# PHYS 1120 Discussion 7. Faraday's law and Inductance

Brief Solutions

**1. Loose helical coil**

A. Forces across a loop

Across a loop, currents are in opposite directions. They repel, opening up the circle.

B. Forces between loops

Between loops, currents are in the same direction. They attract, pulling the windings closer together.

C. Effect of increased current

The greater the current, the greater push to widen the coil (increase its diameter) and shorten it (decreasing the helical pitch).

**2. (20-9) Moving loops near a straight current**

Loop A experiences no change in magnetic flux. Loops B and C, which move away from the wire, experience decreases in magnetic flux. For B, the flux is out of the page; for C, the flux is into the page. The induced currents will be in the direction to maintain the flux, so that means magnetic moments out of the page for loop B and into the page for loop C; corresponding to a counterclockwise current in A and a clockwise current in B.

**3. (20-17) Loops near a growing current**

Bisected ring: Regardless of what the current is doing, the magnetic flux through the ring is zero. With no change in flux, there is no induced emf.

Adjacent ring: the magnetic flux through the ring is toward you (out of the page) and growing; the induced current will create a magnetic field to keep the flux from growing, which means that its magnetic moment is into the page. This requires a clockwise current.

**4. (20-53) Facing rings**

The current-carrying ring has a magnetic moment to the right. When the left ring moves toward the right ring, it increases the rightward magnetic flux within the right ring. To counter that flux change, a counterclockwise current is induced in the right ring.

**5. Specified solenoid**

The conditions of this solenoid are windings density $n = 50/\text{cm} = 5000/\text{m}$, radius 2.50 cm = 0.0250 m, length $L = 15.0$ cm = 0.0150 m. This means that the total number of windings is $nL = 750$ and the area of a winding is $\pi r^2 = 1.9635 \times 10^{-3}$ m$^2$.

A. $B$ field in solenoid with $I = 2$ A

The magnetic field in the solenoid is $B = \mu_0 n I = (4\pi \times 10^{-7}\ \text{T} \cdot \text{m/A})(50/\text{m})(2\ \text{A}) = 6.283 \times 10^{-5}$ T.

B. Magnetic flux through one winding

$\Phi = BA = (6.283 \times 10^{-5}\ \mathrm{T})(1.9635 \times 10^{-3}\ \mathrm{m}^2) = 1.2337 \times 10^{-7}\ \mathrm{T} \cdot \mathrm{m}^2$. I haven't mentioned to my class that a $\mathrm{T} \cdot \mathrm{m}^2$ is a weber, symbol Wb.

C. Magnetic flux through all windings

750 times the flux in one winding, $9.254 \times 10^{-5}$ Wb.

D. Emf when current decreases

The emf is $\varepsilon = -\Delta\Phi/\Delta t = -(-9.253 \times 10^{-5}\ \mathrm{Wb})/(2\ \mathrm{s}) = 4.626 \times 10^{-5}\ \mathrm{Wb/s} = 4.626 \times 10^{-5}\ \mathrm{V}$.

E. Inductance

Conveniently, I made the rate of change of current $\Delta I/\Delta t = 1$ A/s, so form $V = L\ \Delta I/\Delta t$ we get $L = V/(\Delta I/\Delta t) = (4.626 \times 10^{-5}\ \mathrm{V})/(1\ \mathrm{A/s}) = 4.626 \times 10^{-5}\ \Omega \cdot \mathrm{s} = 4.626 \times 10^{-5}\ \mathrm{H}$.

F. Total charge flow

If the decrease is constant, the total charge transported is 2 coulombs. This may take some thinking to confirm, but it is exactly the same math as asking how many meters a body travels when stopping in 2 seconds from an initial speed of 2 meters per second.

G. Total work done by the solenoid

The voltage is constant $V = 4.626 \times 10^{-5}$ V, acting on a total charge of 2 coulombs, so the work done is $W = VQ = (4.626 \times 10^{-5}\ \mathrm{V})(2\ \mathrm{C}) = 9.253 \times 10^{-5}$ J.

## 6. Coil rotating in a magnetic field

Before the question is even asked, we can deduce from the setup that it will involve an emf induced around the square loop by a changing magnetic flux according to Faraday's law.

The coil is a square 2.80 cm = 0.0280 m on a side, which gives it an area of 7.84 $\mathrm{cm}^2$. The magnetic field is 1.25 tesla, so we can find a maximum flux of $\Phi = BA = (1.25\ \mathrm{T})(7.84 \times 10^{-4}\ \mathrm{m}^2) = 9.8 \times 10^{-4}$ Wb. In the 28 turns, that means a total flux of $27.44 \times 10^{-3}$ Wb. The flux goes to zero from this maximum value in 0.335 seconds, which makes an induced emf of $-\Delta\Phi/\Delta t = (27.44 \times 10^{-3}\ \mathrm{Wb})/(0.335\ \mathrm{s}) = 0.0819$ V. We are also told that the resistance of the coil is $R = 0.780\ \Omega$.

A. Average emf in the coil

Above, we found that to be 0.0819 V.

B. Average current in the coil

Ohm's law tells us $I = V/R = (0.0819\ \mathrm{V})/(0.780\ \Omega) = 0.105$ A.

## 7. Transformer

We are given that the windings ratio $N_1/N_2 = 13$, so we also know that $V_1/V_2 = N_1/N_2 = 13$. We also know that the input power equals the input power, $V_1 I_1 = V_2 I_2$. We are told the input voltage $V_1 =$ 120 V, and input current $I_1 = 250$ mA. From this we deduce power $P = V_1 I_1 = (120\ \mathrm{V})(250\ \mathrm{mA}) =$ 30 W.

a. Output voltage $V_2$

From $V_1/V_2 = 13$, we get $V_2 = V_1/13 = 9.12$ V.

b. Power

We already found this to be 30 watts.