University of Wisconsin-Madison
Engineering Physics Department
Fall 2010 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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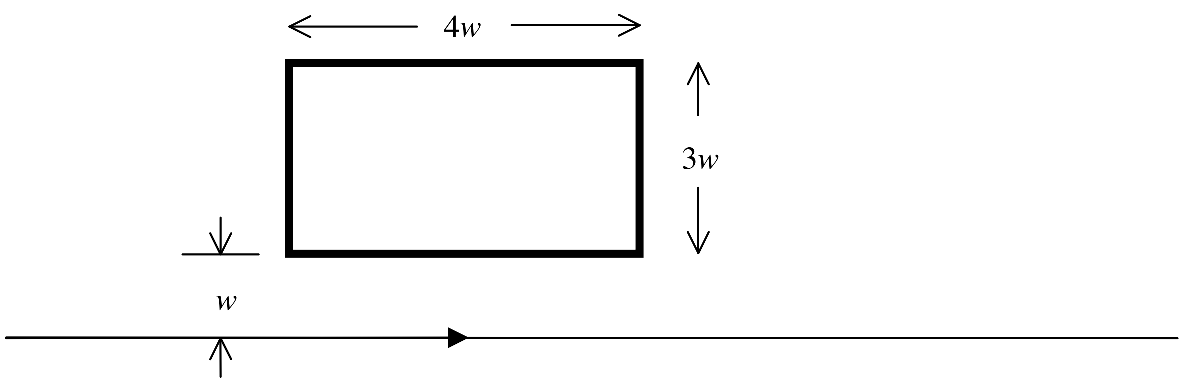
Problem 1.

A rectangular conducting loop of dimensions 3 w and 4 w lies adjacent to a long straight wire as shown below. The wire carries a time-dependent current I, which is held at $I=I_0$ and then, at $t=0$, is ramped down according to $I=I_0 exp(-kt)$, where $k<<c/w$.



a) (6 points) If the loop has resistance R and inductance L, determine the direction and magnitude of the current in the loop as a function of time for $t>0$.
b) (2 points) Determine this current for the case where $L/R<<1/k$.
c) (2 points) Still assuming $L/R<<1/k$, determine the totoal energy dissipated in the loop for $0<t<\infty$.

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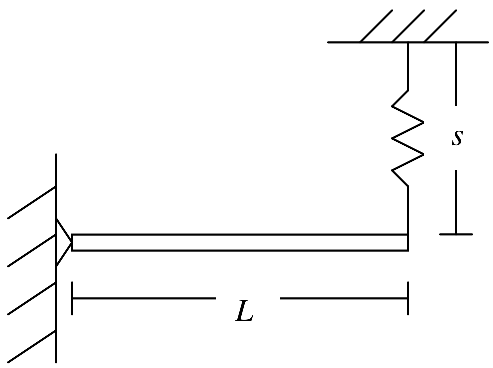
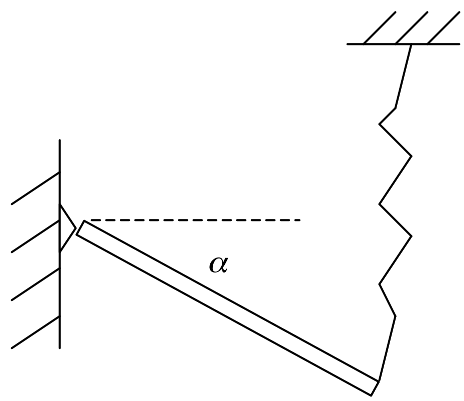
Problem 2.

A uniform rod of length L and mass M is supported by a hinge on one end and by a spring on the other, as shown in the figure. When the rod is horizontal, the spring's orientation is vertical, and the spring is not stretched. The spring constant is k, and its unstretched length is s.



Spring is not stretched; forces are not balanced.



Spring balances rod's weight.

a. (6 points) Find an expression that relates the angle α made by the rod with respect to horizontal in terms of L, M, s, k, and the gravitational constant g when the spring balances the weight of the rod at equilibrium. This does not need to be a closed-form equation for α.

b. (4 points) Find a closed-form expression for α when the spring is very stiff and displacement is small.

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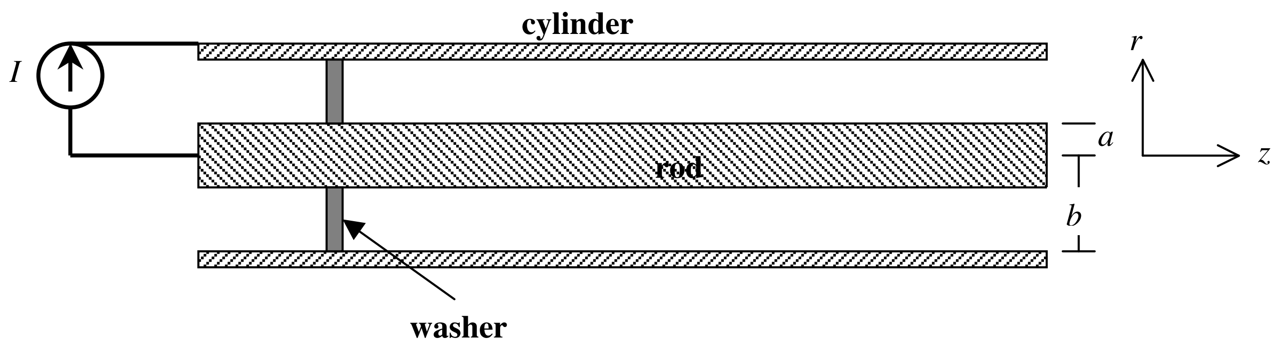
Problem 3.

An electromagnetic washer gun consists of a conducting cylinder of inner radius b and a conducting rod of radius a mounted along the axis of the cylinder. When a conducting washer of inner radius a, outer radius b, and mass M is placed on the rod, it makes electrical contact with both the rod and cylinder but is free to slide in the axial direction. A cross section of the configuration is illustrated in the figure below. The washer gun is powered by an electrical circuit that provides a constant current I.



a. (5 points) Find an expression for the kinetic energy of the washer as a function of time t in terms of a, b, M, I, and the permeability of free space μ_0 with the washer starting at rest at t=0. [Friction is assumed to be negligible. Ignore the effects of any fringe fields.]

b. (5 points) Find an expression for the applied voltage V as a function of time if the electrical resistance is negligible.

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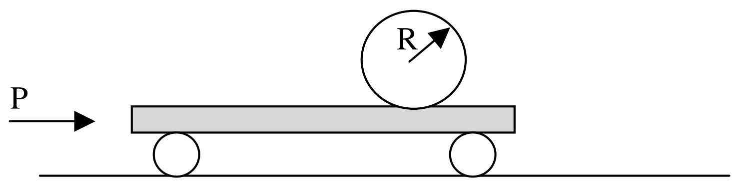
Problem 4.

A solid cylinder of mass m, radius R, and radius of gyration k is resting on a cart of mass M. The coefficient of static friction between the cylinder and the cart is μ. What is the largest horizontal force (P) that can be applied to the cart before the cylinder slips relative to the cart?



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Problem 5.

A rectangular door of width w and mass M closes under the action of an elastic torque $T = -k\theta$ and a viscous torque $T = -c\dot{\theta}$. Calculate the coefficient c for the door to close at the fastest rate without oscillation in terms of w, M, and k.

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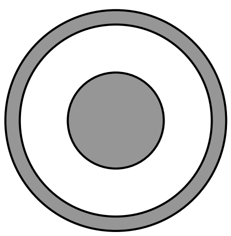
Problem 6.

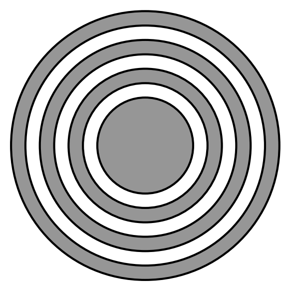
Calculate the capacitance of:

a. (5 points) a spherical capacitor of inner radius a=1cm and outer radius b=2cm, filled with a dielectric of relative permittivity ε_r=2.5.

b. (5 points) a conducting sphere of radius r=1cm, covered with 3 layers of dielectric (ε_r=2.5) of thickness d=2mm, alternated with 3 layers of metal, also of thickness d. The leads are connected to the inner and outer conductors.

[Ignore any effects of the leads on symmetry.]





Cross sections of the capacitors; part a. is shown at left and part b. is shown at right. Conductors are shaded, dielectric material is white, and dimensions are not to scale.