Magnetic Inductance and Faraday's Law

Objective

Become familiar with the phenomenon of magnetic inductance and Faraday's Law.

Theory

As moving electric charges or currents produce magnetic fields that can affect the motion of other moving charges via magnetic force,

$$F = qvBsin\ \theta$$

where B is the strength of the magnetic field, v is the speed of moving charge, and θ is the angle between the magnetic field and the speed of the moving charge._There also exists a reverse relationship between the magnetic and electric fields described by Faraday's law. This law states that magnetic fields can produce electric fields that can affect electric charges directly via electric force $F = qE$.

This connection between electric and magnetic fields was first discovered by Michael Faraday in 1831. According to Faraday's law, time-varying magnetic field produces a circular electric field that can generate in closed electric circuits electric current in the amount proportional to the time-derivative of the magnetic field.

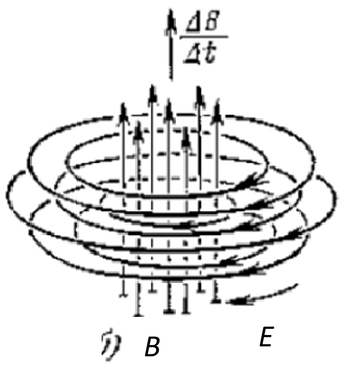

Figure 1 Faraday's Law is the statement of experimental relationship between magnetic and electric fields. According to Faraday's law, time-varying magnetic field creates in space a circular electric field that can drive electric current in closed electric circuits in the amount proportional to the time-derivative of the flux Φ_B of the magnetic field through that circuit.

The electromotive force created by such circular electric field inside an electric circuit equals the time-derivative of the flux Φ_B of the magnetic field passing that surface's area,

$$\mathcal{E}_B = \frac{d\Phi_B}{dt}$$

This statement is known as the Faraday's law.

The simplest device demonstrating Faraday's law consists of two coils of wire A and B with alternating current of the form $I = I_0 \sin 2\pi t/T$ passed through the first coil A. Alternating current in coil A creates a magnetic field that periodically changes its direction, as the current in the coil flows back and forth. Accordingly, the magnetic field's flux through the second coil B also changes together with the magnetic field.

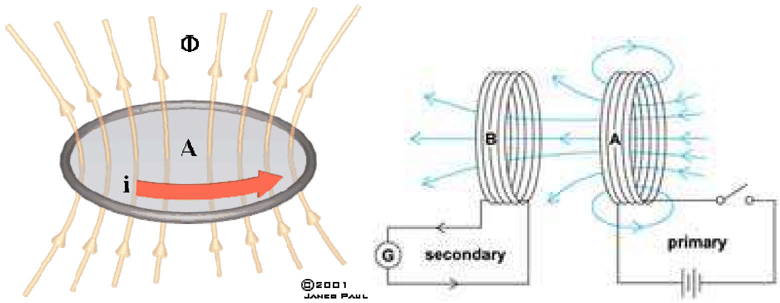

Figure 2 Alternating electric current in a wire coil creates magnetic field that periodically changes its direction. As this alternating magnetic field passes a second coil, it creates "induced" electric current in the amount determined by the Faraday's law, $\mathcal{E} = \frac{d\Phi_B}{dt}$, where Φ_B is the flux of the magnetic field as it passes the second coil.

The change in magnetic field passing the second coil produces electromotive force in that coil in the amount defined by Faraday's law, $\mathcal{E}_B = \frac{d\Phi_B}{dt}$, and respectively creates electric current in it. This effect is called *magnetic induction* and the current created in the second coil is called *induced current*. The effect is also sometimes called magnetic or inductive coupling of electric circuits.

One simple way to increase magnetic coupling is to put inside the coils a bar made from a strongly magnetic material such as iron – so called "ferromagnetic core". Iron core has the effect of concentrating the magnetic field inside it, effectively driving all the magnetic field created by the first coil through the second coil.

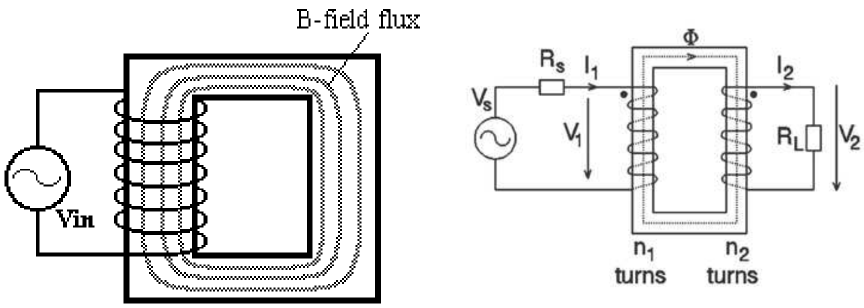

Figure 3 Ferromagnetic core placed inside a coil has the effect of concentrating the magnetic field produced by the current in that coil inside the core, therefore driving nearly all of the magnetic field from the first coil through the second coil.

When all of the magnetic field produced by first coil is made pass through the second coil, as in the example above, it can be shown that the electromotive force created inside one loop of the second coil should exactly equal the voltage drop in one loop of the first coil, produced due to generation of magnetic field, $\mathcal{E}_1 = \mathcal{E}_2 = \mathcal{E}$.

This property of magnetic inductance has following interesting effect. If the first coil contains n_1 loops and the second coil contains n_2 loops, the total voltage drop on the first and the second coil have to be related as $\mathcal{E}_{tot,1}:\mathcal{E}_{tot,2} = n_1:n_2$, since $\mathcal{E}_{tot,1}:\mathcal{E}_{tot,2} = n_1\mathcal{E}_1:n_2\mathcal{E}_2 = n_1:n_2$.

Equipment

- Electric circuit experiment set.
- Electric cables.
- Multimeter.
- Coil A, n_1=__________.
- Coil B, n_2=__________.

Procedures

1. Make sure that the power is turned off. Implement the circuit in diagram A using coil B and AC power source. **NOTE:** Once complete, verify your circuit with the instructor and obtain permission to proceed.
2. Connect multimeter to coil A in “AC voltage” mode, turn the power on and take the measurement of the induced voltage in coil A far away from coil B and near coil B, by placing coil A directly on top of coil B.
3. Turn the power off. Place coil A on the iron core. Replace the top iron-core bar to complete the iron core, and fix it in place using screw-press. Connect multimeter to coil A in “AC voltage” mode. Turn the power on and take the measurement of the voltage induced in coil A with the iron core in place.
4. Turn the power off and connect multimeter to coil B in “AC voltage mode”. Turn the power on and take the measurement of the voltage lost in coil B producing magnetic field with the iron core in place.
5. Turn the power off and implement the circuit in diagram A using coil A. Connect multimeter to coil B in “AC voltage mode”. Turn the power on and take the measurement of the voltage induced in coil B.
6. Turn the power off and connect multimeter to coil A in “AC voltage mode”. Turn the power on and take the measurement of the voltage lost in coil A producing magnetic field.

ALYSIS (TO BE PERFORMED IN THE REPORT)

7. Explain your measurements in 2). Why induced voltage is zero far away from coil B and not zero nearby? Why the ratio $\mathcal{E}_{tot,1}:\mathcal{E}_{tot,2}$ is different from $n_1:n_2$ in 2)?
8. Use your measurements in 3) and 4) to calculate $\mathcal{E}_{tot,1}:\mathcal{E}_{tot,2}$ in 3-4). Does it agree with the theoretical value $n_1:n_2$ for that situation?
9. Use your measurements in 5) and 6) to calculate $\mathcal{E}_{tot,1}:\mathcal{E}_{tot,2}$ in 5-6). Does it agree with the theoretical value $n_1:n_2$ for that situation?

ELECTRIC CIRCUIT DIAGRAMS

Circuit A;