1996

Devices to display electromagnetic rotation

Tom Greenslade
Kenyon College, greenslade@kenyon.edu

Follow this and additional works at: https://digital.kenyon.edu/physics_publications

Part of the Physics Commons

Recommended Citation
Devices to display electromagnetic rotation
Thomas B. Greenslade Jr.

Citation: The Physics Teacher 34, 412 (1996); doi: 10.1119/1.2344506
View online: http://dx.doi.org/10.1119/1.2344506
View Table of Contents: http://scitation.aip.org/content/aapt/journal/tpt/34/7?ver=pdfcov
Published by the American Association of Physics Teachers

Articles you may be interested in
The physics of air-bag sensors
Phys. Teach. 34, 524 (1996); 10.1119/1.2344552

Animated displays VI: Electrostatic motors and water dropper
Phys. Teach. 34, 491 (1996); 10.1119/1.2344540

Electromagnetic coillage launcher for space applications

An eclectic outsider: J. Willard Gibbs on the electromagnetic theory of light

The Michelson experiment in the light of electromagnetic theory before 1900
Devices to Display Electromagnetic Rotation

By Thomas B. Greenslade, Jr.

Michael Faraday is best known for his discovery of electromagnetic induction, first published in 1831. The applications of this work, ranging from electrical transformers to tuning circuits, have had enormous influences on our modern lifestyle. Less well known, although having an effect of the same magnitude, is his discovery of electromagnetic rotation.

In the summer of 1821, while working at the Royal Institution of London, Faraday started to repeat the recently published experiments of H.C. Oersted on the deflection of a compass needle by the current passing through a nearby wire. When he first started examining the situation in which a bar magnet was parallel to the current-carrying wire, Faraday assumed that the force on the magnet or the wire would be along the line connecting them. To his surprise, he discovered that the force was to the side. The wire would tend to travel in circles around a fixed magnet pole, or the magnet pole would tend to travel in circles around a fixed wire.

The apparatus pictured here to illustrate the phenomena of electromagnetic rotation was made by Daniel Davis, Jr. (1813–1887), a "magnetical instrument maker" of Boston. He worked closely with members of the American scientific community, including electrical inventor Charles Grafton Page, and produced a catalog, *Davis's Manual of Magnetism*, which was issued in various editions from 1842 to 1851. Some of these devices, such as Barlow's wheel, remain as basic demonstrations of physical principles; others have led to technologically important devices.

My hope is that physics teachers and students will use the pictures and descriptions of these devices to create modern versions of them and use them as the basis for blackboard diagrams.

![Fig. 1. Faraday's rotating wire apparatus.](Image)
Electromagnetic Rotation

Figure 1, taken from an article by Faraday,\(^2\) shows both possible cases of the relative motion in electromagnetic rotation. Current passes from the top conductor to a mercury bath, shown with its usual negative meniscus. On the lefthand side, a bar magnet, submerged partly in the mercury, is pivoted freely at its lower end, and the upper pole describes a circle around the fixed current-carrying wire. The righthand apparatus shows the same magnet, again submerged in mercury with only one pole showing, but this time held in place. The lower end of the pivoted current-carrying wire now describes a circle around the magnet. A description of the apparatus is also contained in Sutton.\(^3\) Note the large surface area of mercury exposed to the atmosphere. (Recall how dangerous such an arrangement would be in a closed room.) In both cases a current element interacts with magnetic field lines at right angles to it to produce a force in a mutually perpendicular direction.

Faraday’s discovery led directly to the apparatus in Fig. 2,\(^4\) first described by Peter Barlow in 1822,\(^5\) and now known as Barlow’s wheel. A copper wheel with its edge cut into a dozen or more points ran in the bearings of the swan’s neck, and as the wheel revolved, the points dipped, one by one, into a mercury-filled trough in the base between the poles of the magnet. A battery connected to the center of the wheel and to the mercury pool caused a current to pass radially through the wheel and perpendicular to the magnetic field lines; the interaction between the field and the current made the wheel revolve.

The toothed wheel that Barlow used is effectively a series of stiff wires mounted radially. William Sturgeon soon recognized that the points were not essential, and later versions of the apparatus used a smooth-edged copper wheel. In Barlow’s original experiments, a current-carrying wire was suspended in place of the wheel. He wrote: “After having been repeating Mr. Faraday’s rotating experiment, the young man who was assisting me [James Marsh] wished to try the effect of the horse-shoe magnet upon the freely suspended galvanic wire, as it hung with its lower end in the mercury. The wire was immediately thrown into a rapid oscillating motion, flying completely out of the mercury; when the contact being thus broken, it fell by its own gravity to be again projected, and so on, as long as the action of the battery lasted.”\(^6\) A cut of Marsh’s apparatus from the 1842 edition of the Manual of Magnetism is shown in Fig. 3.

Rotational motion could be given to current-carrying wires using the apparatus in Fig. 4, which Davis called a revolving wire frame. Here the current is carried downward along the light frames of copper wire that are pivoted on sharp points resting on agate bearings at the top of each end of the permanent U-magnet. Free rotation along with continuous electrical contact is provided by mercury cups in the tops of the frames; the lower ends of the wire dip into mercury-filled ivory troughs.

The analysis of the direction of rotation is straightforward, using the righthand rule, and knowing the direction of the field lines running from the north to the south pole. With the current downward in both frames, the frames contra-rotate. The nineteenth-century analysis was quite different: a magnetic pole was known by experiment to rotate in a certain direction around a current-carrying wire, and Newton’s Third Law was then used to shift to the situation in which the pole was stationary and the wire free to move.

Faraday had discovered that the wire would revolve around the magnetic pole even if the magnet itself rotated with the wire. Joseph Abbot\(^8\) developed the appa-
Apparatus in Fig. 5 to demonstrate the phenomenon. A comparison between this apparatus and Abbot's illustration shows that the device originally had two conductors coming out from opposite sides of the brass ring at the top of the magnet, and curving down to dip into the annular ring of mercury.

Apparatus to demonstrate the inverse case, in which the isolated magnetic pole is made to revolve around the current-carrying wire, is shown in Fig. 6. The magnet itself is offset in the middle, and the current is parallel only to the upper half of the magnet, being led off at the midpoint of the magnet by the wire dipping into the mercury trough. The advantage of this 1828 design by Francis Watkins (who was the curator of philosophical apparatus at the London University) over the original Faraday demonstration is the reduction in the amount of mercury needed: a narrow annulus instead of a trough.

There are other variations on the basic idea of the current-carrying wire revolving around the isolated pole. Ampere discovered in 1821 that the current may be carried through the upper half of the bar magnet itself, which is pivoted to rotate about its own axis. The Davis apparatus in Fig. 7 shows how mercury contacts are used to make continuous electrical connections to the bottom and middle of the rotating magnet. Reversing the direction of the current causes it to revolve in the opposite direction.

Electric Motors

The remaining pieces of apparatus may be recognized more readily as motors. The majority of these were designed by Charles Grafton Page (1812-1868) or developed from his suggestions. Page, at various times in his positions of physician, patent examiner, and patent agent, spent the years from 1836 to 1839 as an electrical scientist and inventor. The biography of Page by Robert C. Post gives a very clear picture of the scientific environment in which Page worked, and should be read by those who are trying to understand the emergence of American science in the first half of the nineteenth century.

In 1837, Page developed an electromagnetic apparatus in which a current-carrying coil was made to revolve between the poles of a U-magnet. The key point of identification is the pole-changer (today we would call this a commutator), which is used to reverse the direction of the current in the ring every half turn (see Fig. 8). This invention of Page consists of a pair of silver semicircles placed on either side of the shaft and insulated from each other and from the shaft. The ends of the coil are soldered to the semicircles, and contact from the external galvanic circuit is made through a pair of leaf springs passing through insulating sleeves in the magnet. Page wrote: "I believe this is the first instance of the rotation of a conductor, effected by reversing its tangential action." Davis offered a second version in which the coil was rectangular, with the long axis vertical. Rotation rates up to 10,000 rpm were reported.
In the paper in which he describes the rotating coil, Page also shows the coil replaced with “the electro-magnetic cylinder of Ampere” which has a “helix...wound on a cylinder of hard wood, loaded with two buttons, one at each end, to give it weight.” The step to the revolving electromagnet of Fig. 9 consists of replacing the wood armature with one of soft iron. The design of the pole-changer can be seen clearly with this apparatus. In the illustration in the second edition of the Manual, the connections to the voltic circuit were made through mercury-filled cups, which have been replaced by the more familiar, and much safer, screw terminals on the instrument shown.

Some Davis motors were equipped with bells to aid in measuring their rotation rate. A version of the Page motor was made with the entire system inverted, the U-magnet opening downward, and the rotating armature at the bottom of the shaft. A worm gear on the shaft drove a large gear that drew back a hammer every 100 revolutions, and the falling hammer struck the bell. The extra mechanism did slow down the rotation rate of the armature somewhat. A more instructive variation of the basic design was the replacement of the permanent U-magnet with the equivalent electromagnet.

The design of the Page rotating electromagnet has survived in the small, permanent-magnet direct-current motor, albeit with the magnetic circuit shaped in a more favorable fashion. For the rest of the century these basic Page-type motors were often used to drive siren disks, rotating mirrors, Newton’s color disks, etc., as well as being demonstrations in their own right. The nineteenth-century physics instructor regarded the apparatus as more than a motor. Benjamin Silliman’s 1860 text shows a woodcut of the Page motor as made by Davis, and writes: “Page’s revolving electro-magnet affords satisfactory evidence of the great rapidity with which a mass of soft iron may receive and part with magnetism.”

**Conclusion**

Antiquarians and pure historians of science study historical apparatus for its own sake, placing it in historical, technological and human contexts. The teaching physicist requires that the apparatus earn its own place by demonstrating physical principles. The clean and simple designs of the Davis and Page instruments lend themselves admirably to showing the phenomena.

The two largest collections of Davis apparatus are in the Collection of Historical Scientific Instruments at Harvard University and at the Smithsonian Institution. I would be interested in hearing from faculty members at other institutions that have one or more pieces of Davis apparatus.

**References**

1. Besides Page, Davis collaborated with Robert Hare of the University of Pennsylvania, Benjamin Silliman of Yale, Moses Farmer (an inventor of electrical apparatus), Joseph Henry (at that time at Princeton), and John Webster of Harvard.


4. Taken from Davis’s *Manual of Magnetism* (Daniel Davis, Jr., Boston, 1842), p. 94. This sold for $3.50. Note the Davis product signatures of slightly flattened brass feet and turned brass finial.


7. From apparatus collection of Colby College; also in Davis’s *Manual of 1842*, p. 87. Cost $8; height 26 cm.


9. From Harvard University apparatus collection. Originally two wires curved out from brass band around top of magnet and dipped into mercury-filled annular trough. Height 32 cm.
A Space-Time Lullaby
(Indebtedness to Eugene Field)

Eddington, Einstein, and Jeans one night
Sailed off on an ether wave,
Sailed on a curve of celestial light
Into the cosmic cave.
"Where are you going and what do you seek?"
The Infinite asked of the three;
"We have come to measure a stellar streak
By the Quantum Theory
On which the universe leans—"

Said Eddington, Einstein, and Jeans.
They sailed and sailed in a relative way
Through a non-mechanical space,
Through a metaphysical night and day
At a post-Newtonian pace.
"Where are you going and why do you go?"
A Photon asked of the three;
"We have come to prove the inertial flow
Of an abstract density,
By gravitational means..."

Said Eddington, Einstein, and Jeans.
And the Infinite shrank as an Infinite should,
To a finite chamber of gas;
The Photon burst, as was well understood,
Into particles forming mass.
"But what am I?" cried the Lord to the three,
With a perfectly sweet intention;
"Why you are a part of our new theory,
Provided you cause no dissention,
Nor provoke unscholarly scenes..."

Said Eddington, Einstein, and Jeans.
And for all we know they are sailing still
These three, in Eventless Time;
But they must depend on an Abstract Will
To weather the nebular slime.
And should they come back, as perhaps they may
From that astronomical shore,
The spirit of Physics will lead the way,
And the prophets will number four,
With Jeans in command of the squad
Of Eddington, Einstein, and God.

Herbert Gerhard Bruncken

[This poem was printed in the April 1963 issue of The Physics Teacher. Reuben Alley drew it to our attention, suggesting that it bears reprinting.]