University of Wisconsin-Madison
Engineering Physics Department
Spring 2013 Qualifying Exams

# Classical Physics

You must solve 4 out of the 6 problems.
Start each problem on a new page.

**SHOW ALL YOUR WORK.**
**WRITE ONLY ON THE FRONT PAGES OF THE WORKSHEETS, NOT ON THE EXAM PAGES**

Grading is based on both the final answer and work done in reaching your answer. All problems receive an equal number of points.

Clearly indicate which problems you want graded. If you do not indicate which problems are to be graded, the first four solutions you provide will be graded.

1. ______
2. ______
3. ______
4. ______
5. ______
6. ______

$\mu_0 = 4\pi \times 10^{-7}$ H/m $\qquad \varepsilon_0 = 8.854 \times 10^{-12}$ F/m

Center of mass moments of inertia:

$$I_{disk} = \frac{1}{2}MR^2 \qquad I_{sphere} = \frac{2}{5}MR^2 \qquad I_{rod} = \frac{1}{12}ML^2$$

$I = Mk^2$ (where $k$ is the radius of gyration)

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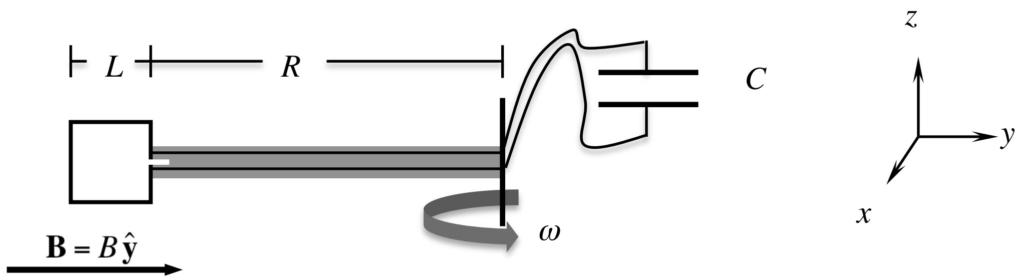
**Problem 1.** A square loop of wire of length $L$ on each side and resistance per unit length $\rho$ is mounted on the end of an arm of length $R$ that rotates at angular frequency $\omega$. There is uniform, time-independent magnetic field of magnitude $B$ pointing in the $y$-direction (normal to the axis of rotation). Leads to a small gap in the loop connect to a capacitor of capacitance $C$.




What is the charge on the capacitor as a function of time for steady oscillating behavior if the impedance of the leads along the arm and to the capacitor and the self-inductance of the loop are negligible?

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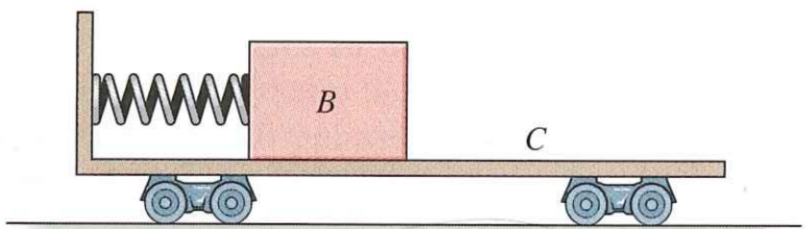
**Problem 2.**

Block *B* has a mass of 50 kg and rests on the surface of a cart that has a mass of 75 kg.

a) (8 points) If the spring, which is attached to the cart and not to the block, is compressed $0.2\ \text{m}$ and the system is released from rest, determine the velocity of the block relative to the ground when the spring returns to its undeformed length. Neglect the inertia of the wheels, the mass of the spring, and friction. The spring constant *k* is 300 N/m.
b) (2 points) Describe, qualitatively, the changes you would expect if friction between the block and the cart were taken into account.



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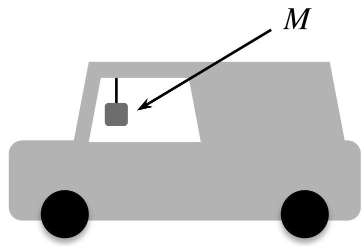
**Problem 3.** An object of mass $M$ hangs from a linearly elastic cord of spring constant $k$ and unstretched length $L_0$ within a vehicle.




a) (7 points) What is the length $L$ of the cord when the vehicle moves at constant speed $V$ around a turn of radius $R >> L_0$ in terms of $M$, $V$, $R$, $L_0$, and gravitational acceleration $g$?

b) (3 points) What is $L$ when the vehicle reaches speed $V$ around a curve of radius $R >> L_0$ with speed increasing at rate $A$? Assume that any oscillations of the mass are completely damped, and provide the length in terms of $M$, $V$, $R$, $L_0$, $g$, and $A$.

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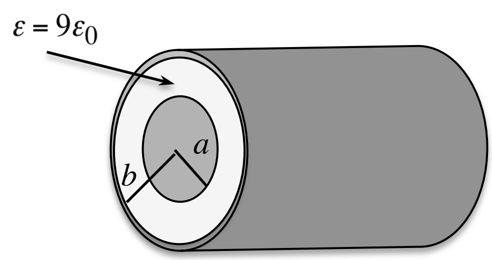
**Problem 4.** The gap of a coaxial waveguide is filled with dielectric material of relative permittivity 9. The radius of the inner conductor is $a$, and the inner radius of the outer conductor is $b$. The electric and magnetic fields in the gap are azimuthally symmetric and oscillate at $\omega$ rad/s. The electric field is purely radial, and its magnitude is inversely proportional to radius $r$, *i.e.* the lowest-order mode.




a) (3 points) What is the orientation of the wave's magnetic field, and how does its magnitude vary with $r$?

b) (3 points) What is the wavelength in terms of the parameters provided and the speed of light in free space ($c$)?

c) (4 points) What is the time-averaged power flowing through the waveguide if the amplitude of the electric field at the surface of the inner conductor is $E_0$? [Provide your result in terms of $E_0$, $c$, the permittivity of free space $\varepsilon_0$, and the dimensions of the waveguide, $a$ and $b$.]

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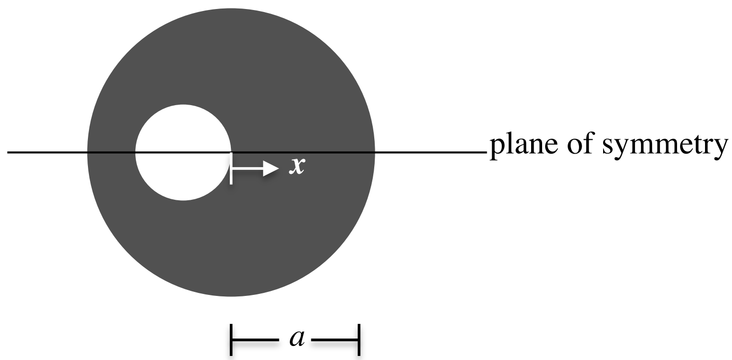
**Problem 5.** A long cylindrical region of radius $a$ is filled with uniform positive charge-density $\rho$, except for an offset cylindrical channel of radius $a/6$, as shown in the cross-sectioned view below. What is the electric field (magnitude and direction) over locations $|x| < a$ on the plane of symmetry?



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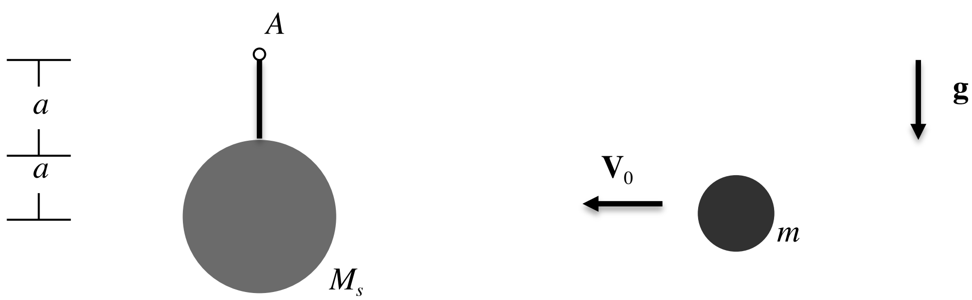
**Problem 6.**
A solid sphere of mass $M_s$ and radius $a$ hangs from an inextensible rope of length $L = a$ that is supported at point A. A second object of mass $m$ moves on a horizontal path that passes through the center of the sphere, leading to an elastic collision on impact.




Ignoring the mass of the rope, what initial velocity $V_0$ of mass $m$ is required so that the sphere makes a complete revolution without the rope becoming slack? [Express your result in terms of $M_s$, $m$, $a$, and gravitational acceleration $g$, and ignore gravitational effects on the trajectory of the second object.]