On Lorentz forces

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Warm-up problems

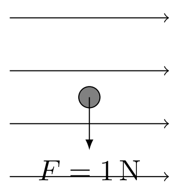
1. Draw a diagram to show Fleming's left hand rule to determine the direction of the force on a current carrying wire, making it clear what each digit (fingers and thumb) represents. What factors might increase the force on the wire?

2. Draw a diagram to show how a d.c. electric motor works, and use it to explain how the torque on the coil changes during rotation.

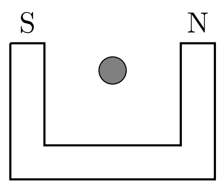
3. Write down the equation for the force on a charged particle moving perpendicular to the field lines of a magnetic field, and identify and explain the definition of the unit used to measure the magnetic flux density B.

Regular problems

4. In the following diagram, a uniform magnetic field of strength 2.5 T is directed toward the right, and a wire of length 10 cm lies perpendicular to the plane of the paper (shown in cross section) carrying electric current. The force on the wire is also shown, and has magnitude 1 N. What is the size and direction of the current?



5. The diagram shows a horseshoe magnet with its north and south poles marked. Between the poles is the cross section of a wire, carrying electric current towards us out of the plane of the paper.



   (a) Add to the diagram a few magnetic field lines showing the direction of the magnetic field (due to the magnet) near the wire.
   (b) Show the direction of the force acting on the wire under these circumstances and describe how you worked this out.
   (c) Does the magnet experience a force? If so, in what direction? If not, why not?

(d) Suppose the wire is rotated so that it lies in the plane of the paper, with the current going from left to right. What would be the direction of the force on the wire now?

(e) Suppose that you were told that a wire carrying a current into the plane of the paper experiences an upward force. What would you infer must be the direction of the magnetic field?

6. (a) What is the equation that gives the force F on an electron of charge e that enters perpendicularly a uniform magnetic field of magnetic flux density B at a velocity v?

   (b) What is the equation that gives the centripetal force F on a particle of mass m moving in a circle of radius r with a velocity v?

   (c) By equating these two, derive an equation that gives the radius of an electron's orbit in a magnetic field.

   (d) Show that the time taken for one orbit is

$$T = \frac{2\pi m}{Be}$$

   (e) If the speed of the electron changed to $2v$, what effect, if any, would this have on

      i. the orbital radius,

      ii. the orbital period?

7. Describe the paths of

   (a) a neutron,

   (b) a proton, and

   (c) an α particle,

   when each is directed at right angles to the same magnetic field and at the same velocity, stating quantitatively, where appropriate, any differences.

Extension problems

8. In a similar setup to that in question 5, 5 cm of wire is placed between the poles of a horseshoe magnet which is placed on a balance. When no current flows, the balance reads 272.0 g. When a current of 2 A flows, the reading on the balance is 274.0 g. Calculate the magnetic flux density between the poles of the magnet.

9. This question is about J.J. Thomson's experiment to determine the specific charge of the electron.

   (a) Thomson set up an electric field so that its force on the electrons exactly cancelled the magnetic force on them. Show that, in this case, the velocity of the electrons is given by the ratio of the electric field strength to the magnetic field strength, E/B.

   (b) Then, Thomson switched off the magnetic field, so that there is only an electric field. There is then no force in the x-direction and an electric force in the y-direction. Where have you seen such a situation before?

   (c) Show how Thomson could a measurement of the y-distance and x-distance travelled by the electron beam to determine the specific charge of an electron, e/m_e.

$$\left.\begin{array}{l} x(t) = \frac{E}{B}t \\ y(t) = \frac{eE}{2m_e}t^2 \end{array}\right\}$$