

# Repeating the electromagnetic experiments of Michael Faraday

John Bradley

**Teachers and students are encouraged to read Faraday's own accounts of his experiments. Some may find it worthwhile to repeat some of the experiments themselves.**

Faraday's experiments in September 1821 were the start of his researches in electromagnetism. His experimental techniques and direction of thought show a clear understanding of the developing science. The fact that he knew that he had made a discovery on the first day, and that his subsequent experiments were to compare his observations with those of Ampère, show the same awareness. In fact, he wrote how well prepared he was (Faraday 1823). He explained that while preparing a paper on the state of the science at that time (Faraday 1821a), he had spent the previous three months reading all of the recently published papers on electromagnetism and repeating for himself many of the experiments described in them. He had also assisted Humphry Davy in electromagnetic experiments over the previous year, including the deflection in a rotating manner of an electric arc with a magnet. So, on 3 September, he was very well prepared for the work that followed, and well aware of the experimental work and techniques of other philosophers.

This article is written to encourage the reading of Faraday's own accounts of his experiments. As James Clark Maxwell said in the preface to his *Treatise in Electromagnetism* in 1873:

'I would regard it as an accomplishment to communicate to others the same delight which I have found myself in reading Faraday's researches.'

It is also hoped that some teachers or students might try repeating the experiments either in a

modern version or by attempting faithfulness to the original version (see figures 1 and 2). In either case, there are rewards of increased knowledge and acquisition of skills; it is also very enjoyable.

## September 1821 experiments

On 3 September, Faraday started by repeating one of Oersted's 1820 experiments in which a vertical conducting wire was moved along the side of a horizontal magnetic needle. In the first sketch in his Diary that day (see figure 1) the needle would appear to be suspended, as he is recording forces at its centre. On closer examination, he found that, as the wire approached the pole of the needle, the attractive and repulsive forces increased, but then reversed as the wire passed the pole and reached the end of the needle. A dot has appeared in the second sketch, which could indicate that the needle is now pivoted. Certainly, the experiment is easy to repeat in a few seconds with a pivoted needle, but is very difficult with a freely suspended needle (Gooding 1989).

Paragraphs 4–13 outline the experiments made during the rest of the day (see figures 1 and 2 and also David Gooding's article in this issue). Finally, he achieved a rotation, that is, a wire moved continuously around a magnet.

The following day, he made a new apparatus with greater sensitivity. This is the one normally used today to demonstrate Faraday's discovery (see figure 2 of David Gooding's article):

'A deep basin with a bit of wax at the bottom and then filled with mercury, a magnet stuck upright in wax so that the pole is just above the surface of the mercury, then a piece of wire floated by cork, at lower end dipping into mercury and above into a silver cup as before, and confined by wire or capillary attraction from leaving the M. Pole.'

He was also successful in making a vertical floating needle rotate round the conductor, but was

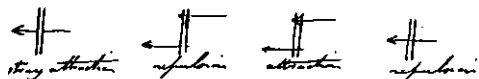
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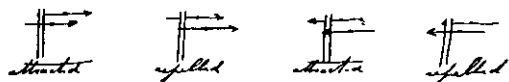
SEPT. 3RD, 1821.

Electromagnetic expts. with Hare's Calorimotor. To be remembered that this is a single series?

1. Position of the expt. wire A'.
2. Positions at first ascertained were as follows



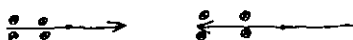
3. On examining these more minutely found that each pole had 4 positions, 2 of attraction and 2 of repulsion, thus



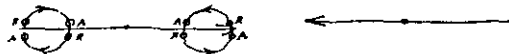
4. Or looking from above down on to sections of the wire



5. Or



6. These indicate motions in circles round each pole, thus



Hence the wire moves in opposite circles round each pole and/or the poles move in opposite circles round the wire. To establish the motion of the wire a connecting piece was placed upright in a cork on water; its lower end dipped into a little basin of mercury in the water and its upper entered into a little inverted silver cup containing a globule of mercury; the arrangement of battery poles always as at first.

**Figure 1.** Thomas Martin's transcription of Faraday's *Diary* for 3 September 1821. The sketches are vol 1, p 49). (Reprinted by courtesy of The Director of The Royal Institution.)

unable to make a magnet rotate on its own axis. So in a remarkable series of simple steps, Faraday had moved from Oersted's experiment to discovering the rotation of conductors and magnets around each other.

Similar experiments by French philosophers had demonstrated linear attractive forces between conductors, or between conductors and magnets. Their apparatus tended to be robust with fixed pivots. Ampère had also experimented with a current-carrying wire wound as a helix and believed it behaved exactly like a magnet (Williams 1989).

Faraday was familiar with this work. That he was able to produce a rotational effect, which no one else had reported, appears to be due to the freedom of movement provided by the way in which he designed and assembled his apparatus. He later mentioned that the difficulty with all rotational experiments 'was to make the apparatus sufficiently delicate for motion, yet affording sufficient mass of matter for contact'. This problem is also found when trying to repeat them.

Faraday spent the next few days in a fuller exploration of the rotational effects. He repeated many of Ampère's experiments to explain Ampère's observed linear forces in terms of his own observed rotational forces. These experiments provide an interesting set of phenomena which can help a student understand basic electromagnetic effects.

Faraday found that the type of effect, rotational or linear, depended on the wire/pole combination: a single-wire/single-pole combination produced rotational effects, while a double-wire/single-pole combination or a single-wire/double-pole combination produced linear effects. He demonstrated this on 4 September by connecting two wires from a voltaic cell into a basin of water with a little mercury in the bottom for good contact. A magnetic needle, inserted through a cork to float vertically, moved in a straight line between the wires. When the needle was floated horizontally, it moved to the nearest wire, not by either pole but by its centre point. Removing the wire and placing it on the other side of the needle, caused the needle to move away from it. He deduced that the apparent linear forces could be explained by rotational forces around the wires (see figure 3(a)).

On 5 September, he experimented with an apparatus designed by De la Rive. The apparatus was:

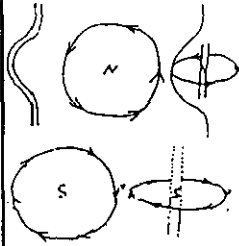
'a small voltaic combination floated by a cork, the ends of the zinc and copper slips come through the cork and are connected above by a silked wire which has been wrapped four or five times round a cylinder, and tied so as to form a close helix about one inch in diameter. When placed on conducting water it is very obedient to the magnet and serves admirably to transfer the experiments with straight wires into similar ones with helices.'

The experiments demonstrated that this floating helix would recede from the magnet, turn round to approach it and move along it to its centre. Freedom of movement was again fundamental to the experiment. The movement was explained by a horizontal section through the apparatus (see figure 3(b)). The movement of the helix was the resultant effect of the pole passing between two wires with currents in opposite directions.

On 6 September, with the same apparatus, he showed that:

'a circular wire forming part of the connection between the poles of a battery, would be directed by the earth's magnetism to stand in a plane perpendicular to the magnetic meridian.'

The apparatus was slightly improved by placing it in a small flask of its own, to avoid the unsteadiness caused by the gas liberated from the plates.



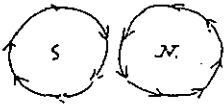
power brought perpendicularly to this wire did not make it revolve as Dr. Wollaston expected, but thrust it from side to side. 8, 9. The wire then bent into a crank form, thus, and by repeated applications of the poles of the magnets the following motions were ascertained, looking from above down on the circle described by the bent part of the wire, different Magnetic poles shewn by letters, North pole in centre. The rod in the circle is merely put there to shew the front and back part.

10. Magnetic poles on the outside of the circle the wire described\*.

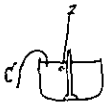
11. The effort of the wire is always to pass off at a right angle from the pole, indeed to go in a circle round it; so when either pole was brought up to the wire perpendicular to it and to the radius of the circle it described, there was neither attraction nor repulsion, but the moment the pole varied in the slightest manner either in or out the wire moved one way or the other:

12. The poles of the magnet act on the bent wire in all positions and not in the direction *only* of any axis of the magnet, so that the current can hardly be cylindrical or arranged round the axis of a cylinder?

13. From the motion above a single magnet pole in the centre of one of the circles should make the wire continually turn round. Arranged a magnet needle in a glass tube with mercury about it and by a cork, water, etc. supported a connecting wire so that the upper end should go into the silver cup and its mercury and the lower move in the channel of mercury round the pole of the needle. The battery arranged with the wire as before. In this way got the revolution of the wire round the pole of the magnet. The direction was as follows, looking from above down [see diagram].  
Very Satisfactory, but make more sensible apparatus.

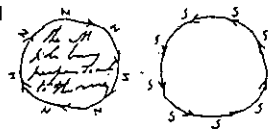


#### TUESDAY, SEPT. 4.



14, 15†. Apparatus for revolution of wire and magnet. A deep basin with bit of wax at bottom and then filled with mercury, a Magnet stuck upright in wax so that pole just above the surface of mercury, then piece of wire floated by cork, at lower end

\* [10]



† [14, 15]

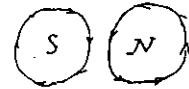


Figure 2. Continuation of Martin's transcription (Martin 1932-6, vol 1, p 50). (Reprinted by courtesy of The Director of The Royal Institution.)

In the remaining days he compared the magnetic characteristics of various current-carrying helices and magnets, including hollow cylindrical magnets. He disagreed with Ampère's view that they were identical (Williams 1989). He examined the location of the poles of a bar magnet by holding it over a vertical needle, stuck through a cork floating on water. It moved to a point on the axis of the magnet a little distance in from the ends. Placing a piece of soft iron at the end of the magnet caused the needle to float towards the end of the soft iron. Similar results were obtained with a horseshoe

magnet, but when the soft iron bridged the gap between the poles as a keeper, the floating magnet moved the other way, along the arm of the horseshoe (see figure 3(c)). He also noted that similar poles of magnets 'repel at most distances, attract at small distances and adhere'. This observation may seem surprising, but is true with weak iron magnets. The series of experiments 'On some new electromagnetical motions' was published in December (Faraday 1821b). When Ampère read the paper, he repeated the experiments, developed new versions of his own, and was also able to

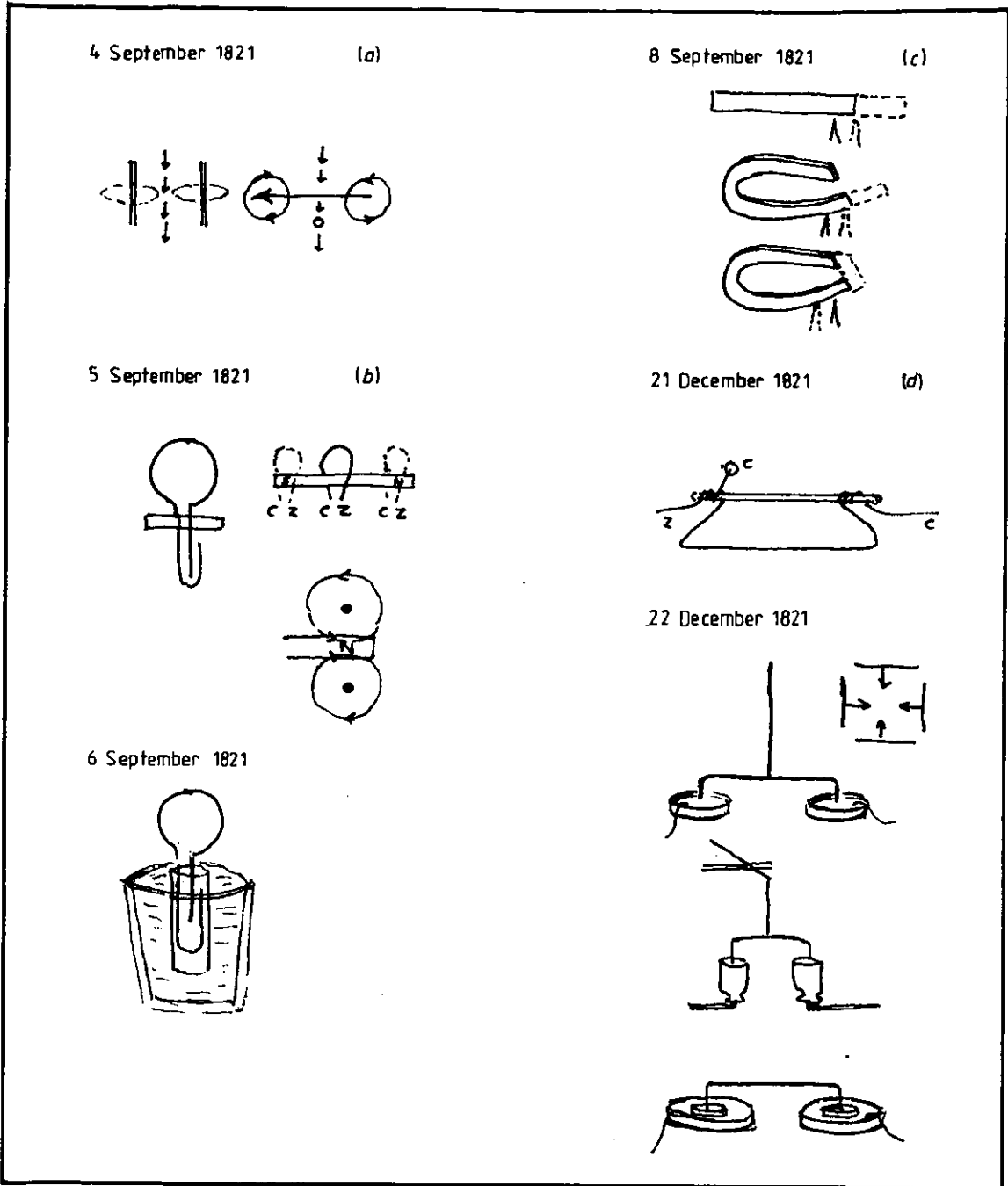


Figure 3. Various sketches from Faraday's *Diary* (see Martin 1932–6).

make a current-carrying magnet rotate on its own axis.

### December 1821 experiments

In December Faraday continued the experiments (see figure 3(d)). First, a horizontal crank-shaped

wire, balanced on a pivoted glass rod and connected to a battery, was made to move up and down by the Earth's magnetism. Next, a horizontal wire, hung from the ceiling by a silk thread and dipping into two basins of mercury, moved horizontally and laterally when a current passed. The direction of motion was always at right angles

to the wire itself, and he concluded 'It was evidently the attempt of the wire to rotate round the pole of the Earth.' He repeated the experiment with the wire supported by cork floats, but the motion was sluggish due to the surface tension of the mercury on the cork floats.

Ampère had earlier found that a pivoted loop of wire, in which a current passed, would rotate in the Earth's magnetism. Faraday appears to be repeating this experiment (but using a horizontal wire instead of a loop in order to reduce the effect to the rotation of a single wire about a single pole). Finally, on 25 December, he repeated his 5 September rotational experiment, but this time the wire was inclined at an angle greater than the angle of dip, and he used the Earth's magnetism instead of a magnet.

### Repeating Faraday's experiments today

Faraday's experiments demonstrate basic electromagnetic effects, and can be rewarding for students to repeat. The apparatus can be simple and the results are qualitative. There is indeed no set apparatus nor particular ways of assembling it together. Half the fun comes from assembling it; thus the student is in a similar position to any scientist reading Faraday's report and trying to verify his findings. Some experiments do not work until skills in balancing power, sensitivity and mechanical freedom have been gained. In class, individual groups can select and assemble the apparatus in their own way for a specific experiment, or groups can attempt different experiments and share their learning.

The main decision is whether to use traditional materials of the time or modern equivalents. A sensible approach is to achieve the effect with modern materials first, and then consider whether traditional materials can be obtained. Traditional materials are described in books and papers of the day. Faraday's own book *Chemical Manipulations* (Faraday 1827) provides a good reference. A design for a compact voltaic cell can be found in his diary for 17 January 1834, although plate areas as small as six square inches ( $39 \text{ cm}^2$ ) were used by Sturgeon in apparatus he designed for public demonstration in the mid-1820s.

I suggest using a constant DC power supply unit initially. A car battery charger will work equally well. An ammeter should be provided in the circuit to show that the circuit is made, even if the effect is absent. A car battery can be used, but the circuit resistance of the apparatus would then need to be juggled because there are high short-circuit currents inherent in the experiments.

Many experiments involved mercury, which needs to be replaced by dilute salt solution or weak acid today in accordance with safety regulations. Both have a lower conductivity than mercury, and gassing tends to reduce the time for which the experiment will function, although reversing the polarity will extend the time a little. Other materials are no longer freely available: for example, wire was usually of iron, either bell-pull wire or haberdasher's silked wire.

Probably the quickest and cleanest way of illustrating some of the effects is suggested by Colin Siddons (1962). He repeated many of the 1821 experiments, and found that the current required to mechanically move a wire made the wire glow red hot and sag. However, balancing power, sensitivity and mechanical freedom, he successfully used narrow strips of aluminium foil. A narrow strip of aluminium foil, hanging alongside a vertical bar magnet, will immediately wrap itself round the magnet when connected to a power supply. Similarly, a catenary of foil hanging between two supports will deflect laterally in the Earth's field, while a loosely hanging loop will open slightly and then twist into the meridian. Oliver Lodge used gold thread from military uniforms as a similar flexible conductor in his 1889 book *Modern View of Electricity*.

It can prove difficult to make a current-carrying wire rotate in the Earth's magnetism; usually only partial rotation can be achieved. Making a current-carrying magnet rotate on its own axis is worth attempting. Ampère achieved this using a narrow glass jar in which a magnet floated with its upper half above the mercury, and a current passed between the top of the magnet and the mercury. However, the effect can be achieved by clipping a wire to the end of a small magnet, floated vertically in weak salt solution, the wire being free to rotate in an upper terminal. Another rotation experiment to try is that described by Faraday on 22 January 1822. He had reasoned that the rotational forces were due to the current of electricity and the magnetic pole, and that the wire and the iron only gave location to these forces. Therefore in his 4 September experiment, the wire ought to move round the magnet though the magnet turned with it. Tying the wire to the magnet achieved this effect. Again, the same suspension is useful when repeating this experiment.

I have only given details of Faraday's 1821 experiments. His 1831 experiments on induction can also be repeated easily using a modern mirror galvanometer. These become more interesting using Faraday's galvanometer, which can be made

*Article concluded on page 312.*

in five minutes to his instructions. A needle is first magnetized, then broken in two and inserted in opposite directions through a short piece of dried grass to form an astatic pair. This assembly is then suspended by a length of unspun silk in a glass jar to protect it from draughts, and a coil of 15 turns of copper wire placed alongside the lower needle. The galvanometer will be sensitive to a few hundred microamps with little trouble, and can be made more sensitive by experiment. It can also be used instead of an ammeter in the rotation experiments.

In summary, I hope this article will encourage others to read Faraday for themselves. They will find that this quickly puts them in a position to critically read what others have written about him, and they will not be alone in being dissatisfied with merely logical explanations of discovery (Crawford 1985). Repeating the experiments can add meaning to the original text, and the practical aspects can appeal to science students. It also adds to the appreciation of the depth of skills embedded in early electromagnetic experiments and, although

no new facts are provided, it illuminates the nature of both the man and his work.

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