

Electromagnetic induction and Faraday's laws

A guide for group leaders

Hello to you, the group leader!

These notes are designed to help you run a special kind of science teacher group meeting.

This kind of meeting is about helping teachers to feel comfortable with doing practical work, and organising their own lessons so that their students do the activities.

This workshop assumes that your participants know quite a lot about the topic, and now they want to make it interesting and exciting for their students. On the www.science Teaching Alive.com you will find Teachers' Notes that give teachers information about this topic.

Also on the website there's the skeleton of a student worksheet that your group can develop.

Some personal preparation for the workshop

Brian talks about the history of Michael Faraday (at **0:50** in the video). It's worth telling the group something about this remarkable man who had very little formal schooling. You can find some of his life story on these websites:

http://en.wikipedia.org/wiki/Michael_Faraday – it opens with a useful short summary

<http://www.magnet.fsu.edu/education/tutorials/pioneers/faraday.html> This piece also has a description of his damaging experiences in school

<http://www-history.mcs.st-and.ac.uk/Biographies/Faraday.html>

http://www.bbc.co.uk/history/historic_figures/faraday_michael.shtml

<https://www.faraday.st-edmunds.cam.ac.uk/Faraday.php>

And at <http://www.rigb.org/our-history/michael-faraday>, you can see an interactive on-line exhibition of Faraday's laboratory.

Suggestions for your workshop programme

A. Welcome and introduction

After the usual welcome and admin discussion, tell everyone what you hope the workshop will produce. Remind them that a workshop means participation and in workshops things get **produced** – the thing might be a new understanding, or an issue resolved, or a physical thing made or a document written. They have to produce, not just listen.

Here are three products that could come out of this workshop (you have to decide on this):

- 1 A double coil that you can use for explaining how a transformer works.
- 2 A min-galvanometer that reveals the induced voltage in a coil
- 3 A worksheet to guide students in their own investigation.

B. Give a short description of Michael Faraday's life and work

This should not take more than about 3 minutes. But omit this if you are short of time in the workshop.

C. Do a quick revision of a few basic ideas

Again, keep it short, about 5 minutes, otherwise the workshop becomes a lecture session.

- 1 **The direction of a magnetic field** is defined as being the lines of magnetic force **from North to South**, and a small magnetic compass needle shows the direction of the field
- 2 **The magnetic field of a bar-magnet** looks like **Figure 1**. In places where field lines are drawn close together, it means that the field is strong at that place.
- 3 **The shape of the field lines around a straight current-carrying conductor** is a cylinder of concentric circles; you see this when you hold a plotting compass at positions all around the conductor (This was done in the video *Teaching the motor effect*). If the thumb of your right hand points in the direction of the *conventional* current, your curled fingers show the direction of the magnetic field. See **Figure 2**.
- 4 **The shape and direction of the field inside a coil**
See **Figure 3**. The curled-fingers rule also helps you work out the shape of the magnetic field inside a coil when a current is flowing around the coil. Take one turn of the coil in your right hand and point your thumb in the direction of the current at that place; your fingers will curl around inside the coil and show the direction of the field inside.

Figure 1 Plotting compasses needles will point in the directions of the arrows in the field lines.

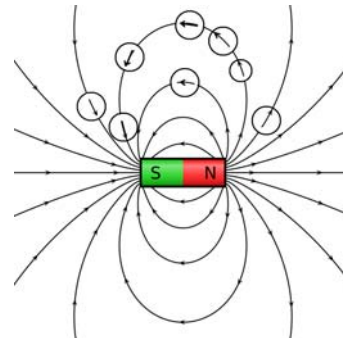


Figure 2

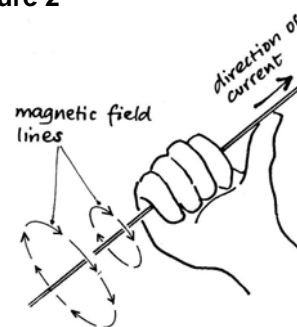
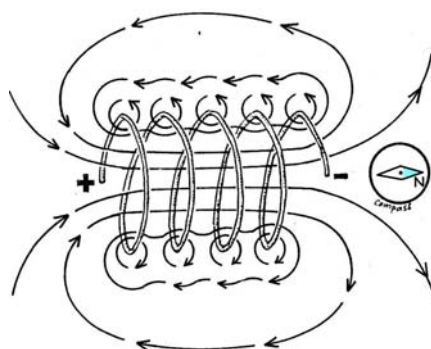


Figure 3 The current in this coil is flowing from the + towards the -. The arrows show the shape of the field.



D. Using the video

Before you play the video, ask the group to watch it to identify the key concept in electromagnetic induction that comes through the video. (A good answer is that a changing magnetic flux through a coil will induce a current in the coil.)

Then show the video right through.

1:30 The discussion on “what if Faraday had not seen the connection between a changing magnetic field and a current?”

If Faraday had not seen these hidden connections, life would indeed be very different for us¹. As I suggested in the video *Teaching the motor effect*, ask the group to name as many appliances as they can that use electric motors.

Take them through the various spaces they know: cars, garage workshops, kitchens, lounges, farms, factories, trains, and so on.

Of course none of these things would work unless Faraday's principles are used to **generate** the electricity in the first place. Ask the group to list things that generate electricity.

Answers could begin with the wind-up fly-wheel torch that Brian shows at the beginning of the video and then move on to portable petrol-engined generators, wind-turbine generators, hydro-power generators and of course the big generators in power-stations.

Answers to the question on motors should include car wiper motors, car starter motors, car cooling fans, car windscreen washers, car power-steering. In the garage workshop or factory there are alarm sirens, electric drills, grinders, saws and screw-drivers. Around the house there are air-conditioners, household fans, food-mixers, tape drives, CD drives, computer hard drives, fans in computers, in microwave ovens, fridge motors, children's toys like cars Outside and on farms there are

E. Hand out the materials and equipment

2:16 – 2:40 Let teachers wind their own coils – they will need them in their own teaching.

The white tube you see can be plastic pipe, a roll of paper or a small plastic bottle. It should be wide enough to push a magnet in and out. Check on the size of magnets you have.

Brian actually winds two coils on the same former – you don't see him wind the second coil because the video was edited. Wind two coils - one with about 50 turns and another with 100 turns.

It's a good idea to put some sticky-tape over the windings to hold the wire in place.

2:45 – 3:10 The galvanometer – you may find one of these instruments in the laboratory. It is really a super-sensitive ammeter set up so that the needle is in the middle of the scale.

If you can't find one of these instruments, Brian (at **5:35**) shows how to make a galvanometer from a plotting compass.

Alternatively, use a digital multi-meter. Set the dial to read milli-volts (direct current or DC). The read-out display will show a number like 0.14 indicating milli-volts in the positive direction but if the current goes the other way, it will show a minus sign next to the numbers, like -0.15.

¹ Other scientists such as Joseph Henry in America were making similar discoveries. Heinrich Lenz in Russia (writing in German) and Nikolai Tesla in America were working in the same area of electricity and magnetism. It often happens in science that people reach similar conclusions independently of each other.

3:10 - 5:35 Faraday's laws: The variables that affect the size of the induced current

The teachers should check that they can get the same effects that Brian shows, using their equipment.

5:35 – 7:12 Making your own mini-galvanometer

Use the thinnest copper wire you can find, and wind as many turns of the wire around the bottle-top as you can. (Just make sure that people can still see the compass-needle.) Leave enough wire to keep the mini-galvo far from the big magnet you are moving around.

At **6:22** Brian tells people to place the mini-galvo so that the needle is lying parallel to the coil. In other words, they must place the coil so that the wires lie North-South, because the plotting compass will respond to the Earth's magnetic field and lie North-South.

But at **6:46** Brian points out that the needle might also respond to the steel frame underneath the table! So check under the table and move away from steel water-pipes, window-frames, etc.

7:12 – 8:19 The transformer

The teachers have now seen several ways to illustrate Faraday's law. Now the video moves on the transformer. You see in the video that a changing magnetic flux in the first coil (called the primary) causes a changing flux in the other coil (called the secondary) even though there is no electrical connection between the two coils.

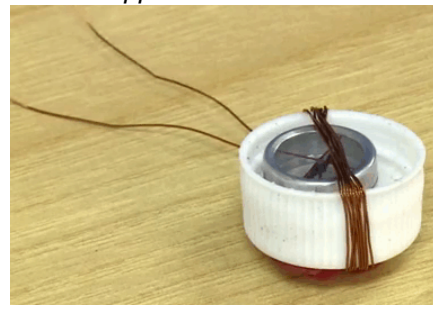
The key point here (that students often don't understand) is that the secondary produces a potential difference (emf) **only** when the current in the primary changes. Notice how at **7:50 – 7:56** Brian shows that if the current from the battery keeps on flowing in the primary coil, there is no change in the secondary coil until the current stops.

Now the next important thing about the transformer is that the number of turns of wire in the primary and secondary are different. Remember, the more turns of wire a coil has, the more times a changing flux links through the coil, and therefore the bigger is the emf that is induced.

So the emf in your secondary coil will be bigger than the battery voltage across the primary; the bigger voltage lasts only for a fraction of a second, of course.

Transformers are designed to work with alternating current (AC) because the magnetic flux in the primary keeps changing as the current keeps changing direction.

Figure 4 The mini-galvo is made from a plotting compass inside a coil of copper wire.



Terminology

A coil is a length of wire that is wrapped around a shape or former, and its shape is a ring or tube. Each time the wire goes around the former, we call that one "*turn*". So you get a coil with 50 turns of wire. We also talk about the *turns* of wire as the *windings*. You might know of some repair businesses that called armature *re-winders*. An *armature* is the iron core of an electric motor or generator or transformer. An armature holds all the wires in place and multiplies the magnetic field of the turns of wire.

English offers some problems to students, doesn't it?

We *wind* wire around a former, and say we have *wound* 50 turns of wire. "Wind" (pronounced why-nd) is spelled just like wind that blows the leaves of a tree. "Wound" (pronounced wow-nd) is spelled just like the wound that you get if you cut yourself.

Have a thought for them when they battle with the language!

8:18 – 9:30 Making it all relevant to student's lives

The wall sockets we plug appliances into all provide alternating current (AC). In South Africa the effective voltage is 230 volts and in other countries it may be 115 volts.

Make the point that all the transformers Brian shows work with AC. If you put DC into them, you'd get no voltage across the secondary except for the instant that you switch on or switch off.

You really need to have some appliances that use transformers opened up to that people can see the primary and secondary coils. Notice that the secondary coil has much less copper wire on it if this is a step-down transformer. Cell phone chargers step mains voltage down to about 4.2 volts (the output voltage should be written on the charger somewhere).

Electric welding-machines (arc-welders) are really transformers that step down 230 V to much lower voltages, but can produce extremely large currents, large enough to heat steel to 6 000°C and vaporise it.

However, a microwave oven uses a **step-up** transformer that steps up 230 V to about 4 000 V, so the secondary will have many more turns of wire on it.

Try to get a bicycle dynamo for the meeting. It's ideal if you can have one to take apart (see the photos in the Teachers' Notes). However, if the owner does not want you to take it apart, let people spin the roller (the part that rolls on the bicycle tyre). They will feel that it does not roll easily but seems to be gripped and then released by something inside. What they are feeling is the effect of passing the magnets and wire coils past each other. Each wire coil is wound around an iron core that gets magnetised by the permanent magnet as it passes. Ask people why you have to pedal harder when using the dynamo to light the bicycle lamp.

A safety warning: Don't connect an opened-up transformer to the 230 V mains. The casing that you removed protected people against high voltages inside.

When most people have completed the activities, sum up in a discussion:

- can we do this in our classrooms? If not, why not?
- What questions will we use to focus the students' activities?
- How do the activities we have done relate to what's in the students' textbooks?

F. Now move to the final product of the workshop – a student worksheet.

You will find a suggestion on how to design this, if you look at the menu on the website. Teachers will want to take a copy of the worksheet you produce in the meeting, so try to have a photocopier available, or provide pens and sheets of blank paper.

What to prepare

Items	Where to get them
Copies of the Teachers' Notes and copies of the Student Worksheet-starter - enough for each teacher	
Thin copper wire that has varnish insulation on it. You'll need many metres of this if you want your teachers to leave with coils to use in their lessons.	Old motors and transformers have lots of copper wire. Old loudspeakers also have copper wire, and it is extremely thin. Try appliance repair shops. You might have to pay something, because copper is valuable.
Thin copper wire with plastic insulation. This kind of wire takes more space on a coil but will also work.	You can get this from builders' shops, hardware stores. Get the very thin twin-flex that is used in wiring burglar alarms, and split the two halves. You can also get such wire from old computer cabling that has many thin wires inside a sleeve.
Magnets. Try to get some very strong magnets. Bar magnets are useful because you can push them into the coils and pull them out to see the effect.	See the video Salvaging magnets for teaching on the www.scienceteachingalive.com website. Also try industrial suppliers.
Non-magnetic formers for winding coils. Plastic conduit tubing or rolls of paper will be suitable.	
Iron cores for the coils. Large bolts or nails are suitable	Motor repair workshops, building sites, hardware shops
Insulated leads with crocodile clips - about two per group	School electricity kits; some hardware shops
Plotting compasses. You'll need at least one per group but get as many as possible.	Equipment suppliers such as Scientific Teaching Aids in Durban, South Africa www.science.co.za
Bicycle generator, also called a bicycle dynamo. To take apart - see Teachers' Notes for pictures. These are becoming harder to find because bright LED lights have begun to replace dynamos.	In Africa, try trading stores, Chinese importers and markets.
Old transformers, to show primary and secondary coils. Any appliance that works on both mains and battery will have a transformer to step down the voltage from 230 V to about 12 V or whatever the appliance runs on.	Transformers come in all sizes, from small ones in cell phone chargers to big ones in microwave ovens.
Instant-heat soldering irons (shaped like a hand-gun) are an excellent example of step-down transformers. The heating-tip is actually a part of the secondary coil	Buy these in hardware stores, or get burned-out ones from a handy-man or mechanic.
Wind-up torch or another type of torch that you recharge with energy from your own arm. An example of this is the shake-shake torch – it has a coil connected to a bright LED bulb and a strong magnet slides up and down through the coil when you shake the torch. It's made of clear plastic so the students can see the magnet sliding up and down through the coil.	Hardware stores. In South Africa, Midas motor-spares dealers and some hardware stores stock them; Chinese markets import them.