University of Wisconsin-Madison
Engineering Physics Department
Fall 2007 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. _____

Useful constants and formulae:

$\mu_0 = 4\pi \times 10^{-7}$ H/m $\qquad \varepsilon_0 = 8.85 \times 10^{-12}$ F/m

c $= 3 \times 10^8$ m/s $\qquad g = 9.81$ m/s^2

$I_{cyl} = \frac{1}{2} MR^2 \qquad I_{sphere} = \frac{2}{5} MR^2$

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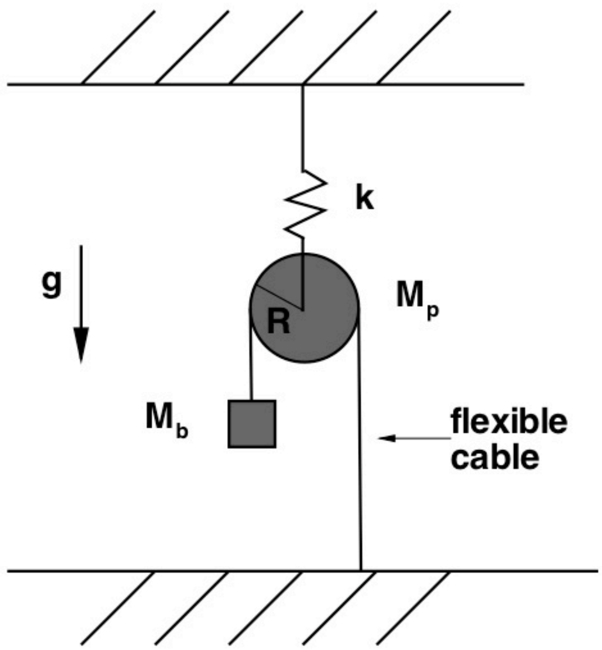
Problem 1. A pulley of mass M_p and radius R is suspended from a massless spring with spring constant k (force per unit length). A flexible inextensible (can't be stretched) massless cable runs over the pulley and suspends a block of mass M_b, as shown in the figure. Friction between the cable and the pulley forces the pulley to rotate about its axis without slip when there is motion in the system. Gravitational acceleration of magnitude g acts downward.



a. (4 points) Find a relation for the distance the spring is stretched in equilibrium.

b. (3 points) Find the equation of motion for the system in terms of a single dependent variable.

c. (3 points) Find a relation for the angular frequency of small-amplitude oscillations.

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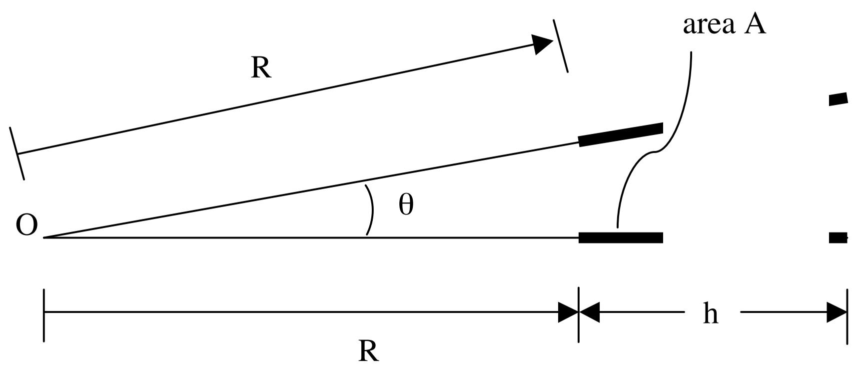
Problem 2. Consider a rectangular plate capacitor in which the plates are not parallel, as shown below. The plates have an area $A=hd$, where d is the depth into the page and h is the width. The plates are separated by a dielectric with a relative permittivity k.

a) (2 points) Sketch the field lines between the plates, assuming the capacitor is charged.
b) (2 points) Calculate the capacitance of this device, approximating the field lines as straight lines. Ignore edge effects.
c) (2 points) Calculate the capacitance of this device, approximating the field lines as circular arcs, centered at point O.
d) (2 points) Which of these estimates predicts the greater capacitance at $\theta = \pi / 16$?
e) (2 points) Based on these results, what can we say about the actual capacitance of the device?



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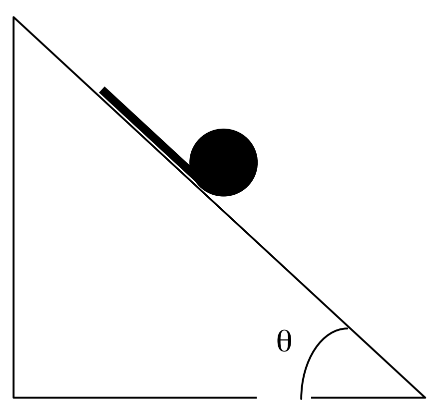
Problem 3. A length (L) of flexible, inextensible, non-sticky tape is wound up, and the roll, which has a radius that is much larger than the tape thickness, is placed on an incline of angle θ. The free end of the tape is held in place and the roll is allowed to unwind down the hill, subject to the force of gravity.

a. (5 points) Find an equation of motion that describes the position of the roll as it unwinds along the hill.
b. (5 points) How much time does it take to unwind 1/10 of the length of tape, starting with zero initial velocity? [Justify any approximations that you use in your derivation.]



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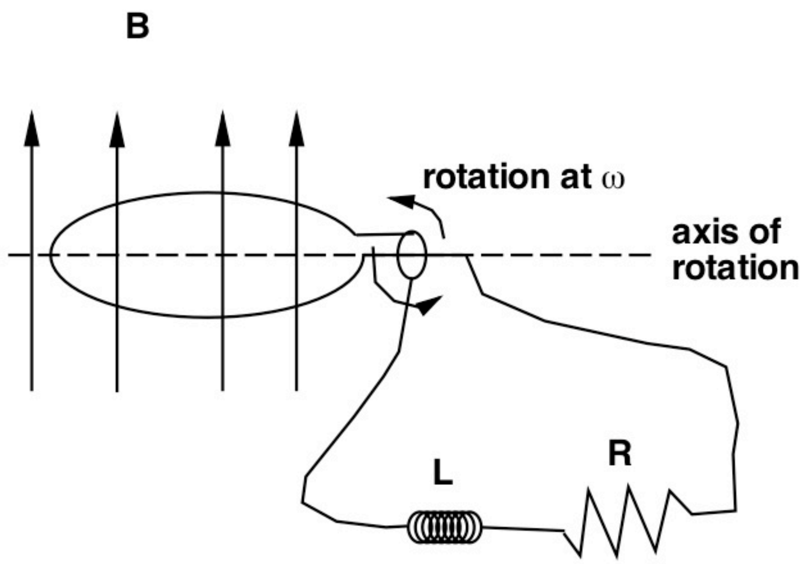
Problem 4. A circular loop of wire of radius 20 cm is mechanically driven to rotate in a static magnetic field of 1 T at angular frequency ω=100 s^{-1}. Ends of the loop are kept in electrical contact with a circuit that has a resistor (R) of 5 Ω and an inductor (L) of 1×10^{-4} H. Find the amplitude of the current that flows through the circuit long after any initial transient behavior. [Justify any approximations in your numerical solution.]



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Problem 5. Two identical, stationary spheres of mass *m* are placed in contact. A third identical sphere is given a velocity *V* and aimed at the contact point between the first two spheres. Determine the speed and direction of each of the spheres after the resulting collision, assuming the impact is elastic.

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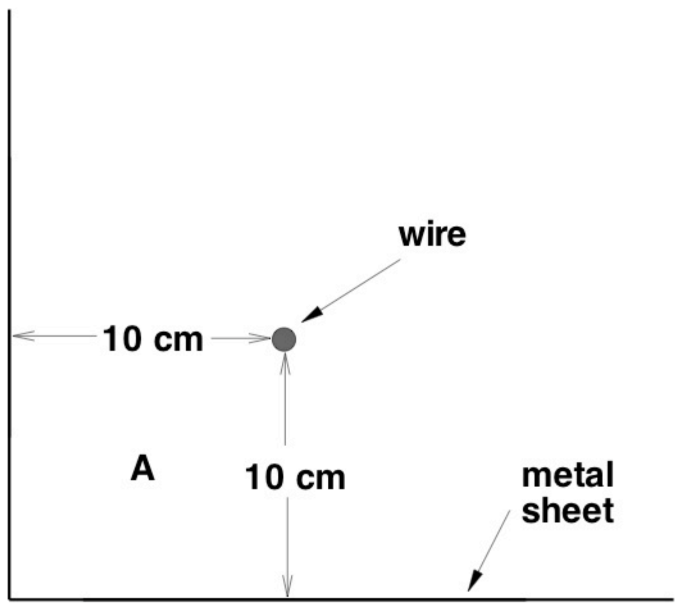
Problem 6. A large sheet of metal is creased along a straight edge to make a 90-degree bend. A thin straight wire carrying 100 A of electrical current is oriented parallel to the crease and located 10 cm from both faces of the metal sheet, as shown in the figure. If the sheet of metal acts as a perfect conductor, what is the strength of the magnetic field at the location marked by the "A" in the figure, halfway between the wire and the crease?



Cross section of the bent sheet of metal (heavy line) and the wire (dot). Electrical current flows along the wire in the direction out of the page. Consider the metal to extend upward and to the right to distances large relative to the position of the wire.