Student ID Number: ________

PRELIMINARY EXAMINATION

Department of Physics

University of Florida

Part B, August 15, 2019, 14:00–17:00

Instructions

1. You may use a calculator and CRC Math tables or equivalent. No other tables or aids are allowed or required. You may **NOT** use programmable calculators to store formulae.

   (a) All of the problems will be graded and will be tabulated to generate a final score. Therefore, you should submit work for all of the problems.

   (b) For convenience in grading please write legibly, use only one side of each sheet of paper, and work different problems on separate sheets of paper. The sheets for each problem will be stapled together but separately from the other two problems.

   (c) Your assigned student **ID Number**, the **Problem Number**, and the **Page Number** should appear in the upper right hand corner of each sheet. Do **NOT** use your name anywhere on the Exam.

   (d) All work must be shown to receive full credit. Work must be clear and unambiguous. Be sure that you hand your completed work to the Proctor.

   (e) Each problem is worth 10 points.

   (f) Following the UF Honor Code, your work on this examination must reflect your own independent effort, and you must not have given, nor received, any unauthorized help or assistance. If you have any questions, ask the Proctor.

University of Florida Honor Code: We, the members of the University of Florida community, pledge to hold ourselves and our peers to the highest standards of honesty and integrity. On all work submitted for credit by students at the University of Florida, the following pledge is either required or implied: *"On my honor, I have neither given nor received unauthorized aid in doing this assignment."*

DO NOT OPEN EXAM UNTIL INSTRUCTED

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DEPARTMENT OF PHYSICS
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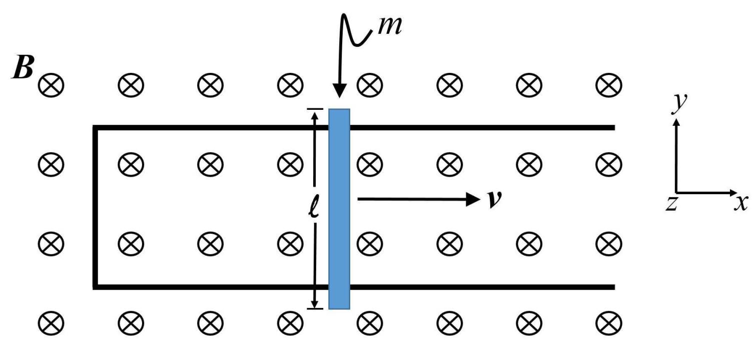
B1. Sliding rail. A metal bar (mass m, length ℓ, cross-sectional area A, conductivity σ) slides on a horizontal, frictionless, perfectly conducting rail in a uniform magnetic field, as shown in the figure below.



(a) **[2 points]** If the bar moves with velocity v in the $+x$ direction, what is the current in the circuit (direction as well as magnitude)?

(b) **[2 points]** In the same situation as (a), what is the force on the bar? Be sure to give the direction as well as the magnitude

(c) **[2 points]** If the initial velocity of the bar is v_0 at time $t = 0$, what is the expression for the velocity at later times t?

(d) **[2 points]** If the initial velocity of the bar is v_0, how far does the bar slide before stopping?

(e) **[2 points]** Show by explicit integration that the energy produced in Joule heating is equal to the initial kinetic energy of the bar.

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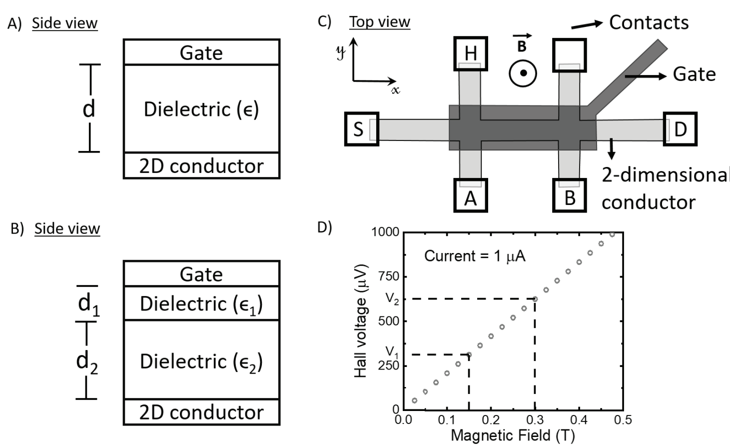
B2. In this problem, you will develop a simple model for a field effect transistor (FET) in the presence of a magnetic field. Similar devices have been used to perform the first measurements of the quantum Hall effect, whose discovery was awarded the Nobel prize in 1985. The device consists of a two-dimensional conductor (2DC) connected with ohmic contacts. A metallic gate, which is another thin conductor to which a voltage can be applied, is also present and is separated from the 2DC by dielectric layers, as illustrated in Fig A and B. In this simple model, we will treat the 2DC as a metal.



(a) [**1 point**] Calculate the capacitance of the FET with area A shown in Fig. A.

(b) [**2 points**] Calculate the capacitance of the FET with area A shown in Fig. B.

(c) [**2 points**] In modulation-doped FETs, there is usually an electron density n_{2D} in the 2DC when the gate is grounded. Using the result from part b) and assuming an infinitesimally thin 2DC, find the magnitude and polarity of the threshold voltage V_t of the FET as a function of n_{2D}. V_t is the lowest gate voltage for which conduction through the 2DC is allowed in the x-direction, as shown in Fig. C. This will occur for infinitesimal charge density in the 2DCs.

(d) [**3 points**] If a constant and uniform current I is flowing between the source (S) and the drain (D) of the FET depicted in Fig. C, there will be a voltage drop across contacts A and B. In the presence of a small magnetic field $\mathbf{B}$ perpendicular to the FET plane (pointing out of the page), a voltage will also develop across contacts A and H. This phenomenon is known as the Hall effect. For a FET having electrons as charge carriers, find the magnitude and polarity (by indicating which contact is at the largest potential) of this Hall voltage.

(e) **[2 points]** Fig. D shows the Hall voltage (in μV) as a function of magnetic field when the gate is grounded and 1 μA is flowing between S and D. $V_1 = 312.5\ \mu$V and $V_2 = 625\ \mu$V. Assuming the design of Fig. B with 50 nm of hafnium oxide ($\epsilon_1 = 19\epsilon_0$) and 200 nm of AlGaAs ($\epsilon_2 = 12\epsilon_0$) as dielectrics, find V_t. You can use $e = 1.6 \times 10^{-19}$ C and $\epsilon_0 = 8.85 \times 10^{-12}$ F m^{-1}.

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B3. Here you will estimate the classical radiation from an electron bound to a proton. The electron has charge $Q = -e$ and mass m. The proton has charge $+e$ and infinite mass. Take the force binding the electron to be an inward-directed Coulomb force.

The Larmor formula for radiated power from accelerated motion of a charge Q is

$$P = \frac{\mu_0 Q^2 a^2}{6\pi c} \left(P = \frac{2Q^2 a^2}{3c^3} \text{ in gaussian units} \right)$$

where μ_0 is the vacuum permeability, a is the acceleration, and c is the speed of light. For parts a, b, c and f only you should first find an equation and then the numerical value. Some constants (to the accuracy you need them) are below.

(a) [**2 points**] Calculate the orbital velocity v and show it is relatively small with respect to c.

(b) [**1 point**] Calculate the radiated power. (Because $v \ll c$ you can use the Larmor formula.)

(c) [**2 points**] Radiation means a loss of energy. Calculate the starting energy $\mathcal{E}$: the sum of the electron's classical kinetic energy and its potential energy when $r = a_0$, the Bohr radius. (Take $V = 0$ when $r \to \infty$.)

(d) [**2 points**] Find the time rate of change of energy, $d\mathcal{E}/dt$. (Hint: the radius will be changing.)

(e) [**1 point**] Find the time rate of change of the radius.

(f) [**2 points**] Calculate the time required for the orbital radius to reduce from the 0.5 Å value it starts with to zero.

The orbital radius for hydrogen is $a_0 = 5 \times 10^{-11}$ m (0.5 Å).

The electron mass is $m = 9 \times 10^{-31}$ kg (9×10^{-28} g).

The magnitude of the charge of electron and proton is $e = 1.6 \times 10^{-19}$ C (4.8×10^{-10} statcoulombs).

The speed of light is $c = 3 \times 10^8$ m/s (3×10^{10} cm/s).

The permittivity of the vacuum is $\epsilon_0 = 9 \times 10^{-12}$ C/N·m^2 (1 in the gaussian system).

The vacuum permeability is $\mu_0 = 4\pi \times 10^{-7}$ N/A^2 (1 in the gaussian system).