(only 2+4 are to be done) A2 – Physics

Charged particles in both electric and magnetic fields

One particular use of the combination of the two fields is in a device called a **velocity selector**. For this device the two fields are arranged at right angles to one another as shown in Figure 3.

The pink circle is a region of magnetic field of flux density B down into the page. In the space between the pair of plates, there is an electric field of field strength E from top to bottom, shown in green. A positively charged particle, with charge Q and shown in red, enters the two fields with velocity v. The force the electric field exerts on the particle will be QE downwards. The force the magnetic field exerts on the particle, found using Fleming's left-hand rule, will be BQv upwards.

Any particle that is undeflected from its straight line path through the fields has zero resultant (net) force acting on it, and therefore $QE = BQv$. Q cancels to give $E = Bv$ or $v = E/B$.

The fact that Q cancels out implies that any charged particle, positive or negative, passing undeflected through the space where both fields exist has a velocity equal to the ratio E/B of the fields. By measuring B and E the value of the velocity of the particle can be determined.

If the particles have a range of speeds when they enter the space where both fields exist, the force due to the electric field will be the same for all particles with the same charge. The force due to the magnetic field will increase with the speed of the particles. Slow particles have a smaller force exerted on them by the magnetic field. QE will be greater than BQv, so the slow particles will be deflected downwards by the fields. On the other hand, a fast particle will have a larger force exerted on it by the magnetic field than by the electric field, so it will be deflected upwards. The result of this is shown in Figure 4.

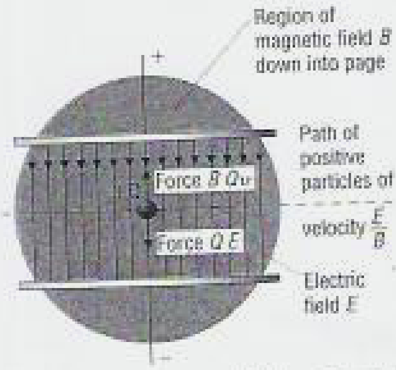

Figure 3 A positive particle travelling in a vacuum and acted upon by both an electric and a magnetic field

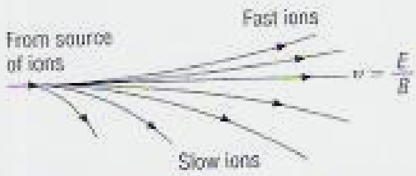

Figure 4 Particles of varying speeds travelling through a velocity selector

Questions

1 Here are three possible paths of an electron in a vacuum: A straight line, B circular path, C parabolic path. Which path best describes the motion of an electron initially moving:
   (a) at right angles to a magnetic field, **(b)** at right angles to an electric field and **(c)** parallel to a magnetic field?

✓ 2 (a) Calculate the magnitude of the force on an electron moving at 2.0×10^{7} m s^{-1} as it enters a region of uniform magnetic field of flux density 5.0×10^{-3} T perpendicular to its path.
   (b) Calculate the acceleration of the electron and hence the radius of its orbit in the field.

3 Figure 5 shows a beam of protons passing through a hole into a region where there is a uniform electric field of strength E.
   (a) Copy the diagram and sketch on it a possible path for the protons.
   (b) A uniform magnetic field of flux density B is now applied at right angles (into the plane of the diagram), and the electric field is switched off. Sketch a possible path for the protons.
   (c) The electric field is switched on again. Explain why it is now possible for some of the protons to pass undeflected to the detector.

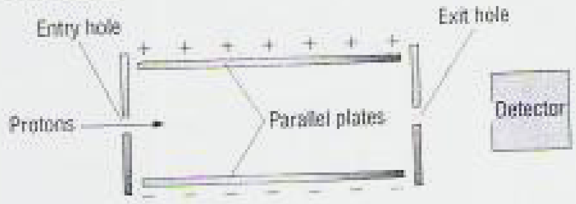

Figure 5

✓ 4 The fuel in nuclear fission reactors to generate electricity is $^{235}_{92}$U. In natural uranium over 99% is $^{238}_{92}$U and only 0.7% is $^{235}_{92}$U. In one 'separation process', each atom of natural uranium is combined with six atoms of fluorine to make the molecule UF_6. The molecules are ionised and, using a velocity selector, made into a beam of particles each with the same velocity.
   (a) Explain why the UF_6 ions of $^{238}_{92}$U have more momentum than those of $^{235}_{92}$U.
   (b) The ion beam passes through a region of uniform magnetic field directed at right angles to their velocity as shown in Figure 6 before being collected in a trap.
   The figure shows the path of the UF_6 ions of $^{235}_{92}$U. Copy the diagram and add the path of the UF_6 ions of $^{238}_{92}$U.
   (c) Hence explain how this device works as a separator. Why would UF_6 ions of $^{238}_{92}$U reach the collector if the apparatus was not kept under a good vacuum?

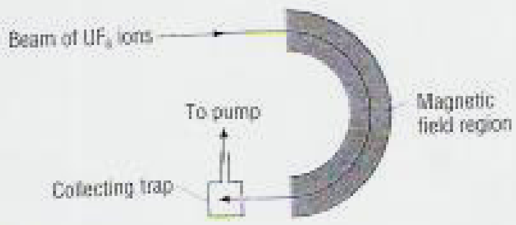

Figure 6