The Electrical Equivalent of Heat

and

Magnetic Current Induction

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**Objective**: This lab has two parts: first, demonstrating that energy is conserved when electrical energy is converted to heat in a resistor, wherein water will be heated via Joule heating (in actuality we will be verifying the conversion value between the Joule and the calorie); second, to measure the *emf* that is induced in a coil by dropping a magnet through a coil. In the first part, in order to capture the heat energy produced by the resistor, the resistor will be contained in a waterproof casing and submerged in water, where it is assumed that the water will absorb and capture all but negligible amounts of the heat energy. In the second part, a magnet will be dropped through a solenoid, and the voltage through the coil will be measured as a function of time. All data will be collected and produced with computer software and appropriate measurement hardware.

**Theory**

*Part I*

In general, energy produced or transferred by some processed is found by:

[1]

where energy is measured in joules (J), power is measured in watts (W), and time is measured in seconds (s). This is intuitive because power is the time rate of energy transfer.

For the purposes of this experiment, we are concerned with the energy converted to heat and released by a resistor in an electrical circuit. It is known that this heat is produced from the impedance of electron flow through the resistor, and it takes *emf* (electro-motive force, which is a misnomer; it is actually electrical energy, not force) to counter the deceleration caused by the resistor and maintain electron flow. This electrical power that is lost and converted to heat is defined as:

[2]

where current I is measured in Amps (A), voltage V (or *emf* ε) are measured in volts (V), and resistance R is measured in ohms (Ω).

In order to measure the energy dissipated by the resistor, water will be used to capture this heat. The heat energy Q required to produce a temperature change in a substance is modeled by:

[3]

where m is the mass of the substance being heated or cooled in grams (g), c is the specific heat of the substance in joules per kilograms Kelvin (J / (g \* K)), and ΔT is the change in temperature produced measured in Kelvin (K). It should be noted that it is common to refer to heat energy using the calorie unit, equal to 4.184 Joules. Important to know for this experiment, the specific heat of water is 1 cal / (g \* K) = 4.186 J / (g \* K).

In summary, the theory behind this experiment is simple and straightforward, it is a simple verification of conservation of energy, where *emf* is converted to heat via a resistor (commonly referred to as *Joule heating*), and the heat is then transferred to water via conduction. The “before and after” energy values should agree, and, to synthesize and restate, should agree in the following manner:

[4]

*Part II*

Due to the magnetic forces charges exert on one another, it is possible to induce a current in a conductor by passing a magnet past said conductor, or through a surface surrounding a conductor (not a solid surface, like that of the conductor, but rather a shape in the mathematical sense). The magnetic flux, or “flow” of magnetic force, is what produces this current, or rather the *emf* that drives this current. The flux through the surface that is the inner area encircled by loops or coils of wire, like in a solenoid, can be found (using the simplistic cross-product analog for perpendicular vectors) by the following equation:

[5]

where, assuming that the wire coils are circular, the magnitude of the magnetic field B is measured in Tesla (T), the circular area of each loop (surface) is measured in square meters (m2), and θ is the angle between the normal of the surface and the B field. The flux 𝞍B is measured in Webers (Wb). Important to note, in derived units, the Weber is equivalent to a volt\*second.

The rate of change and the count of these fluxes can be used to find the induced *emf*:

[6]

where N is the number of loop areas that the flux is passing through, and the change in time Δt is measured in seconds, which combined with the change in flux term produces the rate of change in the flux. This equation is known as Faraday’s Law. It follows that to find the total change in flux can be found by:

[7]

An important concept to discuss concerning the induction of current/*emf* via magnetic flux is the concept of the work. It is known that magnetic fields do no work, despite the fact that it takes work/energy (i.e. *emf*) to produce a current. Energy must be conserved, so where does the energy come from? Magnetic fields, in the current induction case, can do no work, since they act perpendicularly to the motion of the charges, via the Lorentz force. Without providing a legitimate proof, let it be known that the work is actually done by whatever work is performed to either move the magnetic field source, or the wire itself. In the case of our experiment, it is gravity that accelerates the magnet downward that is providing this work/energy.

**Procedure**

*Part I*

This experiment will require data collection software, a power amplifier, an encased resistor, a Styrofoam cup or other calorimeter-type apparatus, water, a temperature probe, and a mass scale for finding the mass of the necessary parts of the lab apparatus.

The experiment is set up by finding the mass of the cup/calorimeter, filling it with the water, and then finding the mass of the water to be heated. The resistor should be connected to the power supply, and the power supply and temperature probe need to be connected to the data collection software interface. The resistor and temperature probe should be placed in the calorimeter and secured by the lid/cover for the cup/calorimeter. It is important that the resistor is fully submerged or else it may burn up when it receives power.

The experiment is performed by heating the water from 3 degrees below room temperature to 6 degrees above. The water should be gently stirred during the heating process to ensure uniform heating of the water. When the data is collected, record the data, using tables when necessary. Use the data to calculate the conversion factor from calories to Joules, and verify this value using the percent difference method with the accepted conversion value.

*Part II*

This experiment will require data collection software, a solenoid built into an RLC circuit, a voltage sensor, a photogate, and a magnet.

The setup is as follows: The solenoid is placed over the edge of the table and a magnet can fall through. The photogate is placed above the top opening of the solenoid such that an object about to enter the solenoid will have to pass through the gate. The voltage terminals of the RLC circuit and the photogate are then connected to the data software interface.

The experiment is performed by starting the data collection procedure, and then dropping the magnet through the photogate and the solenoid. The data is collected by the computer, and the data collection software computes the integrals of the function of voltage and time. The function/data will produce two peaks, or rather, a peak and then a valley below the x-axis. The values of these integral segments will represent the positive flux as the magnet falls into the solenoid, and the negative flux as the magnet falls out of the solenoid, respectively. These values should be recorded, and repeated a few times to ensure accuracy.