Problem Set 9. Faraday's law and induction — Due: 31 March 2023
Electromagnetism and Light — at 3:00 pm

Reading: *Sternheim and Kane*, chapter 20, sections 3–8; chapter 21, sections 1–7
Electromagnetism and Optics, chapter XII, sections 5–7; chapter XII; chapter XV.

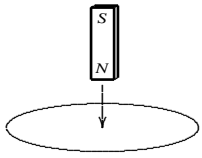
Please show all of the necessary steps in solving the following problems. Full credit will only be given for complete solutions.

1. A circular loop of wire has a resistance of 20.0 Ω and a radius of 5.00 cm. Its normal is parallel to a uniform magnetic field of magnitude 2.00 T. The loop is rotated so that in 0.400 seconds its normal is perpendicular to the field.

a. Find the average induced emf, $\bar{\mathscr{E}}$.
b. Find the average induced current, $\bar{I}$.

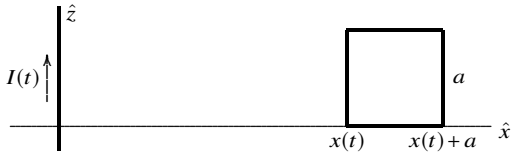
2. A bar magnet is dropped through a loop of wire. What is the direction of the current that flows in the loop, clockwise or counterclockwise, when the magnet is

a. above the loop,
b. half-way through the loop, and
c. below the loop?
d. Please roughly sketch the induced current $I(t)$ as a function of time, assuming that the speed of the magnet is constant. In the plot, let $I(t) > 0$ be a counterclockwise current and $I(t) < 0$ be a clockwise current. Plot the behaviour from when the magnet is far away above the loop until it is far away below the loop.



3. A square loop of wire is placed next to a straight, infinite wire, through which a current $I(t)$ flows. The loop, whose sides are of a length a, is at a distance $x(t)$ from the long wire. The resistance of the loop is R.

a. Calculate the current induced in the loop when $I(t)$ is changing, but $x(t) = b$ is fixed.
b. If $I(t)$ is increasing, is the current in the loop circulating in a clockwise or counterclockwise direction?
c. Calculate the current induced in the loop when I is constant, but $x(t)$ is changing instead.



4. A certain type of wire is able to carry up to a 15.0 A (rms) current. How much power can this wire supply

a. at a 120 V (rms) alternating current and
b. at a 230 V (rms) alternating current?

5. A transformer has 100 turns in one coil and 500 turns in the other coil. This transformer is connected to a 120 V power line. What is the voltage across the other side if

a. the 100 turn coil is connected to the power line or if
b. the 500 turn coil is connected to the power line?

6. When the current in a solenoid is increased uniformly from 0 A to 10.0 A in 10 seconds, the self-induced emf is 8.00 V.

a. What is the inductance L of the solenoid?
b. How much energy is stored in the solenoid when the current is 10.0 A?

7. A solenoid with N coils, cross-sectional area A, and length ℓ, has a current I flowing through it. The interior of the solenoid is filled with a material with a magnetic constant K_m.

a. What is the magnetic field B inside the solenoid?
b. How much energy per unit volume is stored inside this solenoid? Express the answer in the given parameters.
c. The energy per unit volume can be written as $\kappa B^2/K_m$. Verify this statement and determine the constant κ.

8. A solenoid produces a magnetic field of 2.000 T when it is in a vacuum. When the solenoid is then filled with some material, its magnetic field drops to 1.992 T.

a. What is the magnetic constant of this material?
b. Of which kind of magnetic material is it made?