University of Wisconsin-Madison
Engineering Physics Department
Spring 2012 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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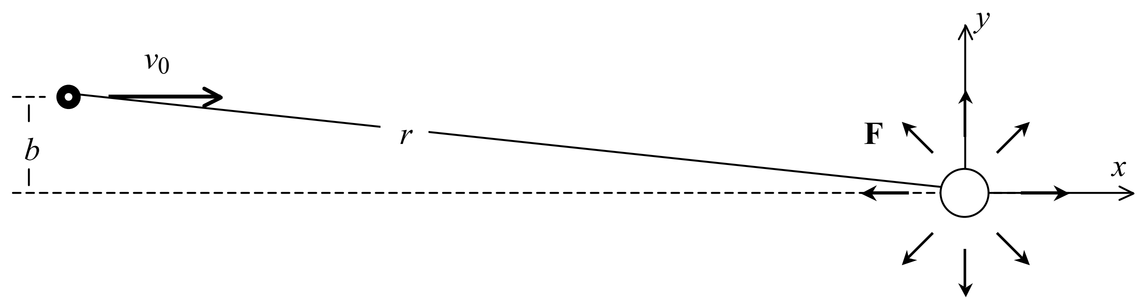
Problem 1.

A particle of mass m moves through a central force field, where the force has magnitude Kr^{-3} and points in the radial direction away from the origin, $r = 0$. Initially, when the particle is very far from the origin, its velocity is $v_0\hat{\mathbf{x}}$ and its vertical position is $y = b$.



a) (2 points) What is the potential energy distribution associated with this central force?

b) (6 points) In terms of the constants m, b, v_0, and K, what is the smallest value of r over the particle's trajectory?

c) (2 points) What is the kinetic energy of the particle when it reaches the location of smallest r?

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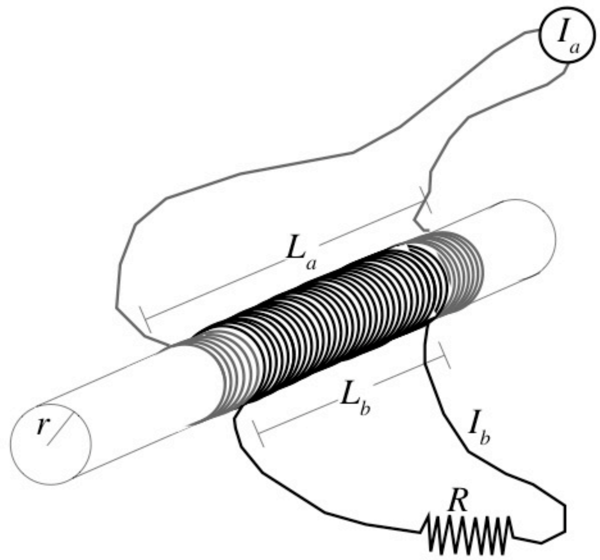
Problem 2.
A transformer is constructed by wrapping one wire (the primary) around an insulating rod of radius r with N'_a turns per unit length over a length L_a of the rod. A second wire (the secondary) is wrapped with N'_b turns per unit length on top of the primary over a length L_b, where $r \ll L_b < L_a$. The secondary is connected to a resistor of resistance R Ohms. The resistance of the secondary wire and the inductance of the leads are negligible.



The current in the first circuit alternates in time such that $I_a(t) = I_0 \sin(\omega_0 t)$, where I_0 and ω_0 are constants. Answer the following assuming that all transient effects have damped.

a) (8 points) What is the current as a function of time in the secondary circuit?

c) (2 points) What resistance R maximizes the power dissipated in the secondary circuit?

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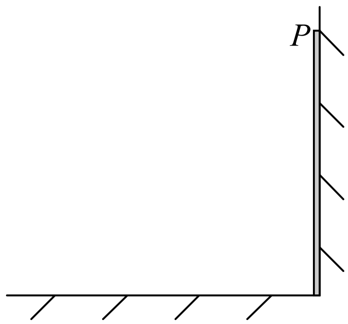
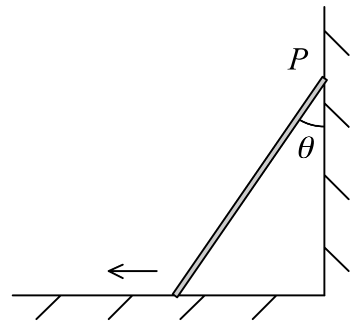
Problem 3.

A ladder of length l and mass m initially stands vertically on a frictionless floor against a frictionless wall, and starts slipping.



Initial position



In motion

a) (5 points) Suppose that the tip P of the ladder is constrained to remain in contact with the wall. Determine the final angular velocity ω_f of the ladder when P touches ground.

b) (5 points) Consider conditions where P is not constrained to remain in contact with the wall. Determine the angle θ for which the ladder loses contact with the wall.

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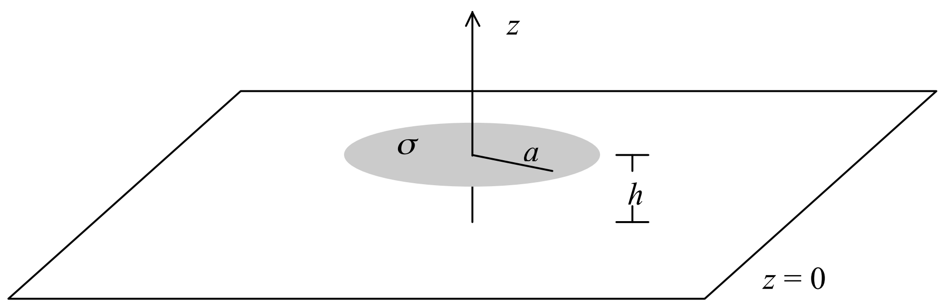
Problem 4.
A disk of radius a has uniform electrical charge per unit area of σ. The disk is located a distance h above a conducting plane, as shown in the figure.



a) (2 points) Is the magnitude of the electrical field below the disk ($0 \le z < h$) larger or smaller than conditions where the conducting plane is absent? Provide a very brief explanation. [z=h is the location of the disk.]

b) (8 points) Find the z-component of the electric field (in the presence of the conducting plane) along the geometric axis of the disk for $0 < z < +\infty$.

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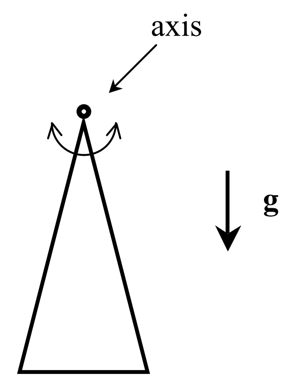
Problem 5.
A thin rod of mass M and length L is bent into an isosceles triangle where the two equal-length sides are twice as long as the third side.

What is the angular frequency of small-amplitude rigid-body oscillations about an axis that is perpendicular to the plane of the triangle and located at the corner with the smallest angle?



Sketch of isosceles triangle hanging from a pivot.

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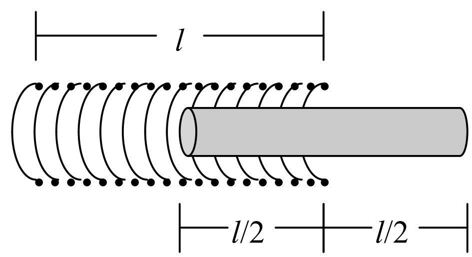
Problem 6.

An n = 700 turns/m solenoid of length l = 60 cm and radius r_s = 5 cm carries a current that is held fixed at I = 3 A. A cylinder of magnetically permeable material with μ_r = 800, radius r_c = 2 cm, and length l is held concentric with the solenoid. Calculate the force acting on the cylinder when it is positioned halfway inside the solenoid, as shown below.

[Assume that only the portion of the permeable material that lies within the solenoid becomes magnetized.]



Cutaway view exposing permeable cylinder within solenoid.