Section	Group	Name	Signature
Grade			
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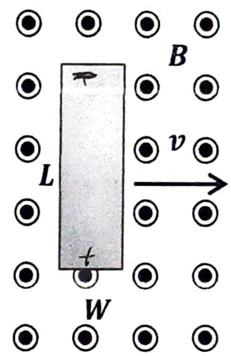
Materials: *PhET simulation "Faraday's Law"* https://phet.colorado.edu/en/simulation/faradays-law

After this activity you should know: · *Why a motional EMF is produced when a conductor moves thru a magnetic field· Be able to find the magnitude and direction of the voltage difference · Know what magnetic flux is ● know there is a net EMF around a closed loop only if the magnetic flux through the loop changes with time.*

1. A solid rectangular metal bar of length L and width W is dragged at speed v through a region of uniform magnetic field B as shown.



   a. What is the direction (left/right/top/bottom/in/out/zero) of the magnetic force on the conduction electrons in the bar?

   ~~Down~~ UP

   b. The magnetic force will lead to a charge separation in the bar. Which is true?
   - The left end is positive and the right is negative.
   - The left end is negative and the right is positive.
   - The bottom end is negative and the top is positive.
   - The bottom end is positive and the top is negative.

   c. The charge separation will generate an electric field inside the bar. The electric field will grow until the electric and magnetic forces on the charges balance. What is the magnitude and direction of the electric field inside the bar? Give magnitude E in terms of B, v, L and/or W. *Think: we've done something similar before.*

   $\cancel{q}vB = \cancel{q}E$

   $E = vB$

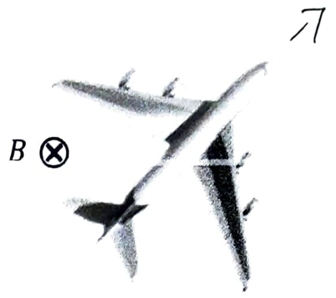
   d. The electric field will generate a voltage difference across the bar. What is true of the voltage difference?
   - The left end is at a higher voltage than the right.
   - The right is at a higher voltage than the left.
   - The bottom end is at a higher voltage than the top.
   - The top is at a higher voltage than the bottom.

   e. Write the magnitude of the voltage difference in terms of B, v, L and/or W. *Hint: the electric field is uniform so that voltage difference is easy to find.*

   $\Delta V = Ed$

   $\Delta V = vBL$

2. An Airbus A380 flies over Ellesmere Island in the Canadian Arctic at 300 m/s (1080 km/hr or 670 mi/hr). The airplane is 65 meters long and has a wingspan of 80 meters. The Earth's magnetic south pole is at Ellesmere Island so the Earth's magnetic field points straight downwards with a magnitude of $5 \times 10^{-5} T$.



   a. Which end of the plane is at the highest voltage?

   • left wing • right wing • front • back

   b. What is the voltage difference between the points on the plane with the highest and lowest voltage?

$$\Delta V = vBL = 300\,(5\times10^{-5})(80)$$

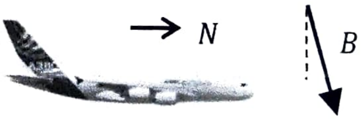
$$= 1.2\,V$$

   c. How would this answer change if the airplane was flying directly northwards at the equator where the Earth's magnetic field is also directly northward?

It would be 0

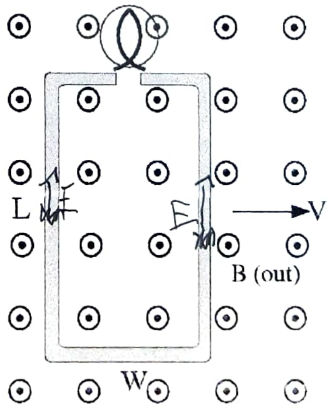
   d. The airplane is flying north over Erie. At our latitude, the Earth's magnetic field is mostly downwards at an angle of 11^o north of vertical. What is the voltage difference between the wingtips now?

$$300\,(5\times10^{-5})\sin(11)\,(80)$$



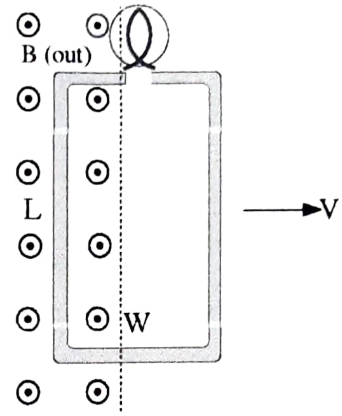
$$= 0.22897\,V$$

3. Can we use the motional EMF to light a light bulb? We drag a rectangular conducting frame with a light bulb connected as shown. Which is true?



- The light bulb will light up due to a clockwise (CW) current generated by the CW motional EMF.
- The light bulb will light up due to a counterclockwise (CCW) current generated by the CCW motional EMF.
- ~~The light bulb will not light up since the magnetic force will generate a CCW EMF on the left side of the frame and a CW EMF on the right side.~~
- The light bulb will not light up since the magnetic force will generate a CW EMF on the left side of the frame and a CCW EMF on the right.

4. We now repeat the experiment except now the left side is in the uniform magnetic field but the right side is in zero field. What happens when the frame with the light bulb is dragged across this region?



   i. The light bulb will light up due to a CW current generated by the net CW net motional EMF.
   ii. The light bulb will light up due to a CCW current generated by the CCW net motional EMF.
   iii. The light bulb will not light up since the magnetic force will generate a CCW EMF on the left side of the frame and a CW EMF on the right side of the frame.

5. British physicist Michael Faraday (1791-1867) realized that a net EMF is induced in a loop if the amount of magnetic field going through the loop changes. The amount of magnetic field through the loop is the magnetic flux:

$$\Phi_m = \int \vec{B} \cdot d\vec{A} = \int B \cos\phi \, dA$$

where ϕ is the angle between $\vec{B}$ and the normal to the surface and the integral is over the area of the loop. This an open surface so the net magnetic flux is not necessarily zero. (The magnetic flux through a closed surface must be zero since B field lines never begin nor end.)

This expression simplifies if $B\cos\phi$ is uniform. In this case, the magnetic flux is

$$\Phi_m = B \cos\phi \, A$$

Therefore, the magnetic flux can be changed by changing the magnetic field B, the ange ϕ or the area A.

   a. Watch the real magnet and coil demo at: https://psu.mediaspace.kaltura.com/media/1_7fgi1cd7. Open https://phet.colorado.edu/sims/html/faradays-law/latest/faradays-law_en.html and place the magnet so it is at rest with the north pole is just inside the pickup coil. Click on "Field Lines" to show the magnetic field lines. Answer the following:

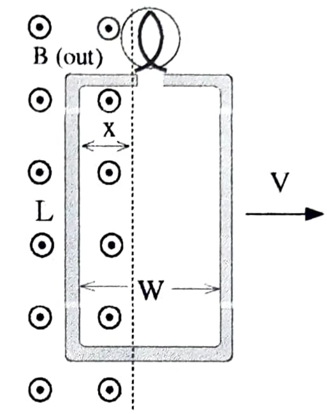
i. There is a magnetic flux through the pickup coil due to the magnet.	True	False
ii. The magnetic flux through the pickup coil is changing .	True	False
iii. is a current induced in the pickup coil.	~~True~~	False

   b. Now move the magnet slowly away from the pickup coil. Which statements are true as you move the magnet away from the coil?

i. There is a magnetic flux through the pickup coil due to the magnet.	True	False
ii. The magnetic flux through the pickup coil is changing .	True	False
iii. is a current induced in the pickup coil.	True	False

   c. Based on your observations which statement is true?
      i. There is no magnetic flux through the pickup coil when the magnet is stationary. There is only magnetic flux when the magnet is moving. There is only EMF induced in the pickup coil when the magnet is stationary.
      ii. There is magnetic flux through the pickup coil both when the magnet is stationary and when the magnet is moving. However, when the magnet moves, the value of B at the coil changes. The magnetic flux changes and therefore an EMF is induced in the pickup coil.
      iii. There is magnetic flux both when the magnet is stationary and moving and there is also an EMF induced in the pickup coil in both when the magnet is stationary and when the magnet is moving.

5. Faraday's Law says that the EMF is induced when the magnetic flux through the loop changes. The EMF induced in the loop is equal to:



$$|\mathcal{E}| = \left|\frac{d\Phi_m}{dt}\right|$$

We want to apply Faraday's Law to the frame being dragged out of a magnetic field. Here x is the width of the frame that is in the magnetic field. Note that x will change with time.

a. Write an expression for the magnetic flux through the frame in terms of B, W, L and/or x.

$\Phi_m = BxL$

b. Substitute your expression for the magnetic flux into Faraday's Law and take the time derivative to determine the magnitude of the induced EMF in the frame. We want the magnitude, so you don't need to worry about the sign right now. Answer in terms of B, v, W and/or L. *Notice that when you take the time derivative only x will change with time. Think about what dx/dt is from Physics 211. Your final answer should look very familiar.*

$-N\frac{d\,BxL}{dt} =$ $\quad -1($

$B = \frac{d}{dt} BLx$ $\quad BL\frac{dx}{dt} = BLv$

c. The resistance of the circuit is R, what is the current induced in the frame?

$I = \frac{BLv}{R}$