Faraday's Principle And Air Travel In The Introductory Labs

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ABSTRACT

We all know that we must improve the quality of teaching in science at all levels. Not only physicists but also many students from other areas of study take the introductory physics courses in college. Physics introductory laboratories (labs) can be one of the best tools to help these students understand applications of scientific principles that affect our lives. However, traditional labs are considered by many students, especially non-physics majors, as uninteresting due to the lack of real life applications. In this study, we develop a lab experiment that uses air travel to understand one of the most important concepts in physics: the induced voltage per Faraday's law.

Keywords: Faraday's Principle; Introductory Labs; Real Life Physics

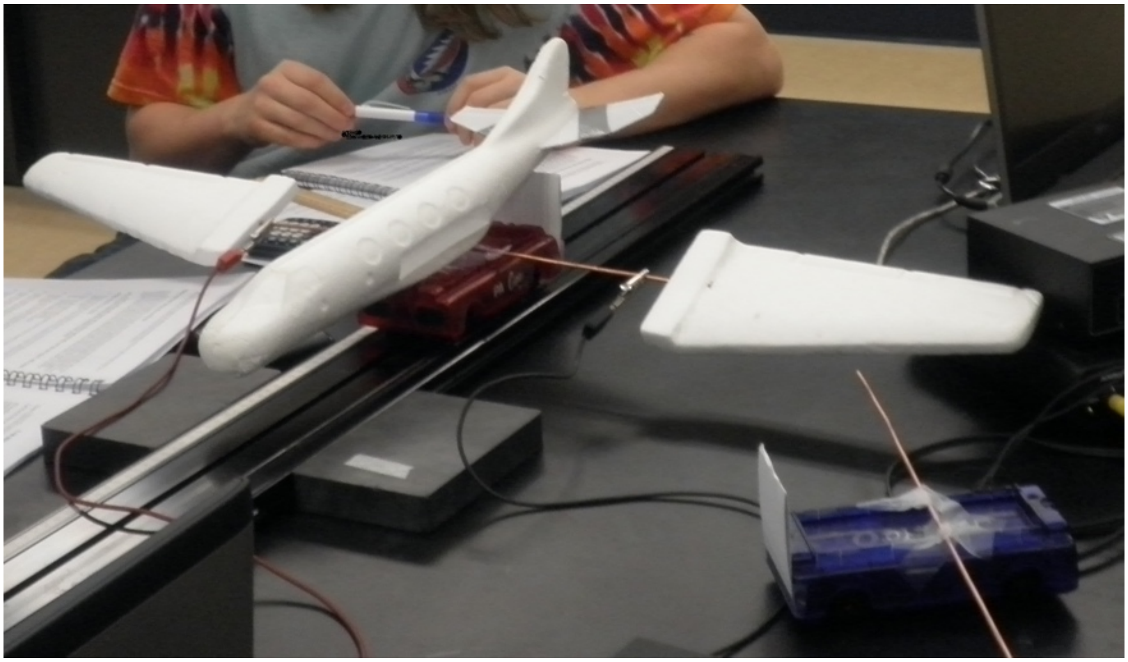
INTRODUCTION

One of the concepts that students do not grab well is Faraday's law of induction. A magnet in relative motion with a coil/solenoid leads to the production of a voltage across the coil called induced voltage – this is usually the experiment students do in a physics lab to understand Faraday's law. Often life-science majors and other majors who require taking physics courses in college cannot see the connection between the concepts of induction to their field of study by doing this traditional experiment. This kind of experience makes students devalue the physics course and see it as an obligation rather than a needy course. In their recent article, Meredith and Redish (2013) emphasized the importance of reinventing physics for life-science majors. As an alternative to a traditional experiment on Faraday's law, we developed a lab experiment that mimics the induced voltage generated across the wings of an airplane when it flies through the magnetic field of the Earth. This experiment shows the application of physics to real-life and provides hands-on, stimulating and interesting curriculum in a laboratory environment.

PROCEDURE AND MEASUREMENTS

We used a copper rod of *length l* of 0.6 m to model the wings of an airplane, see Figure 1. The copper rod was attached to a PASCO cart on a PASCO bench. We used two blocks of magnets to symbolize the Earth's magnet. The two ends of the rod were connected to a PASCO voltage sensor to measure the induced voltage **ε** across the rod while the rod was in motion at speed ***v*** over the blocks of magnets. A motion sensor measured the speed of the rod. A computer with Science Workshop Interface was used to collect data and draw plots.

Figure 1. A copper rod, partially covered with white 'airplane" foams, is attached to a cart similar to the blue cart shown on the bottom right of the figure. We placed two block magnets on the table under the model plane, to simulate the Earth's magnetic field.

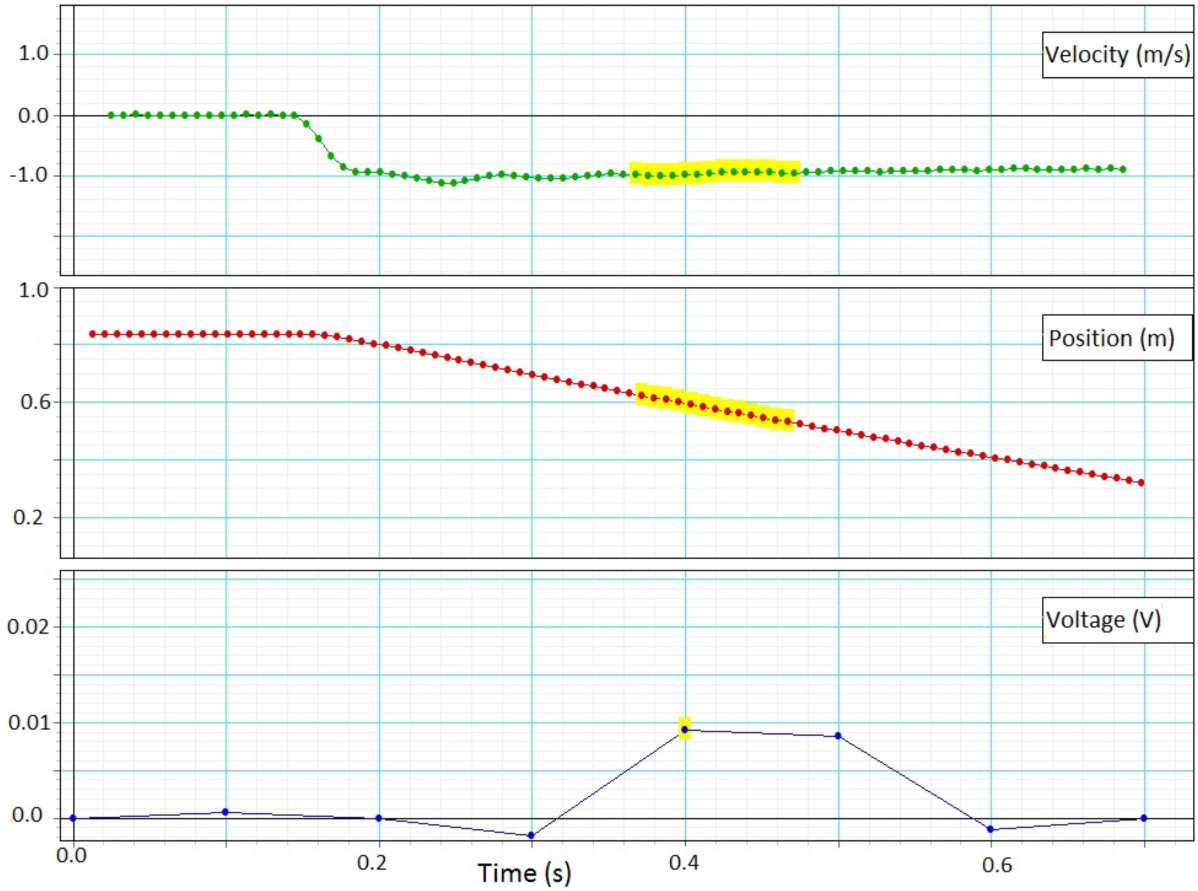


For mathematical simplicity, we assume that the magnetic field B from the block magnets is perpendicular to *l*. As presented in typical undergraduate Physics textbooks (Segway & Vuille, 2012), we show students how to derive equation (1) from Faraday's law to get the induced voltage ε generated across a moving metal rod through a perpendicular magnetic field:

$$\varepsilon = B\, l\, v \quad (1)$$

The student holds the cart with the attached copper rod and moves it uniformly as fast as possible over the magnets. The student succeeds after few trails to reach a fairly constant speed when the copper rod is over the magnets. The computer records the speed of the cart holding the rod, the position of the cart/rod, and the induced voltage ε generated across the ends of the rod. We show typical measurements in figure 2. The cart/rod passes over the magnets at the region highlighted in yellow in figure 2 – in that region, the speed *v* is 1 m/s and the corresponding induced voltage ε is about 9 milliVolts (mV). With these values of *v* and ε with *l* = 0.6 m, the mean magnetic field B from the magnets at the location of the rod can be calculated (using equation 1) to be equal to 1.50×10^{-2} Tesla. Different students can move the cart/rod at different speeds by hand, but they use the same kind of block magnets. Hence every student is expected to get approximately the same value for B, independent of the speed of the cart/rod.

Figure 2. Typical measurements obtained by students.



Top: velocity of the copper rod vs. time; **Middle:** the corresponding position of the copper rod vs. time; **Bottom:** The corresponding induced voltage across the copper rod vs. time

INSPIRING INQUIRY

Students are then asked to calculate the voltage induced between the 70 m tips of the wings of an airplane traveling at 280 m/s – a typical question in some textbooks (Giancoli, 2005). With $\boldsymbol{l}$ = 70 m, $\boldsymbol{v}$ = 280 m/s, and B = 50 μT for the magnetic field of the Erath, the induced voltage can be calculated using equation (1) to be 1.0 V. Then the student is asked if this voltage across the tips of the wings has any effect on a person if that person's seat is at the wings location for an overseas flight. While nobody so far knows the answer to this question, we hope life-science students and other students get alerted to the possibility of adverse health problems due to the induced voltage generated when we fly.

We point out to the students that that hammerhead sharks get affected by the magnetic field of the Earth when they swim (Klimley, 2003). Per Faraday's law, the motion of their elongated head through the magnetic file field of the Earth will induced voltage in their heads. And the reason that they have an elongated head is probably to increase the value of $\boldsymbol{l}$ (the length of the Hammerhead shark's head) in equation (1) and thus increasing the induced voltage so that can help the shark to navigate, using the Earth's magnetic field. The strength of this induced voltage depends on the speed and direction of the movement of the ionic fluids in the shark's head relative to the local magnetic field of the Earth. While scientists understood the effect of the induced voltage created by motion through the magnetic field of the Earth in the Hammerhead shark's head, there was no study to quantify the induced voltage on the human head while flying through the magnetic field of the Earth. Similar to the hammerhead sharks, the human head has ionic material in the neurons of the brain and one can comfortably speculate that there will be an induced voltage in the human brain and might have some effect.

CONCLUSION

Physics is a required course in college to life-science students, education students, forensic program students, geology students and chemistry students. Moreover, many humanity majors choose a physics course to fulfill their GEC (General Education Courses) requirement. Some of these humanity majors will one day work in an administrative or political position in science and health – a well-designed experiment that bridges physics to the real world is an invaluable learning experience for many students.

We know that electrical signals in the brain travel within neurons, which have dendrites and axons. Axons send signals to other neurons by secreting neurotransmitters at synapses (Seung, 2012). In axons, per Hardin, Berton, Kleinsmith and Beckler (2012), brief pulses of electrical signals known as action potentials are triggered when the electric potential changes from the resting potential of negative 60 mV to the threshold potential of negative 40 mV--that is a 20 mV potential difference.

Typically, the students get excited when they see generation of voltage in the copper rod just by moving it over magnets. We can take advantage of this excitement and challenge their thinking to consider a quite common real life situation. We can imagine that a strip of the human brain can act like the conducting copper rod (as the brain cells can conduct electricity) during its passage through the magnetic field of the Earth while flying in an airplane. Equation (1) will then yield an induced voltage of 1.4 mV across a strip of brain of length $\boldsymbol{l}$ = 0.1 m (approximately the width of the brain) moving at the airplane speed of 280 m/s through the magnetic field of the Earth of 50 μT. How does the 1.4 mV affect our brain which has neurons? The induced voltage of 1.4 mV calculated above for the strip of the brain is 7% of the 20 mV potential difference required for the neuron to "fire." Can this 1.4 mV affect the electricity of the neuron and thus our health? We leave the student to wonder stimulating his/her scientific curiosity.

AUTHOR BIOGRAPHIES

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