Section 11: Magnetic Fields and Induction
(Faraday's Discovery)

In this lesson you will

- describe Faraday's law of electromagnetic induction and tell how it complements Oersted's Principle
- express an understanding that for induction to take place, there must be relative change between an external field and a conductor (there must be a relative motion, or the external field must change in intensity)
- provide a detailed analysis of the interaction of magnetic fields to show the direction of the induced current
- define *alternating current*
- show how Faraday's iron ring apparatus incorporates both Faraday's Law and Oersted's Principle

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Remembering Oersted and Introducing Faraday

Oersted's principle states : when a current passes through a straight conductor there will be a circular magnetic field around the conductor.

As a general extension of Oersted's principle you can say that **when a charge moves it creates a magnetic field.** (**This is the basic principle of electromagnetism.)**

Michael Faraday discovered an **exactly opposite** phenomenon: when a magnetic field moves near a conductor it makes any free charge in the conductor move--that is, **a changing magnetic field creates a current.** That statement is referred to as Faraday's Law. See page 670 of text.

A magnetic field can change in two ways:

- It can move physically.
  - i) move a bar magnet back and forth, then its magnetic field also moves back and forth and
    ii) keep the magnetic field stationary and move the conductor back and forth using some outside force.
- It can change by having its intensity or strength increased or decreased.
  - This is most easily done with an electro-magnet since all one has to do is increase or decrease the current through the coil.

A cautionary note

Oersted's Principle required a power source to create a current in th straight conductor. This was also the case in other sections (7 – 8), for example when the motor principle was done. **(Electromagnetism)**

In this lesson, and the remaining lessons in this unit the current in the conductor **is not** caused by a power source; rather **it is induced by the changing magnetic field** that is around or permeating the conductor. **(Electromagnetic Induction)**

We say the current is induced by a changing magnetic field (Faraday's Discovery).

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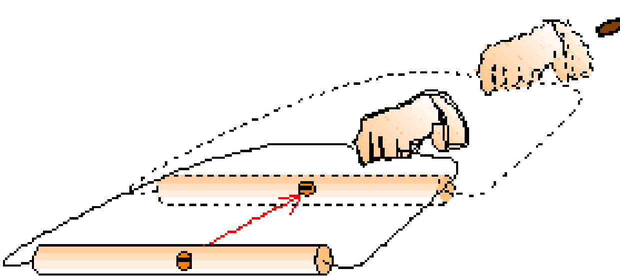
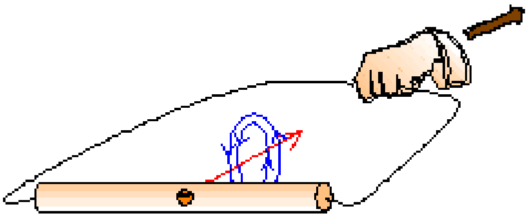
Some diagrams that illustrate Faraday's Discovery

A straight conductor moves in a magnetic field

Before we drag the conductor through a magnetic field, let us move it with **no magnetic field present** . The picture shows the conductor being pulled into the screen. There is no external magnetic field and no power source. Only one of many billions of electrons is depicted. Because the conductor moves, so does the electron. And as discovered by Oersted, whenever charge moves, a magnetic field is created. For the representative electron shown, this magnetic field is illustrated by the circles. Using left-hand rule #1, we can confirm that the arrows are pointing in the proper direction, which is up on the right hand side of the red path, and down on the left hand side of the red path.

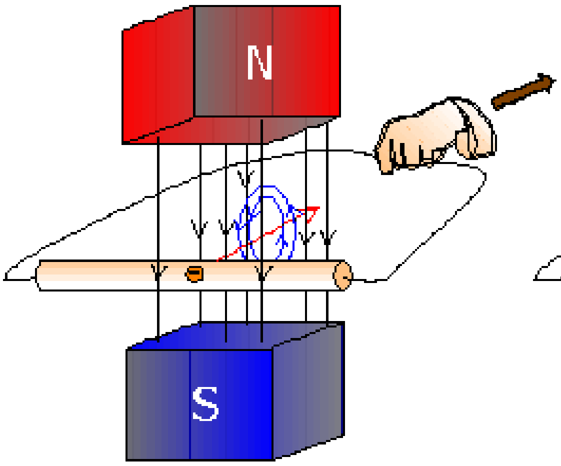


The electron is one of zillions being pulled in the direction of the red arrow.



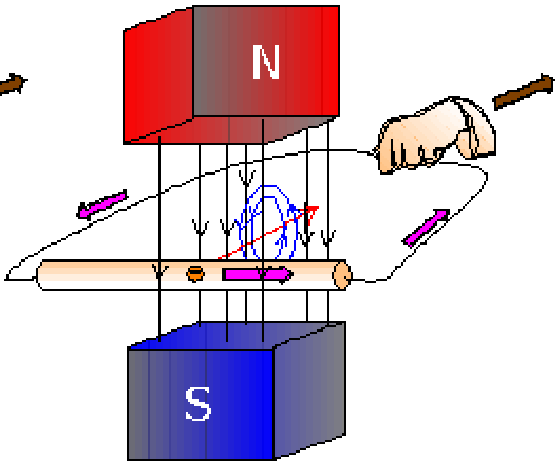
Each moving electron induces a circular magnetic field about its path as described by Oersted's Principle. (Use left-hand rule #1).

Next we make the conductor move through a magnetic field. Note that this is the same as if the conductor were still and the magnetic field was moving. That is, **relative to the conductor, the magnetic field is changing** . According to Faraday's Law, a current will be induced in the conductor. Of course, the conductor must be in a circuit for the current to flow. You can see the circuit because there is a wire attached to the ends of the conductor. The next picture shows why the current is induced as explained by Faraday



On the LHS of the red path the black and blue fields repel each other

On the RHS of the red path the black and blue fields attract each other



This interaction of the black and blue fields means that the free electrons are forced to the right. That is, a current (pink arrow) has been induced by the motion

In the left hand region of the fields, the permanent field and the induced (circular) field are in the same direction (downward). Fields in the same direction **repel** each other.

In the right hand region, the permanent field is still directed downward, but the induced (circular) field is directed upward. So, in this second region the fields **attract** each other because they are in opposite directions.

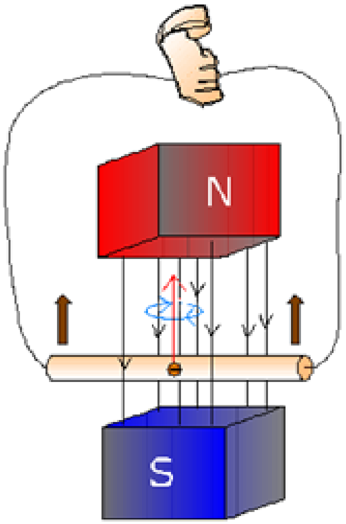
Therefore, the electron is repelled from the left and attracted to the right. All of this means that the electron, along with billions like it, are forced to the right in the conductor.

The relative motion of the conductor and the external magnetic field has induced a current in the conductor--Faraday's Law.

The very important thing to keep in mind is this: ***either the conductor must move, or the magnetic field must move, or the magnetic field must change in intensity in order that for the current to be induced***. If the conductor just sits in the field, there will be no current produced. Somehow, the conductor must "cut through" the lines of force.

This is a marvelous discovery because **we can produce electricity without have a battery in the circuit. All we need is relative motion between a magnetic field and a conductor in a closed loop in the field.**

In order for a current to be induced in the moving conductor, the conductor must cut through the field lines (or else the moving field must cut through the conductor). If you look back to the last picture you will see that the motion ofthe conductor is perpendicular to the magnetic field lines. It is this condition which induces the largest current. If the conductor moves **parallel** to the lines of force, **no current is induced** .



Conductor is moving parallel to the lines of force. No current is induced.

This is illustrated in the next picture. Note thatthe path of the representative electron (the red arrow) is now such that the **circular magnetic field** is **perpendicular** to the permanent field. Because the fields are perpendicular, they cannot interact. Therefore, the electron feels no force due to the external field, and there will be no induced current. If the conductor is pulled through at some angle, then there will be aninduced current greater than zero but less than than the maximum that results when the conductor cuts the field lines at 90° (as was the case in the earlier pictures of this lesson.)

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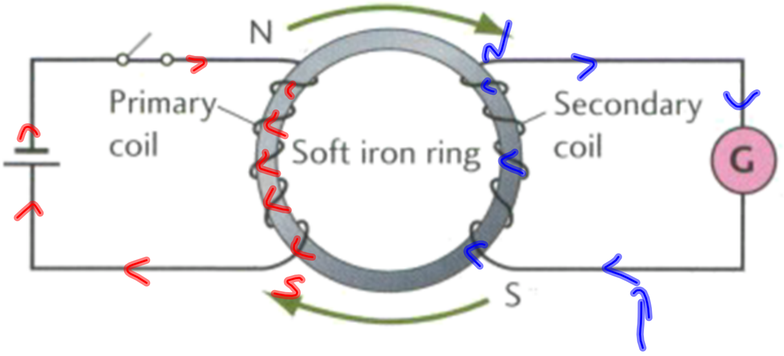
Faraday's iron ring apparatus



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- The primary coil has a current source, the secondary does not.
- When the switch in the primary circuit is closed, current flows creating an electromagnet (Oersted's Principle)
- The magnetic field cuts through the secondary coil **inducing** a current.
- A current is induced as long as the magnetic field is changing.
- Once the field is established, the induced current in the secondary coil stops.
- When the switch is turned off, the current in the primary coil dies and the field slowly collapses.
- Now current is induced in the secondary coil in the opposite direction.
- The current in the secondary circuit is zero as long as the current in the primary circuit is constant – which means, in turn, that the magnetic field is constant. It does not matter whether the constant value of the magnetic field is zero or nonzero.
- When the magnetic field passing through the secondary coil increases, a current is observed to flow in one direction in the secondary circuit; when the magnetic field decreases, a current is observed in the opposite direction.
- **A CURRENT IS INDUCED ONLY AS LONG AS THE MAGNETIC FIELD IS CHANGING.**
- If the switch is repeatedly opened and closed, the galvanometer will indicate an alternating current, first one way and then another. If you could open and close the switch 10 times in 1 second then you would create a 10 cycle **AC** current in the secondary coil.

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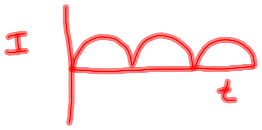
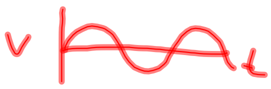
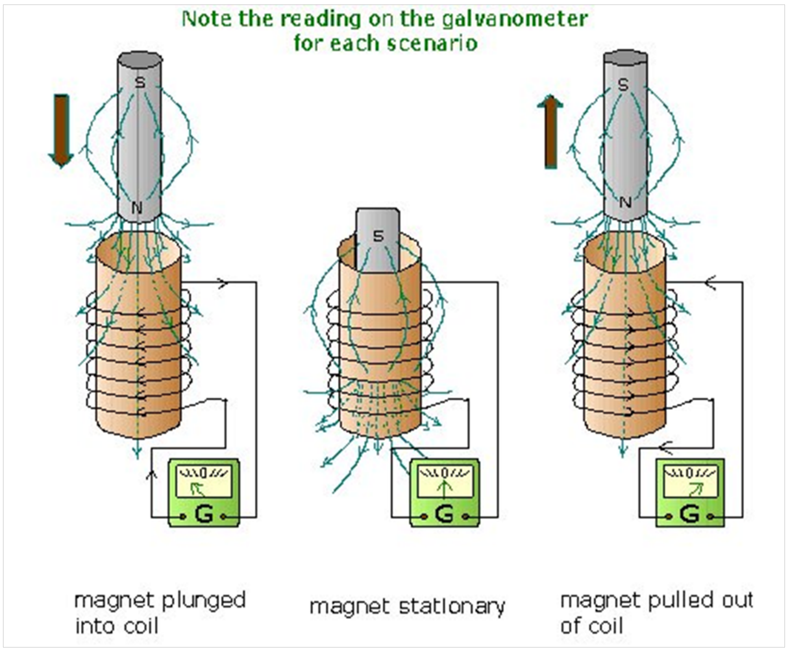
DC Current – produced by a dry cell
! current travels in one direction
! DC voltage and DC current

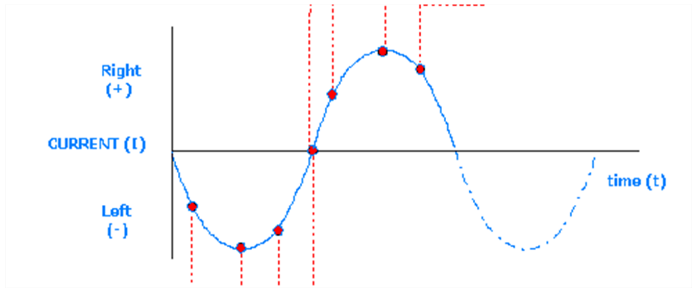


AC Current ! Current does not travel in the same direction all the time.
! Current does not have a constant magnitude.
! Can produce AC current by opening and closing a switch.



PRODUCTION of AC CURRENT



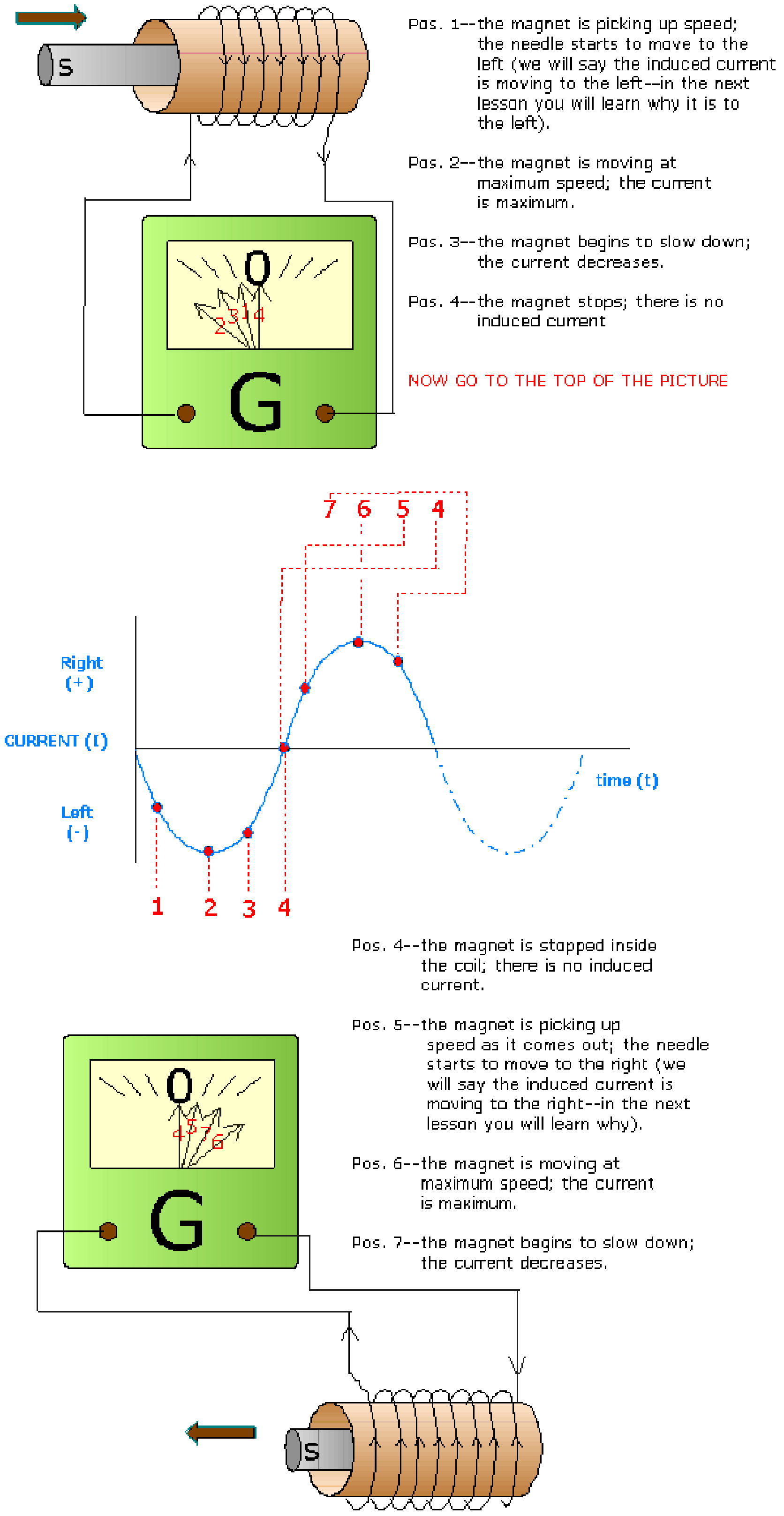


In the left hand picture, the magnet is pushed into the coil, the field lines cuts through the coil, and a current is induced. Let's say the galvanometer needle is deflected to the left. (You will learn how to determine the direction later.

In the middle diagram, the magnet is stopped and the galvanometer reads 0. There is no induced current because the magnetic field is not changing with respect to the conductor.

In the right hand diagram, the magnet is pulled from the coil. Now the field is moving opposite to the direction in which it moved in the left hand picture. Therefore, the current induced will flow in the opposite direction, and the galvanometer is deflected to the right.

As the magnet is pushed and pulled from the coil, the galvanometer needle will show that the current reaches a maximum in one direction, then goes to zero and reaches a maximum in the other direction, thus producing an AC current.



Pos. 1--the magnet is picking up speed; the needle starts to move to the left (we will say the induced current is moving to the left--in the next lesson you will learn why it is to the left).

Pos. 2--the magnet is moving at maximum speed; the current is maximum.

Pos. 3--the magnet begins to slow down; the current decreases.

Pos. 4--the magnet stops; there is no induced current

NOW GO TO THE TOP OF THE PICTURE

Pos. 4--the magnet is stopped inside the coil; there is no induced current.

Pos. 5--the magnet is picking up speed as it comes out; the needle starts to move to the right (we will say the induced current is moving to the right--in the next lesson you will learn why).

Pos. 6--the magnet is moving at maximum speed; the current is maximum.

Pos. 7--the magnet begins to slow down; the current decreases.