

## Concepts of this Module

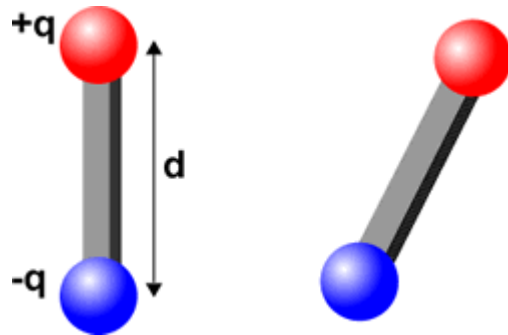
- Interactions of permanent magnets with other magnets, conductors, insulators, and electric charges.
- Magnetic fields of permanent magnets, current carrying coils, and a current carrying straight wire.
- Introduction to induction.

**NOTE:** for most setups the North poles of the magnets are colored **red**.



### Course Concepts Activity 1

- A. You are supplied two bar magnets, with the *North* and *South* poles marked. Do the same poles attract or repel each other? Do the opposite poles attract or repel each other?
- B. Imagine that you have two electric dipoles, each of which consists of equal and opposite electric charges  $+q$  and  $-q$  separated by a constant distance  $d$ . Would the positive “poles” (i.e. charges) of the dipole attract or repel each other? What about the opposite “poles”? Is there any difference between the interaction of two electric dipoles and two bar magnets?

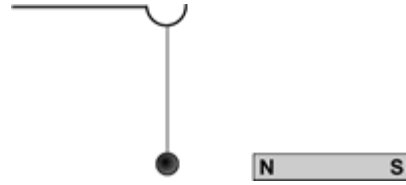


### Expt Activity 2

**Caution:** The balls and stands that you will use in this Activity are a little fragile. Please handle them with care. When you are finished with this Activity, leave the apparatus on the tabletop instead of putting them back in the bins where they can get damaged.

In **Electricity and Magnetism Module 1** you may have used a white pith ball, which is an insulator, and a black Aluminum coated pith ball, which is a conductor, both hanging by strings from stands. In this Activity you are given those two balls again plus a small carbon steel ball hanging by a string from a stand. The steel is also a conductor. In this Activity you will use one of the two supplied bar magnets.

- A. Does the North Pole of the magnet exert a force on the pith ball? How about the South Pole of the magnet? Repeat for the Aluminum coated pith ball.
- B. Does the North Pole of the magnet exert a force on the carbon steel ball? Is the force attractive or repulsive?
- C. *Predict* whether or not the South Pole of the magnet will exert a force on the carbon steel ball. Will it be attractive or repulsive?
- D. Check your prediction. Were you correct? Explain.
- E. Does the magnet interact with other insulators and conductors in the room? What about the whiteboard? Generalize your observations about the interaction of the magnet with insulators and conductors.



### **Course Concepts** Activity 3

In addition to the bar magnet of Activity 2, you are supplied an unmagnetised soft iron rod. Imagine that you don't know which object is the magnet. Using only these two objects find a way to determine which object is the magnet.

### **Course Concepts** Activity 4

In Electricity and Magnetism Module 1 Activity 1 you may have put an electric charge on a length of sticky tape by suddenly peeling it off the tabletop and hanging it from the cupboard. You may wish to refer to the Student Guide for that Module and/or your lab book to refresh your memory. Repeat that procedure.

1. Does the magnet exert a force on the charged tape? Is there a difference between the North and South poles?
2. You are supplied with an unmagnetised soft iron rod. Does it exert any forces on the charged tape? Are there any differences between the interaction of the tape with magnet and with the metal rod?
3. What can you conclude about the interaction of stationary electric charges with magnetic fields?

### **Expt** Activity 5

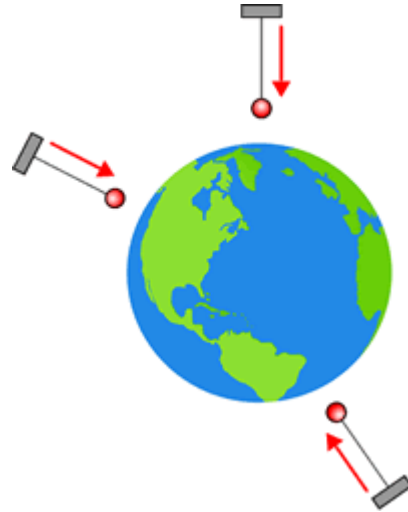
We can describe the fact that the Earth exerts a gravitational force on all objects near it by saying:

1. The Earth creates a *gravitational field* in all regions of space around it.
2. The gravitational field exerts a gravitational force on all objects in the field.

A convenient definition of the gravitational field is that it is equal in magnitude and direction to the acceleration due to gravity  $\vec{g}$  at that point in space. Then the gravitational force exerted on a mass  $m$  in the gravitational field is:

$$\vec{F} = m\vec{g}$$

We could measure the direction of the gravitational field by taking a mass hanging from a string and observing in what direction the mass hangs. The figure to the right illustrates.



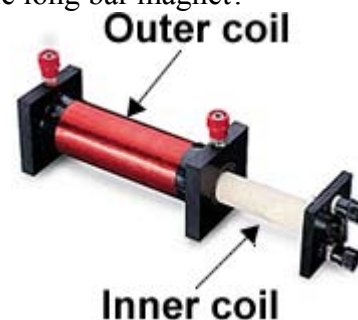
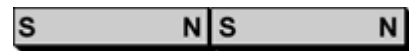
A compass is a little bar magnet that is free to rotate. In this Activity we will use a simple compass to measure the direction of the *magnetic* field around various objects. The procedure is similar to the one we described for determining the gravitational field. We will use the following standard convention:

**The direction of an external magnetic field is parallel to the orientation of the compass, and points from the South to the North direction as marked on the compass.**

All of the fields you will map are sufficiently strong that the Earth's magnetic field is negligible.

Be sure when you are mapping a magnetic field that all other magnets and metals are as far away as possible.

- A. Map the magnetic field around one of the bar magnets using the compasses. Use your results to sketch the magnetic field "lines" around the bar magnet. Be sure to include arrows on the lines to indicate the direction of the magnetic field.
- B. Place the two bar magnets together, with the North pole of one in contact with the South pole of the other, as shown. Map the magnetic field of the combination and sketch the field lines including the direction of the field. Do you think the field any different from that of a single long bar magnet?
- C. In Activities 11 and 12 below you may be using the pair of wire coils shown to the right. Here you will use only the *outer* coil, and you may place the inner coil to the side. You are supplied with a plastic plate with a rectangular hole cut in it. Place the outer coil in the hole. You will place the compasses on the Plexiglas

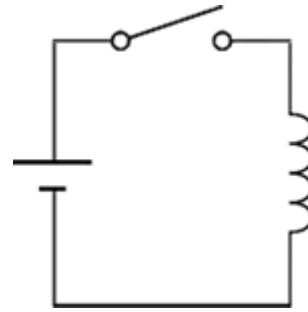


You will connect the 6V battery to the red sockets on the outer coil, with a switch to avoid draining the battery.

The switch you will use is called a *Contact Key*: this type of switch is only on when you hold it down.



The symbol for a coil is shown to the right.



So the circuit diagram of the experiment you will do is:

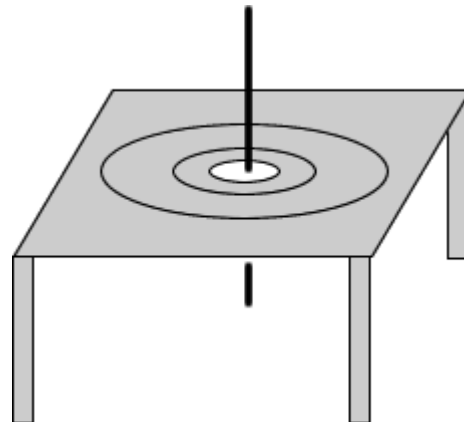
Use the compasses to map the magnetic field around the coil, and draw field lines including the direction. Compare your results to Parts A and B.

- D. In terms of its magnetic field we can model the Earth as a big bar magnet. Is the magnetic North pole located at the geographic North pole (where Santa's workshop is located) or at the geographic South pole (where the penguins live)?



 **Course Concepts** **Activity 6**

- A. In Activity 5 Part C you found the magnetic field of a coil of wire. Here you will investigate the magnetic field of a single straight wire carrying a current. You will orient the wire vertically through a hole in a Plexiglas stand, and place compasses on the stand. Sketch the fields lines around the wire.

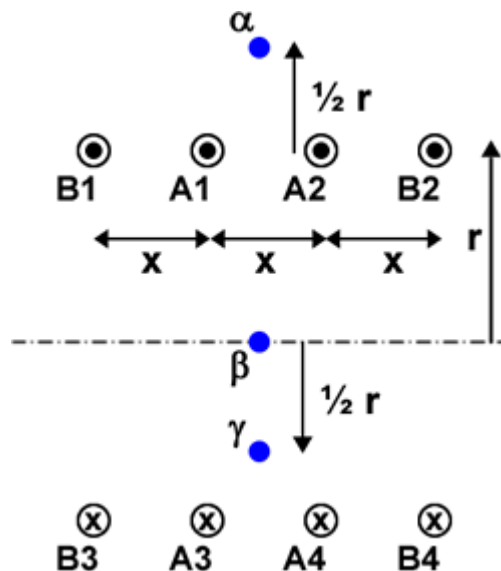


- B. In Electricity and Magnetism Module 2 you may have used a *clamp meter* to measure the current in a wire. Can you now explain how that meter works? If yes, do so.
- C. In Part A you used a vertical current carrying wire passing through a hole in a Plexiglas stand to map the magnetic field. Here you will investigate how the magnitude of the magnetic field varies with distance from the wire. You will measure the magnetic field with a *Giant Magnetoresistance (GMR)* sensor. These devices use a quantum mechanical effect which makes resistances vary when it is in an external magnetic field; for the keen some further details appear in the Appendix.

The rest of this Activity is still under development.

### Course Concepts **Activity 7**

In Activity 5 you mapped the magnetic field of a coil carrying an electric current. In Activity 6 you explored the magnetic field of a single straight current carrying wire. Here is a figure of a few of the wires of a coil.



The current in the upper wires is out of the plane of the paper, and the current in the lower wires is into the plane of the paper.

- A. Sketch the total magnetic field at point  $\alpha$  due to currents **A1** and **A2** indicating its magnitude by the length of the vector line. You do not need to do a detailed calculation of the magnitude of the field, just a rough estimate. You may wish to label this line “A upper”. On the same sketch add the total magnetic field at point  $\alpha$  due to currents **A3** and **A4**, perhaps labeling the line “A lower”. So what is the direction and magnitude of the total magnetic field at  $\alpha$  due all four **A** currents?

- B. Repeat Part A for the **B** currents. So for a real coil of many “turns” of wire, what is the direction of the total magnetic field at a point reasonably far from the ends of the coil?
- C. Repeat Parts A and B for the point  $\beta$ , which is on the axis of the coil and far from the ends.
- D. Repeat Parts A and B for the point  $\gamma$ . Compare to your result from Part C.



### Course Concepts Activity 8

- A. In Part B of Activity 5 you made a big bar magnet by joining two smaller magnets together and determined its magnetic field. In Electricity and Magnetism Module 3 Activity 9 you may have determined the *electric* field of an electric dipole, which is two equal and opposite charges separated by some distance; the figure for Activity 1 of this module shows two such dipoles. Are there any differences between the shape of the magnetic field of a big bar magnet and the shape of the electric field of an electric dipole?
- B. If you have an electric dipole and cut it in half along its axis you end up with an isolated positive charge and an isolated electric charge. If you take the big bar magnet of Part B Activity 4 and take it apart into two smaller magnets, do you end up with an isolated magnetic North “charge” and an isolated magnetic South “charge”? What about if you took one of the small bar magnets and sawed it in half [don’t actually do this!]? Can you think of any reason why we never observe an isolated magnetic “monopole”?

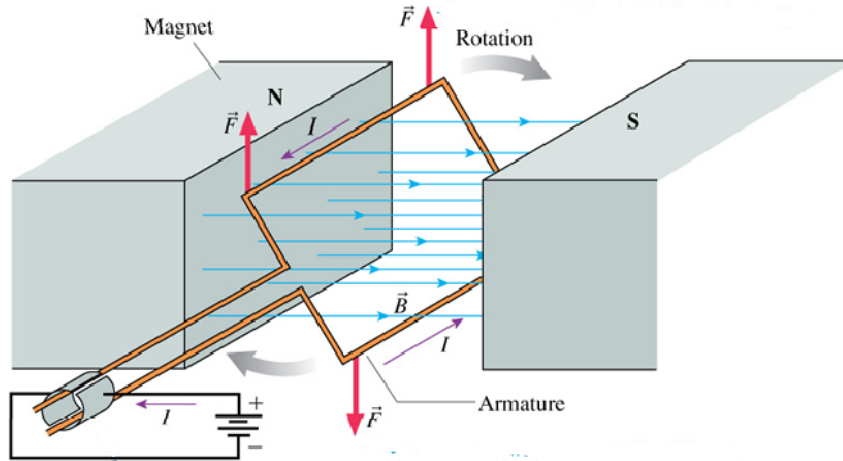


### Course Concepts Activity 9

The force exerted on a moving charge is given by:

$$\vec{F} = q\vec{v} \times \vec{B} \quad (1)$$

- A. The direction of this force is always perpendicular to the velocity of the charge. Can this force ever do work on the charge?
- B. Here is a figure of a typical electric motor:



A current in the loop experiences the forces shown due to the magnet. Eqn. 1 describes the forces. Is this fact consistent with your answer to Part A? Do motors do work? Explain.

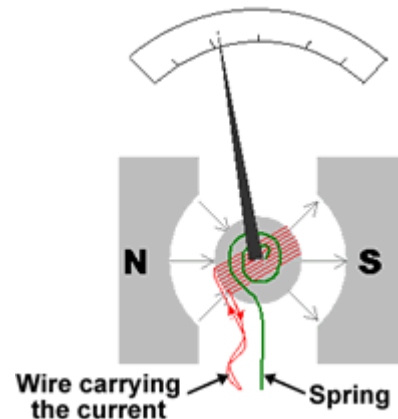


### Expt Activity 10

A *galvanometer* is a type of ammeter. Typically, they have a coil of wire through which the current to be measured flows. A magnetic field from a permanent magnet exerts a torque on the coil of wire that is proportional to the current. A spring exerts a torque opposite the torque due to the current-magnetic field interaction. So at equilibrium the deflection of the pointer of the meter is proportional to the current.

Many galvanometers are capable of detecting very small currents, but often are not as accurate as more modern instruments. Some galvanometers do not even attempt quantitative measurements of the value of the current but are just used to detect their presence and direction.

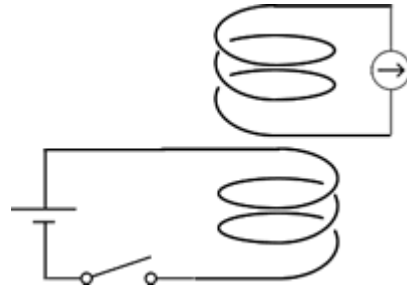
Although sometimes a galvanometer is represented in circuit diagrams as an ammeter, it is usually drawn as shown to the right.



In 1831 Faraday asked an interesting question. His reasoning was:

**Electric currents cause magnetic fields. Is the converse true: do magnetic fields cause electric currents?**

A diagram of the apparatus he used to try to answer this question is shown to the right. A battery is connected to a coil of wire, which will generate a magnetic field when the switch is closed. A second coil of wire is connected to a galvanometer. If the magnetic field from the first coil causes electric currents in the second coil, then the galvanometer could show a current provided it is sensitive enough. In the actual experiment, the two coils of wire were concentric with each other.



A photograph of the coils you will be using appears as part of Activity 5 above.. In the photograph the inner coil is slid partly out from the outer one. In this experiment the inner coil should be slid all the way into the outer coil. The battery and switch should be connected to the *outer* coil using the red banana sockets, and the galvanometer should be connected to the *inner* coil using the black banana sockets.

In Activities 3 and 4 you may have used a unmagnetised soft iron rod. This rod comes with the coils, but is **not** part of the apparatus for this Activity. Please be sure to set it aside and do not use it here.

The switch you will use is called a *Contact Key*: this type of switch is only on when held down. Please do not leave the switch closed for too long: this will drain the battery.

Also please do not connect the battery to the inner coil: the resistance of that wire is so small it will either quickly drain the battery or trip the circuit breaker on the battery.

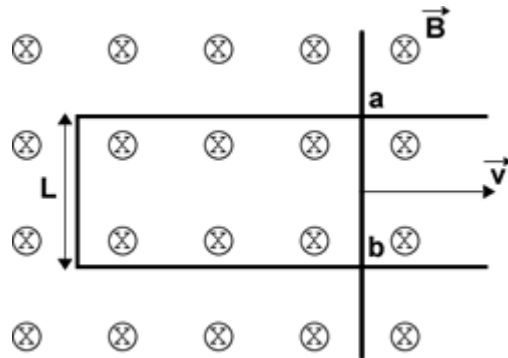
What is the answer to Faraday's original question? Is there anything else going on or is this just a failed experiment?

## Course Concepts **Activity 11**

You are supplied a soft iron cylinder, which you may have used in Activities 2 and 3. Insert the rod completely into the hole in the inner coil of the setup you used in Activity 10 and repeat the experiment. What happened? Why is the result different from the earlier one?


**Course Concepts Activity 12**

A U-shaped conducting wire has a straight vertical wire resting on and making electrical contact with it. There is a uniform magnetic field  $\vec{B}$  directed into the page. The vertical bar is being pulled to the right at a constant velocity  $\vec{v}$ . At some moment in time the contact between the U-shaped and the vertical wires is at points **a** and **b**.

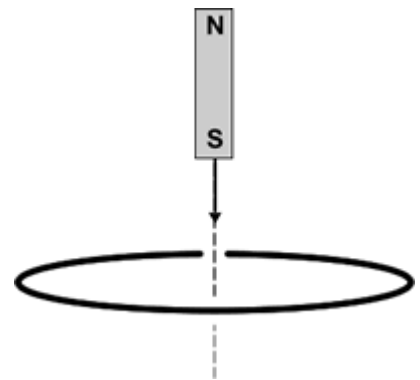


- What is the force, magnitude and direction, exerted on the electrons in the vertical wire by the magnetic field?
- If an electric field in the vertical wire were to exert the same force on the electrons as the answer to Part A, what would be its magnitude and direction?
- If the electric field of Part B is constant, what is the potential difference  $\Delta V$  between points **a** and **b**?
- The magnetic flux  $\Phi_B$  through the loop consisting of the U-shaped wire and the vertical wire is the magnitude of the magnetic field  $B$  times the area  $A$  of the loop. What is the rate of change of the magnetic flux?
- Compare your answers to Parts C and D. Explain.

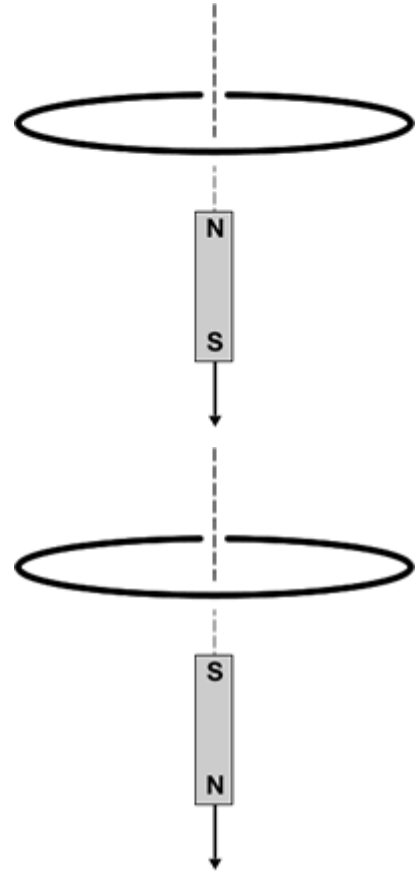

**Course Concepts Activity 13**

Lenz's Law is often stated: "The direction of an induced current is such that the induced magnetic field opposes the *change* in the flux." However, an alternative statement is: "The direction of induced current opposes its cause." You may find that the second form is useful for this Activity.

- A bar magnet is falling towards a circular loop of wire as shown. The falling magnet induces a current in the wire. The current in the wire exerts a force on the falling magnet. What is the direction of the force exerted on the magnet?



- B. The magnet has fallen past the loop of wire and is now accelerating away from it. Now what is the direction of the force exerted on the magnet?



- C. The magnet is falling away from the loop as in Part B, but the poles of the magnet are reversed. What is the direction of the force exerted on the magnet?

- D. If your answers to Parts A, B, and C were opposite to the correct answers, would this violate any physical principles?

## Appendix

Here we discuss *Giant Magnetoresistance* (GMR) and how the effect is used to measure a magnetic field. GMR was discovered independently in 1988 by Grünberg and Fert; they were awarded the Nobel Prize in Physics in 2007 for their discovery. It is now used extensively in read heads of computer disc drives.

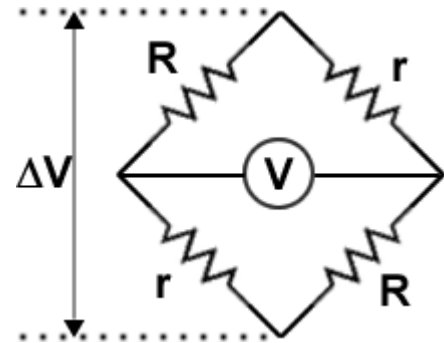
GMR is a quantum mechanical effect that produces significant decreases of resistance in the presence of an external magnetic field. GMR materials are commonly comprised of alternating very thin layers of various metallic elements. As described by IBM:

The key structure in GMR materials is a spacer layer of a non-magnetic metal between two magnetic metals. Magnetic materials tend to align themselves in the same direction. So if the spacer layer is thin enough, changing the orientation of

one of the magnetic layers can cause the next one to align itself in the same direction. Increase the spacer layer thickness and you'd expect the strength of such "coupling" of the magnetic layers to decrease. But as [an IBM research team] made and tested some 30,000 different multilayer combinations of different elements and layer dimensions, they demonstrated the generality of GMR for all transition metal elements and invented the structures that still hold the world records for GMR at low temperature, room temperature and useful fields. In addition, they discovered oscillations in the coupling strength: the magnetic alignment of the magnetic layers periodically swung back and forth from being aligned in the same magnetic direction (parallel alignment) to being aligned in opposite magnetic directions (anti-parallel alignment). The overall resistance is relatively low when the layers were in parallel alignment and relatively high when in anti-parallel alignment.

A GMR sensor that measures magnetic fields uses four such resistors in an arrangement called a *Wheatstone bridge*. The two resistors **R** are shielded from the magnetic field, and the two resistors **r** are exposed to it. The sensor is driven with an applied voltage  $\Delta V$ , which is 5 volts in our case. Then we measure the voltage **V**. It is fairly easy to show that:

$$V = \Delta V \frac{(R - r)}{(R + r)}$$



Further information on GMR sensors is at: <http://www.nve.com/Downloads/lowfield.pdf>.

This Guide Sheet was written by David M. Harrison, Dept. of Physics, Univ. of Toronto in January 2008. Activity 4 is from Lillian McDermott et al, **Tutorial in Introductory Physics**, Magnets and Magnetic Fields I.B, (Prentice-Hall, 2002), pg. 113. Parts of Activity 5 are similar to Priscilla W. Laws et al., **Workshop Activity Guide**, Module 4, Unit 28, (John Wiley, 2004), pg. 725.

The figure of the electric motor is slightly modified from Fig. 32.48 of Randall D. Knight, **Physics for Scientists and Engineers** (Pearson, 2004). The figure of the mechanism of a galvanometer is slightly modified from a version at Wikipedia: <http://en.wikipedia.org/wiki/Galvanometer>.

The quotation from IBM in the Appendix is from <http://www.research.ibm.com/research/gmr.html>, accessed February 5, 2008. The date stamp of the html file is March 16, 2004.

Last revision by David Harrison, Lilian Leung, and Brian Wilson: March 20, 2011.