***👓 INSTRUCTORS MANUAL: TUTORIAL 12***

***Motional EMF***

**Goals**:

1. Familiarize students with motional EMF

**This tutorial is based on:**

* Written by Mike Dubson and Ed Kinney. Modified by Rachel Pepper

**Reflections on this tutorial:**

This tutorial seemed very engaging for students and the ending was a surprise for many. This is a tutorial where getting to the end matters. A couple groups finished in about an hour, but other groups took around an hour and half. Students had not seen this in class but didn’t seem to mind. They knew that they had seen much of it before in a previous class.

**Part 1:**

Part **1c** was difficult for many students and required instructor guidance for almost all groups, however, more guidance has been added, so students may not struggle as much next time. For part **d** there was some confusion about whether the force on the q is electric or magnetic (I think there is no E-field in this configuration). In part **f** a couple of the slower groups did not think much about the sign because they were anxious to finish, and required instructor questioning. One group was very pleased that the had derived emf = - d flux/ dt by themselves.

**Part 2:**

In part **a**, nearly all groups did not know Stokes law, and we encouraged them to try to figure it out using pictures/unit analysis/ deciding if both sides were both scalars or vectors. With some help all groups came to the right answer without looking it up. A couple groups spent a lot of time debating this, which I’m not sure is how we want them to allocate their time. One group thought that the surface was a closed surface (like in Gauss’s law), another group initially had E dot da on one side of the integral. I saw another person who had the correct expression for E but had just dB/dt on the other side (when it should have been in an integral).

For part **c** many students thought there was no E field outside the solenoid because there was no B field there. This led to some good discussions in groups. Some wrote that E would be collinear with B. In part **d** a few students did not draw loops, and it turned out they were thinking about the same loops they used to find B in Ampere’s law. Students may require prompting to think about the underlying symmetry that allows them to choose the loop they choose. For part **e** One group wrote downs E=0 without drawing a loop/doing a calculation. Nearly everyone was surprised when they realized that the loop they had drawn still included a changing B field.

**✯ TUTORIAL 12: MOTIONAL EMF ✯**

**Part I. Motional EMF**

v

B(in)

A neutral metal bar is being pulled at constant velocity, speed v, to the right through a uniform magnetic field of magnitude B, as shown. The bar has been moving for some long time, and has achieved a dynamic steady-state.

(A) What is the magnetic force on charges in the bar (direction and magnitude)?

(B) In the diagram at right, sketch the distribution of charges in the bar.

(C) What is the electric field in the bar (direction and magnitude)? *Hint: remember that the bar has reached a dynamic steady-state.*

B(in)

v

L

Now consider a rectangular metal loop of height L, moving to the right with speed v, which is exiting a region with a constant magnetic field, magnitude B.

(D) The emf around any loop is defined as .

What is the emf around the metal loop?

(E) What is the magnetic flux  through the metal loop? (Define any new symbols used.)

(F) Compute the time derivative of the flux through the loop d/dt and compare with your computed emf. There is a +/- sign that you should worry about.

**Part II. Faraday’s Law**

Faraday’s Law is  .

1. What is Stokes’ Law? Use Stokes’ Law to rewrite Faraday’s Law in integral form.

(B) Consider a very long solenoid of radius R with n turns per length and current I. Compute the B-field everywhere.

(C) Suppose the current I in the solenoid is increasing at a steady rate I(t) = C t, where C is a constant. Where do you think there is there an E-field? (Inside the solenoid? Outside? Everywhere? Nowhere? ) What do you think the E-field look like? For now, just use your intuition, we’ll check with calculations later.

(D) Use Faraday’s Law in integral form to compute the electric field inside the solenoid. Specify the loop you chose for the integral.

R

I (increasing)

Top View of Solenoid

(E) Use Mr. Faraday to compute the E-field outside the solenoid.

R

I (increasing)