University of Wisconsin-Madison
Engineering Physics Department
Fall 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 $\quad \varepsilon_0 = 8.854 \times 10^{-12}$ F/m

$G = 6.67 \times 10^{-11}\ \mathrm{m^3/kg \cdot s^2}$ $\quad M_e = 5.97 \times 10^{24}$ kg $\quad R_e = 6{,}371$ km

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 geostationary orbit is a circular orbit above the equator for which the period is 1 day. [Relevant physical constants appear on the exam cover page.]

a) (5 points) What is the elevation (distance from the surface of the Earth) of such an orbit for a satellite of mass *m*.

b) (5 points) What is the velocity of this satellite?

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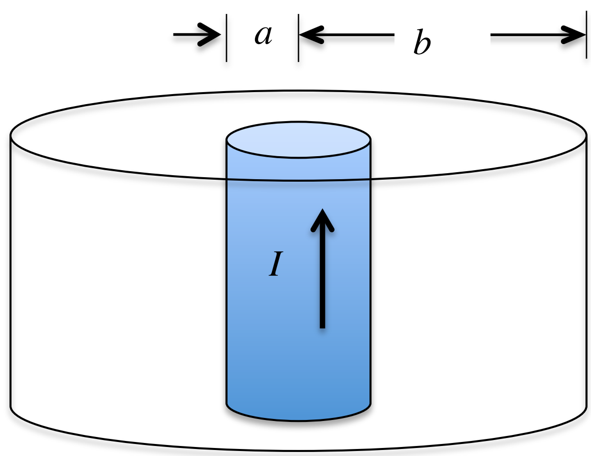
Problem 2. Electrical current I flows axially along an infinitely long cylinder of radius a, and the current density is uniform over the cross-section of the cylinder. An infinitely long, electrically conducting cylindrical shell of radius $b = 4a$ is concentric with the cylinder. The annular region between the cylinder and the cylindrical shell is evacuated. Determine the magnetic energy per unit length of this configuration in terms of I and a.



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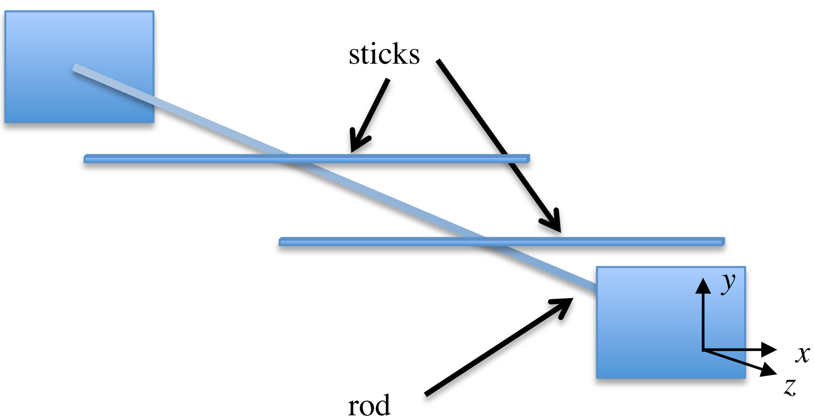
Problem 3. When a thin rod of length L (not shown in the sketch) is twisted about its axis, it responds with a spring constant of k_θ (units: N-m per radian of twist).

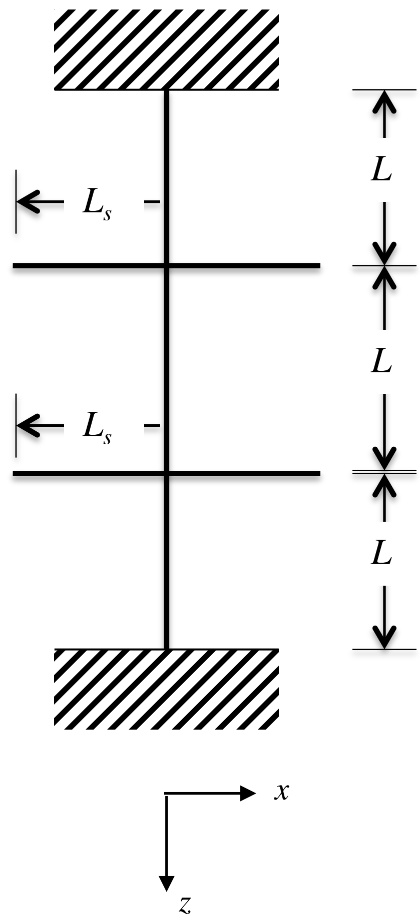
A rod of the same material and diameter has length $3L$ and is rigidly mounted at both ends. The midpoints of rigid sticks of mass m_s and length L_s are rigidly mounted to the rod at positions that are 1/3 and 2/3 along the rod, as shown in the figure below.

What are the natural frequencies of all possible small-angle oscillations of the sticks rotating and twisting the rod about its axis (shown as the z-axis in the figure)? Express your answer in terms of m_s, L_s, and k_θ.

Top View

Perspective





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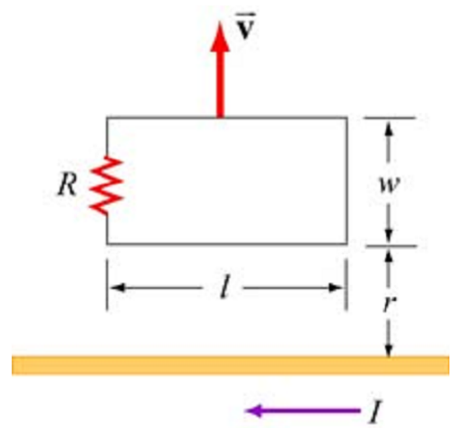
Problem 4. A rectangular loop of length l and width w moves with constant velocity $\vec{\mathbf{v}}$ away from an infinitely long straight wire carrying current I in the plane of the loop, as shown below.

a) (8 points) Assuming that the total resistance of the loop is R and that the self-inductance of the loop is negligible, find the current in the loop at the instant that the near side of the loop is a distance r from the wire.

b) (2 points) What is the direction of the current induced in the loop? (Is it clockwise or counter-clockwise with respect to the view shown in the figure?)



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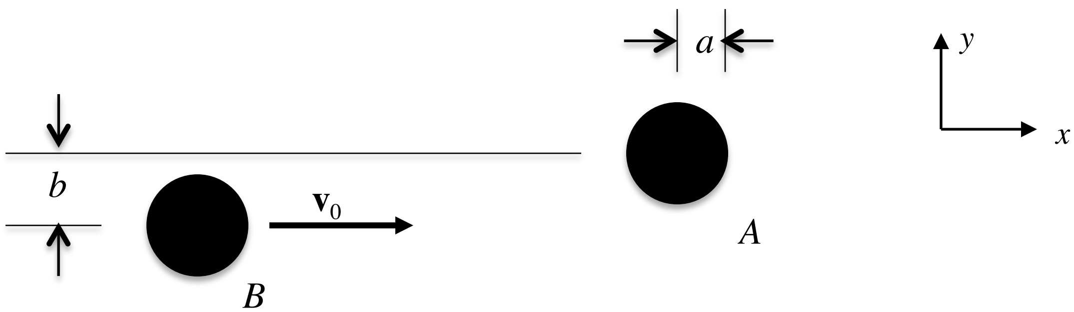
Problem 5. A sphere (labeled A in the figure) of mass m and radius a is initially at rest in the laboratory frame. A second sphere (B) with the same mass and radius initially travels toward sphere A, aimed so that its center is offset from the center of A by a distance b (the impact parameter). Assume that the response to the ensuing collision is elastic.



a) (8 points) For conditions where there are no frictional forces during the contact and in terms of the parameters a, b, and v_0, what is the velocity vector of sphere B after the collision occurs?

b) (2 points) Briefly describe how the response and required analysis change if the surfaces of the spheres are rough, and the contact occurs without slip.

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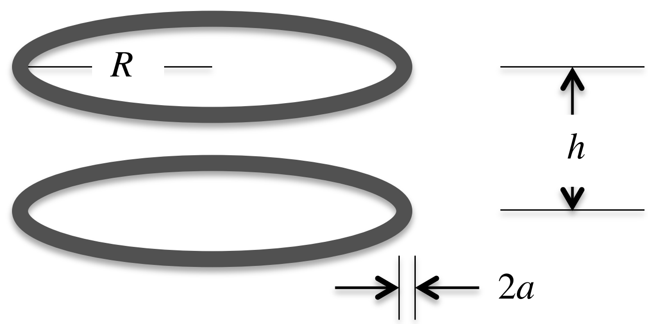
Problem 6. A capacitor is made from two circular loops of conducting wire. The radius of the wires is a, and the loops have radius R. They are arranged to lie in parallel planes, separated by a distance h, and the centers of the loops forms a line that runs perpendicular to both planes.



What is the capacitance of this configuration in the limit $a << h << R$?

State any approximations that you use to obtain your results.