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Physics

Module 5 & 6

TRIAL PREPARATION LECTURES

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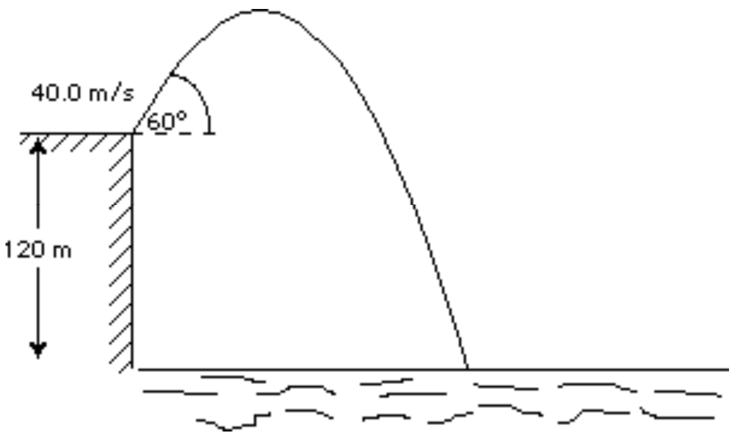
Physics - Modules 5 and 6

For each question, there is space for you to take notes on relevant points related to each question.

Question 1

As shown in the diagram below, an object is projected off the top of a 120 m high ocean cliff, with a velocity of 40.0 m s^{-1}, at an angle of 60° above the horizontal.



a) What will be the maximum height reached above sea level?
b) How long will the object be in the air?
c) How far from the base of the cliff will the object land?
d) What will be its velocity as it enters the sea?

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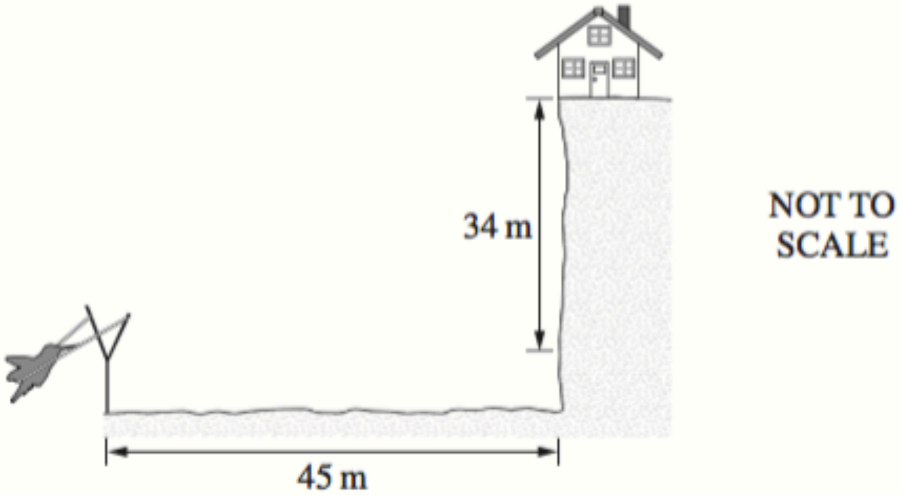
Question 2

A toy bird is launched at 60° to the horizontal, from a point 45 m away from the base of a cliff.



Calculate the magnitude of the required launch velocity such that the toy bird strikes the base of the wooden building at the top of the cliff, 34 m above the launch height.

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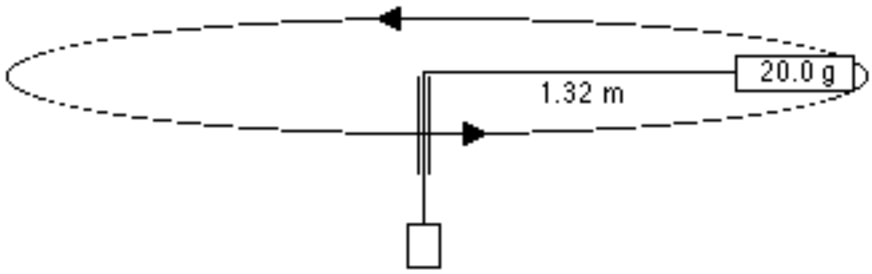
Question 3

Two weights are connected by a light inextensible string. The string passes through a smooth glass tube. One mass (20.0 g) is rotated in a flat arc as shown. At a certain rotation rate, it is observed that the hanging weight is stationary. It was found that the rotating mass took 5.84 seconds to complete 10 revolutions. The radius of the circular path followed by the mass was 1.32 m.



a) What is the instantaneous velocity of the 20.0 g mass?
b) What is the centripetal acceleration of the mass?
c) What is the centripetal force acting on the 20.0 g mass?
d) What provides this force?
e) Calculate the mass of the hanging weight.

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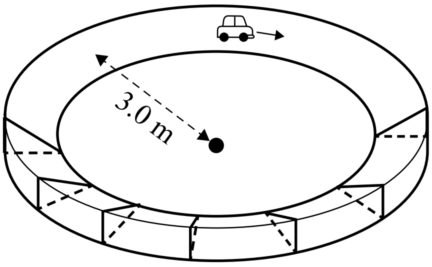
Question 4

A model car of mass 2.0 kg is placed on a banked circular track. The car follows a path of radius 3.0 m. The motor maintains it at a constant speed of 2.0 m s^{-1}.
The angle of bank is such that there are no sideways frictional forces between the wheels and the track.



a) Draw a diagram showing all the forces acting on the car using solid lines and label each force. Show the resultant force as a dotted line, labelled F_R.

b) Calculate the required angle of bank of the track, in degrees, to maintain the 2.0 kg car at 3.0 m s^{-1} on the 3.0 m circular path with no sideways friction between the wheels and the track. Show your working.

Question 5

Discuss the importance of Newton's Law of Universal Gravitation in understanding and calculating the motion of satellites.

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Question 6

Ganymede is the largest of the moons of Jupiter, orbiting at a distance of 1.07 million km from the centre of Jupiter, in an orbit with a period of 7 days and 3 hours. It has a mass of 1.48×10^{23} kg and a diameter of 5268 km.

a) What is the orbital velocity of Ganymede?

b) Make use of the data provided to determine the mass of Jupiter.

c) What would be the surface gravity on Ganymede?

Question 7

A proton is fired perpendicularly into an electric field at 50 000 m s^{-1} as shown. The plates are 40.0 cm apart and have a potential difference of 10 000 V between them.

a) Sketch the path the proton will follow once it enters the electric field. Justify your answer.
b) What force will act on the proton in the electric field?
c) What will be the acceleration of the proton?
d) How far will the proton travel before it hits one of the parallel plates?

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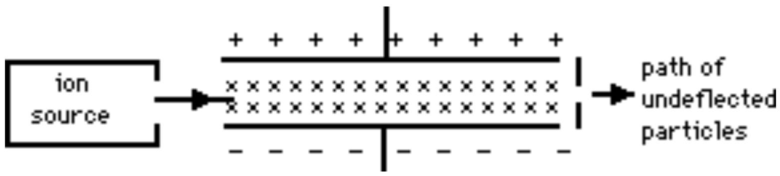
Question 8

A velocity gate for charged particles can be made by allowing a stream of charged particles to pass through an area where an electric field is crossed (i.e. perpendicular) to a magnetic field, as shown.



a) Show that the only particles that come through the crossed fields undeflected have a velocity given by: -

$$v = \frac{E}{B}$$

b) The magnetic field is provided by a 2.0×10^{-3} T magnet. The plate separation is 5.0 cm. What voltage must be supplied to provide undeflected ions of velocity 2.5×10^{7} m s^{-1}?

c) What modifications (if any) would need to be made to the velocity gate to accommodate negative particles? Explain your answer.

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Question 9

In a mass spectrometer, a velocity filter ensures that charged particles entering the device all have the same velocity. A sample is suspected of containing a Group 1 metal. When placed in the mass spectrometer, an electron is removed from each atom of the sample and the ions formed are accelerated to 1.719×10^5 m s^{-1}. They then enter a magnetic field of 0.200 T. The ions from the sample underwent a circular path of radius 196 mm.

a) Calculate the mass of the ions being tested.

b) Identify the element contained in the sample.

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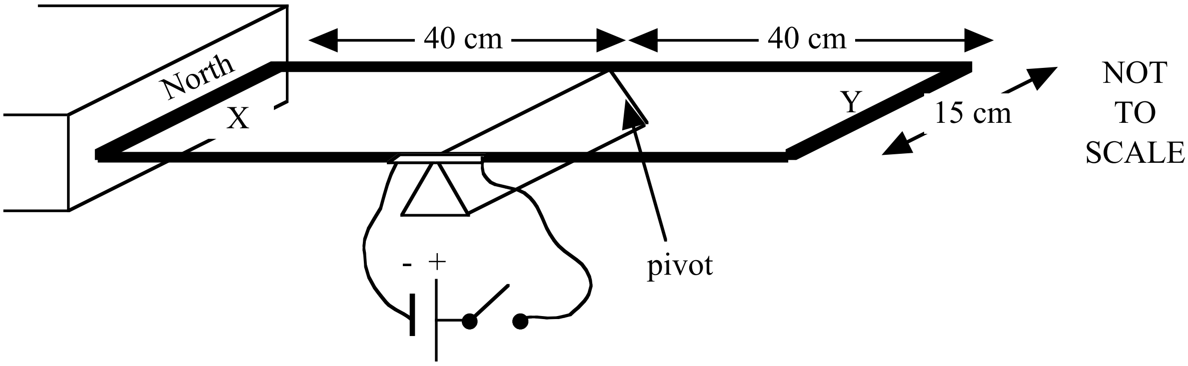
Question 10

A rectangular wire loop is connected to a DC power supply. Side X of the loop is placed next to a magnet. The loop is free to rotate about a pivot.



When the power is switched on a current of 30 A is supplied to the loop. To prevent rotation, a mass of 50 g can be attached to either side X or side Y of the loop.

a) On the diagram indicate where the mass should be placed to prevent rotation and determine the torque provided by the 50 g mass.

b) Calculate the flux density around side X.

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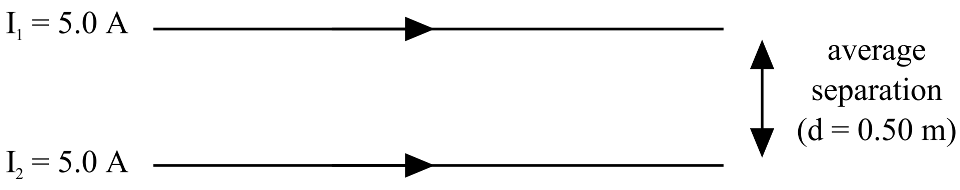
Question 11

A physics student wanted to investigate the forces of attraction (F) between two parallel current-carrying conductors carrying currents I_1 and I_2 (also known as Ampere's Law) as shown by the diagram and equation below.



$$\text{Ampere's Law - } \frac{F}{l} = \frac{\mu_o}{2\pi}\frac{I_1 I_2}{r}$$

μ_o = magnetic permeability constant
l = common length of conductors

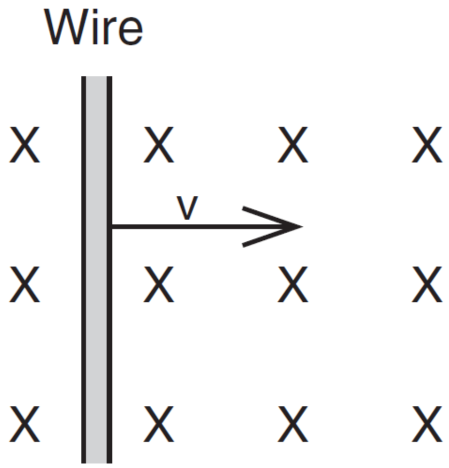
The student noticed that as the length (l) of the parallel conductors was increased the force of attraction (F) between the conductors also increased. Their data is shown in the table below.

Length (m)	*Force between conductors ($\times 10^{-6}$ N)*
1.00	9.0
1.20	10.8
1.40	12.5
1.60	14.2
1.80	16.2

a) Plot the force and length values from the table and draw the line of best fit.
b) Determine the slope of the line of best fit.
c) Use the slope calculated in (b) above and the Ampere's Law equation to determine the experimental value of the magnetic permeability constant μ_o.

Question 12

A metal conductor is moving at velocity v through a magnetic field as shown.



Magnetic field directed into page

a) Describe the structure of a metal at an atomic scale.
b) Explain why the cations in the metal will experience a force as the conductor is moved AND explain why the cations remain in position despite this force.
c) Explain why delocalised valence electrons will experience a force as the conductor is moved through the magnetic field and will move as a result of that force.
d) As a result of the force, explain which end of the conductor will become negatively charged.
e) Is there any way to change the size of the electric field produced across the ends of the conductor? Explain your answer.
f) The ends of the conductor are now joined by a wire that is external to the magnetic field. Explain the direction of the resulting induced conventional current that flows through the conductor.
g) As a result of the induced current, the conductor will now experience a force. In what direction will the force on the current due to the induced current be?
h) Why can't the current be induced in the opposite direction?
i) Identify where Faraday's law and Lenz's law applied in this situation.

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Question 13

a) Draw a labelled diagram of a step down transformer showing all the essential features.
b) Explain how two features of the transformer you have labelled decrease energy loss.

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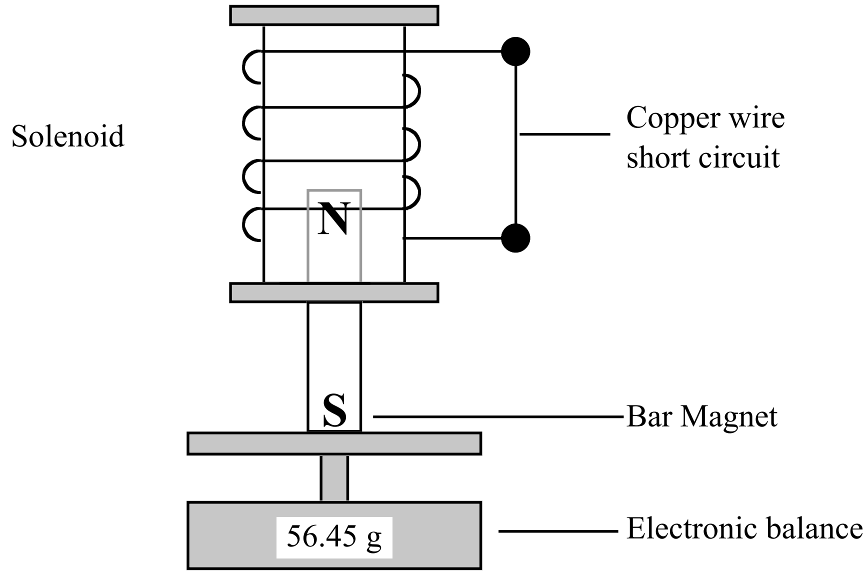
Question 14

A bar magnet is placed on a sensitive electronic balance as shown in the diagram. A hollow solenoid is held stationary, such that the magnet is partly within the solenoid. The solenoid is then lifted straight up without touching the magnet. The reading on the balance is observed to change briefly.



a) Why does a current flow in the solenoid?

b) Explain the reason for changes in the reading of the electronic balance as the solenoid is removed.

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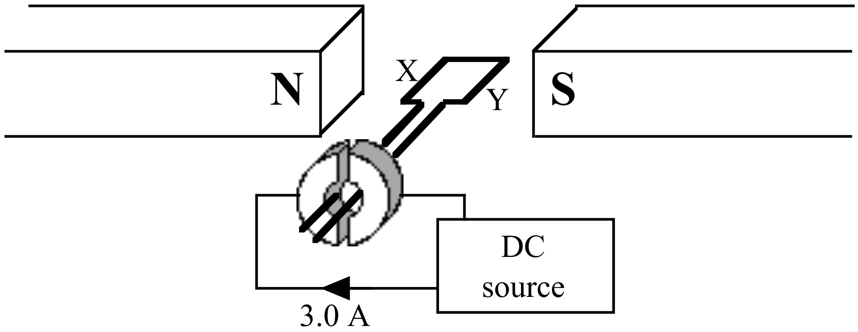
Question 15

A square loop of wire is placed in a uniform magnetic field of 0.10 T as shown.
The loop is free to rotate, and has a current of 3.0 A supplied to it though a split ring commutator. The sides of the loop are each 20 cm long.



a) What force exists between sides X and Y of the loop?
b) What is the force exerted on side Y of the loop due to the magnetic field?
c) Compare the torque on the loop in the position shown to the torque on the loop when it has completed a quarter revolution. Explain your answer.

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Question 16

The photographs show the readings on a multimeter correctly attached to a DC electric motor while it is connected to an 4.0 V DC power supply. In one of the photos, the DC motor is being allowed to turn without any load being attached to it. In the other photo, the axle of the motor is being prevented from turning while it is still attached to the power supply.

Photo X

Photo Y

a) Which of the photos shows the readings on the multimeter when there is no load being applied to the motor? Justify your answer.
b) Calculate the resistance of the coils of the motor.
c) Explain the difference in the readings shown on the multimeters in the photographs.
d) Explain how this situation is related to the law of conservation of energy.

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Sample Answers

Question 1

a) Vertically $u = 40\sin 60 \text{ m s}^{-1}$, $a = -9.8 \text{ m s}^{-2}$, $v = 0 \text{ m s}^{-1}$, $s = ?$

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

$$\therefore s = \frac{v^2 - u^2}{2a} = \frac{(0 \text{ m s}^{-1})^2 - (40.0\sin 60 \text{ m s}^{-1})^2}{2 \text{ x } -9.8 \text{ m s}^{-2}} = 61 \text{ m}$$

So, height above sea level = 120 m + 61 m = 180 m

b) Vertically when object hits surface of sea

$u = 40\sin 60 \text{ m s}^{-1}$, $a = -9.8 \text{ m s}^{-2}$, $s = -120 \text{ m}$, $t = ?$

$$\therefore -120 = 40.0\sin 60t - 4.9t^2$$

i.e. $-4.9t^2 + 40.0\sin 60t + 120 = 0$

$$\therefore t = \frac{-40.0\sin 60 \pm \sqrt{(40.0\sin 60)^2 - 4 \text{ x } -4.9 \text{ x} 120}}{-9.8}$$

$t = 9.6$ s (other answer is -2.6 s).

c) Horizontally $V_{av} = 40.0\cos 60 \text{ m s}^{-1}$, $t = 9.6$ s, $s = ?$

$$V_{av} = \frac{s}{t} \qquad \therefore s = V_{av} \text{ x } t = 40.0\cos 60 \text{ m s}^{-1} \text{ x } 9.6 \text{ s} = 190 \text{ m}$$

d) Vertically $u = 40.0\sin 60 \text{ m s}^{-1}$, $a = -9.8 \text{ m s}^{-2}$, $s = -120 \text{ m}$, $v = ?$

$$v^2 = u^2 + 2as \qquad \therefore v = \pm\sqrt{u^2 + 2as} = \pm\sqrt{(40.0\sin 60)^2 + 2 \text{ x } -9.8 \text{ x } -120} = \pm 60 \text{ m s}^{-1}$$

Must be -60 m s^{-1}, as heading vertically down when enters sea.

Horizontally $V_{av} = 40.0\cos 60 \text{ m s}^{-1}$

Velocity on entering sea

$$V = \sqrt{(-60)^2 + (40.0\cos 60)^2} = 63 \text{ m s}^{-1}$$

$$\tan\theta = \frac{60}{40.0\cos 60} \qquad \therefore \theta = 72°$$

Object enters sea at 63 m s^{-1} at 72° below horizontal.

Question 2

Horizontally $V_{av} = V\cos 60 = \frac{V}{2}$, s = 45, t = ?

$$V_{av} = \frac{s}{t} \qquad \therefore t = \frac{s}{V_{av}} = \frac{45}{\frac{V}{2}} = \frac{90}{V}$$

Vertically s = 34, a = –9.8, $u = V\sin 60 = \frac{\sqrt{3}V}{2}$, $t = \frac{90}{V}$

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

$$34 = \frac{\sqrt{3}V}{2} \text{ x } \frac{90}{V} - 4.9 \text{ x } \left(\frac{90}{V}\right)^2$$

$$34 = 45\sqrt{3} - \frac{39690}{V^2}$$

$$V = 30 \text{ m s}^{-1}$$

Question 3

a) $v_{inst} = \frac{\text{distance covered}}{\text{time}} = \frac{10 \text{ x } 2\pi \text{ x } 1.32 \text{ m}}{5.84 \text{ s}} = 14.2 \text{ m s}^{-1}$ AATTTCP

b) $a_c = \frac{v^2}{r} = \frac{(14.2 \text{ m s}^{-1})^2}{1.32 \text{ m}} = 153 \text{ m s}^{-2}$ TTCOTCP

c) $F_c = ma_c = 0.0200 \text{ kg x } 153 \text{ m s}^{-2} = 3.06 \text{ N}$ TTCOTCP

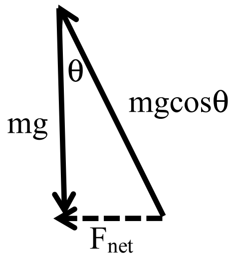
d) The tension in the string.

e) If hanging mass is stationary, then it has zero acceleration.
Hence, centripetal force acting on 20.0 g mass must also be the Tension in the string, which must also be equal to the weight of the hanging mass.

$$\text{Weight} = mg = 3.06 \text{ N} \qquad \therefore m = \frac{3.06 \text{ N}}{9.8 \text{ N kg}^{-1}} = 0.31 \text{ kg}$$

Question 4

a)



b) For no friction, all F_{net} is resultant of normal reaction force and gravity.

F_{net} is the centripetal force moving car in circular path.

$$\tan\theta = \frac{F_{net}}{mg} = \frac{\frac{mv^2}{r}}{mg} = \frac{v^2}{rg} = \frac{(3.0\ \text{m s}^{-1})^2}{3.0\ \text{m x } 9.8\ \text{m s}^{-2}} = 0.31 \qquad \therefore \theta = 17°$$

Question 5

For a satellite of mass m, exhibiting (almost) uniform circular motion, $F_c = \frac{mv^2}{r}$.

For the satellite, this force is provided by the gravitational field of the planet of mass M.

$\therefore \frac{mv^2}{r} = \frac{GmM}{r^2}$ From this result, the orbital velocity can be calculated. $v = \sqrt{\frac{GM}{r}}$

Also, since $v = \frac{2\pi r}{T}$, this value can be substituted into the equivalence between centripetal and gravitational force.

$\therefore \frac{m\left(\frac{2\pi r}{T}\right)^2}{r} = \frac{GmM}{r^2}$. This can be rearranged to give $\frac{r^3}{T^2} = \frac{GM}{4\pi^2}$ which is Kepler's Law.

Hence, Newton's law of universal gravitation can be used to provide valuable information about the motion of satellites, including the orbital velocity, period and radius of their orbits.

Note: - this is the answer to a 4 mark question. If more marks given, could elaborate on answer to include escape velocity, gravitational potential energy, etc.

Question 6

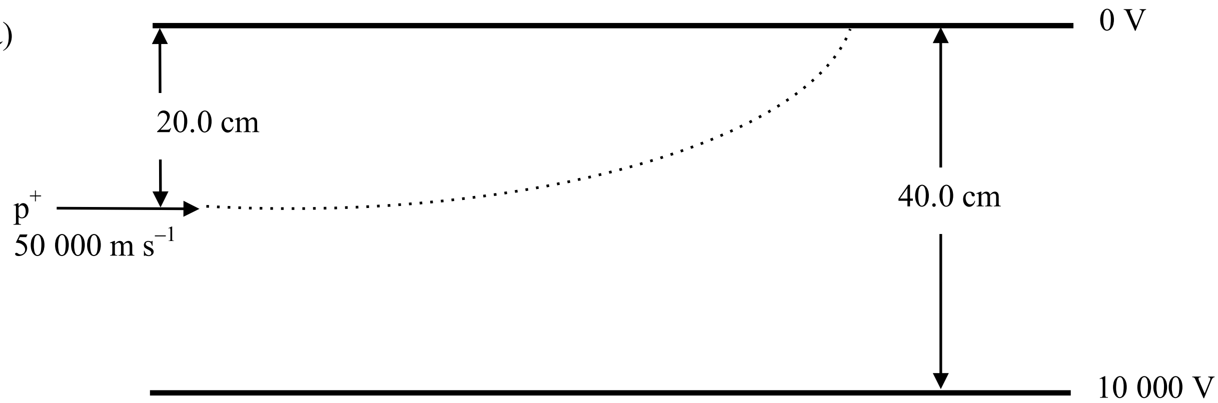
a) $v = \frac{2\pi r}{T} = \frac{2\pi \text{ x } 1.07 \text{ x } 10^9 \text{ m}}{171 \text{ x } 3600 \text{ s}} = 10900 \text{ m s}^{-1}$

b) $v = \sqrt{\frac{GM}{r}}$ $\quad \therefore M = \frac{v^2 r}{G} = \frac{(10921 \text{ m s}^{-1})^2 \text{ x } 1.07 \text{ x } 10^9 \text{ m}}{6.67 \text{ x } 10^{-11} \text{ N m}^2 \text{ kg}^{-2}} = 1.91 \text{ x } 10^{27} \text{ kg}$

c) $g = \frac{GM}{r^2} = \frac{6.67 \text{ x } 10^{-11} \text{ N m}^2 \text{ kg}^{-2} \text{ x } 1.48 \text{ x } 10^{23} \text{ kg}}{(2.634 \text{ x } 10^6 \text{ m})^2} = 1.42 \text{ m s}^{-2}$

Question 7

a)



Electric field acts in a direction from the positive plate to the negative plate. In original direction of travel, no force exists, so displacement is directly proportional to time. However, proton will be accelerated toward negative plate, and so displacement in that direction will be proportional to the square of time. Combining these two motions produces a parabolic path.

b) $E = \frac{F}{q} = \frac{V}{d}$ $\quad \therefore F = \frac{qV}{d} = \frac{1.602 \times 10^{-19} \times 10000}{0.400} = 4.01 \times 10^{-15} \text{ N}$

c) $a = \frac{F}{m} = \frac{4.01 \times 10^{-15}}{1.673 \times 10^{-27}} = 2.39 \times 10^{12} \text{ m s}^{-2}$ toward negative plate

d) "Vertically" $a = 2.39 \times 10^{12} \text{ m s}^{-2}$, $u = 0 \text{ m s}^{-1}$, $s = 0.200$ m, $t = ?$

$s = ut + \tfrac{1}{2}at^2 \qquad \therefore t = \sqrt{\frac{2s}{a}} = \sqrt{\frac{2 \times 0.200}{2.39 \times 10^{12}}} = 4.09 \times 10^{-7} \text{ s}$

"Horizontally" $V_{av} = 50\,000 \text{ m s}^{-1}$, $t = 4.09 \times 10^{-7}$ s, $s = ?$

$V_{av} = \frac{s}{t} \qquad \therefore s = V_{av} \times t = 50000 \times 4.09 \times 10^{-7} = 0.0205 \text{ m}$

Question 8

a) To pass through the crossed fields undeflected, the net force acting on the charged particles must be zero. Hence, the force due to the electric field must be equal in magnitude but opposite in direction to the force due to the magnetic field.

I.e. $\Sigma F = ma = 0 = F_{electric} - F_{magnetic}$

$\therefore F_{electric} = F_{magnetic} \qquad \therefore qE = qvB \qquad \therefore v = \frac{E}{B}$

b) Since $v = \frac{E}{B} = \frac{V}{Bd} \qquad \therefore V = Bdv = 2.0 \times 10^{-3} \times 0.050 \times 2.5 \times 10^{7} = 2500\ \text{V}$

c) The velocity of undeflected particles does not depend on either the magnitude OR the sign of the charge. Hence, no modification would need to be made.

Question 9

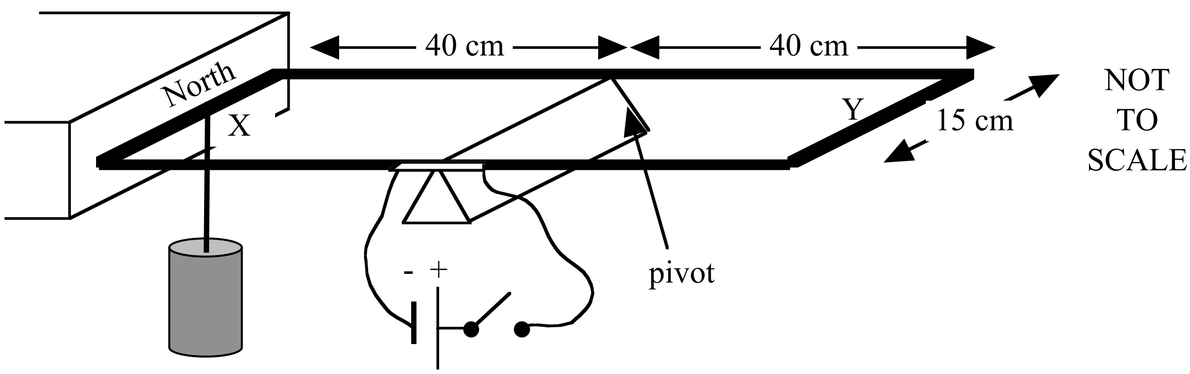
a) $\frac{mv^2}{r} = qvB\sin\theta \qquad \therefore m = \frac{qBr\sin\theta}{v} = \frac{1.602 \times 10^{-19} \times 0.200 \times 0.196}{1.719 \times 10^{5}} = 3.65 \times 10^{-26}\ \text{kg}$

b) Atomic mass $= \frac{3.65 \times 10^{-26}\ \text{kg}}{1.661 \times 10^{-27}\ \text{kg amu}^{-1}} = 22.0\ \text{amu}$

Sample is Group 1 metal, then most likely to be sodium (Atomic mass = 22.99 amu).

Question 10

a)



Mass needs to be hung from left hand end of current balance. Force on section X due to magnetic field is directed upward, so mass has to provide a force downward.

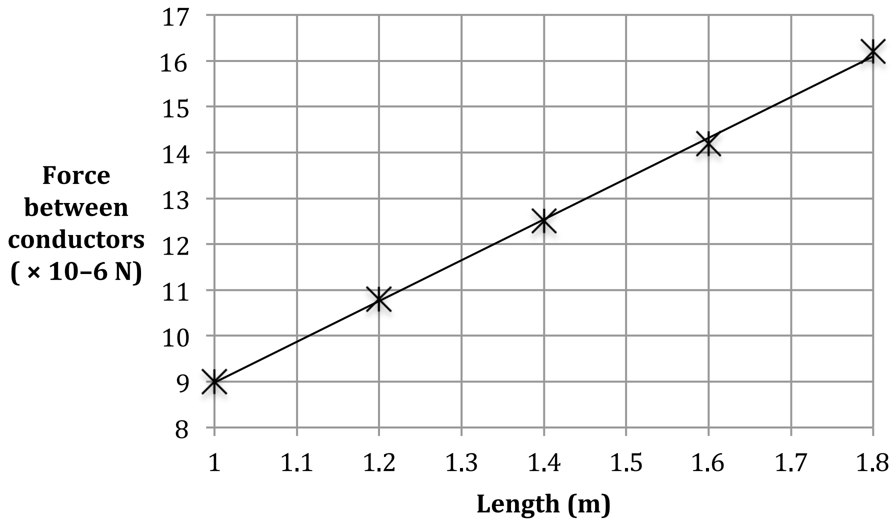
$\tau = Fr = mgr = 0.050\ \text{kg} \times 9.8\ \text{N kg}^{-1} \times 0.40\ \text{m} = 0.20\ \text{N m down}$

b) Since there is no rotation, $F_{mag} = F_{grav}$

$mg = BIl \qquad \therefore B = \frac{mg}{Il} = \frac{9.8\ \text{N kg}^{-1} \times 0.050\ \text{kg}}{30\ \text{A} \times 0.15\ \text{m}} = 0.11\ \text{T to the right}$

Question 11

a)



b) From graph, LOBF appears to go through two of the data points. Will use them to determine gradient. Graph could also be extrapolated to go through (0,0).

$$\text{Gradient} = \frac{\text{rise}}{\text{run}} = \frac{(12.5\times10^{-6} - 9.0\times10^{-6})\ \text{N}}{(1.40-1.00)\ \text{m}} = 8.8\times10^{-6}\ \text{N m}^{-1}$$

c) From Ampere's law, $\therefore F = \left(\frac{\upsilon_o}{2\pi}\frac{I_1I_2}{r}\right)l$ Hence, graph plotted above is of the form

$F = ml$. Gradient of graph is $\frac{\upsilon_o}{2\pi}\frac{I_1I_2}{r} = 8.8\times10^{-6}\ \text{N m}^{-1}$

$$\therefore \upsilon_o = \frac{2\pi r\times 8.8\times10^{-6}\ \text{N m}^{-1}}{I_1I_2} = \frac{2\pi\times0.50\ \text{m}\times8.8\times10^{-6}\ \text{N m}^{-1}}{5.0\ \text{A}\times5.0\ \text{A}} = 1.1\times10^{-6}\ \text{N A}^{-2}$$

Actual value is $4\pi\times10^{-7}\ \text{N A}^{-2} = 1.3\times10^{-6}\ \text{N A}^{-2}$

Question 12

a) At an atomic scale, the outer (valence) electron shells of metal atoms overlap. In metals, valence electrons are not bound strongly to an individual atom. Instead, through the overlap between valence electron orbits, electrons readily transfer between metal atoms. Hence, a metal can be thought of as metal cations, locked in a crystal lattice, in a sea of delocalised valence electrons.

b) As the conductor is moved to the right, each cation can be thought of as conventional current, moving to the right, in a magnetic field. Using the right hand rule, they will experience a force toward the top end of the conductor. However, the force they experience is not enough to break the metallic bonds in the metallic lattice and so the cations do not move.

c) Since the electrons can move freely through the metal structure, when the conductor moves to the right, each delocalised valence electron can also be considered to be moving to the right and so can be thought of as a conventional current moving to the left. Applying the right hand rule, the delocalised valence electrons, which are free to move, will experience a force toward the bottom end of the conductor and hence will move in that direction.

d) The bottom end of the conductor will attain a negative charge relative to the top end, as there will be a higher concentration of electrons at the bottom end of the conductor compared to the top end.

e) There will come a time when, at a particular speed that the conductor is moved through the field, the force on the electrons due to the motor effect pushing them toward the bottom of the conductor will be balanced by the electrostatic repulsion of the negatively charged end of the conductor. Hence, the size of the electric field between the top and bottom end of the conductor will not change any further. However, if the speed of the conductor through the magnetic field is changed, then the force acting on the electrons will also change (effectively have changed the magnitude of the current to the left as the conductor moves to the right in the magnetic field). The faster the conductor moves, the bigger the force and so more electrons will be forced to the bottom end of the conductor. This will create a larger electric field between the top and bottom of the conductor.

f) When the ends of the conductor are connected externally, then the electrons can leave through the bottom negative terminal, travel through the external wire (where they don't experience a force due to the magnetic field) due to the electric field between the top positive terminal and the bottom negative terminal, and re-enter the conductor through the top terminal. They now experience a force due to the magnetic field, moving them through the conductor from top to bottom. Since electrons are moving downward through the conductor, the induced conventional current is moving up through the conductor, out the top positive terminal, through the external circuit from the positive terminal to the negative terminal, and then back up through the conductor.

g) Using right hand rule, conventional current (induced) through the conductor is up, magnetic field is into page, so conductor will experience a force to the left (i.e. in a direction opposing the direction it is moving).

h) If the current was induced in the opposite direction, force would be to the right on the conductor. This would increase its speed, causing a bigger current to be induced, increasing force, and hence speed, etc. The increase in kinetic energy of the conductor would violate the law of conservation of energy as no work is being done to produce the energy.

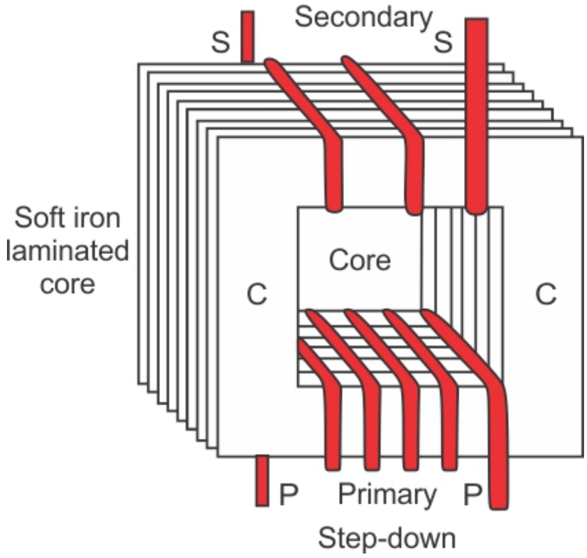
Instead, with conventional current induced the way it actually occurs, work has to be done on the conductor to keep it moving through the field to continue to produce electrical energy. I.e. we are converting one form of energy to another, not creating energy from nothing as would happen if the current was induced in the opposite direction.

i) Faraday's Law applied when the conductor was moving relative to the magnetic field. This caused an emf to be induced across the ends of the conductor due to movement of electrons to bottom end of conductor.

Lenz's Law applied as the direction of the induced emf created a current that was in a direction to produce a magnetic field that interacted with the external magnetic field in a way that a force was applied to the conductor in a direction that opposed the original motion that produced the emf.

Question 13

a)



b) To try to achieve complete flux linkage between the primary and secondary coil so minimal energy is lost, the coils are placed in close proximity to each other and a soft iron core is used for maximum flux linkage. However, using a solid iron core would mean that eddy currents of considerable magnitude would be induced in it as it is a conductor in a changing magnetic field. To limit the production of induced eddy currents in the iron core, it is constructed from many very thin laminations that are electrically insulated from each other. The very thin nature of each soft iron lamination prevents large eddy currents from forming but still allows the magnetic effect of the soft iron core to maximise flux linkage between the coils.

Question 14

a) As the solenoid is lifted, it is moving relative to the magnetic field of the bar magnet and so its coils are cutting through lines of flux. An emf will be induced across the solenoid (Faraday's Law). Since the ends of the solenoid are connected by the copper wire short circuit, a current will flow in the solenoid.

b) The direction of the current induced in the solenoid will be such that a magnetic field will be produced that attempts to oppose the motion producing the emf initially. I.e., a south pole will be induced at the lower end of the solenoid. This will apply a force upward on the bar magnet, reducing the reading on the balance as the net force is reduced. If the solenoid is totally removed, no upward magnetic force will be acting on the bar magnet and so the balance will return to the reading of 56.45 g.

Question 15

a) $\frac{F}{l} = \frac{\upsilon_o}{2\pi}\frac{I_1 I_2}{r}$

$$\therefore F = \frac{4\pi \times 10^{-7}\ \text{N A}^{-2} \times 3.0\ \text{A} \times 3.0\ \text{A} \times 0.20\ \text{m}}{2\pi \times 0.20\ \text{m}} = 1.8 \times 10^{-6}\ \text{N repulsive}$$

b) $F = BIl\sin\theta = 0.10\ \text{N A}^{-1}\ \text{m}^{-1} \times 3.0\ \text{A} \times 0.20\ \text{m} \times \sin 90 = 0.060\ \text{N down}$

c) In the position shown, torque is maximised since the force is acting perpendicular to the coil.

$$\tau = nBIA\sin\theta = 1 \times 0.10\ \text{N A}^{-1}\ \text{m}^{-1} \times 3.0\ \text{A} \times (0.20\ \text{m})^2 \times \sin 90 = 0.012\ \text{N m}$$

After one quarter revolution, force acting on side X will still be vertically down. However, angle the force makes to the coil will now be zero, so no component of the force will be contributing to the torque. Hence, torque, after one quarter revolution, will be zero.

Question 16

a) Photo X shows the current drawn by the motor when no load is placed on it. As the coil of the motor turns in the magnetic field it is inducing a back emf across the turns of the motor coil, reducing the net voltage across the coils. Hence, for the fixed resistance of the coil, there is less overall current running through it.

b) Using the data from photo Y, $V = IR \quad \therefore I = \frac{V}{R} = \frac{4.0\ \text{V}}{4.17\ \text{V A}^{-1}} = 0.96\ \text{A}$

c) When the coil is prevented from turning, no back emf is induced and so the full 4.0 V of the supply emf is across the resistance of the coil, increasing the current drawn, so a higher reading is shown than when there is no load on the motor.

d) If the emf induced in the coil had been in the same direction as the supply emf, then the net voltage across the coil would have been higher than 4.17 V. Hence, a larger current than 0.96 A would have flowed. This would increase the torque of the motor, causing it to spin faster. This would have induced a larger emf again, increasing the current, etc. So, the motor would gain more and more mechanical energy without any further input of electrical energy. This violates the principle of conservation of energy, which states that energy cannot be created or destroyed, but can be converted from one form into another.