TAP 414- 4: Investigating electromagnetic induction

Inducing emfs

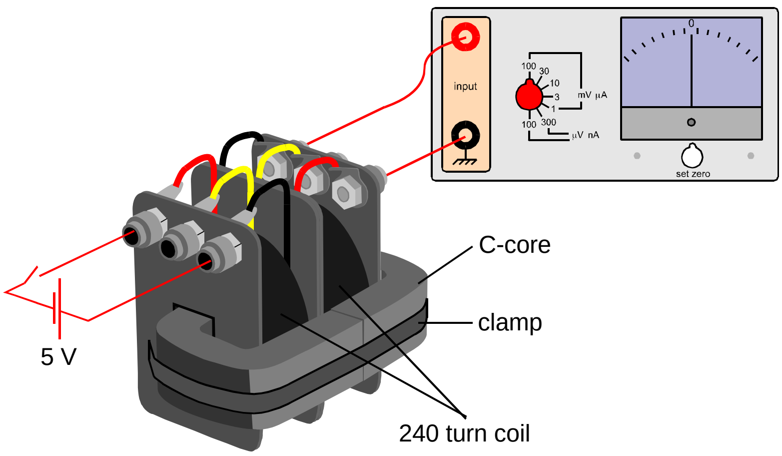
Oersted had demonstrated that an electric current produced a magnetic field. Faraday suspected that a magnetic field would produce an electric current. Others worked on this problem as well, most notably Joseph Henry in the USA. The major breakthrough was to see that it was changing magnetic fields that induce an electric field, not static ones.

You will need:

- ✓ two 240-turn coils
- ✓ two C-cores
- ✓ mild steel bar, 30 cm long
- ✓ about eight 4 mm leads
- ✓ microvoltmeter
- ✓ spst switch
- ✓ power supply, 5 V dc
- ✓ signal generator
- ✓ oscilloscope

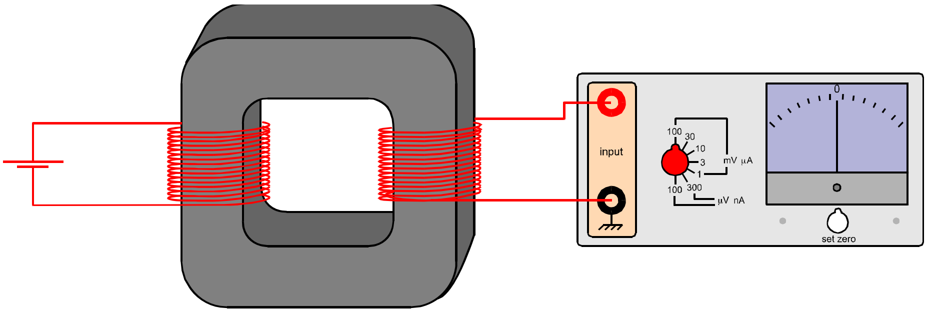
Making and breaking circuits

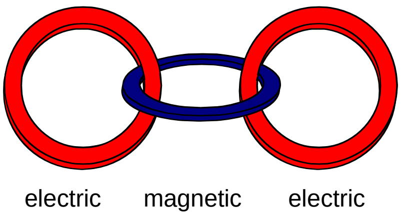
1. Set up the apparatus as shown in the diagram.



2. Close the switch. What happens?
3. Open the switch again. Is that what you expected?

When the switch is closed, there is a potential difference between the terminals of the primary coil (the one connected to the power supply). The primary coil has become part of an electric circuit, in which electrons will drift as a current. This current has grown from zero to some value and therefore the corresponding magnetic flux around magnetic circuit changes from zero to some value. During this changing situation, from no current to some steady state current, the changing magnetic flux in the C-core induces an emf in the secondary coil.





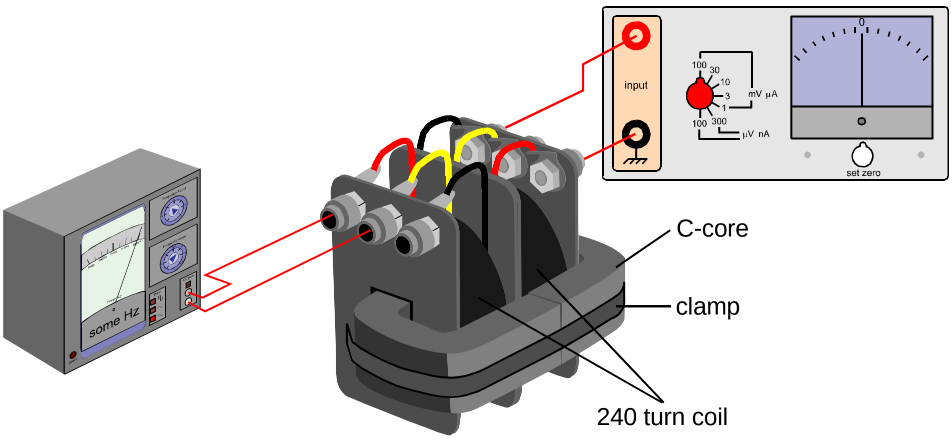
The interlocking electric and magnetic circuits are quite crucial to the operation of electromagnetic machines such as transformers. A break in the primary electric circuit leads to a change in the magnetic circuit and correspondingly induces an emf in the secondary electric circuit.

4. What do you expect to happen when the magnetic circuit is broken by separating the C-cores whilst a steady current is in the primary coil? Try it and then explain the effect.

Changing currents:

Using alternating current

Rather than switching the current on and off manually, an alternating current can be used, supplied by a signal generator. Take care to demand less than 1 A from the signal generator.



1. Set the signal generator to produce a square wave oscillating below 1 Hz. This is just like the previous experiment, switching the current on and off.

2. What is the effect of changing the frequency of the input? (You may need to adjust the output of the signal generator to make sure that the peak current in the coil is the same for each frequency tried.) Here you may want to switch from using the

microvoltmeter to using an oscilloscope, if the needle on the microvoltmeter has trouble keeping up with the changing voltage.

3. What is the effect of changing the peak current in the primary circuit at a fixed frequency?

4. What is the effect of using only 120 turns on the secondary?

5. Finally begin to deconstruct the core. First remove the clips and then make an air gap. Then remove the core altogether. Thread the coils onto a 30 cm steel rod (perhaps from a clamp stand). Vary the separation of the coils.

6. Describe what the core of a transformer does, relating this to what you have just tried.

What would happen if…?

Using what you have discovered, can you now predict the outcome of repeating this experiment with triangular and sinusoidal waves rather than square waves? Try to predict how the output would change and then check whether or not you are right.

What you have seen

1. Faraday's law of electromagnetic induction: when the flux linked with a circuit changes, the induced emf is proportional to the rate of change of flux linkage. The magnitude of the induced emf, E, is given by

$$E = -N \frac{\mathrm{d}\Phi}{\mathrm{d}t}$$

that is, the magnitude of the induced emf in the circuit is equal to the rate of change of flux linked by the circuit.

2. Lenz's law: the direction of the induced emf is such that it tends to oppose the motion or change causing it.

3. The effect of:

- Number of turns: increasing the number of turns in the secondary coil increases the induced emf; so increasing *N* means that the total change in flux is greater over each cycle.
- An iron core: increases the induced emf because flux density in iron is much greater than the flux density in air so the total change in flux is greater over each cycle.

Practical advice

This is a quite crucial demonstration or experiment to help students become familiar with Faraday's law and Lenz's law and the action of a transformer. It could be tackled in a number of different ways. It can work with the class all gathered round as a demonstration discussion. It is unlikely to be the case that there are enough meters to allow class experimentation so the only other choice is to arrange for each group of students to tackle the experiment in turn. If there do happen to be two suitable voltmeters then one can be connected to the primary side of the circuit for comparison. This is a very elegant demonstration.

In the first part, students should see that it is a change in the magnetic flux that induces the emf. Making or breaking either the primary electric or the magnetic circuit will achieve this and induce an emf in the secondary.

Alternative approaches

It may be that oscilloscopes are available in larger numbers than microvoltmeters. If that is the case the experiment can be done with a primary solenoid with about 10 turns of wire wrapped round it as a secondary. One of the oscilloscope inputs is connected across a 15 W resistor and essentially displays the signal in the solenoid, which comes from the low-impedance output of a signal generator. This beam is used to trigger the time-base. The other input is connected to a ten-turn coil wrapped around the centre of the solenoid. Using the oscilloscope may well display the phase differences between primary and secondary more clearly than they can be seen using the meters, and make a better link with drawing graphs of varying current, flux and induced emf.

Social and human context

Changing magnetic fields are required to induce emfs; that this was not discovered earlier may seem remarkable to students. Faraday worked on the problem intermittently during the 1820s, finally publishing his result in 1831. Henry had probably discovered the effect a couple of years earlier but not published his discovery. Just what was the problem? Well, two issues could emerge. One is that things are rarely as obvious as they seem from the retrospective view of school science. The other is technological. One very real problem was getting insulated wire. Faraday built much of his own apparatus and insulated wire by wrapping calico around it by hand. The experiments were not quite so easy technically as we show them in the lab today.

External reference

This activity is taken from Advancing Physics chapter 15, 70E