An Electromagnetic Induction Flashlight Experiment

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In the last several years, the electronics industry has released hand generator-powered flashlights, which are advertised as the end of battery-powered flashlights. This has become possible because of recent advances in capacitor, magnet, and LED technology. Nevertheless, the physics behind these flashlights is fairly simple.

New capacitor technology has increased voltage and capacitance while maintaining a small size. Neodymium magnets have both large magnetization and large coercive fields while remaining small in size. Improvements in LEDs make them comparable with the brightness of conventional incandescent bulbs while using significantly less power. The drawback of LEDs is that they are polarity-sensitive devices and therefore only operate efficiently with dc sources.

The shaker flashlights used in this experiment have only five components: a hand generator (see Fig. 2), an LED, a capacitor, a switch, and a full-wave bridge rectifier. Combining these components to make a flashlight fosters a rich understanding of some interesting physics:

- The students learn how mechanical energy is converted into electrical energy.
- They learn how alternating current (which is ill-suited for storage) can be rectified to be well-suited for storage.

This experiment is from our conceptual physics lab course for nonscience majors, in which we strive to emphasize the everyday applications of each lab. It is an ideal conclusion to an electricity section, because the technology involved is both cutting edge and common to students' everyday life. Upon completion of this lab, the students will not only have built a shaker flashlight but will have a good understanding of the ac adapters (which contain full-wave bridge rectifiers) they use to charge their cell phones and mp3 players.

Concepts

Hand Generators: An AC Source

This lab provides an opportunity to distinguish between the two types of currents: direct current (dc) and alternating current (ac). Batteries and charged capacitors are good examples of direct-current sources; they supply voltage with constant sign (either positive or negative) as time goes on. Wall sockets provide a supply of alternating current.

An alternating current means the direction of current flow alternates. This behavior is also denoted by an alternately positive or negative voltage in the circuit. A positive voltage provides current flow in a certain direction across a device, from the positive to negative terminal. A negative voltage provides current flow in the opposite direction across the device, from the negative to positive terminal.

When a magnet passes through a coil, as it does in our hand generator, it generates a double pulse. When one pole enters the coil, a voltage is induced with one sign (either positive or negative) across the terminals of the generator. When the opposite pole leaves the coil, a voltage is induced with the opposite sign. This type of double pulse is referred to as an ac pulse. The hand generators used in this lab consist of a powerful neodymium magnet in a tube with a coil wrapped around it, and therefore generate an ac pulse for each pass of the magnet through the coil.

Many devices (such as light bulbs) operate with either an ac or dc source. However, some devices (such as diodes, batteries, and some capacitors) are sensitive to voltage polarity. When the only available source is an ac source, an ac adapter can be used to convert an alternating current into a direct current and therefore provide a dc source for polarity-sensitive devices. A constituent part of an ac adapter is the diode, or rather four diodes arranged in a configuration that is called a full-wave bridge rectifier.

Diodes and Full-Wave Bridge Rectifiers

Diodes are the electronic version of a turnstile. A turnstile's gate allows people to pass only in one direction. Diodes also allow current to flow in only one direction; current is not permitted to flow in the opposite direction. This gate-keeping feature of the diode will allow us to rectify an ac source into a dc source.

An LED can only operate a given current in one direction. A single rectifier diode would provide such a dc source, but it would only retain half the signal from an ac pulse. To capture the entire ac pulse from the hand generator to power the LED, the current needs to be routed so that both pulses of current pass across the device in the same direction. The full-wave bridge rectifier is a combination of diodes arranged such that the entire signal is preserved. Figure 1 shows the two current paths mapped out by green and red arrows. One current path travels from left to right, and the alternate direction travels from right to left, but both pass through the LED in the same direction. With the use of an ac adapter, the ac source becomes a dc source for the LED.

Storing Electrical Energy with Capacitors

It is straightforward to convert mechanical energy into electrical energy, which then needs to be stored. It would be inconvenient to shake the flashlight the whole time it is operating, and it would also be hard to shine pulsing light on a particular object.

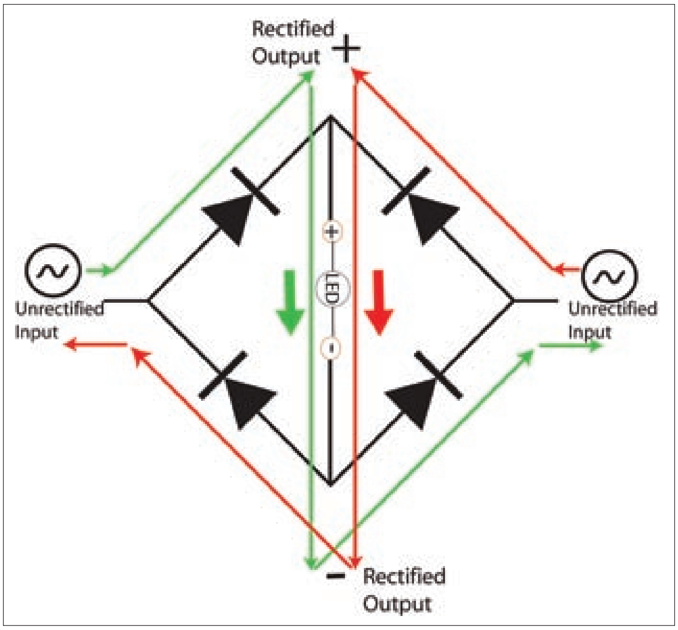

Fig. 1. Full-wave bridge rectifier.

Capacitors can store electrical energy and then release it as needed. They can be charged by a pulsing or steady source, so long as it is direct current. Using a rectifier, we can charge the capacitor with the hand generator and finally provide a steady, direct current to the LED. This creates a constant, bright beam of light on command just like a conventional battery-powered flashlight.

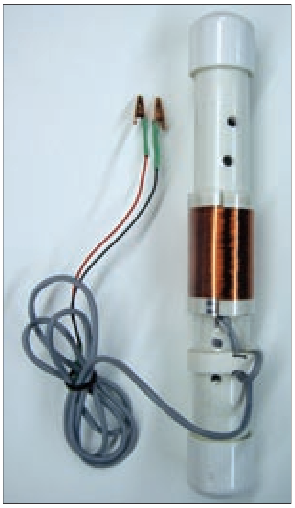

Fig. 2. Hand generator.

Fig. 3. Flashlight board.

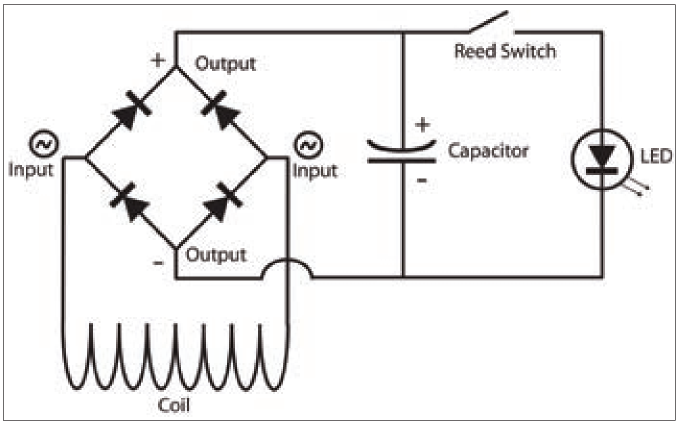

Fig. 4. Flashlight schematic.

Apparatus

There are only five components required for this lab: a hand generator, a capacitor, an LED, a switch, and four rectifier diodes. Connections are made using a standard stock of alligator leads.

The hand generators can be built easily using simple tools and materials. The chamber is made with PVC pipe and caps. The coil is wound with 30-gauge copper magnet wire with alligator leads soldered on each end. Our magnet is an inexpensive 1-in cylindrical neodymium magnet.

For improved lifespan of the electronic components, we attached them to acrylic "flashlight" boards. Alternatively, each electronic part could be used individually for easier production. More information on construction can be found on our website.[1] Additional information on the induction flashlights can be found at Ref. 2.

Experiment

Our labs follow an exploration-analysis-application cycle. In the exploration stage, the student groups investigate the properties of the hand generator and the diodes (both LED and rectifier diodes). They build a few simple LED and rectifier diode circuits. Initially, with a single LED and rectifier diode aligned alike, a single, brief pulse of light is observed per pass of the magnet through the generator coil. When the diodes are then counter-aligned, no flash is observed. The expectation is that the students will develop some informal concepts about the type of current the hand generator produces and how a diode behaves in a circuit.

In the analysis stage, through discussion, the lecturer formalizes concepts about current direction and diode function. From a more practical point of view, engineering flaws of a flashlight with only an LED and a hand generator are discussed. There are three main flaws: the LED strobes, half the mechanical energy of the operator is wasted, and the flashlight must be shaken while it is operating. The schematic and function of a full-wave bridge rectifier are introduced.

In the application stage, the students solve the engineering flaws and create a smoothly operating flashlight. They first build full-wave bridge rectifiers and use the rectified current to power the LED. This time, a double pulse of light is observed per pass of the magnet. The students have solved the wasted mechanical energy problem, and they must now solve the shaking and strobe-effect problems. Using the hand generator to charge a capacitor that will in turn power the LED is suggested to the groups. The students include the capacitor in the circuit, finally constructing a flashlight that operates smoothly.

Conclusion

The construction of this experiment requires some effort, but the components have a myriad of potential uses. This experiment elegantly concludes a section on electricity with a simple but rigorous application. The students must build on several concepts to optimize the flashlight. The full-wave bridge rectifier is a difficult concept, but it gives a rich understanding of diodes and ac circuits. There is a powerful "A-ha!" moment when the students compare the single pulse of just the hand generator across the LED with the double pulse of the rectified hand generator. Additionally, the students are utilizing materials that have only very recently become available and affordable; this adds a contemporary relevance missing from many other electricity labs.

References

1. http://www.lsa.umich.edu/physics/demolab.
2. For an excellent article on the engineering of the Forever Flashlight, see R.J. Nelson, "The Forever Flashlight II – Batteries Not Required," (November 2006); http://www.msscweb.org/Public/Forever%20Flashlight%20R2%20sans%20path.pdf.

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