

## ELECTROMAGNETIC INDUCTION

Most of our electric energy needs come from an electric power plant that use large generators to produce electric energy that is then transferred by transmission lines.

**QUES:** How is the electric energy produced by these electric generators?

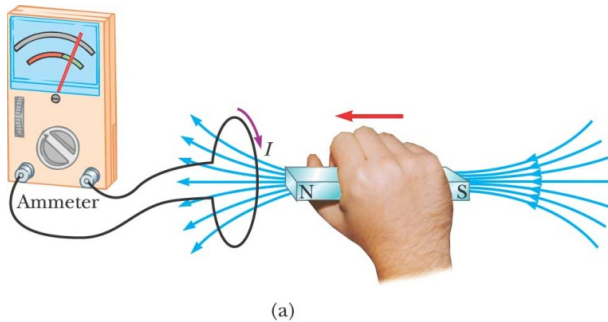
**ANS:** The generators use electromagnetic induction to generate an EMF when their coils of wire in the generators are rotated in a magnetic field. The source of energy to rotate the coils are:

1. Falling water from a dam (Hydroelectric Power Plant) (80% - 95% efficiency)
2. Burning fossil fuels (coal, natural gas, petroleum) (Thermal Power Plant) (32% - 48% efficiency)
3. Nuclear reactor (Nuclear Power Plant). (33% - 37% efficiency)

### **What is electromagnetic induction???**

Let's consider the following experiments:

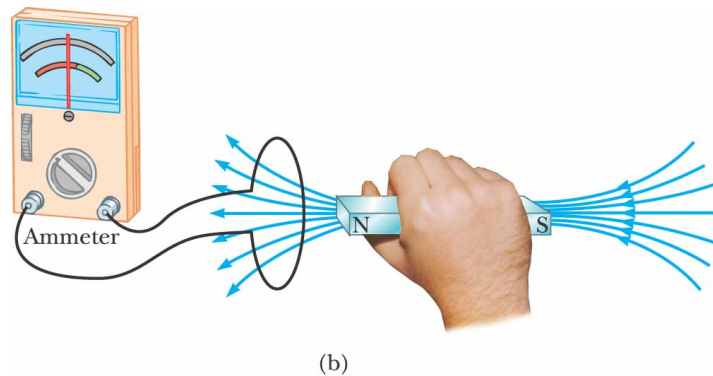
#### **Experiment 1: Moving a Bar Magnetic Toward a Stationary Loop.**



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When a magnet is moved toward a loop of wire connected to a sensitive ammeter, the ammeter deflects as shown, indicating that a current is induced in the loop.

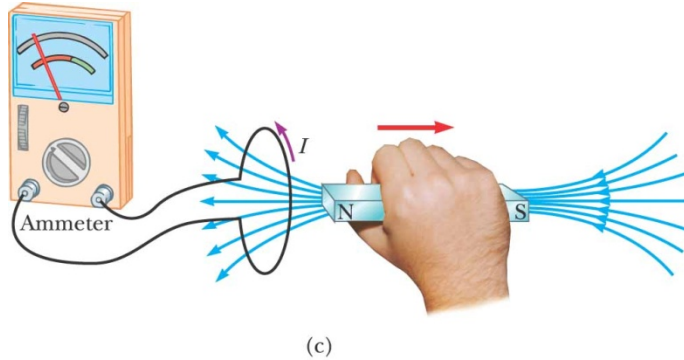
#### **Experiment 2: Bar Magnetic Stationary relative to Loop.**



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When the magnet is held stationary, there is no induced current in the loop, even when the magnet is inside the loop.

### **Experiment 3: Moving a Bar Magnetic Away from a Stationary Loop**



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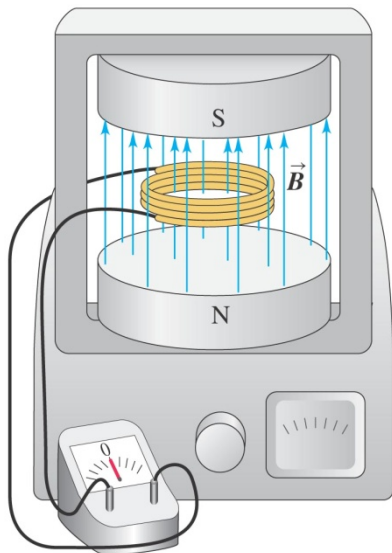
When the magnet is moved away from the loop, the ammeter deflects in the opposite direction, indicating that the induced current is opposite that shown in Experiment 1. Changing the direction of the magnet's motion changes the direction of the current induced by that motion.

The experimental results would be similar if the loop was moving and the magnetic was stationary.

*From these experimental results, we must conclude that a current is setup in a circuit as long as there is relative motion between the magnet and the loop. That is, a current is set up in a circuit even though there are NO batteries present in the circuit!!!*

Such current is called an induced current and we say it is produced by induced EMF.

### **Experiment 4: Rotating Loop (coil) In a Uniform B-field.**



When the coil is rotated in the uniform B-field, an induced current and thus an induced EMF is also set up in the loop.

QUES: What causes the induced current and the corresponding EMF?

## ANS: Changing Magnetic Flux!

A general statement that summarizes these experiments is called Faraday's Law of Induction:

### FARADAY'S LAW OF INDUCTION

The EMF induced in a circuit is directly proportional to the time-rate of change of the magnetic flux through a circuit.

$$\boxed{\begin{array}{l} \varepsilon = -\frac{d\Phi_B}{dt} \\ \varepsilon = -\frac{d}{dt}\left(\int \vec{B} \cdot d\vec{A}\right) \end{array}} \quad \text{Faraday's Law}$$

From this expression we can see that an EMF can be induced in a circuit in several ways:

1. The magnitude of **B** can vary with time.
2. The area of the circuit can vary with time.
3.  $\theta$  between **B** and **dA** can change with time.
4. Any combination of these can occur.

The negative sign in Faraday's Law is a consequence of another law called Lenz's Law which we'll look at shortly.