Question 1:

i) Lines radially outward from central charge
   The number of lines coming out of centre charge is twice that going into either of the others
   (i.e. if the central charge has ten lines, each of the negative ones will have five)
   Lines radially into the negative charges

ii) The equipotentials are perpendicular to the field lines at all points
    The equipotentials are more tightly packed where the field lines are more tightly packed

iii) The horizontal components of force from the left hand and right hand charges on the test charge cancel one another out – so we need to only consider the vertical components of the force on our test charge (i.e. the force in the y-direction). However the students show this (either by stating it, or working it out):

\[ F_{\text{net}} = F_+ + 2F_{-\text{vert}} \]

i.e. the net force is the force from the +ve charge +2 x the vertical force from one of the negative charges.

Vertical force due to the positive charge (the one with +0.20 C), \( F_+ \) is given by
\[ F_+ = \frac{q_+q_0}{4\pi\varepsilon_0 r^2} = \frac{0.2 \times 0.1 \times 10^{-9}}{4\pi\varepsilon_0 \times (0.05)^2} = 71.902 \text{ N} \]

The vertical force due to one of the negative charges, \( F_{-\text{vert}} \) is given by:
\[ F_{-\text{vert}} = \frac{q-q_0}{4\pi\varepsilon_0 r^2} \sin \theta \]
where \( \tan \theta = \frac{y}{x} = \frac{1}{2} \), giving \( \sin \theta = 0.447 \), therefore
\[ F_{-\text{vert}} = \frac{q-q_0}{8\pi\varepsilon_0 r^2} = \frac{0.1 \times 0.1 \times 10^{-9}}{8\pi\varepsilon_0 \times (0.1^2 + 0.05^2)} = -3.2140 \text{ N} \]

Therefore
\[ F_{\text{net}} = F_+ + 2F_{-\text{vert}} = 71.902 - (2 \times 3.2140) = 65.5 \text{ N} \], in the +y-direction.
Question 2:

a) i) The net flux through any closed surface surrounding a charge $q$ is given by $\frac{q}{\epsilon_0}$, and is independent of the shape of that surface.

ii) $\Phi_E = \oint E \cdot dA = \frac{q_{\text{in}}}{\epsilon_0}$

b) i) Using Gauss' law, determine how the electric field varies as a function of distance from the centre of the solid sphere.

Exterior to the outer shell, the total enclosed charge = 0, and so therefore $\Phi E \cdot dA = 0$, and therefore $E_{r>c} = 0$

Between $r = b$ and $r = c$, we're in the interior of a conductor that is in equilibrium, so again, $E = 0$. Therefore:

$E_{r>b} = 0$

Between $r = a$ and $r = b$, the total enclosed charge = $Q$. Therefore $\Phi E \cdot dA = \frac{Q}{\epsilon_0}$

To determine $dA$, choose a Gaussian sphere. Therefore $\Phi E \cdot dA = E \cdot (4\pi r^2) = \frac{Q}{\epsilon_0}$

Therefore:

$E_{a<r<b} = \frac{Q}{4\pi\epsilon_0 r^2}$

Interior to $r = a$, the amount of charge $\rho$ depends on the volume of the sphere interior to $a$, multiplied by the volume charge density of the solid sphere, $\rho$.

Thus $q_{\text{in}} = \rho V_{\text{in}} = \frac{4}{3} \pi \rho r^3$, where $\rho = \frac{Q}{(\frac{4}{3}\pi a^3)}$

To calculate $E$, again choose a Gaussian sphere. Therefore $\Phi E \cdot dA = E \cdot (4\pi r^2) = \frac{q_{\text{in}}}{\epsilon_0} = \frac{4\pi \rho r^3}{3\epsilon_0}$

Thus $E_{r<a} = \frac{\rho r}{3\epsilon_0}$, and subbing in for $\rho$ gives us:

$E_{r<a} = \frac{Qr}{4\pi\epsilon_0 a^3}$
ii) Sketch the variation of the electric field as a function of radius

![Electric Field Diagram]

**Question 3:**

a) \[ \Delta V = - \int_{a}^{b} E \cdot ds \], and as the field is constant, this becomes \[ \Delta V = -E \int_{a}^{b} ds = -E (b - a) \]

Thus: \[ \Delta V = -Ed \], i.e. \[ E = \frac{\Delta V}{d} \]

Therefore \[ |E| = \frac{240}{0.0500} = 4800 \text{ V/m} \]

b) To pass through without being deflected, the electric force, \( F_E \) and the magnetic force \( F_B \) should be equal and opposite, so that the net force on the ions equals zero.

Therefore \[ F_{net} = 0 = qE + qv \times B \]

Rearranging to get \( v \) gives:

\[ v = \frac{E}{B} \]

Plugging in the numbers:

\[ v = \frac{4800}{0.284} = 16.9 \times 10^4 \text{ m/s} = 16.9 \text{ km/s} \]

c) After leaving the velocity selector, the ions are accelerated by the magnetic field, with that field providing a centripetal force. They therefore follow a circular path before impacting the detector, as shown in the figure.
Equating the magnetic force to the centripetal force gives us:

\[
F_B = F_c \rightarrow qvB = \frac{mv^2}{r} \rightarrow r = \frac{mv}{qB}
\]

Since \( v, q \) and \( B \) are constant, radius of the path followed by an ion is proportional to its mass. Therefore, the most massive species (in this case Benzene, of mass 78 amu) will hit the detector furthest from the velocity selector (peak C), whilst the least massive (water, mass 18 amu) will hit closest to the selector (peak A), with the remaining species (Ethanol, mass 34 amu) in between (peak B).

d) From before: \( r = \frac{mv}{qB} \)

The ions hit the detector screen a distance of twice this radius from where they leave the velocity selector.

The mass of normal water is 18 amu, and is therefore \( 18 \times 1.66 \times 10^{-27} \text{ kg} = 2.988 \times 10^{-26} \text{ kg} \)

The mass of deuterated water is 19 amu, and is therefore \( 19 \times 1.66 \times 10^{-27} \text{ kg} = 3.154 \times 10^{-26} \text{ kg} \)

The charge on the ions is \( 1.602 \times 10^{-19} \text{ C} \), and their velocity is \( 1.69 \times 10^4 \text{ m/s} \), with \( B = 0.284 \text{ T} \)

The separation between their peaks is

\[
\Delta r = 2r_{\text{HDO}} - 2r_{\text{H.2O}} = \frac{2v(m_{\text{HDO}}-m_{\text{H2O}})}{qB}
\]

Substituting in the numbers:

\[
\Delta r = \frac{2 \times 1.69 \times 10^4 (3.154 \times 10^{-26} - 2.988 \times 10^{-26})}{1.6 \times 10^{-19} \times 0.284} = 1.23 \times 10^{-3} \text{ m} = 1.23 \text{ mm}
\]

Question 4:

a) The electrons experience a force to the right.

The right hand rule gives the direction of the force on a proton. You point your fingers in the direction of the velocity, curve them in the direction of the field, and your thumb gives the direction of the force on a proton. The force on the electron would be directly opposite this (i.e. 180 degrees different).

Sketch or description of right hand rule, as described above. This would be fine for the mark:
b) **Counter clockwise**

ii) **Direction of current**

\[
\begin{align*}
\text{Velocity} & \quad F_B \\
\text{F}_{\text{App}}
\end{align*}
\]

iii) The motional emf is: 
\[ \epsilon = -Blv \]

Since \( = IR \), we can say 
\[ l = \frac{v}{R} = \frac{|v|}{R} = \frac{Blv}{R} \]

Therefore, subbing numbers in: 
\[ l = \frac{0.50 \times 1.5 \times 8.0}{3.5} = 1.7 \text{ A} \]

iv) There is no acceleration, and so therefore the net force on the bar is zero. In other words, the magnitude of the applied force must equal the magnitude of the magnetic force.

Thus \( F_{\text{app}} = BlI \)

Therefore, subbing numbers in: 
\[ F_{\text{app}} = 0.50 \times 1.7 \times 1.5 = 1.275 \text{ N} = 1.3 \text{ N} \]