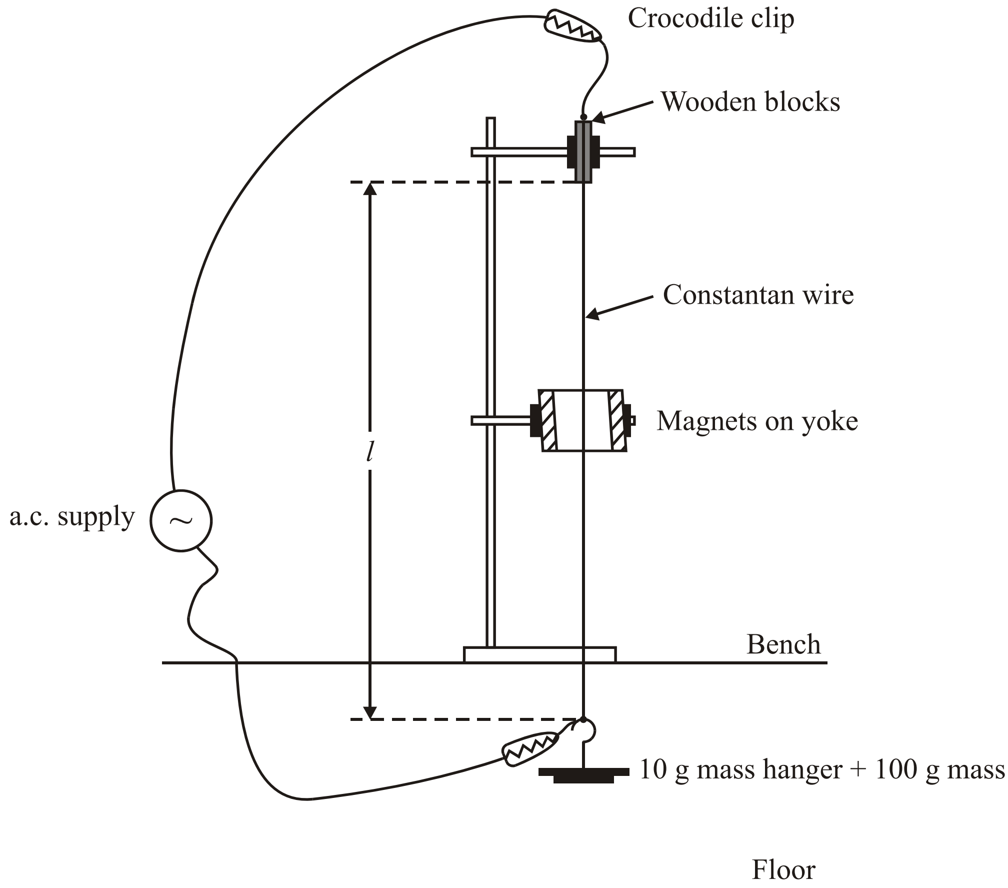
(3)
(Total 16 marks)

120. (a) The apparatus shown in the diagram below has already been set up for you.



(i) Measure the length l of the wire between the bottom of the wooden blocks and the top of the mass hanger.

l = ...

(1)

(ii) Determine an average value for the diameter *d* of the wire. Explain carefully how you ensured that your value was as accurate as possible.

....

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(3)

(iii) Switch on the a.c. power supply. Add further slotted masses to the 10 g mass hanger and 100 g mass until the wire is vibrating in its simplest mode with the largest possible amplitude. Record the total mass *m* of the mass hanger and masses used to produce the largest amplitude.

m = ...

(1)

(iv) Evaluate k where

$$k = \frac{f^2 d^2 l^2}{mg}$$

where f is the frequency of the a.c. supply, which is given on the card.

....

....

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(3)

(b) (i) Use the voltmeter to measure the e.m.f. E of the dry cell.

E = ...

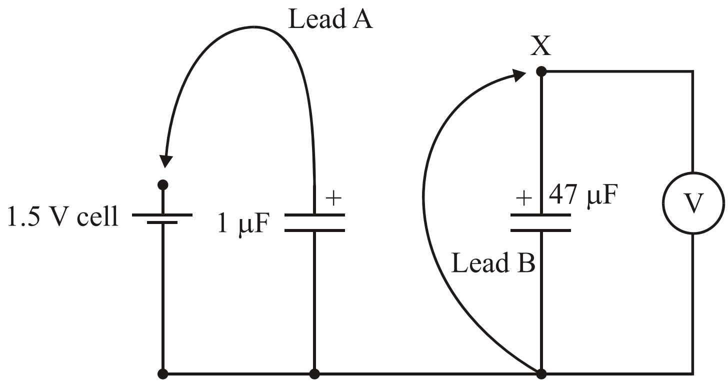
Calculate the charge Q which would be stored on a 1.0 μF capacitor connected to the cell.

....

....

(2)

(ii) If you do not have an auto-ranging voltmeter change the range of the voltmeter to 200 mV d.c. Set up the circuit as shown in the diagram below. Before you connect the lead A to the dry cell have your circuit checked by the Supervisor who will allow you a short time to correct any faults. If you are unable to set up the circuit, the Supervisor will set it up for you. You will lose only 2 marks for this.



(2)

(iii) Ensure that the 47 μF capacitor is discharged by connecting lead B to point X. Then remove lead B from point X.

Connect lead A to the positive terminal of the cell. This charges the 1.0 μF capacitor.

Now connect lead A to point X. This allows the charge to be shared between the two capacitors.

Record the potential difference V across the arrangement immediately after the charge has been shared.

V = ...

Calculate the charge stored on the 47 μF capacitor immediately after sharing.

....

....

(2)

(iv) Compare quantitatively the amount of charge transferred to the 47 μF capacitor to that initially stored on the 1 μF capacitor. Comment on the result you obtain.

....

....

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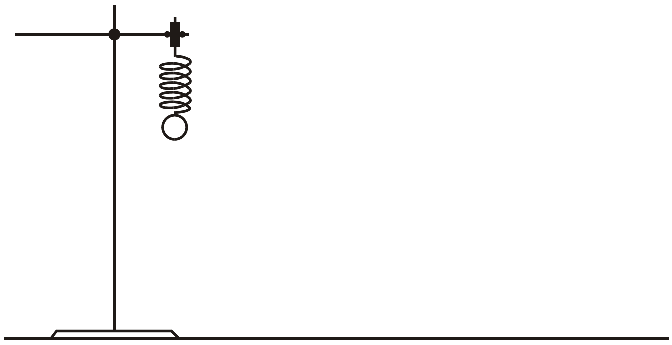
....

(2)
(Total 16 marks)

121. (a) Determine the extension x_1 of the spring when the mass hanger with a 100 g mass (i.e. a total mass of 110 g) is suspended from it. Record your readings in the table below. Add to the diagram below to show how you did this.



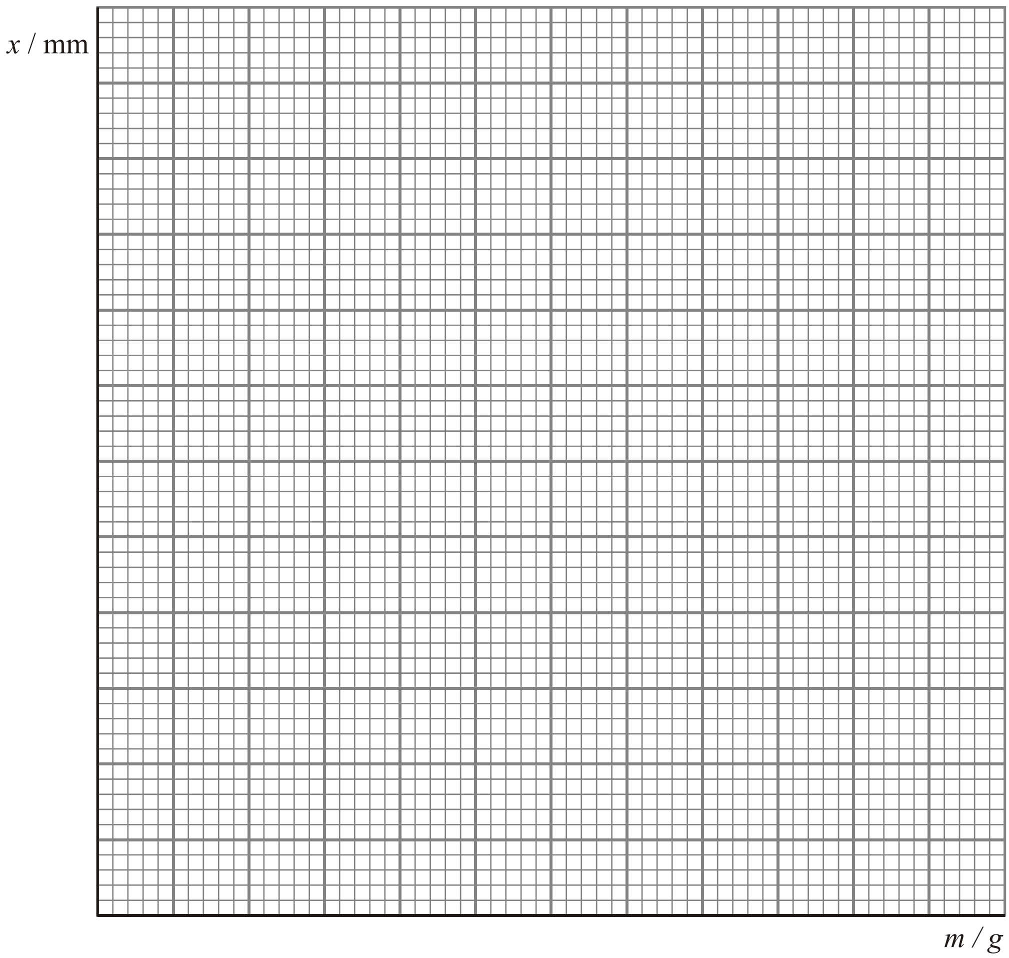
Find the total extension x_2 when a total mass of 210 g is suspended and the extension x_b when the block of wood is suspended.

Record your readings in the table below.

110 g			
210 g			
Block			

Plot your values of x_1 and x_2 on the grid below. Assuming a linear relationship between x and the suspended mass, determine a value for the mass m of the wooden block and its hook.

m = ...



(7)

(b) (i) Determine the period T_1 of small vertical oscillations when 110 g is suspended from the spring.

....

....

Repeat this to find the period T_2 for 210 g and the period T_b for the block.

....

....

....

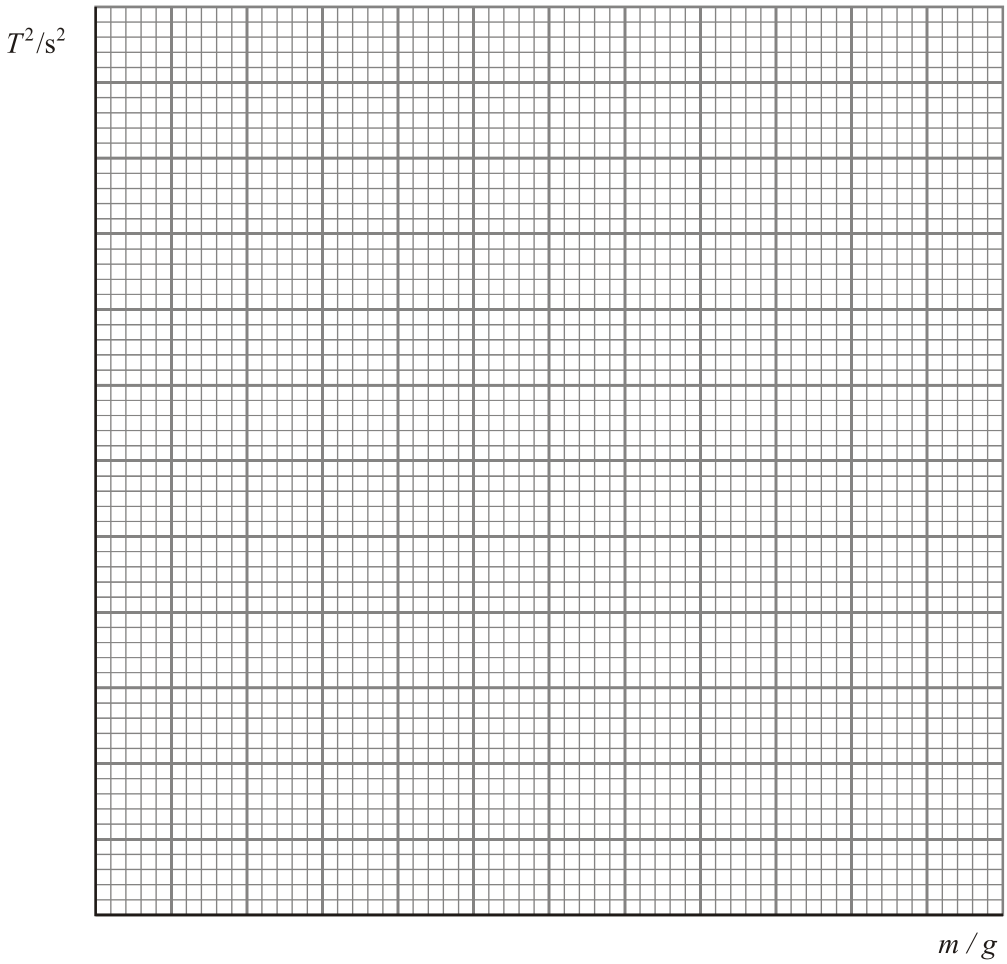
Calculate values for T_1, T_2^2 and T_b^2 in the space below.

T_1^2 = ...

T_2^2 = ...

T_b^2 = ...

Plot your values of T_1^2 and T_2^2 on the grid below.



(ii) Assuming a linear relationship between T^2 and the suspended mass, determine a second value for the mass m of the wooden block and its hook.

m = ...

(5)

(c) Estimate the percentage uncertainty in your value for x_b in part (a) and your value for T_b^2 in part (b).

....

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....

Discuss whether the difference between your two values for the mass of the block and its hook could be accounted for by these uncertainties.

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(4)
(Total 16 marks)

122. *You are to plan an investigation of how the magnetic flux density at the side of a bar magnet depends on the distance d from the axis of the magnet. You are then to analyse a set of data from such an investigation.*

(a) In the investigation the magnetic flux density is to be measured by means of a Hall probe.

(i) Before carrying out the investigation the calibration of the Hall probe has to be checked. This can be done by placing the Hall probe in the centre of a solenoid carrying a current. The following apparatus is available:

- a Hall probe with its power supply
- a meter to measure the output of the Hall probe
- a solenoid
- a variable d.c. power supply for the solenoid
- an ammeter for measuring the current in the solenoid

Draw a diagram of the arrangement you would use to check the calibration of the Hall probe. Show clearly on your diagram the orientation of the sensor at the end of the probe with respect to the axis of the solenoid.

State two other measurements from the solenoid that you would need to determine before the calibration of the Hall probe could be checked.

....

....

(5)

(ii) The magnetic flux density B at the side of the bar magnet is now to be determined as a function of the distance d from the axis of the magnet using the pre-calibrated Hall probe. Draw a diagram of the experimental arrangement. Show clearly on your diagram the orientation of the sensor at the end of the probe with respect to the bar magnet and the distance d.

(3)

(b) In such an investigation it is expected that $B = kd^n$ where k and n are constants. Write this equation in a suitable form to plot a linear graph.

....

……..

The following data were obtained in such an investigation.

B/mT	*d*/mm		
5.26	20		
3.31	25		
2.27	30		
1.67	35		
1.24	40		
1.04	44		

Add your processed data to the table and then plot a suitable graph to test the above equation on the grid below.

(6)

(c) Use the gradient of your graph to determine a value for *n*.

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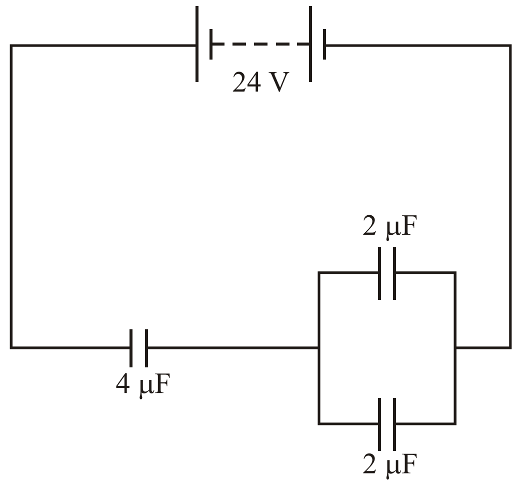
....

(2)
(Total 16 marks)

123. The circuit below shows three capacitors connected to a 24 V battery.



(i) Calculate the equivalent capacitance of the two capacitors connected in parallel.

....

....

Capacitance = ...

(1)

(ii) Hence calculate the charge stored by the 4 μF capacitor.

....

....

....

....

Charge = ...

(3)
(Total 4 marks)

124. (a) (i) State Newton's law for the gravitational force between point masses.

....

....

....

(2)

(ii) Use this law to show that the gravitational field strength g at a distance r from the centre of the Earth, where r is greater than or equal to the radius R of the Earth, is given by

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

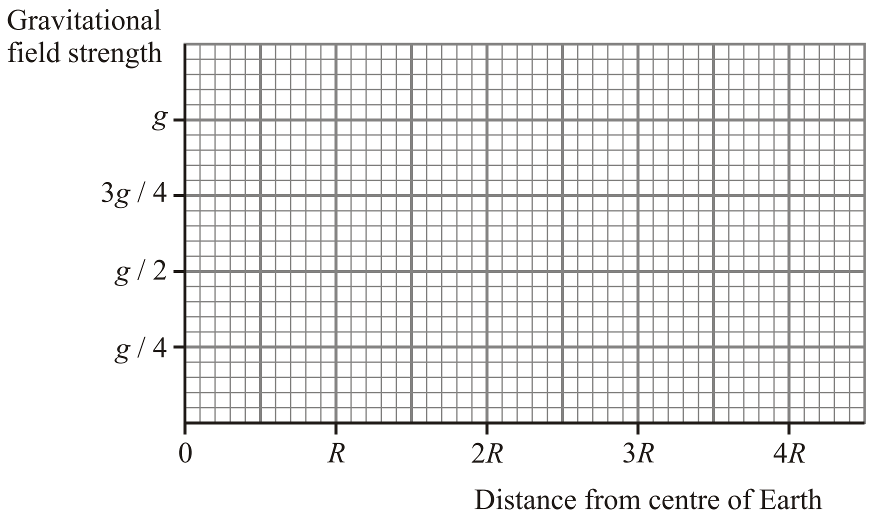
where M is the mass of the Earth.

....

....

(1)

(iii) Use the axes below to plot a graph to show how g varies as the distance r increases from its minimum value of R to a value of $4R$.



(3)

(b) (i) When a satellite, which travels in a circular orbit around the Earth, moves to a different orbit the change in its gravitational potential energy can be calculated using the idea of equipotential surfaces. What is an equipotential surface?

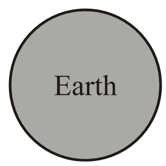
....

....

....

(1)

(ii) Add to the diagram below three equipotential surfaces which have equal changes of potential between them.



(2)

(c) The change in the gravitational potential energy of the satellite when it moves to a different orbit might be calculated using the expression

'weight of satellite × change in height'.

(i) What condition must apply for this to be valid?

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....

(ii) Explain your answer.

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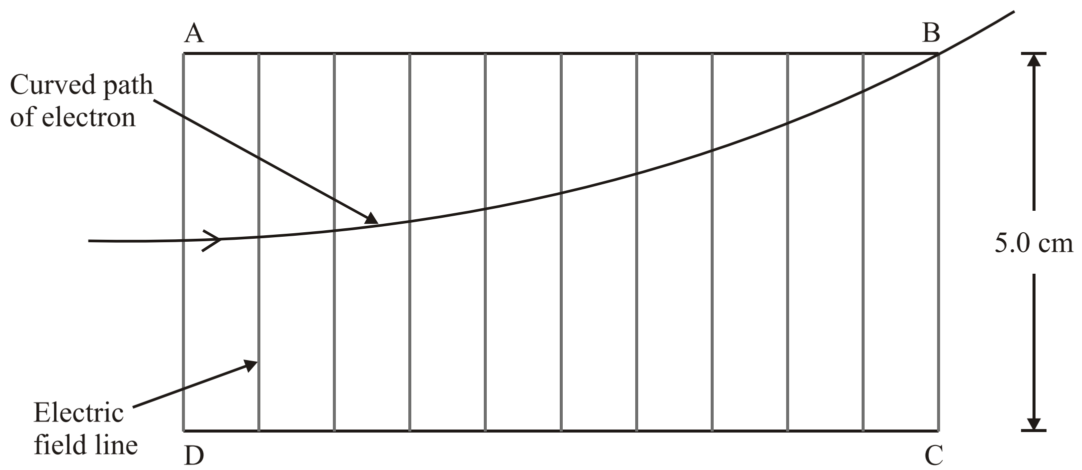
(2)
(Total 11 marks)

125. The diagram shows the path of an electron in a uniform electric field between two parallel conducting plates AB and CD. The electron enters the field at a point midway between A and D. It leaves the field at B.



(a) Mark on the diagram the direction of the electric field lines.

(1)

(b) (i) The conducting plates are 5.0 cm apart and have a potential difference of 250 V between them. Calculate the force on the electron due to the electric field.

....

....

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....

Force = ...

(3)

(ii) State the direction of this force on the electron and explain why it does not affect the horizontal velocity of the electron.

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....

(2)

(c) To leave the electric field at B the electron must enter the field with a speed of 1.30×10^7 m s^{-1}. Calculate the potential difference required to accelerate an electron from rest to this speed.

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....

Potential difference = ...

(3)

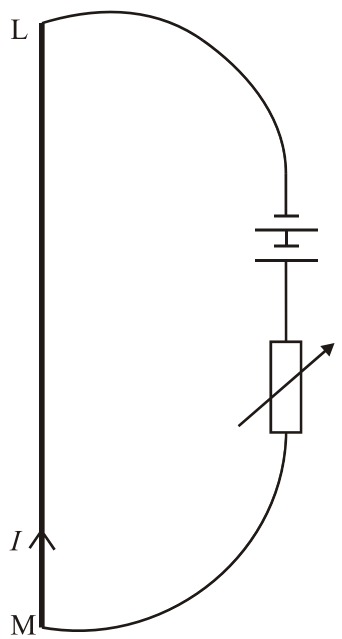
(d) A very thin beam of electrons enters a uniform electric field at right angles to the field. The electrons have a range of speeds.

(i) Draw a diagram to show the shape of the beam as it moves through the field.

(ii) On your diagram label which electrons have the fastest speed.

(2)
(Total 11 marks)

126. (a) The circuit diagram shows a long straight wire LM carrying a current *I* in the direction shown.



Describe how you would investigate the variation of magnetic flux density B with perpendicular distance r from LM in a region around the centre of the wire. You may add to the above diagram if you wish.

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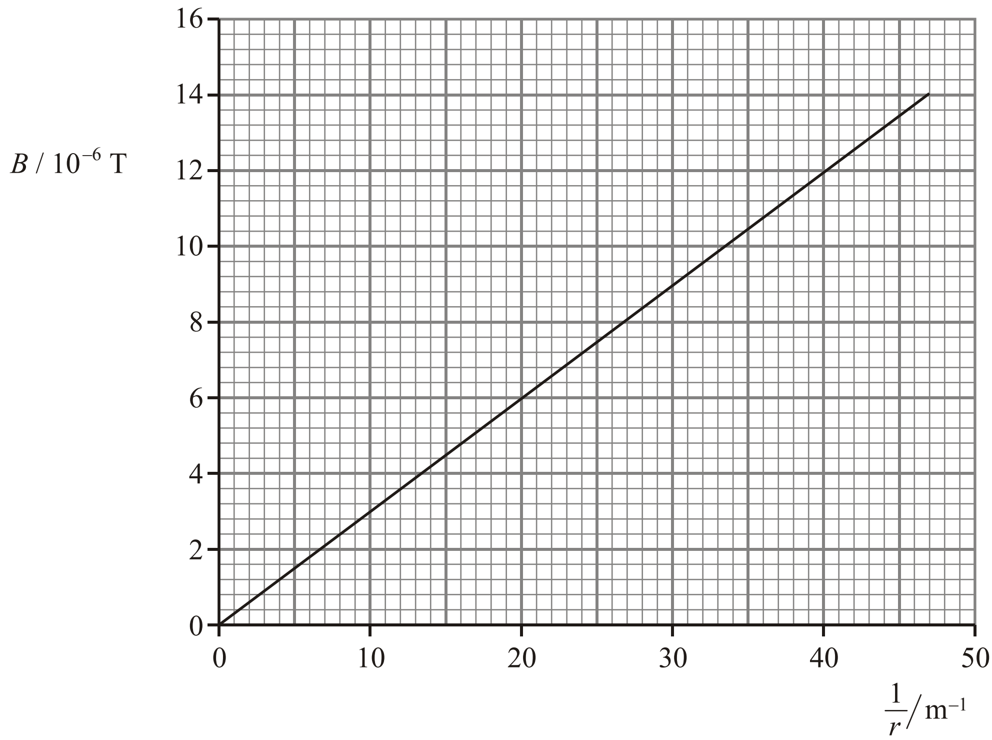
(4)

(b) A typical graph of B against $\frac{1}{r}$ for a straight wire carrying a current I is shown below.



(i) Describe the relationship between B and r shown by the graph.

....

(1)

(ii) Use the graph to determine the value of the current I in the wire.

....

....

....

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....

Current = ...

(3)
(Total 8 marks)

127. Explain the action of a step-down transformer. Your explanation should include reference to the parts played by the primary and secondary coils and the core of the transformer. You may be awarded a mark for the clarity of your answer.

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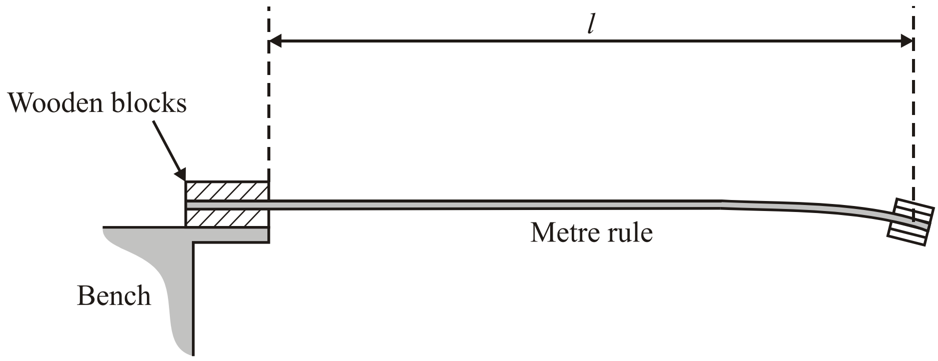
(Total 6 marks)

128. (a) The apparatus shown in the diagram below has already been set up for you.



Measure the horizontal distance *l* from the edge of the bench to the centre of the masses that are attached to the rule. Explain carefully how you determined the value of *l*. You may add to the diagram if you wish.

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Displace the end of the rule vertically so that it performs small vertical oscillations. Determine the period *T* of the oscillations of the rule.

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....

State the precautions that you took to ensure that the period was determined as precisely as possible.

....

....

(8)

(b) Determine values for the width w and the thickness t of the rule.

....

....

....

....

(4)

(c) A property known as the Young modulus E of the wood from which the rule is made is given by the expression

$$e = \frac{16\pi^2 Ml^3}{T^2 wt^3}$$

where M is the value of the mass attached to the metre rule, which is given on the card.

Use your data from parts (a) and (b) to determine a value for this Young modulus.

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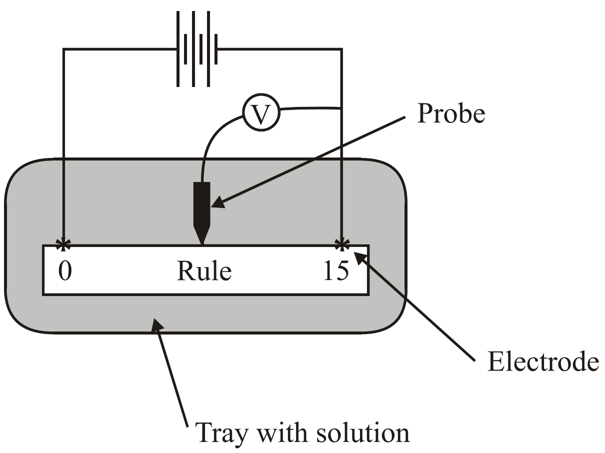
(4)
(Total 16 marks)

129. (a) The apparatus shown in the diagram below has already been set up for you. Note that the two electrodes (indicated by * symbols) are 15.0 cm apart. **You should avoid undue contact with the copper sulphate solution as it could have harmful effects.** If your fingers come into contact with the solution you are advised to wash them.



Connect the power supply and dip the probe vertically into the tank at a point along the edge of the rule a distance *x* of 8.0 cm from the positive electrode. Record the potential difference *V* between this point and the negative electrode.

V = ...

Repeat the above procedure for a range of distances *x* between the probe and the positive electrode. Tabulate your results in the space below. **Disconnect the power supply as soon as you have completed your readings.**

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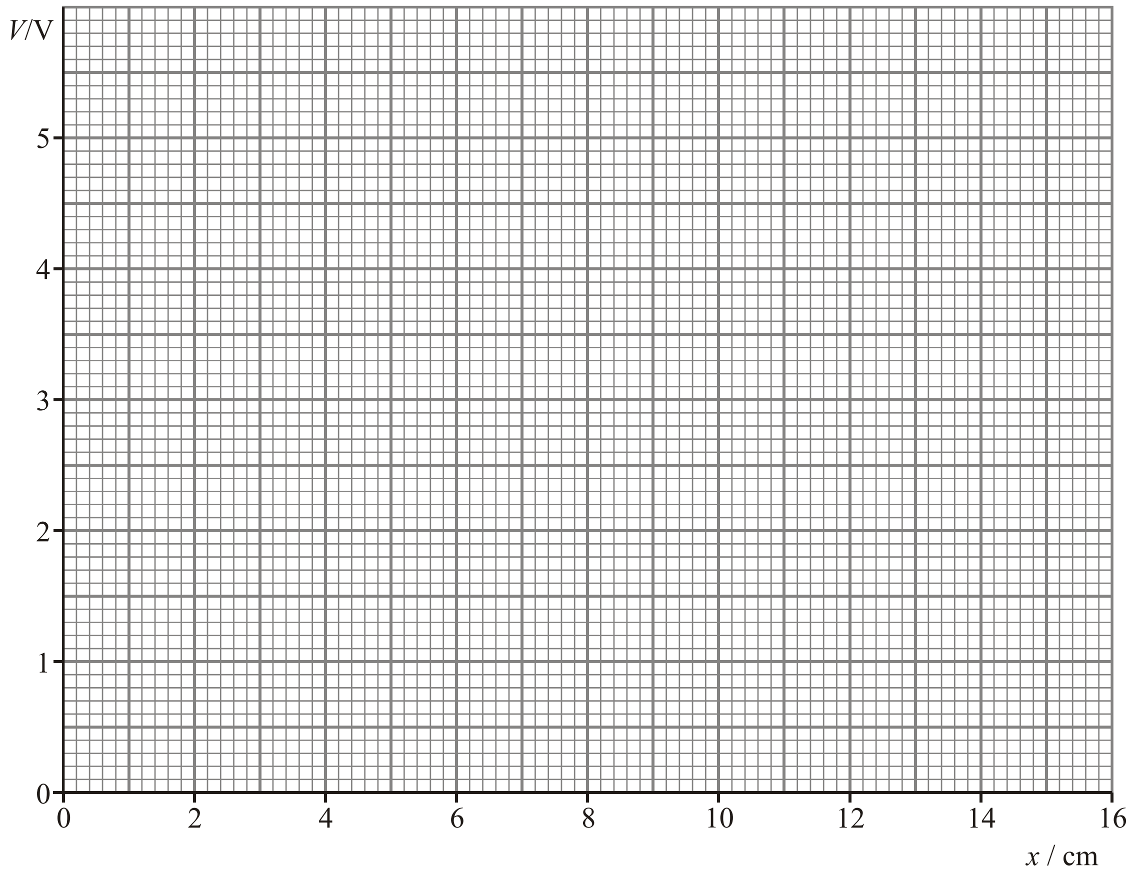
(7)

(b) Using the grid below plot a graph of *V* against *x*.



(2)

(c) The gradient of your graph at any point is equal to the electric field strength E at that point. State the range of x over which E may be considered constant.

Range of x ....

Determine a value for E in this range.

....

....

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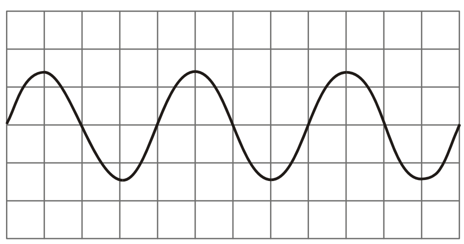
....
(4)

(d) The arrangement shown on page 4 produces an electric field pattern similar to that of a pair of equal and opposite point charges. Sketch the electric field pattern for the pair of charges shown below.

Mark on your sketch the region where the field strength is approximately constant.
(3)
(Total 16 marks)

130. *You are to plan an investigation into an electrical property of a coil using an oscilloscope as a voltmeter.*

(a) An oscilloscope is used to measure the frequency and voltage from the output terminals of a signal generator. With the timebase set at 0.5 ms/div and the voltage sensitivity at 5 V/div the following trace is obtained:



(i) Calculate the frequency of the signal.

....

....

(ii) Determine the peak value V_0 of the voltage.

....

....

(3)

(b) In this part of the question you may assume that the following apparatus is available:

- oscilloscope
- variable frequency signal generator
- coil
- 10 Ω resistor
- connecting leads

A property of a coil, called its impedance Z, is defined as $Z = \frac{V_c}{I_c}$ where V_c is the peak p.d. across the coil and the peak current in it is I_c. Theory predicts that Z varies with the frequency f of the current according to the formula

$$Z^2 = 4\pi^2 L^2 f^2 + R^2$$

where R is the resistance of the coil and L is a property of the coil called its inductance.

Draw the circuit you would use to investigate the relationship between Z and f for the coil using **only** the five items of apparatus listed above.

Describe the readings you would take and how you would determine Z and f. State the graph you would plot to test this relationship.

....

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....

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....

....

(7)

(c) In such an experiment the following data were obtained.

f / Hz	Z / Ω	
200	7.5	
300	9.4	
350	10.5	
400	11.5	
450	12.7	
500	13.8	

(i) Plot a suitable graph on the grid below to test the relationship between Z and f. You should add any column(s) of your processed data to the table.

(4)

(ii) Use your graph to find the resistance R of the coil.

....

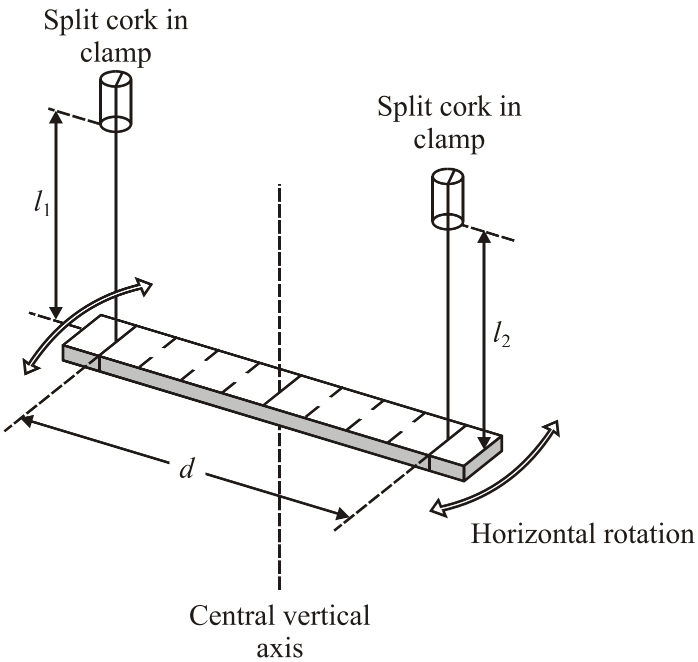
....

....

....

(2)
(Total 16 marks)

131. (a) The apparatus shown in the diagram below has already been set up for you.



Do not alter the lengths of the threads supporting the rule. Measure the average length l of the threads supporting the rule.

....

Check that the distance d between the two threads at the lower end has been set to 40.0 cm with the loops of thread at the 5.0 cm and 45.0 cm marks on the rule. The threads must be vertical at the start of the experiment. Explain how you ensured that the threads were vertical.

....

....

....

....

Twist the half-metre rule about the central vertical axis so that it performs small rotational oscillations about this axis as indicated in the diagram. Determine the period *T* of rotational oscillations of the rule.

....

....

....

....

State any special precautions which you took to ensure that your value of *T* was as precise as possible.

....

....

....

....

(6)

(b) Remove the half-metre rule from the two loops of thread and balance it on the knife edge in order to find the position of its centre of mass.

Scale reading at centre of mass = ...

Place the 50 g mass close to one end of the half-metre rule and move the knife-edge under the rule until the rule balances. Draw a diagram of the arrangement in the space below.

Show the position of the centre of mass of the half-metre rule on your diagram.

Take such measurements as are necessary to determine the mass M of the half-metre rule by the principle of moments. Show all your working and calculations in the space below. You should indicate carefully on your diagram the lengths that you measured.

....

....

....

....

....

....

(7)

(c) A quantity known as the moment of inertia I of the rule is given by the expression

$$I = \frac{Mgd^2T^2}{16\pi^2 l}$$

where g is the gravitational field strength.

Use your data from parts (a) and (b) to determine a value for the moment of inertia of the half-metre rule.

....

....

....

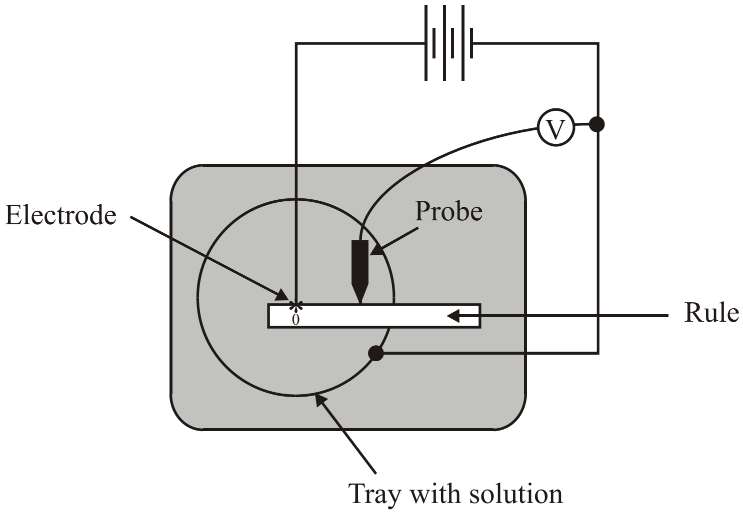
....

....

....

(3)
(Total 16 marks)

132. (a) The apparatus shown in the diagram below has already been set up for you. **You should avoid undue contact with the copper sulphate solution as it could have harmful effects.** If your fingers come into contact with the solution you are advised to wash them.



The central electrode (indicated by a * symbol) is at the centre of the circular coil and the edge of the 15 cm plastic rule lies along a radius of the circle.

Connect the power supply and dip the probe vertically into the tank at a point along the edge of the rule a distance *r* of 4.0 cm from the central positive electrode. Record the potential difference *V* between this point and the negative circular electrode.

V = ...

Repeat the above procedure for a range of distances *r* between the probe and the central positive electrode. Tabulate your results in the space below. **Disconnect the power supply as soon as you have completed your readings.**

....

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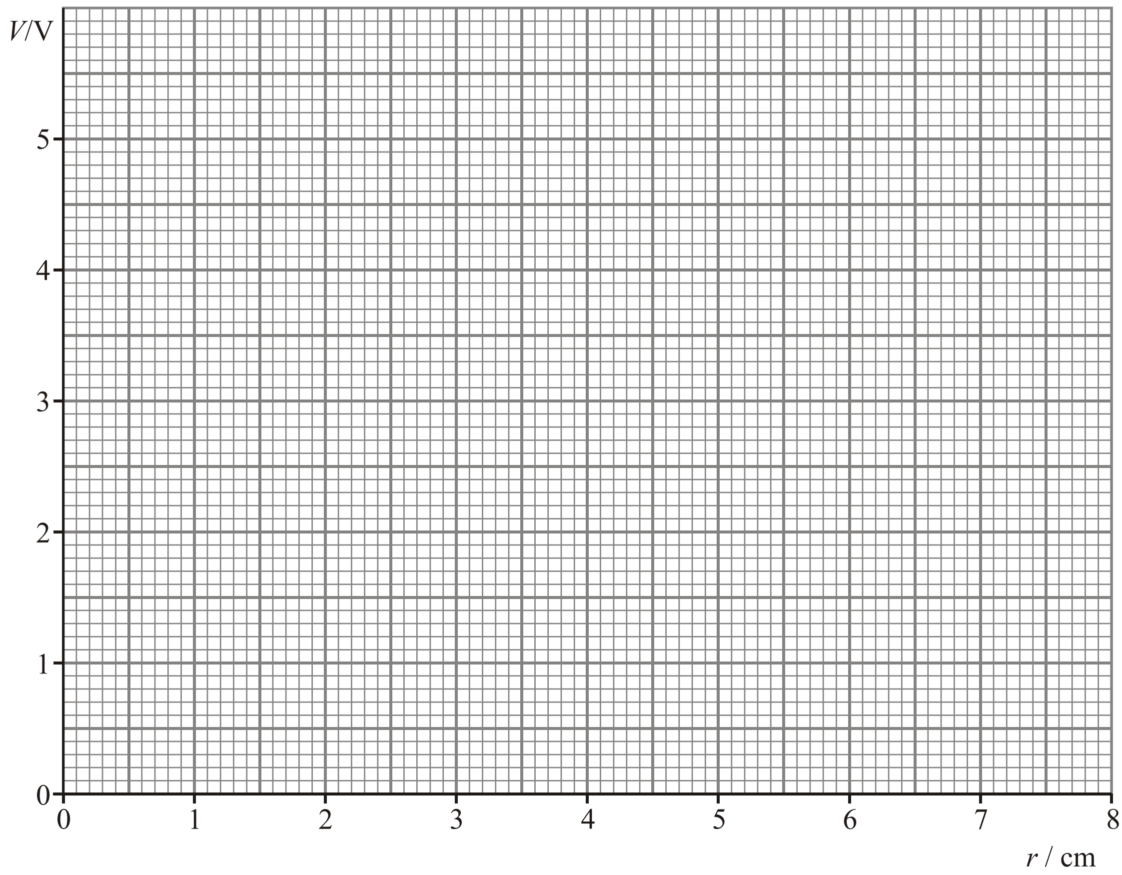
....

(7)

(b) Using the grid below plot a graph of V against r.



(2)

(c) The gradient of your graph at any point is equal to the electric field strength E at that point. Determine values for E at the points where r = 2.0 cm and r = 4.0 cm.

....

....

....

....

....

....

(4)

(d) In this experiment it is suggested that the electric field strength is inversely proportional to the distance from the central electrode. Discuss quantitatively whether your results support this suggestion.

....

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....

....

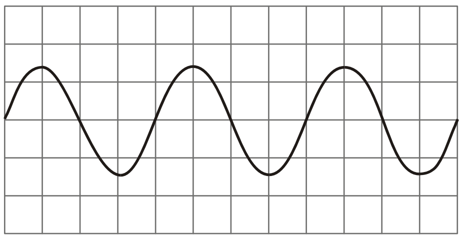
....

....

(3)
(Total 16 marks)

133. *You are to plan an investigation into a property of a capacitor using an oscilloscope as a voltmeter.*

(a) An oscilloscope is used to measure the frequency and voltage from the output terminals of a signal generator. With the timebase set at 1 ms/div and the voltage sensitivity at 2 V/div the following trace is obtained.



(i) Calculate the frequency of the signal.

....

....

(ii) Determine the peak value V_0 of the voltage.

....

(3)

(b) In this part of the question you may assume that the following apparatus is available:

- oscilloscope
- variable frequency signal generator
- capacitor
- 100 Ω resistor
- connecting leads

A property of the capacitor called its reactance, X, is defined as $X = \frac{V_c}{I_c}$ where V_c is the peak p.d. across the capacitor and the peak current in it is I_c.

Theory predicts that X varies with the frequency f of the current according to the formula

$$X = \frac{1}{2\pi fC}$$

where C is the capacitance of the capacitor in the circuit.

Draw the circuit you would use to investigate how X depends on the frequency f of the current using **only** the five items of apparatus listed above.

Describe the readings you would take and how you would determine X and f. State the graph you would plot to test the relationship between X and f.

....

....

....

....

....

....

....

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....

....

(7)

(c) In such an experiment the following data were obtained.

f/Hz	*X*/Ω	
80	41.9	
100	34.4	
125	27.1	
170	20.1	
300	11.4	
500	6.8	

(i) Plot a suitable graph on the grid below to test the relationship between *X* and *f*. You should add any column(s) of your processed data to the table.

(4)

(ii) Discuss the extent to which your graph confirms the proposed relationship.

....

....

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(2)
(Total 16 marks)

134. (a) State **in words** the formula which gives the electric force between two charged particles.

....

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....

(2)

(b) What are the base units of the constant in this formula?

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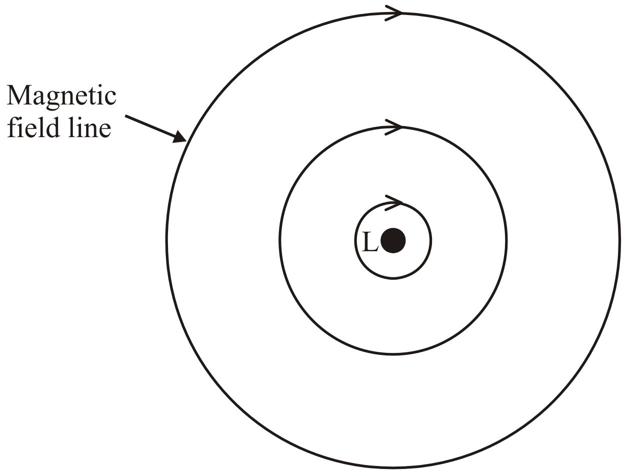
(3)
(Total 5 marks)

135. The diagram below shows the magnetic field due to a current in a long straight wire L, in a plane perpendicular to the wire.



(a) (i) State the direction of the current in L.

....

(1)

(ii) What feature of the magnetic field shown in the diagram indicates that there are no other magnetic fields close to the wire?

....

(1)

(b) A second wire carrying a current of the same size is placed parallel and near to L. The magnetic field along a line joining the wires is investigated and it is found that at a certain distance from L, no magnetic field can be detected. Explain this observation.

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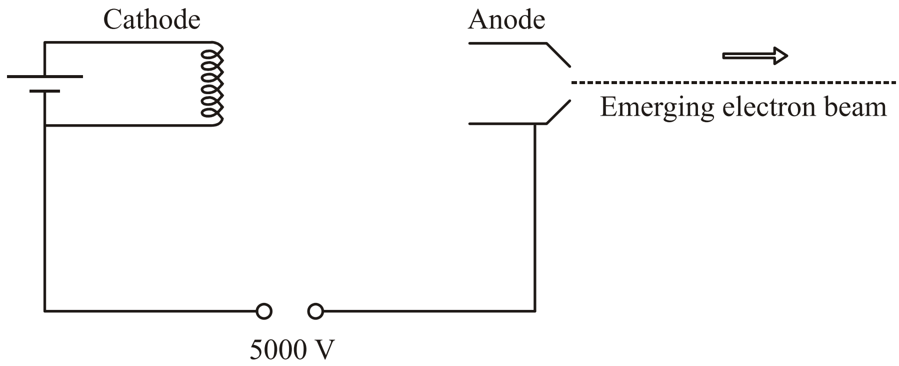
(3)
(Total 5 marks)

136. Electrons are accelerated from rest from the cathode to the anode of a vacuum tube through a potential difference of 5000 V.

Figure 1



(a) Show that the speed *v* of an electron as it leaves the anode is approximately 4×10^7 m s^{-1}.

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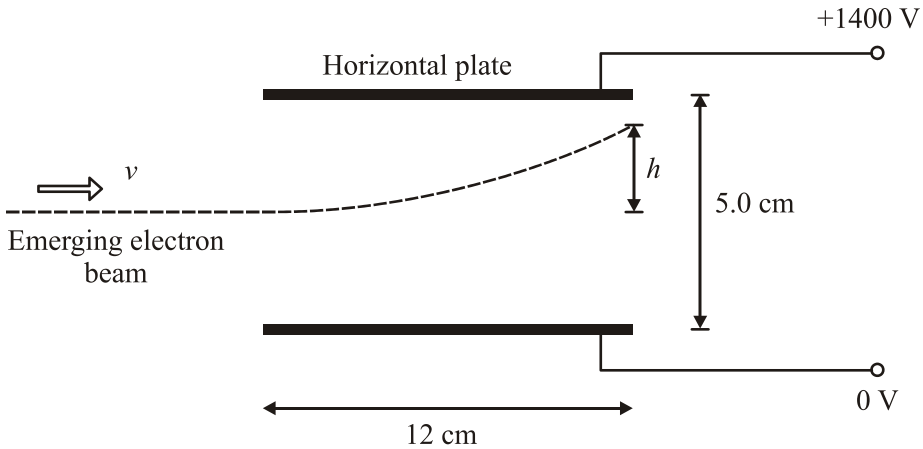
(3)

(b) The emerging beam of electrons follows a parabolic path as it passes between a pair of horizontal parallel plates 5.0 cm apart with a potential difference of 1400 V between them.

Figure 2



(i) Calculate the strength *E* of the uniform electric field between the horizontal plates.

....

E = ...

(1)

(ii) Hence determine the force *F* exerted by this field on each electron.

....

....

F = ...

(1)

(c) An electron experiences an upward acceleration *a* as it travels between the plates. Its vertical displacement *h* after a time *t* is given by

$$h = \frac{1}{2}at^2$$

Calculate the value of *h* as the electron leaves the plates.

....

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....

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h = ...

(4)

(d) (i) Add to Figure 2 the path that the electron beam would follow if the potential difference between the horizontal plates were decreased. Label this path A.

(1)

(ii) Add to Figure 2 the path that the electron beam would follow if the potential difference between the cathode and the anode were decreased. Label this path B.

(1)
(Total 11 marks)

137. (a) State Newton's law for the gravitational force between two point masses.

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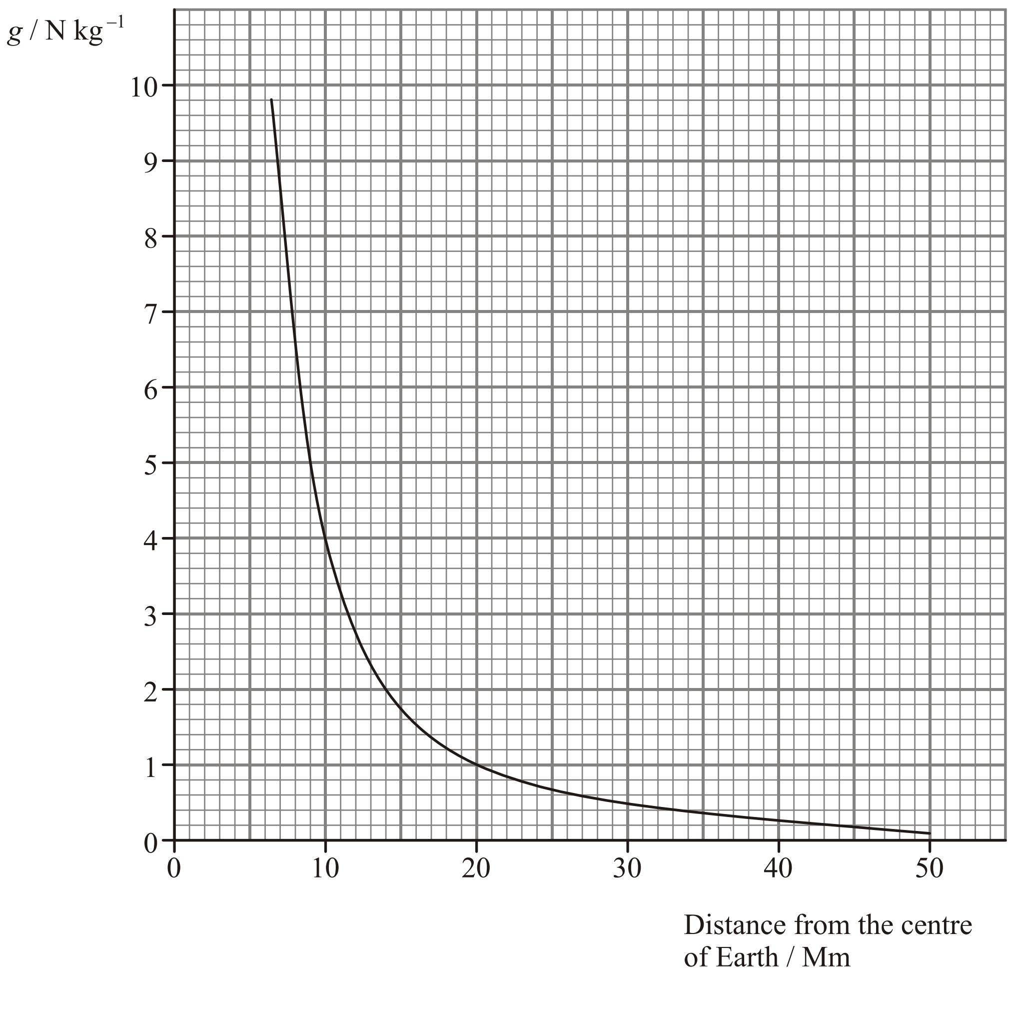
(2)

(b) The graph shows how the gravitational field strength g above the Earth's varies with the distance from its centre.



(i) Use the graph to demonstrate that the relationship between g and distance from the centre of the Earth obeys an inverse square law.

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(3)

(ii) The average distance between the centre of the Moon and the centre of the Earth is 380 Mm. Use information from the graph to determine the Earth's gravitational field strength at this distance.

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Gravitational field strength = ...

(2)

(c) What effect, if any, does the Earth's gravitational field have on the Moon?

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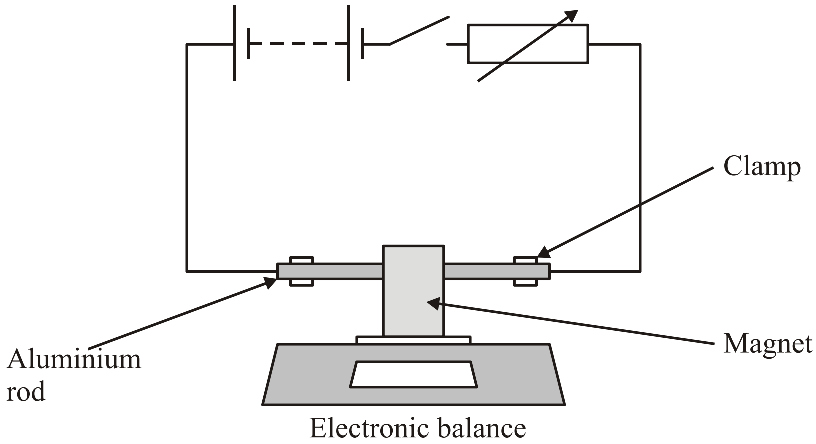
(1)

(Total 8 marks)

138. A U-shaped permanent magnet of mass 85.0 g rests on an electronic balance as shown in the diagram. An aluminium rod connected in a circuit is supported between the opposite poles of the magnet so that it is unable to move.



The switch is closed. The reading on the balance increases to 85.4 g.

(a) (i) Calculate the additional force on the magnet when there is current in the circuit.

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Force = ...

(1)

(ii) Explain how this additional force originates. You may be awarded a mark for the clarity of your answer.

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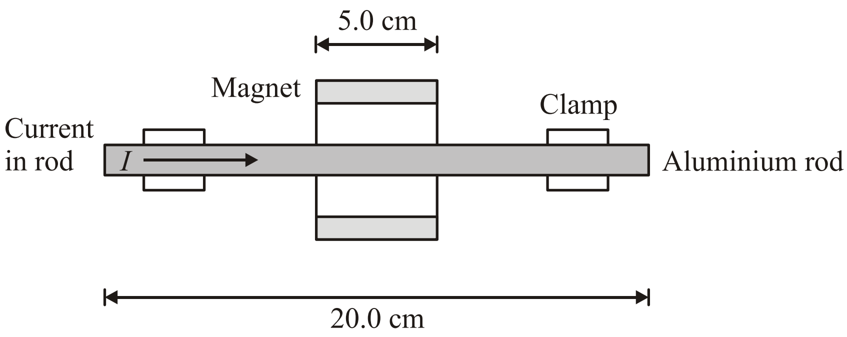
(4)

(b) The diagram below shows a plan view of the rod and the poles of the magnet.

(i) On the diagram **label the poles of the magnet** to indicate the direction of field needed to produce a downward force on the magnet.

VIEW AS SEEN FROM ABOVE



(1)

(ii) The rod is 20.0 cm long and the magnet is 5.0 cm wide. The magnetic flux density of the magnet is 30.0 mT. Calculate the current in the rod.

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....

....

Current = ...

(3)

(iii) The direction of the current is reversed. What would be the new reading on the balance?

....

Balance reading = ...

(2)
(Total 11 marks)

139. (a) (i) Measure the length *l* and the width *w* of the sheet of paper labelled Part (a).

l = ...

w = ...

The paper has a mass per unit area of 80 g m^{-2}. Calculate the mass of the sheet of paper.

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(3)

(ii) Determine the thickness, t, of the sheet of paper.

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Use your measurements to calculate the density of the paper.

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(4)

(b) (i) You are provided with a strip of paper and a clip, suspended from a clamp stand. The pen is to act as a pointer and the pin in the cork is to act as a reference point.

Twist the lower clip by about 45° and release it carefully so that it performs rotational oscillations about a vertical axis.

Determine the period of oscillation T_1.

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....

Explain how you used the pin in the cork to improve the accuracy of your readings.

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(3)

(ii) Replace the strip with the one from the bench. Take care to ensure that the edge of each clip lines up with the marks on the paper.

Twist the lower clip by about 45° and release it carefully.

Determine the period of oscillation T_2.

....

....

(2)

(iii) Measure the distance l_1 between the lines on the shorter strip of paper.

....

Measure the distance l_2 between the lines on the longer strip of paper.

....

Calculate the ratio of T_2/T_1

....

Calculate the ratio of l_2/l_1.

....

Assuming that the experimental uncertainty in each of T_1 and T_2 is 5% and that the uncertainty in l_1 and l_2 is negligible, discuss whether the suggestion that $T_2/T_1 = l_2/l_1$ is valid.

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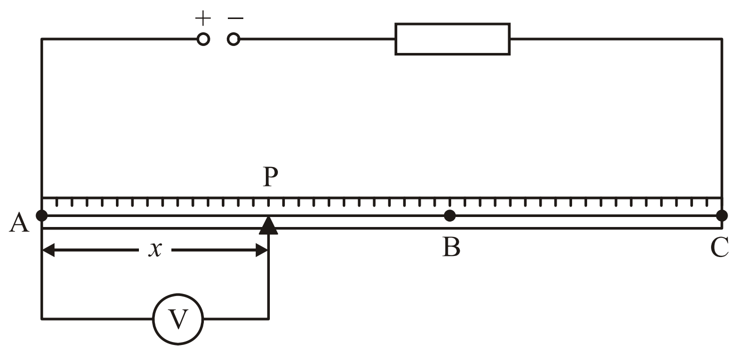
(4)
(Total 16 marks)

140. (a) Set up the circuit as shown in the diagram. The two resistance wires AB and BC, joined at B, are attached to the metre rule. Plug into the crocodile clips at the 0 cm and 100 cm marks to make the connections labelled A and C as shown in the diagram. A 4 mm plug is to be used to make a contact P with the wire. Before switching on the power supply have your circuit checked by the Supervisor. You will be allowed a short time to correct any faults, but if you are unable to set up the circuit the Supervisor will set it up for you. You will lose only 2 marks for this.



(2)

Use the 4 mm plug to make a contact P at about the 50 cm mark and record the distance AP, labelled x. Record also the reading V on the voltmeter.

x = ...

V = ...

(b) (i) You are to take readings of V for different values of x, the distance between A and P. Use the 4 mm plug to make a contact P at different points along the wire AB. Record your readings for V and x below. Switch off the power supply after you have taken your readings.

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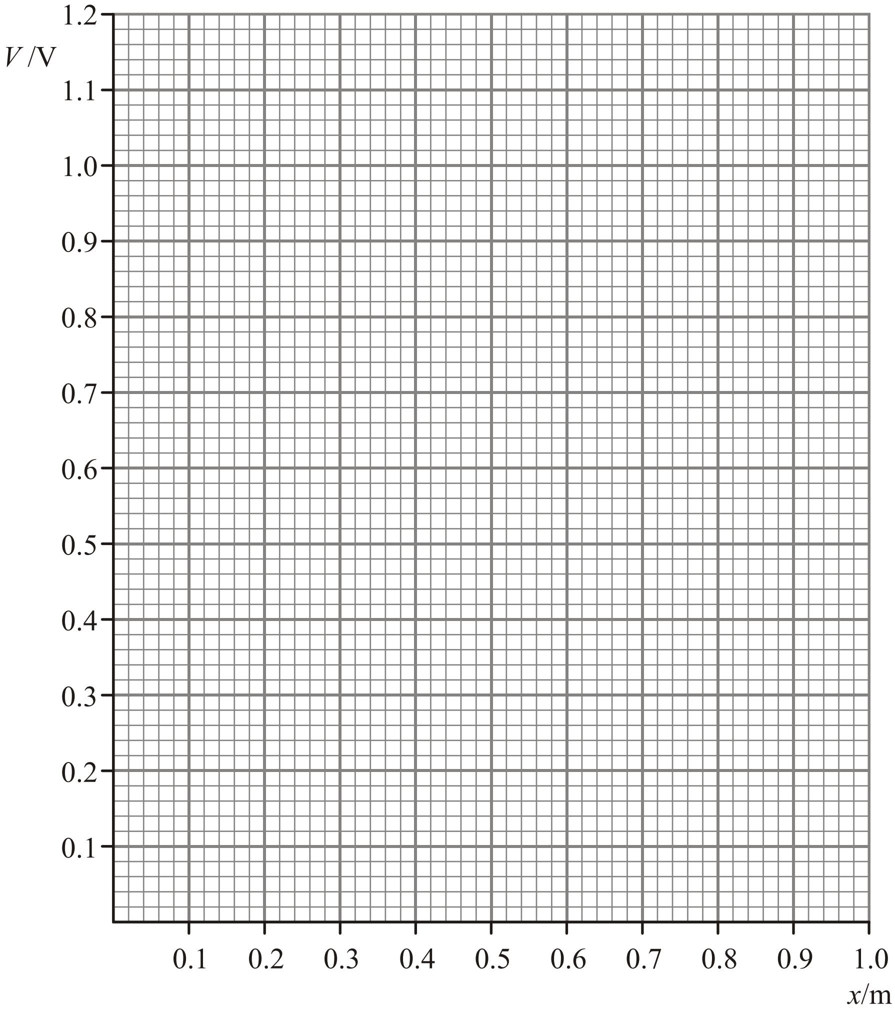
(ii) Plot a graph of your readings on the grid. Label your line X.



(iii) Switch on the power supply and use the 4 mm plug to make a contact P at different points along the wire BC. Record your readings for V and x, where x is the distance between A and P. Switch off the power supply after you have taken your readings.

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(iv) Plot a graph of these readings on the grid above. Label this line Y. Extend the lines X and Y and determine the value of x at their intersection.

x = ...

(7)

(c) Determine the gradients m_X and m_Y of the lines X and Y.

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(3)

(d) It is suggested that the ratio of the gradients should be equal to 0.360. Discuss the extent to which your results support this suggestion.

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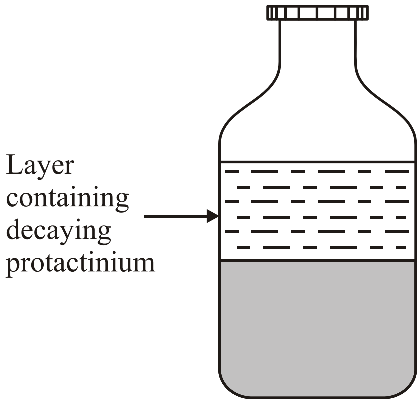
(4)
(Total 16 marks)

141. *You are to plan an experiment to determine the half life of protactinium-234. You are then to analyse a set of data from such an experiment.*

(a) (i) In a protactinium generator protactinium-234, which is a beta-minus emitter, is dissolved in a solvent which forms a layer in a bottle as shown below:



Add to the diagram to show the arrangement you would use to measure the count rate from the protactinium-234.

(3)

(ii) Describe how you would measure the background count at the start of your experiment and how you would make allowance for it.

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(2)

(iii) Describe the readings you would take to determine the half life of the protactinium-234, which is thought to be of the order of one minute.

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(2)

(iv) For radioactive decay, the count rate A after a time t is given by

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

where A_0 = count rate at $t = 0$
and λ = decay constant

Explain why a graph of ln$A$ against t should be a straight line.

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(1)

(b) The following data were obtained in such an investigation:

Background count = 27 min^{-1}

t/s	Count rate/min^{-1}		
0	527		
20	447		
40	367		
60	300		
80	262		
100	216		
120	183		

Use the columns provided for your processed data, and then plot a suitable graph on the grid below to test whether the decay follows the expected pattern.

(5)

(c) Use your graph to find a value for the decay constant λ.

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Hence determine a value for the half life of the protactinium-234.

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(3)
(Total 16 marks)

142. (a) (i) Measure the length l and the width w of the sheet of paper labelled Part (a).

l = ...

w = ...

Use the balance to measure the mass m of the sheet of paper.

m = ...

Use your measurements to determine the mass per unit area of the paper in g m^{-2}.

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(4)

(ii) Describe how you would determine the thickness of the paper. Include in your description any additional apparatus you would require and precautions you would take to make the reading as accurate as possible.

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(3)

(b) (i) You are provided with a strip of paper and a clip, suspended from a clamp stand. The pen is to act as a pointer and the pin in the cork is to act as a reference point. Twist the lower clip by about 45° and release it carefully so that it performs rotational oscillations about a vertical axis.

Determine the period of oscillation T_1.

....

....

Explain how you used the pin in the cork to improve the accuracy of your readings.

....

....

(3)

(ii) Replace the strip with the one from the bench. Take care to ensure that the edge of each clip lines up with the marks on the paper. The pen should be a snug fit in the lower clip.

Twist the lower clip by about 45° and release it carefully.

Determine the period of oscillation T_2.

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(2)

(iii) Calculate the ratio of T_2/T_1.

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Estimate the percentage uncertainty in your value of this ratio.

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(4)
(Total 16 marks)

143. (a) Measure the diameter *d* of the short length of wire.

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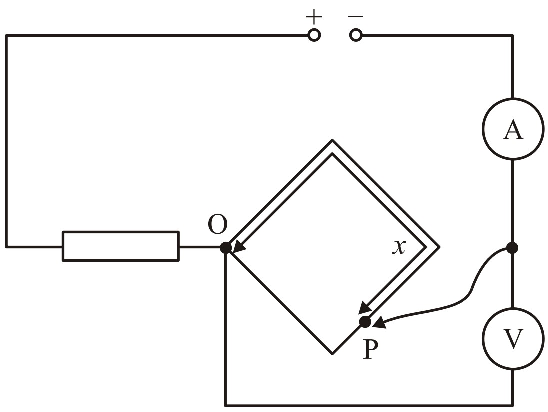
(2)

(b) (i) Set up the circuit as shown in the diagram. A resistance wire is set up as a square. This is the same type of wire as the short length. Plug into the crocodile clip to make contact with the wire at point O as shown in the diagram. This is to be taken as the 0 cm mark. A 4 mm plug is to be used to make a contact P with the wire. Before switching on the power supply have your circuit checked by the Supervisor. You will be allowed a short time to correct any faults, but if you are unable to set up the circuit the Supervisor will set it up for you. You will lose only 2 marks for this.



(2)

(ii) Make a contact P such that $x = 0.650$ m, where x is the distance of P from O measured clockwise round the square. Record the reading V on the voltmeter and the reading I on the ammeter. Calculate the resistance R between O and P.

V = ... I = ...

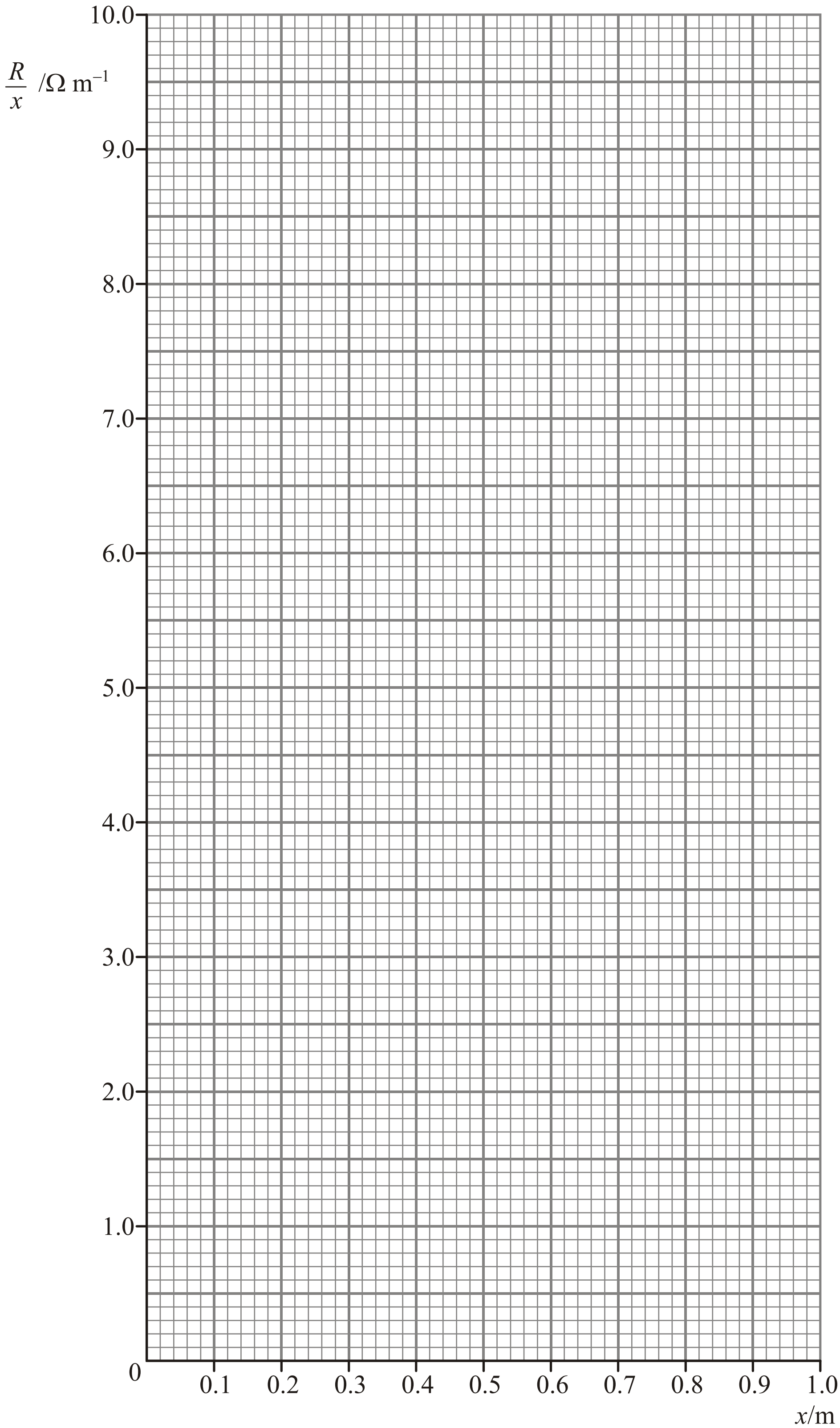
R = ...

Take readings of V and I for different values of $x \geq 0.300$ m. Record your readings below and complete the table for values of R and R/x.

x/m	V/V	I/A	R/Ω	$(R/x)/\Omega\ m^{-1}$

(6)

(c) Plot a graph of R/x against x on the grid below.



(2)

(d) Determine the magnitude *s* of the gradient of your graph.

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(2)

(e) It can be shown that

$$\rho = \frac{\pi d^2 sl}{4}$$

where ρ is the resistivity of the wire
l is the length of wire forming the square = 1.00 m
d is the diameter of the wire which you measured in part (a).

Calculate a value for ρ.

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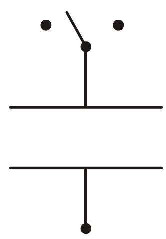
(2)
(Total 16 marks)

144. *You are to plan an investigation of how the current in a capacitor varies with time when it is discharged through a resistor. You are then to analyse a set of data from such an experiment.*

(a) (i) You are provided with the following apparatus:

- capacitor
- 10 kΩ resistor
- (nominal) 1.5 V cell
- microammeter
- two-way switch
- connecting leads
- stopwatch

Complete the diagram to show the circuit you would set up to charge the capacitor and then to measure the current as the capacitor discharges through the 10 kΩ resistor.



(3)

(ii) Describe how you would determine how the current *I* in the capacitor varied with the time *t* of discharge.

....

....

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....

....

....

(3)

(iii) It is suggested that

$$I = I_o e^{-at}$$

where I_o = current at $t = 0$
and a = a constant

Explain why a graph of ln I against t would be a straight line if the relationship were true.

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Estimate the value of I_o expected in this experiment. Show how you arrived at your answer.

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(2)

(b) The following data were obtained in such an investigation.

t/s	I/μA	
10	121.5	
20	97.5	
30	79.0	
40	63.4	
50	51.4	
60	41.7	
70	33.1	

Use the column provided for your processed data and then plot a suitable graph on the grid below to test the suggested relationship.

(5)

(c) Use your graph to find a value for *a*.

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Hence calculate a value for the capacitance C of the capacitor, given that

$$a = \frac{1}{CR}$$

where $R = 10\ \text{k}\Omega$.

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(3)
(Total 16 marks)