Making an Electromagnet

Note: The electrical unit for current is the ampere (A), for voltage the volt (V), and for resistance the Ohm (Ω).

To make an electromagnet, you wind a coil of wire around an iron core and connect the ends of the wire to a battery. You will be more successful if you do some calculations so that the size and length of the wire are a good match to the capabilities of the battery. The following notes provide an example of those calculations.

We will use an alkaline D-cell battery. On Wikipedia, we can see that such batteries have an energy rating of 1.5 ampere-hour (A·h) each, meaning each can supply a current of 1 A for $1.5\,\mathrm{A\cdot h}/1\,\mathrm{A} = 1.5\,\mathrm{h}$. When supplying much less current, a D-cell battery provides 1.5 V, but at a current of 3 A, a specifications sheet from the manufacturer shows that it will only provide about 1.2 V for about 10 minutes. Ohm's Law tells us that if 1.2 V is to cause 3 A to flow through a coil of wire, the resistance of the wire must be

$$V = I \cdot R \;\Rightarrow\; R = \frac{V}{I} = \frac{1.2\,\mathrm{V}}{3\,\mathrm{A}} = 0.4\,\Omega \quad .$$

A commonly available, plastic-insulated wire, called "hook up" wire, is used for making simple circuits. I have some that is 0.60 mm in diameter. Checking the "wire tables" at *http://www.powerstream.com/Wire_Size.htm*, I find that this wire will have about 60 Ω/km or 0.060 Ω/m. For 0.4 Ω, I would need to wind 6.7 m of wire. That is too much. It is better to use "magnet wire" that has a very thin insulating coating so that many turns of wire can be wound in a small space. Magnet wire can be bought on-line at *http://mouser.com* (search for part number 566-8055 for a 1/2 pound spool of #30 magnet wire).

I used that size of magnet wire to make the 4000-turn high voltage coil for a transformer demonstration. My wire is "30 AWG" (American Wire Gauge 30) which the table tells me has 338 Ω/km or 0.338 Ω/m and is 0.254 mm in diameter. 1.2 m of that wire should produce a coil with about 0.4 Ω of resistance. The wire table also tells me that the wire is rated to handle up to 0.86 A, a much less than my intended 3 A. Still, we should be able to make 3 A go through it for a short time without burning out the wire; the wire tables have very conservative (safe) values.

The best iron core would be pure "soft" iron, although steel nails can be used. My wife is delighted to get rid of our vast collection of rusty 16d (16 “penny”) nails. They are 3.7 mm in diameter and 87 mm long. To protect the wire insulation from damage and prevent shorting between the wire and the nail, we need to wrap painter's tape around the nail in a manner that prevents our thinly-insulated wire from touching the metal of the nail. The circumference of the nail, tape layer and two layers of windings averages to about 4.5 mm. The 1.2 m of wire will be used up with about

$$\frac{\text{wire length}}{\pi \cdot (\text{average winding dia}) \cdot (\text{nbr of layers})} = \frac{1.2\,\mathrm{m}}{\pi (0.0045\,\mathrm{mm}) \cdot 2\,\text{layers}} \approx 42\ \text{turns/layer}$$

42 tightly-wound turns would make each layer $(42\,\text{turns}) \cdot (0.254\,\mathrm{mm}/\text{turn}) \approx 11\,\mathrm{mm}$ long. In fact, 42 turns will probably be more like 13 mm of imperfectly-wound turns.

The insulation on this type of magnet wire is usually removed by the heat of a soldering iron allowing the wire to be "tinned" for easy contact. Instead, we will gently scrape the insulation off with a razor blade. It is important not to nick the wire or it can easily break apart with further handling. Also, avoid kinks in the wire; they also weaken it.

The strength of an electromagnet is proportional to the product of the number of turns and the current. For the magnet in the previous paragraph this product is $(2\ \text{layers}) \cdot (42\ \text{turns/layer}) \cdot (3\ \mathrm{A}) = 252\ \mathrm{A} \cdot \text{turns}$.

Designing a stronger magnet involves a trade off: More current requires bigger wire. More turns for the same current requires more voltage.

There is still a magnetic effect without the nail, but the nail greatly enhances the magnetism because iron has magnetic domains that are normally random. The coil aligns the domains with an effect of producing an enhanced magnetic field. Some materials retain their magnetism after the magnetizing field is removed. They are called permanent magnets, but even they will lose their magnetism if heated to a sufficiently high temperature.