University of Wisconsin-Madison
Engineering Physics Department
Fall 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)

Student No.________________

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Fall 2012 Qualifying Exams

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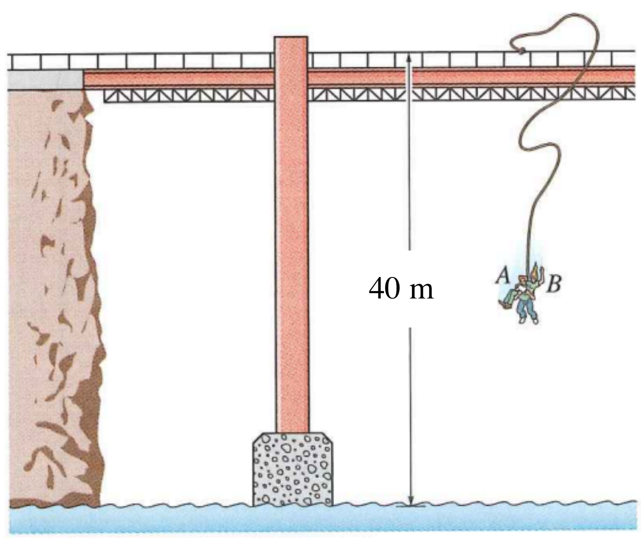
Problem 1.

Two 70 kg students jump from the bridge shown below, holding onto an elastic cord with stiffness 1200 N/m.

a) (3 points) What should the unstretched length of the cord be so that the two students stop just at the surface of the water?
b) (3 points) If one student lets go of the cord when they reach the surface, what will the velocity of the other student be as she passes her original position on the bridge?
c) (4 points) What is the maximum height above the water reached by this second student? (Assume that she does not release the cord.)



Student No.______________

Engineering Physics Department
Fall 2012 Qualifying Exams

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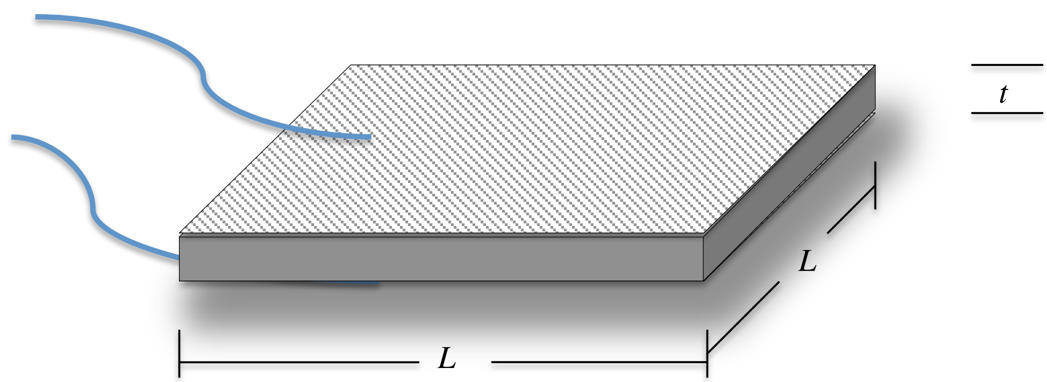
Problem 2.

A capacitor is constructed from two square conducting plates of dimension L on each side. Dielectric material of relative permittivity $\varepsilon_r > 1$ is placed inside the gap of depth $t << L$ between the plates. The dielectric is perforated by three holes of diameter $L/6$ that are completely covered by the conducting plates.



a) (5 points) What is the capacitance of this system for arbitrary locations the three holes?

b) (3 points) If net charge Q is stored in this capacitor, what is the distribution of charges on the inside surfaces of the plates?

c) (2 points) Is it possible to use other electrical-circuit components to determine the location of the holes in the dielectric without disassembling the capacitor? Provide a brief (one or two sentences) justification for your answer.

Examples of possible dielectric shapes:

Student No.________________

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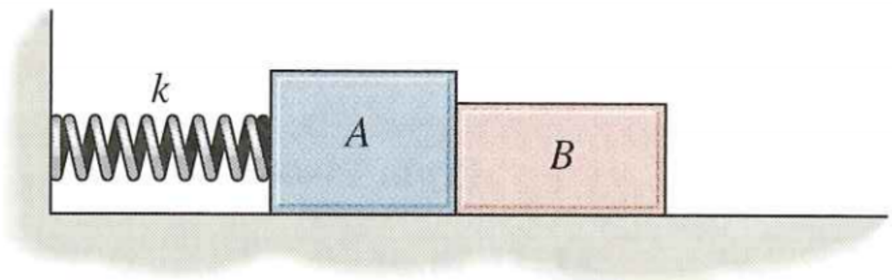
Problem 3.
In the figure below, block A has mass m_A and is attached to a spring of stiffness k and unstretched length l_0. Assuming another mass (m_B) is pressed against block A to the point that the spring is compressed by a distance d, find the value of d that will just lead to separation of the two blocks after release. The kinetic friction coefficient between the blocks and the ground is μ. (Assume that the coefficient of static friction has the same value μ as the coefficient of kinetic friction.)



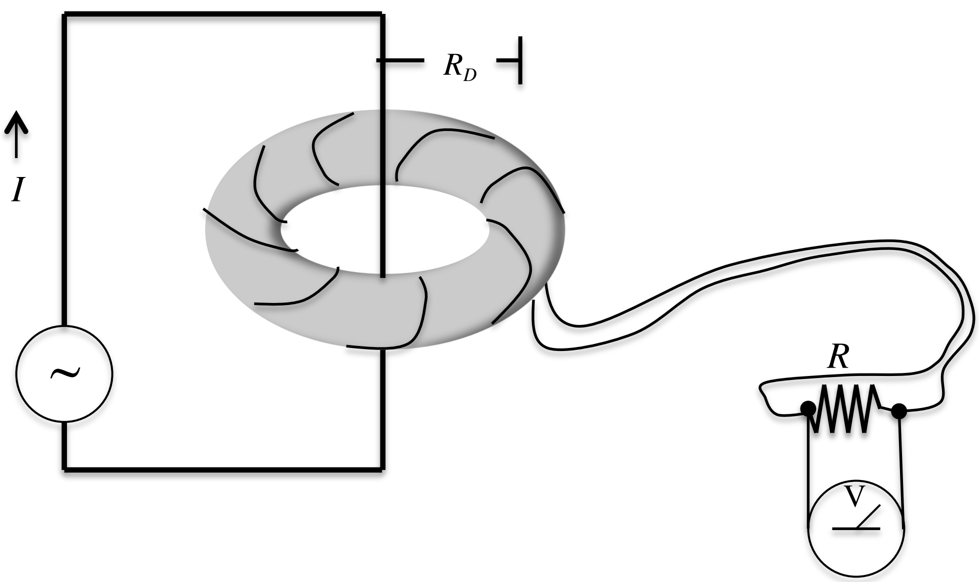
Student No.________________

Engineering Physics Department
Fall 2012 Qualifying Exams

Classical Physics

Problem 4.

A detector for time-dependent magnetic field is made from a donut-shaped insulator wrapped by N turns of wire. The major radius of the donut (geometric center to the center of the circular cross section) is R_D, and its minor radius (radius of the circular cross section) is a. The detector surrounds a current-carrying wire. The leads of the detector are connected to a resistor of R Ohms, and a scope records the voltage as a function of time across the resistor.

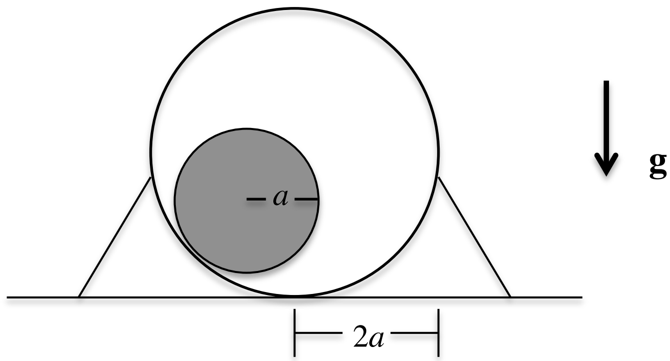


The scope records $V(t) = V_0 \sin(\omega t)$. What is the current $I(t)$ in the driven circuit in terms of the measurements and the parameters of the detector? [The frequency is sufficiently low as to preclude any radiative effects. Also neglect: 1) the resistance of the detector wire relative to R and 2) any impedance of the lead wires.] You may leave your expression in terms of a definite integral.

Engineering Physics Department
Fall 2012 Qualifying Exams

Classical Physics

Problem 5.
A solid cylinder of mass m and radius a rolls without slipping inside a fixed cylindrical shell of radius $2a$. The shell is mounted on a horizontal surface so that the shell's cross-section lies in a vertical plane.



a) (5 points) What is the frequency of small oscillations of the solid cylinder about the bottom of the shell?

b) (5 points) How much energy is required for the solid cylinder to make complete orbits inside the shell?

Engineering Physics Department
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Problem 6.
An “eddy current” brake employs induced currents in a spinning disk to produce a torque which resists the motion. To idealize this situation, consider an insulating disk, spinning about its axis, and covered with a series of radial wires. These wires are attached in such a way that current can flow through a resistor, and the total circuit resistance is R. Connections are made through a pair of brushes, so that current flows through one wire at a time as it passes through a stationary, square region of area a^2 with a perpendicular, uniform magnetic field B. The square patch is located at radius $r >> a$ from the center of the disk.

Derive an expression for the torque when the disk is spinning at ω rad/s.