Motional emf

Select LEARNING OBJECTIVES:

- Apply both the mathematical representation for magnetic force on point charges in magnetic fields and the RHR for cross products to determine how charge is separated via motional emf.

TEXTBOOK CHAPTERS:

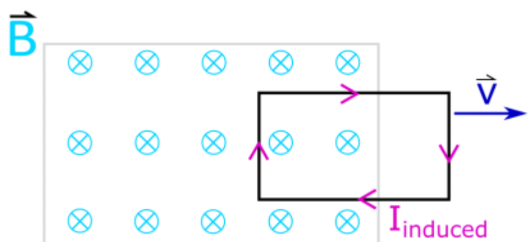
Boxsand :: motional emf

WARM UP: Magnetic field questions?

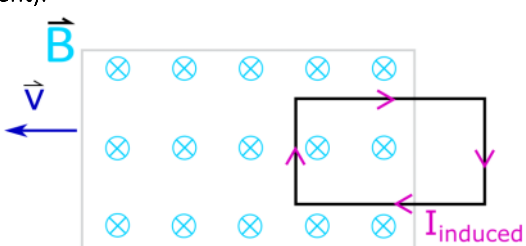
Recall that to establish a current in a wire we must create an electric field inside the wire that pushes the free electrons around inside the conductor's lattice. One method to crease an electric field inside a wire is to use a device that separates charge, effectively doing work on each charge as is bring it from a low electrical potential energy to a high potential energy. The work per unit charge that this device does is called the emf. Do you remember some examples of these devices? There are many different devices we could use to separate charge; devices that rely on mechanical, chemical, solar, and electromagnetic mechanisms. Mechanical and chemical are perhaps the most commonly known mechanisms; an example of a mechanical device that separates charge is the conveyer belt system in a Van Der Graff generator, an example of a chemical device that separates charge is a battery. Solar energy is becoming much more prevalent and I encourage you to research the solar mechanism of separating charge. So as you might imagine, this lecture will introduce the electromagnetic way in which we can separate charge, thus establishing current.

It turns out there are three different electromagnetic ways to establish a current, often referred to as an induced current. Below are examples of three experiments which summarize the three unique ways electromagnetism can create an induced current. We can analyze the first experiment with our current physics tools in our tool belt. However, the other two examples will require us to introduce a new mathematical model, Faraday's law. As we will eventually see, the remarkable thing about Faraday's law is that it can also be used to analyze the first experiment.

Experiment 1 (motional emf): Pull a loop of conducting wire through a magnetic field and current will flow in the loop (induced current).

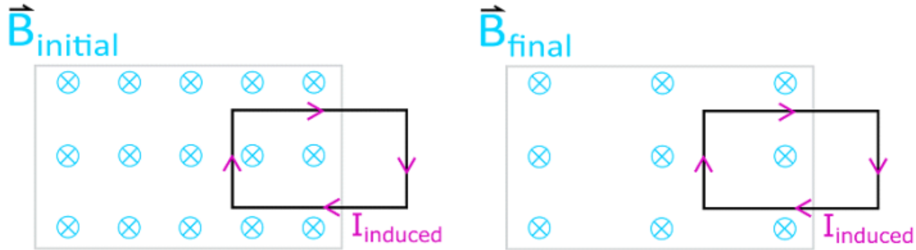


Experiment 2: Move a magnet away or towards a conducting wire loop and current will flow in the loop (induced current).



Experiment 3: With both the magnet and the conducting wire loop stationary, change the strength of the

magnetic field and a current will flow in the loop (induced current).

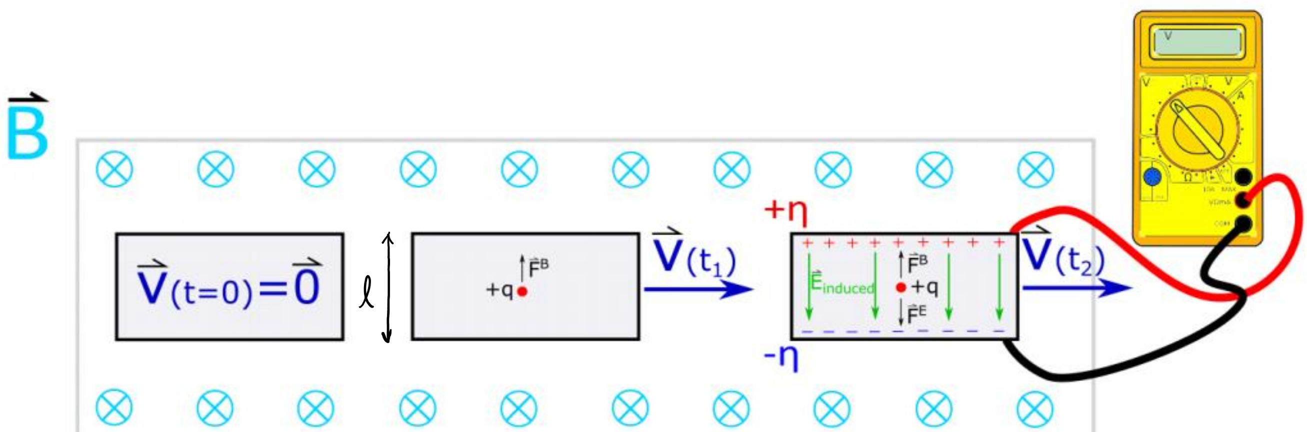


In each of the experiments above, a conducting square loop of wire is used. Although each experiment is different, an induced current is still created. In this lecture we will briefly look at how to analyze a situation similar to the first experiment. In the next lecture we will study Faraday's law which is used to explain experiments 2 and 3, but also can be applied to experiment 1.

<u>Closer look at experiment 1 (motional emf)</u>

Compare experiment 1 to experiments 2 and 3 from the intro paragraphs. The conductor is only moving in experiment 1. When the conductor is moving through a constant magnetic field with respect to time, we refer to the scenario as motional emf. Below is an example of a solid sheet of metal moving through a uniform magnetic field.

- A conductor moving through an external magnetic field generates a voltage difference across itself. "emf voltage"
  - Example: sheet of metal moving through uniform external B-field.



1. A conductor with no initial charge separation has no internal electric field at t=0.
2. As the conductor moves through the external magnetic field, the free charges in the conductor experience a magnetic force causing them to separate (i.e. an induced current is established).
3. The induced current cannot last forever since an induced electric field is created inside the conductor from the charge separation which acts to oppose the magnetic force. At equilibrium the magnetic force is equal and opposite to the electric force on the free charges.

$$\Sigma F_y = m a_y \to 0$$

$$|\vec{F}^B| - |\vec{F}^E| = 0$$

$$|\vec{F}^E| = |\vec{F}^B|$$

$$|q||\vec{E}| = |q||\vec{v}||\vec{B}|\sin\theta$$

|| PLANE E-FIELD

$$|\vec{E}| = |\vec{v}||\vec{B}|\sin\theta$$

$$\frac{\Delta V}{l} = vB\sin\theta$$

$$\boxed{\Delta V = vlB\sin\theta}$$

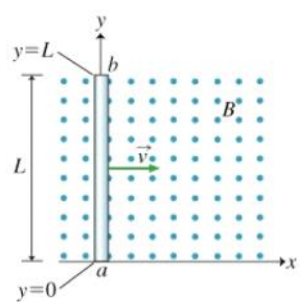
SMALLEST ANGLE BETWEEN $\vec{v}$ AND $\vec{B}$ WHEN TAIL-TO-TAIL

- Other examples of motional emf
  - Rotating conductors in external magnetic fields.
- Summary
  - Moving a conductor through a magnetic field creates a magnetic force on the free charges which then begin to move (induced currents).

The amount of time that it takes for the conductor to reach equilibrium is very small, and once equilibrium is reached there is no current flowing. Going back to the first experiment in the intro paragraphs, this means there would be no induced current if the look of wire is moving completely within the uniform magnetic field. There would only be an induced current when the loop is entering or leaving the uniform magnetic field. A similar analysis that was carried out above for the sheet of metal can be done in the scenario of a loop of wirer leaving or entering a uniform magnetic field. The analysis leads to the same induced emf of the velocity times the width of the wire time the strength of the magnetic field.

PRACTICE: A metal rod is traveling through a magnetic field, as shown in the diagram. What point, a or b, is higher in potential?

1. a
2. b
3. Neither, both are at a high potential.
4. Neither, both are at a low potential.



PRACTICE: A typical freight truck tows an aluminum cubical trailer that is around 14.6 m long and 2.87 m tall. A truck is pulling this trailer due west at a speed of 60 miles/hour where the earth's magnetic field is directly north and has a strength of 50 μT. What is the induced emf across the top and bottom of the trailer.