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PHYSICS 7B, Section 1 – Fall 2013
Final exam, C. Bordel
Monday, December 16, 2013
11:30am – 2:30pm

First Name:_______________________________

Last Name:_______________________________

Student ID Number:_________________________

Section Number:___________________________

Section Time:______________________________

Section GSI:_______________________________

Person Sitting to Left:______________________

Person Sitting to Right:_____________________

You may write on the backs of pages. If you are using any extra sheets, ***append them to the end*** *of the exam, and include a note in the original question to guide the grader to the appended sheet.*

Number of extra sheets:______________________

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<u>Problem 1</u> – Cyclic thermodynamic process (20 pts)

n moles of monatomic ideal gas undergo the cyclic process shown in Fig.1. Starting at point *A* (P_A, V_A), the gas adiabatically expands until its volume triples, ending at point *B*. It is then heated up at constant volume to point *C*, and finally compressed isothermally to its initial state *A*.

a) What is the net work done by the gas over a full cycle?
b) Show on the diagram what represents the net work. Explain.
c) Could that be the work done by a heat engine? Justify.
d) What is the net amount of heat transferred to the gas through a full cycle?

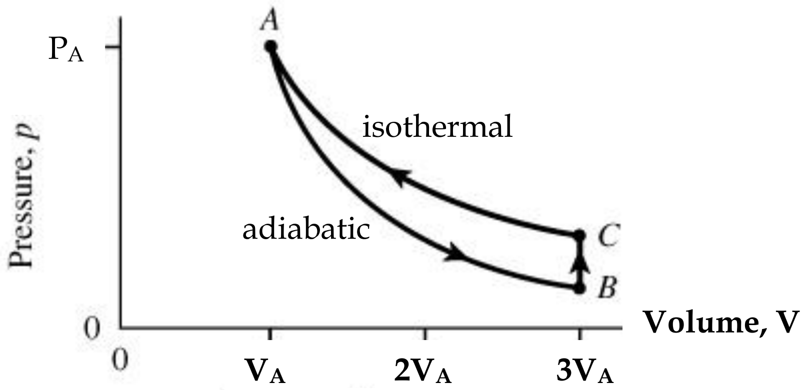

Figure 1

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<u>Problem 2</u> – Electric dipole (20 pts)

We consider an electric dipole of dipole moment $\vec{p} = q\vec{d}$. A polar coordinate system is set up with its origin at the negative charge, and the angular reference along the axis joining the 2 charges.

a) Calculate the electric potential $V(r,\theta)$ produced by the electric dipole, at long distance from the dipole ($r>>d$).
b) Calculate the electric field $\vec{E}(r,\theta)$ produced by the dipole in the same approximation.
c) If the electric dipole is placed in a uniform applied field $\vec{E}_0$, what is the most stable position of the dipole? Explain.
d) Establish the differential equation of motion of the dipole in the uniform electric field in the small angle approximation (assuming no source of friction) and explain without solving the equation what type of motion the solution describes. *Hint: you may want to use some version of Newton's 2nd law.*

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<u>Problem 3</u> – DC circuit (20 pts)

A car battery is a lead-acid type of rechargeable battery that is made up of plates of lead and separate plates of lead dioxide, which are submerged into an electrolyte solution. This causes a chemical reaction that releases electrons and converts chemical energy into electrical energy. As the battery discharges, the acid of the electrolyte reacts with the materials of the plates, changing their surface to lead sulfate. When the battery is recharged, the chemical reaction is reversed: the lead sulfate reforms into lead dioxide and lead.

a) What is the difference between the emf of a battery and its terminal voltage?
b) A good car battery is used to jump-start a car that has a weak battery. The situation can be represented by the following circuit. Explain why the batteries need to be connected as shown in Fig.2 in order to jump-start a car that has a weak battery. Draw the direction of the conventional current I_2 passing between A and B.
c) What is the effect of the additional battery on the current passing through the starter motor, compared to the use of the weak battery only?
d) Once the vehicle has been started, the auxiliary source can be removed. What is the normal charging system that operates when the engine is on?

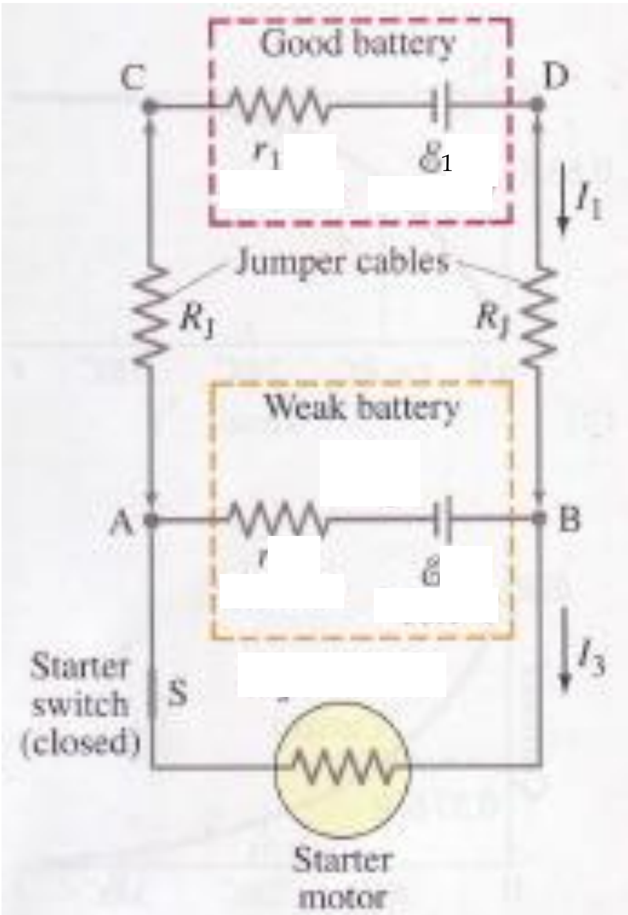

Figure 2

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<u>Problem 4</u> - Motion of a charged particle (20 pts)

A mass spectrometer (Fig.3) is used to measure masses of atoms. Positive ions of mass *m* and charge *q* are produced at the source *S*. As they pass through slit S_1 with a velocity $\vec{v}$ pointing to the right, they enter a region of crossed electric and magnetic fields. The electric field $\vec{E}$ is created by the 2 charged plates noted with (+) and (-) between the 2 slits. The magnetic field in this region is called $\vec{B}_1$ and points out of the page, as shown by the dots on the figure. The ions that pass through slit S_2 experience a magnetic field $\vec{B}_2$, also pointing out of the page, and are finally collected on a detector.

a) Draw the electric field created by the 2 charged plates. Under which condition can this field be considered as uniform?
b) Determine the condition that needs to be satisfied in order for the ions to follow a straight trajectory from S_1 to S_2. Explain why this first chamber is called a velocity selector.
c) What is the trajectory followed by the ions in the region of magnetic field $\vec{B}_2$? Justify. Where should the detector be located in the plane containing S_2 to collect the incoming ions?
d) Determine the mass of the ion in terms of the fields, ion charge, and S_2-detector distance.

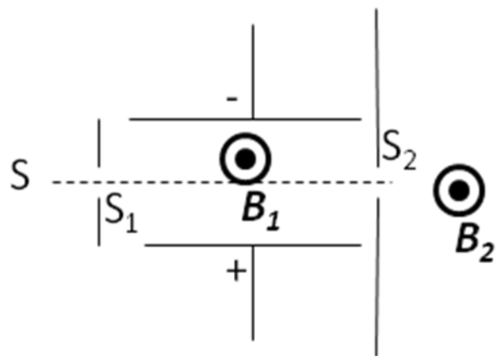

Figure 3

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<u>Problem 5</u> – Sheet of current (20 pts)

A flat sheet of metal of thickness *t* carries a uniform current density $\vec{j}$, as shown in Fig.4.

a) Using Biot-Savart's law, calculate the magnitude of the $\vec{B}$ field created at point P, considering the infinite plane as a succession of infinite wires.
b) Recalculate $\vec{B}$ using a faster method.

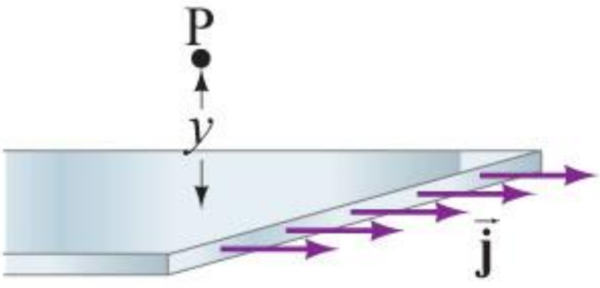

Figure 4

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Problem 6 – Electromagnetic induction (20 pts)

A circular-shaped circuit of radius *r*, containing a resistor of resistance *R* and a capacitor of capacitance *C*, is placed in a uniform magnetic field $\vec{B}$ pointing into the page, as shown in Fig.5. The capacitor is initially uncharged, and at time t=0, the magnitude of the magnetic field starts changing at a rate $dB/dt=a$, $a>0$.

a) Using Lenz's law, determine the direction of the induced current in the closed loop. Justify your answer.
b) Calculate the induced emf ε and draw the emf symbol in the appropriate direction on the closed loop.
c) What is the voltage V_C across the capacitor as a function of time?
d) Draw the equivalent circuit right after t=0 and express the power dissipated by the resistor at t=0.

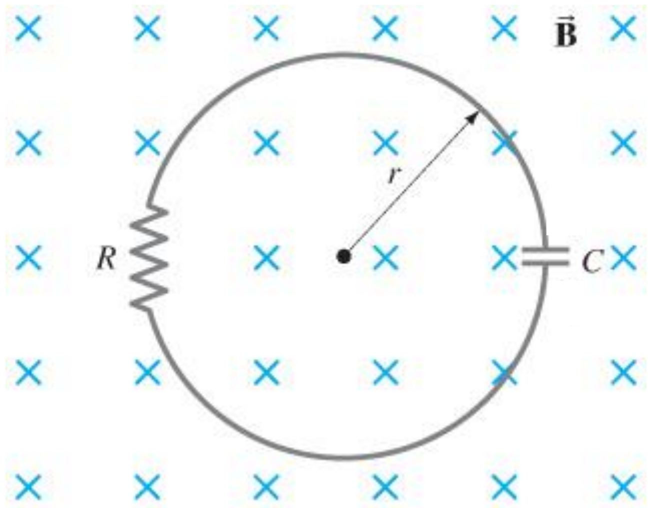

Figure 5

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<u>Problem 7</u> – Toroidal coil (20 pts)

A toroidal coil of inner radius r_1, outer radius r_2 and height h contains N turns and carries a current I. Assume that the current passes from left to right at the top of the cross-section shown below (Fig.6).

a) Determine the direction and magnitude of the magnetic field created inside this toroidal coil.
b) Calculate the self-inductance L using the definition.
c) Calculate the total energy stored in the coil.
d) Recalculate the self-inductance using the energy density.

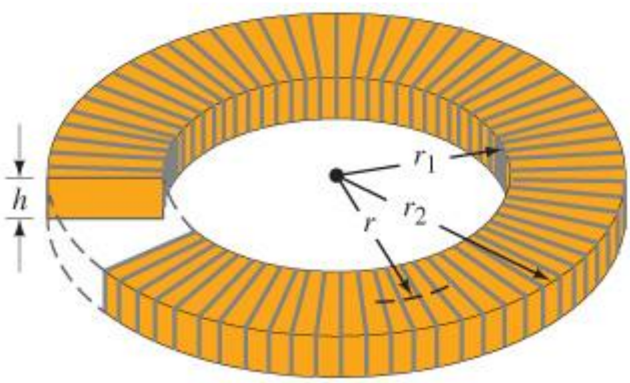

Figure 6

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