Passage V (Questions 27 - 32)

In an experiment designed to study Faraday's Law, a student observed the induced current generated upon migrating three separate loops at uniform speed through a uniform perpendicular magnetic field. The field was created by placing a cylindrical magnet directly above a second cylindrical magnet, such that the loop could be moved through the field between the poles, as shown in Figure 1.

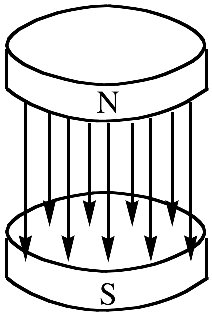


Figure 1 Magnetic field used in the Experiment

In Experiment I, the student pushed through three separate copper loops of varying dimensions all in a way that the area within the loop was parallel with the surface of the magnets. The three loops have the following dimensions.

Loop C: rectangular with edges of 6cm and 8cm. A = 48 cm^2

Loop D: square with edges of 7cm. A = 49 cm^2

Loop E: circular with a radius of roughly 4cm. A = 50 cm^2

The student pushed the loops through at constant velocity, despite the increase in opposing force as the loop entered and exited the field. Each loop was attached to a galvanometer, used to measure the induced electromotive force, ε. The *emf* can be calculated using Equation 1:

$$\varepsilon = -\, d(\mathrm{BA}\cos\phi)/dt$$

Equation 1

where ε represents the *emf*, B is the strength of the external field, A is the area in side the loop, and ϕ is the angle between the field vectors and the vector perpendicular to the surface of the area within the loop.

In Experiment II, the student repeated the steps of Experiment I, but used loops made of tin wire instead of copper.

27. In which experiment did the student observe the GREATEST electromotive force?

A. In Experiment I, because copper is a better conductor than tin.

B. In Experiment II, because copper is a better conductor than tin.

C. In Experiment I, because tin is a better conductor than copper.

D. Both experiments produced the same *emf*.

28. As a conducting loop first enters a magnetic field, it:

A. feels a force that pulls it into the field.

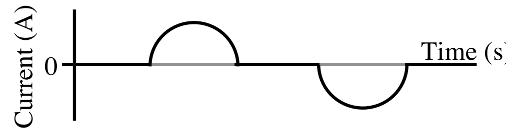
B. experiences a torque that rotates it by 90˚.

C. speeds up with constant acceleration.

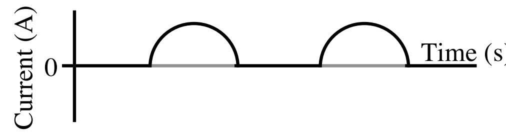
D. experiences an induced current.

29. Which graph accurately reflects the current associated with Loop E in the experiment?

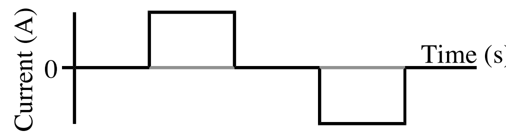
A.



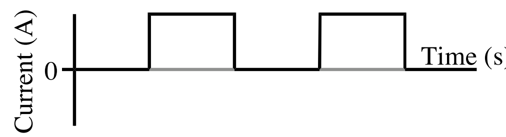
B.



C.



D.



30. What is true for Loop C in Experiment I?

A. It experiences the same *emf* whether it enters the B field with the 6cm side first or the 8cm side first.

B. It experiences a greater *emf* when it enters the B field with the 6cm side first than the 8cm side first.

C. It experiences a greater *emf* when it enters the B field with the 8cm side first than the 6cm side first.

D. It only experiences an *emf* if it enters the B field with the 6cm side first.

31. Which change will NOT increase the magnitude of the current induced into a loop entering a B field?

A. Increasing the area inside of the loop

B. Moving the loop into the field at a faster rate

C. Moving the two magnets closer to one another

D. Using a loop made from a thinner wire

32. If Loop C is moved from the right side of the magnetic field in Figure 1, through the field and then on to the left side, what type of current does it feel upon exiting the field while moving to the left?

A. A clockwise alternating current

B. A counterclockwise alternating current

C. A clockwise direct current

D. A counterclockwise direct current

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27. Choice D is the best answer. The electromotive force results from the induction of charge movement caused by the change in the magnetic flux. This is independent of the material of which the wire loop is made. The materials have different electrical resistances which impacts the current, but that has no impact on the *emf*. This can be verified using Equation 1, which shows that the *emf* depends only on the B field, the area of the loop, and the angle between the normal of the loop and the B field. The equation verifies that the material does not matter. You hopefully can answer this question either intuitively or by taking advantage of the equation they gave. **The best answer is choice D.**

28. Choice D is the best answer. As a conducting loop first enters a magnetic field, it experiences a change in the magnetic flux (the magnetic field within the loop). This induces a current in the loop, making choice **D** the best answer. By generating current, the energy of the moving loop is being converted into current, so energy is drained as it enters the field. As such, it feels a repulsive force as it enters the field, not an attractive force pulling it into the field. Choice A is eliminated. A torque can be felt if the loop had an existing magnetic field (which would be possible if a current were being pushed through it by an external *emf* source.) That is not the case here, so a torque causing it to rotate 90˚ is not viable. Choice B is eliminated. Because of the resistance the loop feels upon entering the field, it actually slows down as it enters the field. This eliminates choice C. **The best answer is choice D.**

29. Choice A is the best answer. As in all cases, as the loop enters the field, the magnetic flux is increasing and as the loop exits the field, the magnetic flux is decreasing. This means that the current moves in opposite directions when the loop is entering versus when the loop is exiting the magnetic field. This eliminates choices B and D. To answer the question from this point, we must determine whether the current is constant or varies as the loop enters and exits the field. In the case of Loop E, the loop is circular. Unlike with a rectangular loop, the area of the loop entering the field (and thus the magnitude of the magnetic flux) changes as the loop enters the field. As the circular loops enters the field, the magnetic flux increases at an increasing rate until the loop is half way in, after which the magnetic flux increases at a decreasing rate. This means that the current will increase in magnitude as lop enters the field until it is halfway into the field, at which time the magnitude of the current will begin to decrease. This is best described in the graph in choice **A**. Even if that doesn't seem completely clear, choice C cannot be correct, because the magnetic flux does not increase at a uniform rate, so current cannot flow at a constant rate during the induction periods. **The best answer is choice A.**

30. Choice C is the best answer. Loop C is rectangular, so it has two possible orientations for entering the field such that the plane of the loop is perpendicular to the magnetic field. The greatest *emf* is felt with the greatest change in flux. When the rectangular loop enters long side (8 cm side) first, it experiences a larger change in flux than when it enters short side (6 cm side) first, assuming it enters with the same velocity in each case. This is simply due to the fact it is wider. This eliminates choices A and B and leaves choice **C** as the likely best answer. It feels an *emf* no matter which side enters first, so choice D is eliminated. **The best answer is choice C.**

31. Choice D is the best answer. The magnitude of the current induced into the loop depends on the rate at which the magnetic flux changes. The greater the rate at which the magnetic flux changes, the greater the induced current. Increasing the area inside of the loop increases the magnetic flux as it enters a magnetic field, so choice A is eliminated. Moving the loop into the field at a faster rate will increase the rate at which the magnetic flux increases, so the current is greater and thus choice B is eliminated. If the two magnets are moved closer to one another, the magnitude of the external B field will increase, resulting in a greater magnetic flux within the loop. This will increase the current, which eliminates choices C. Using a loop of thinner wire causes a greater resistance. Although the magnetic flux does not change, and therefore the induced *emf* does not change, the current is reduced. **The best answer is choice D.**

32. Choice C is the best answer. If Loop C is exiting the field moving to the left, the magnetic flux is decreasing the entire time the loop is leaving the field, so the current will travel in the same direction during the entire time it is exiting the field. This means the current is a direct current, which eliminates choices A and B. Those two choices should have been eliminated based on the idea that alternating current goes both directions, so it cannot be assigned a clockwise or clockwise orientation. To determine the direction of the current, we can address the question in one of two ways. The first way is to apply Lenz's law. Lenz's law states that as the magnetic flux within a loop changes, a current will be induced in the loop that opposes the change in the magnetic flux. In this case, the external magnetic field points down, so upon exiting the region inside of the loops experiences a reduction in the magnitude of the magnetic field pointing down. As such, the current induced in the loop will compensate for the loss by creating a magnetic field pointing down in the region within the loop. This is done by creating a clockwise current in the loop. Choice **C** is the best answer. This can be verified using the right-hand rule. As the loop leaves the magnetic field, only the back edge of the loop is completely immersed in the field. Considering motion of the conducting rod to be to the left and the orientation of the magnetic field to be into the page, the force on positively charged particles in the back edge of the loop will be downward (according to the right hand rule). That push will cause the positive charges to flow in a cyclic fashion, down the back edge, to the left in the lower edge, up the front edge, and to the right in the top edge. This describes a clockwise current in the loop, verifying choice **C** is the best answer. **The best answer is choice C.**