

Workshop Tutorials for Introductory Physics

Solutions to EI7: Magnetism

A. Review of Basic Ideas:

Magnets and magnetism.

In the same way that electrically charged objects produce an **electric** field, magnets produce a **magnetic** field. The force between two magnetic poles is similar to the force between electrically charged particles, the force **decreases** with the square of the distance between them, and like poles **repel** while opposite poles **attract**. However there is a difference - we can isolate negative charge, for example an electron, away from positive charges, but an isolated magnetic pole has never been observed. If you start with a bar magnet and cut it in half you will have **two** magnets, each with a north pole and a south pole. Each time you cut it in half you will still have pieces with a north and a south pole.

There is a relationship between **electricity** and magnetism, which was discovered by Hans Oersted in 1819. During a lecture demonstration he noticed that a wire carrying an electric current deflected the needle in a nearby compass. Not only are magnetic fields produced by permanent magnets, but they are also produced by moving charges, or **currents**.

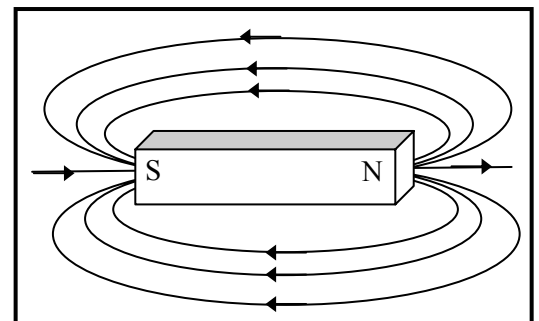
We define an electric field at a point as the electric **force** per unit charge on an appropriate test object at that point. The appropriate object is a small **positive** charge. We can define a magnetic field in the same way. The only difficulty is that magnetic **mono-poles** (a north pole without a south pole, or a south pole without a north pole) don't exist. So what we use as our test object is a current, in particular a moving positive test charge. Experiments have shown that the force on a moving charged particle in a magnetic field depends on the size of the charge and also on the **velocity** of the charge. Note that we use velocity and not speed, as **direction** is important. If the particle is moving parallel to the field it experiences no force, and it experiences the biggest force when it moves at right angles to the field. We can write this as $\mathbf{F} = q\mathbf{v}\mathbf{B}\sin\theta$, where \mathbf{F} is the force on the particle with charge, q , moving with velocity \mathbf{v} through a magnetic field of strength \mathbf{B} , and θ is the angle between the vectors \mathbf{v} and \mathbf{B} . This is the equation that defines magnetic field strength. The SI unit for B is the **tesla**, T, which is equivalent to $\text{N}\cdot\text{A}^{-1}\cdot\text{m}^{-1}$.

B. Activity Questions:

1. Magnets and magnetic fields

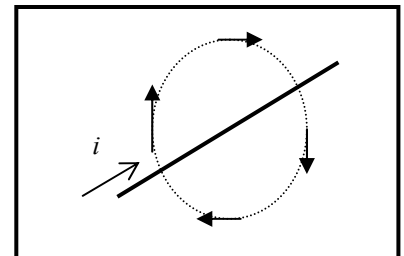
Magnetic field lines start at north poles and end at south poles.

The Earth's magnetic field is like that of a bar magnet, but the Earth's North Pole is in fact a magnetic *south* pole.

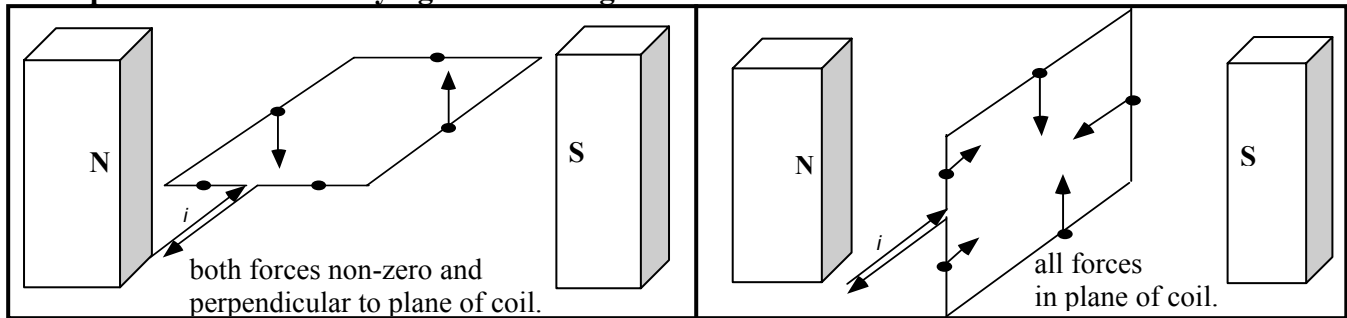


2. Magnetic field around a current carrying wire - Oersted's experiment

When you turn the current on the needles move and point along the magnetic field lines. When you change the direction of the currents the needles swing around to face the opposite way. The field lines form circles around the wire as shown. The direction of the field can be determined by pointing your right thumb in the direction of the current, then your fingers curl in the direction of the field lines.



3. Torque on a current carrying coil in a magnetic field



If held stationary prior to release, the loop on the left is more likely to start turning on its own.

C. Qualitative Questions:

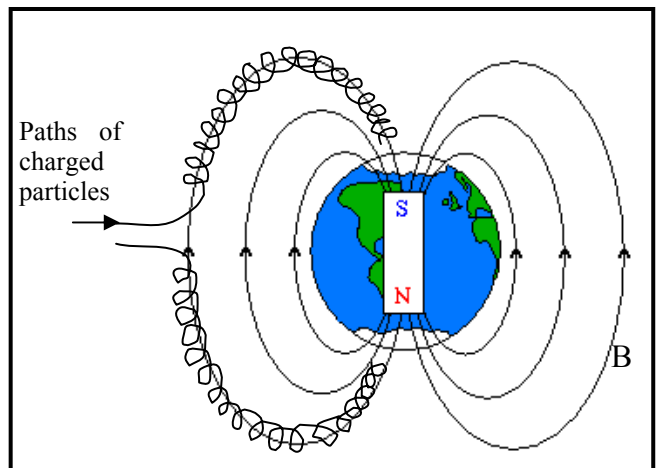
1. The Earth's magnetic field.

a. and b See diagram.

c. The auroras are caused by charged particles entering the earth's magnetic field where they follow a helical path along the field lines either north or south. The light observed as auroras is due to ionization of atoms in the atmosphere when they collide with high speed charged particles. The free electrons resulting from the collisions recombine with other atoms, losing energy in the process which is emitted as light.

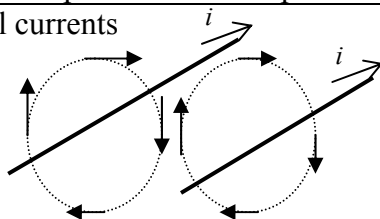
d. Near the poles the field lines are denser, hence the field is stronger. Charged particles tend to become trapped in these regions, hence are more likely to interact with air here and produce the auroras.

See anything strange about this picture? The Earth's North Pole, at the top, is actually the south pole of Earth's magnetic dipole! The north pole of a compass needle is attracted to the North Pole.



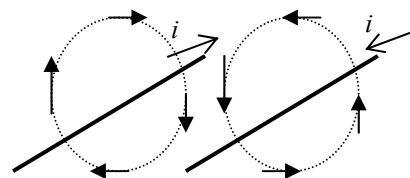
2. Field due to parallel and anti-parallel currents.

a. parallel currents



Fields reinforce each other above and below the blanket, and cancel between the wires.

opposite currents.



Fields tend to cancel each other above and below the blanket, and reinforce between the wires.

b. The wiring on the right gives a lower magnetic field above (and below) the blanket.

D. Quantitative Question:

a. The electron has gained 20 keV in kinetic energy, which is $20 \times 10^3 \times 1.6 \times 10^{19} \text{ J} = 3.2 \times 10^{-15} \text{ J}$.

b. Assuming it started from rest, we can find the velocity from $KE = \frac{1}{2} mv^2$, rearranged for v :

$$v = \sqrt{\frac{2KE}{m}} = \sqrt{\frac{2 \times 3.2 \times 10^{-15} \text{ J}}{9.11 \times 10^{-31} \text{ kg}}} = 8.4 \times 10^7 \text{ m.s}^{-1}.$$

(Note that we have not taken into account relativistic effects here which become important at this speed!)

c. The electron will be deflected out of the page.

d. The magnitude of the force on the electron is
 $F = qv \times B = 1.6 \times 10^{-19} \text{ C} \times 8.4 \times 10^7 \text{ m.s}^{-1} \times 300 \times 10^{-3} \text{ T}$
 $= 4 \times 10^{-12} \text{ N}.$

