Physics 333 – Fall 2021
Due November 5.

Homework 09 - REV A

Instructions:

Each problem should begin at the top of a new sheet of paper. The final answer (numerical or symbolic) should be boxed or written in a different color. Each problem should have your name on the left and, below it, the *SPN*, circled. Problems should (usually) include a 3x3 inch sketch and begin with the general equations and the assumptions you make.

NOTE: The first four problems would make good exam problems for Chapter 4. Please understand them.

SPN 9–01. Do Griffiths Problem 4.18. (– *Capacitor with dielectric.*)

SPN 9–02. A metal wire of length L has a uniform charge Q on it. The wire radius is a and the wire is surrounded by a dielectric insulation (think plastic or rubber) with outer radius b. The insulation has relative dielectric constant ϵ_R.

a: What is $\vec{D}$ for $a < r < b$ and also for $r > b$?
b: What is $\vec{E}$ for $a < r < b$ and also for $r > b$?
c: What is $\vec{P}$ for $a < r < b$ and also for $r > b$?
d: What is ρ_B for $a < r < b$?
e: What is σ_B for $r = a$ and $r = b$?

SPN 9–03. This is exactly the same as the last problem, but now with numbers. You can plug and chug to the results you got for the last problem. $L = 3$ m, $Q = 1\ \mu$ C, a=2 mm, b=5 mm, and $\epsilon_R = 2.5$.

a: What is $\vec{D}$ for $a < r < b$ and also for $r > b$?
b: What is $\vec{E}$ for $a < r < b$ and also for $r > b$?
c: What is $\vec{P}$ for $a < r < b$ and also for $r > b$?
d: What is ρ_B for $a < r < b$?
e: What is σ_B for $r = a$ and $r = b$?

SPN 9–04. A thick rubber tube has inner radius a and outer radius b. There is no free charge on the tube, but it has a uniform polarization $\vec{P} = k\ s\ \ \hat{s}$. Calculate (in two ways) the Electric field $\vec{E}$ for $r < a$, $a < r < b$ and for $r > b$.

a: Use $\vec{P}$ to account for all bound charge (that includes volume and surface charge). Use Gauss's law properly to arrive at $\vec{E}$.
b: Use Eqn. 4.23 to calculate $\vec{D}$, and then 4.21 to get $\vec{E}$.

SPN 9–05. (– *Force on a wire*) Imagine two parallel wires 20 cm long a centimeter apart. If each wire was carrying 3 Amperes in the same direction, what is the force between the wires? It is easy to look up the formula for force between two wires, but I want you to derive it before plugging in numbers. You may use equation 5.16 without derivation, but please derive the magnetic field around one wire beginning with Ampere's law.

SPN 9–06. (– *Force on a current loop*) A square loop of side b lies in the x–z plane and carries a clockwise current I_0. It is centered at the origin. It is exposed to a non-uniform magnetic field $\vec{B} = cx\hat{y}$ Sketch the situation. On the sketch show arrows indicating the direction of the force on each side of the loop. Calculate the magnitude and direction of the total force on the loop.

SPN 9–07. (– *Earth and the Aurora.*) Look up the approximate strength of the Earth's magnetic field (it varies with latitude ... just pick a value). The Aurora borealis is made by the impact of the solar wind on the upper atmosphere. The solar wind is largely protons and electrons impacting the Earth's upper atmosphere at about 400 km/s. The particles are "trapped" on the Earth's magnetic field lines, which more precisely means that they are forced to orbit around the field lines in a helical path and are guided down to the ionosphere.

a: What is the cyclotron frequency of a proton trapped on a terrestrial field line?
b: What is the radius of its orbit around the field line?
c: Repeat these calculations for an electron.

SPN 9–08. (– *Biot-Savart Law on a current loop.*)

a: Use the Biot-Savart law to derive equation 5.41 for the field along the z-axis above a current loop of radius R.
b: Given a current loop an inch across, how large a current do you need to result in a Tesla at the center of the loop?
c: What if you want a Tesla an inch abouve the center of the loop? (Yes ... as Tesla is a big field!)

SPN 9–09. (– *e/m for an electron*) In class we did the e/m experiment. You now know enough to completely work it out. Let's assume you know $q = 1.6 \times 10^{-19}\ C$ and figure out m_e. The electron accelerating voltage was 100 V. (I called it $\phi = 100\ V$ so you wouldn't confuse v for velocity with V for voltage.) Do what you like. The current through the coils was $I = 0.5\ Amp$. Each coil has 140 turns and there were two of them. They were arranged to add, so you could just pretend you had one coil with 280 turns. The coil radius is $R = 140\ mm$. The coils are also $2z = 140\ mm$ apart.

a: Figure out the velocity of the electron after it passes through a 100 V voltage change.

b: Use the Biot-Savart law for a current loop to figure out the field a distance $z = 70\ mm$ above a single 280 turn coil of radius R given above.

c: Use the magnetic force to provide the needed centripetal force for an orbit of radius $a = 7.0\ cm$. This should allow you to calculate m_e. You will be within at least a factor of 3 of the published value.

SPN 9–10. – *Ampere's law for a solenoid.*

a: Sketch a cross section of an "infinite" solenoid and use Ampere's law to derive the field inside the solenoid. Your sketch should include your Amperian loop and an indication of what direction the current is flowing in the wires and what direction the B-field is in.
b: We will measure a solenoid in class. There were 3400 turns in all and the solenoid was 3.5 inches long. Our measured current was (TBA) and the estimated B-field is (TBA). Calculate what the B-field "should have been", and give your views about why the result is not quite the same as what was measured.

SPN 9–11. The charge that enters a wire at time t is $Q(t) = (15 \quad Coulombs)(1 - e^{-t/2.5})$. Find an expression for the current through the wire. What is the current at t=0? t=2.5 s? t=25 s?

SPN 9–12. In a classical model of Hydrogen, the electron orbits the proton in a circular orbit with a radius of 53 picometers.

(a) What is the electron's orbital frequency?

(b) To what current does this correspond?