Motors and Generators

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Introduction

This part of the syllabus draws upon many ideas and concepts from the old HSC syllabus, perhaps with a bit more of a historical twist thrown in. The concepts of the motor effect and the generator effect are taken beyond the basics into such 'realistic' applications as three-phase motors and generators, induction motors and so on.

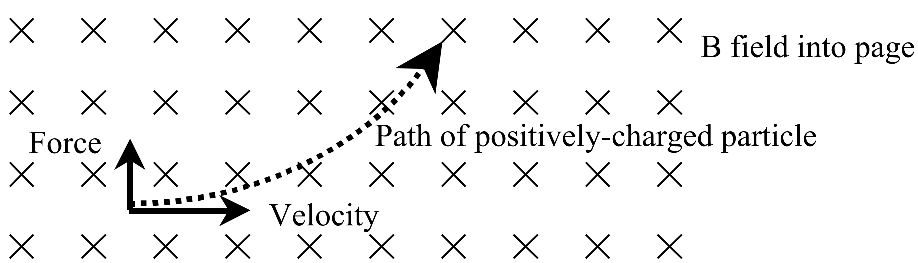
This development of the basic ideas can seem a bit of a stretch, but you can always bring the ideas back to just a few basic principles: the motor effect, its reverse the generator effect, and Lenz's law. Or, if you prefer, you can relate all the ideas back to the concepts of the magnetic force on a moving charge and the magnetic field produced by a moving charge.

Some core physical concepts

While the physics involved with motors, generators and transformers can seem difficult and complex, when you dig down there are really just a few powerful ideas. You can always return to the same concepts when discussing these subjects because, at the core, it's all about magnetic forces on electric charges.

1. A moving charge in a magnetic field experiences a force

A charge q moving with a speed v relative to a magnetic field B experiences a force F equal to



$$F = qvB \sin\theta,$$

where θ is the angle between the direction of the field and the direction of the charge's velocity. The force is in a direction that is perpendicular to both the velocity and the field as given by the 'right-hand rule'.

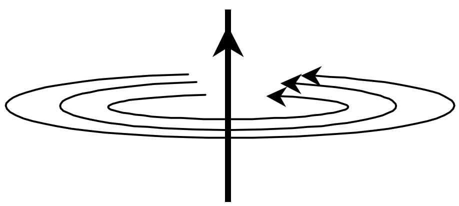
Why? There is no 'why'. This is the way electromagnetism works. A negatively-charged particle (say, an electron) will experience a force in the opposite direction to a positively charged particle. Notice here we have said 'moving relative to the magnetic field'. You can always look at the world from the point of view of the charge — in that frame of reference, the charge is stationary and the magnetic field is changing around it. If the charge is moving, there is a force; if the field is *changing*, there is a force.

2. A moving charge generates its own magnetic field

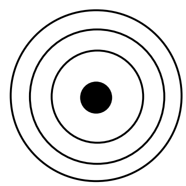
In particular for our purposes here, an electric current produces a magnetic field. The field encircles the current, as given by another ‘right-hand rule’.

Again, there is no point in asking why a current produces a field like this. It does. Electric charge, electric fields, magnetic poles and magnetic fields were all brought together in Maxwell’s equations for the electromagnetic theory. Nature shows us these properties, and the equations describe them — that is all we know.

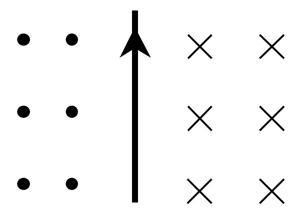
Amazingly, these two ideas can be used to describe everything about motors, generators and transformers. Relating back to these two concepts throughout this section of the course will allow students to get used to the ideas, to practice them and apply them, and maybe even to see the simplicity within complex pieces of machinery like a real generator or motor.



One way of looking at the field around a current-carrying wire



Current out of the page, field lines going anti-clockwise

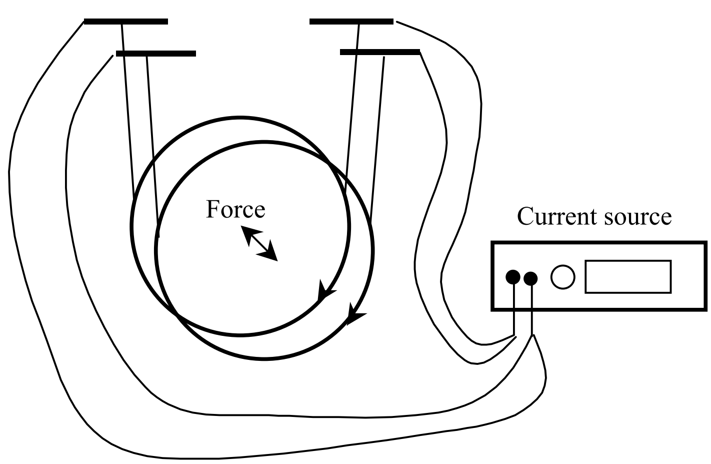


The field as ‘dots’ and ‘crosses’

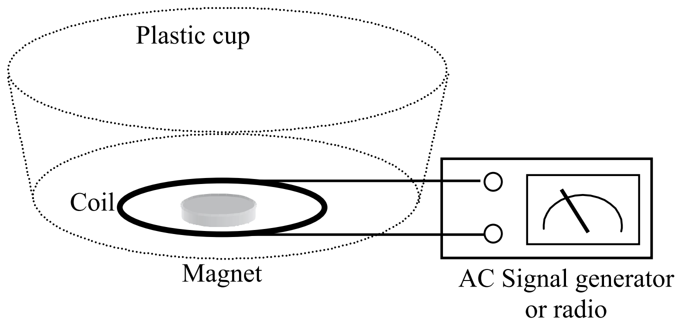
The motor effect

Concept 2 above gives us the basis for the motor effect: if a current flows in a conductor, and the conductor sits in a magnetic field, then the conductor experiences a force on it in the direction you would expect from the right-hand rule. If you have the equipment, you can demonstrate the motor effect on a beam of charge by using a cathode ray tube in which the electron beam is visible and a permanent magnet. The magnetic field bends the electron beam — you’re using a current and a magnetic field to produce a change in motion.

You can do many simple things with the motor effect before you get even close to a motor. Two coils of wire hanging parallel side by side, each carrying a current, will attract or repel depending on whether the currents are in the same or opposite directions.



You can also make the world's simplest loudspeaker — all you need is a signal generator (or a radio with an amplifier), a good strong magnet (neodymium types work well) and a fine, light coil of wire (I find very light gauge wire wound around a light plastic spool works well). Connect the coil to the signal generator set at an audible frequency (somewhere in the hundreds of hertz). Place the magnet in the middle of the coil on the bench, and place a plastic cup or yoghurt tub or



something similar on top. You should be able to hear sound coming from your speaker.

You're hearing the sound because the current in the coil creates a magnetic field. The magnet's own field interacts with the coil's such that the coil is either pushed up or pulled down, depending on the direction of the current in the coil. The up and down moves the bottom of the plastic cup — this is your speaker cone, pushing the air back and forth making sound waves.

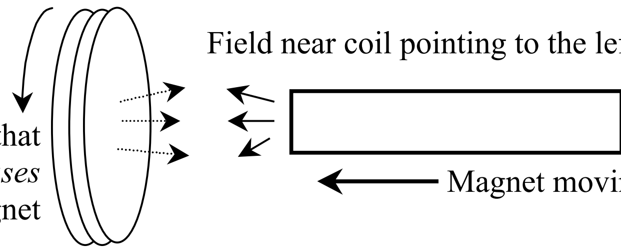
The generator effect

The reverse of the motor effect, the generator effect is a result of concept 1 above: a changing magnetic field near a conductor (either through relative motion of a magnet and the conductor or through an increasing or decreasing field strength) produces an electric current in the conductor. You can always trace this back to the force on a charge from a magnetic field.

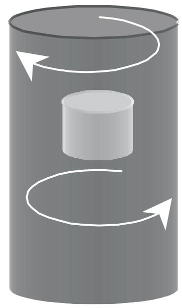
One point associated with these concepts is Lenz's law — that the induced current is always in a direction such that *its magnetic field opposes the changing field that created it*. This, too, can be traced back to the two concepts listed at the start of this paper, but can perhaps be more easily grasped as an application of the principle of conservation of energy. If a changing field produced a current, and that current produced a field that 'assisted' the changing field, you would produce more current, changing the field more, producing more current … quickly you would have a current increasing towards infinity and an out-of-control magnetic field. You would get energy from nothing.

So if the magnetic field is changing one way, the current induced will always oppose this change — if the field is increasing, say, the current will produce a field to oppose this increase. Moving the North pole of a magnet towards a coil will produce a current in the coil that reduces the overall magnetic field.

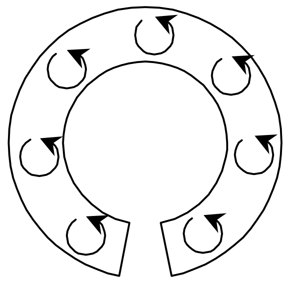
The simplest demonstrations involve a coil, a magnet and a galvanometer. You can use the right-hand rule to work out which way the current is moving in the coil to satisfy Lenz's law.



More interesting is the issue of *eddy currents* because you can do some really nice demonstrations. Get a length of copper pipe (or some other good conductor that is not also easily magnetised) and a really good, strong magnet. Hold the pipe vertically and drop the magnet down the pipe. As the magnet falls, taking its magnetic field with it, eddy currents are induced in the pipe. These produce fields that oppose the field that created them: which the current in a particular part of the pipe pushes back on the magnet as it approaches from above and pulls up on the magnet as it falls away.



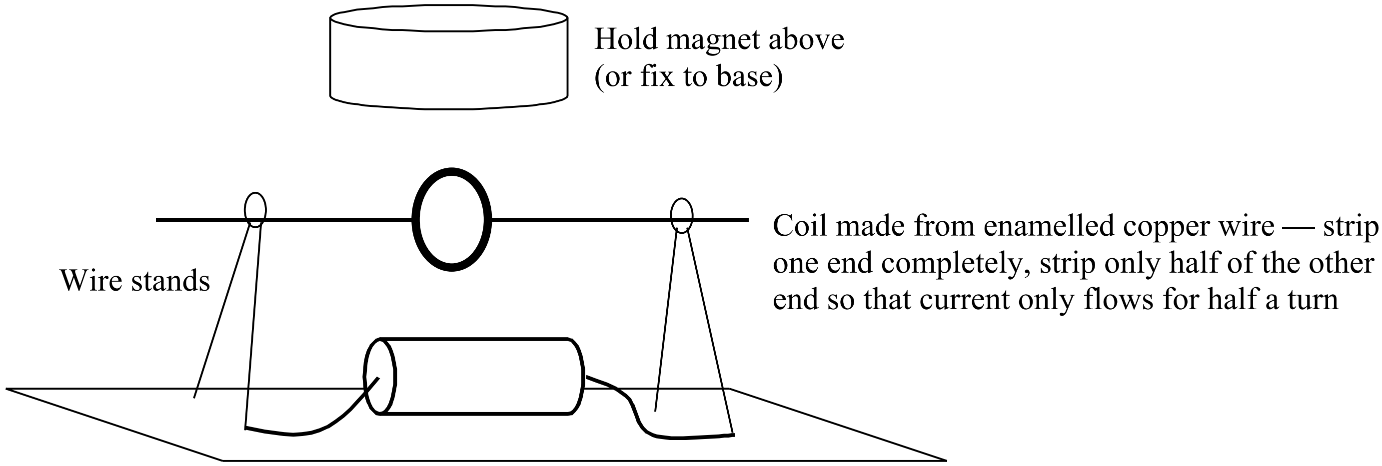
With a really strong magnet you have time to watch it fall. For a twist, if you have the tools, you can cut a thin gap down the length of the tube so that the eddy currents do not have a complete circuit around the pipe. This reduces the amount of current that can flow in the pipe – though it can still flow in small circles within the wall of the pipe.



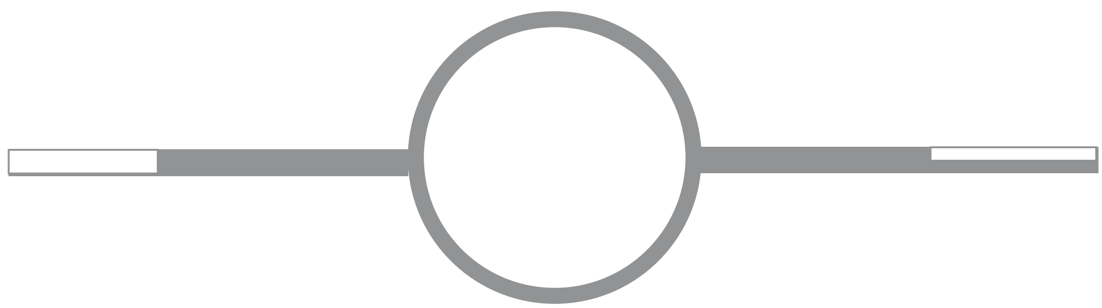
Motors

Applying the motor effect to make a real motor involves some thought. The first step is noting that circular motion is much easier to sustain than linear motion (this is perhaps worth discussing with students — it may or may not be obvious to them, or to you, why a linear motor isn't easy to build).

The DC motor is the easiest to build: all you need is a battery, a magnet, some insulated wire (the type where the wire is galvanised and the coating can be stripped off easily, not the kind sheathed in plastic) and some supporting scaffolding.



A DC motor needs a *commutator* of some kind because you need to swap the direction of the current in the coil twice each rotation. This simple motor has a primitive version of a commutator — the insulation is stripped around only half of one end so that the current only flows during half of each turn:



That's a simple motor. For more complex motors, you may have a motor kit at your school that incorporates split-ring commutators, multiple coils etc. If you don't, we recommend searching for some old commercial motors you can rip apart. Motors from washing machines, starter motors from car engines, motors from toys or household appliances – the older the better, since modern motors are often sealed inside moulded plastic casings that make them hard to get at.

Pull the motor apart and identify the bits. Is it AC or DC? An induction motor? Single or multi-phase? Being able to identify the different parts and figure out how the motor works demystifies the object and reinforces the ideas.

If you can get your hands on a generator — a dynamo from bike, an old fuel generator or similar — you could try pulling that apart to see what you can find. You could try using a motor as a generator, though only some kinds will work this way. (Motors that don't have *permanent* magnets won't work as generators because there is no magnetic field to induce a current unless a current is already flowing … a bit of a circular argument there. Worth seeing if the students can work this out.)

A few web resources

- The UniServe Science site for the Motors and Generators module — a whole pile of information and links: http://science.uniserve.edu.au/school/curric/stage6/phys/motors/
- The UNSW HSC web site: http://www.phys.unsw.edu.au/%7Ejw/HSCmotors.html

- One particularly good link: ‘Magnet Man’ Rick Hoadley, all sorts of experiments and explanations: http://www.execpc.com/~rhoadley/magindex.htm
- Interactive Java tutorials on electromagnetism, including magnetic fields, induction, generators, Lenz’s law, speakers and transformers: http://micro.magnet.fsu.edu/electromag/java/index.html
- The HyperPhysics site at Georgia State University — good set of brief, succinct explanations that are all cross-referenced: http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/elemot.html