University of Wisconsin-Madison
Engineering Physics Department
Fall 2014 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)

Electron: $m_e = 9.1\times 10^{-31}$ kg $\quad q_e = -e = -1.6\times 10^{-19}$ C

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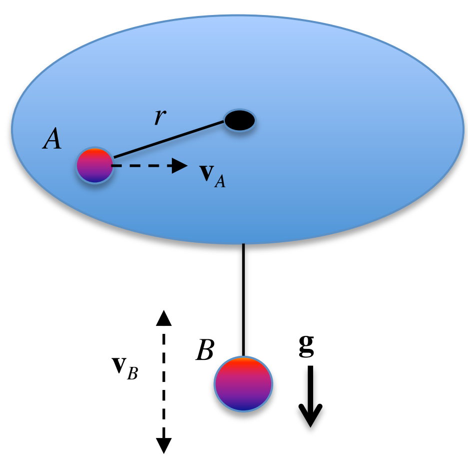
Problem 1. A small sphere (labeled *A*) of mass m_A moves without friction on a horizontal plane. An inextensible massless cord connects sphere *A* to a second object (labeled *B*) of mass m_B through a hole in the plane. In the following, assume that object *B* is only allowed vertical motion.

a) (3 points) Find a relation for the period of motion for sphere *A* that will maintain a circular orbit. Express your relation in terms of the given parameters and the orbit radius *r*.

b) (7 points) Now relax the assumption of circular motion for sphere *A*. Find a differential equation for the radius *r* as a function of time, physical constants, and any constants of the motion.



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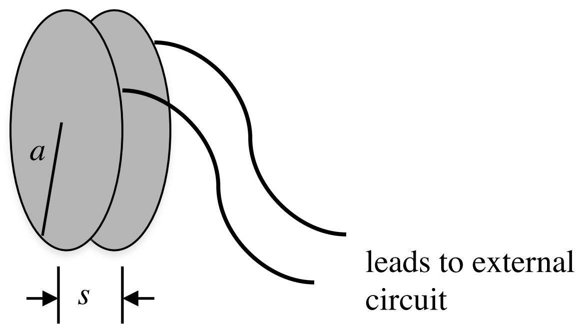
Problem 2. A capacitor is made from two electrically conducting, circular plates of radius a that are initially separated by a distance $s_0 << a$. The gap between the disks contains nothing but air. The plates are brought to a potential difference of V_0 by an external circuit.



a) (5 points) In terms of a, s_0, V_0, and the permittivity of free space, how much work is required to reduce the separation distance to $s = s_0/3$ if the potential difference of V_0 is maintained by the external circuit? Note that positive values of work indicate that mechanical work is done on the system.

b) (5 points) In terms of the same parameters, how much work is required to reduce the separation distance to $s = s_0/3$ if the plates are disconnected from the external circuit before moving them?

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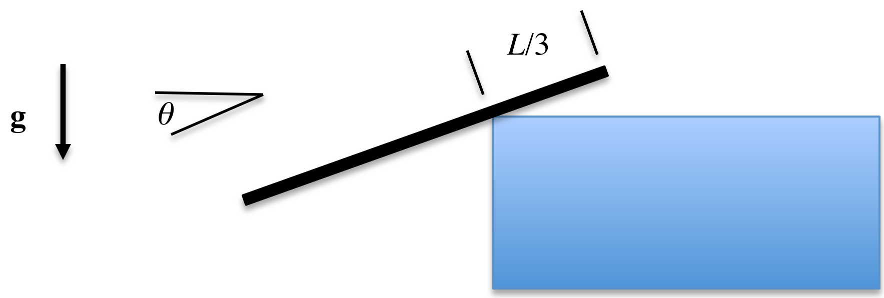
Problem 3. A uniform, slender bar of length L and mass m is initially horizontal on a fixed ledge (as shown below when $\theta = 0$). If the bar is released from rest, determine the angle at which it first begins to slip, assuming that the coefficient of static friction at the corner of the ledge is 0.3.



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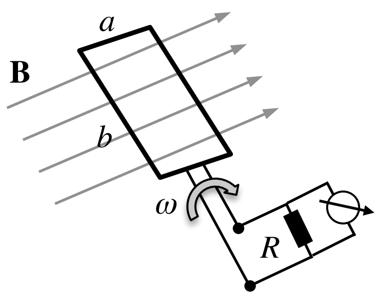
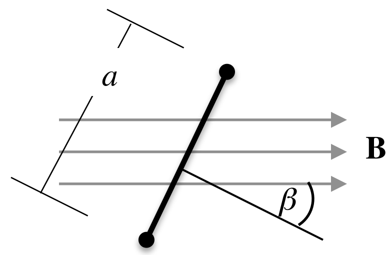
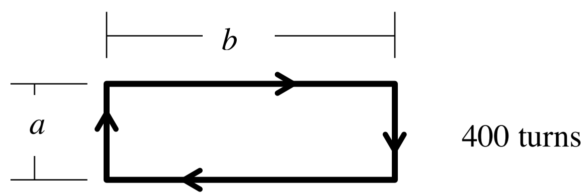
Problem 4. Consider a wire loop with N windings, each with dimensions of length a and height b. The wire loop is closed through a resistor R = 30 Ω and located in a homogenous magnetic field **B** with start angle β relative to the magnetic field.





end view of wire loop at t = 0



winding is in plane

a) (2 points) What is the maximal magnetic flux linked by the loop? Determine an expression and calculate the maximal flux value assuming N = 400, B = 1.4 T, a = 20 cm, and b = 5 cm.
b) (2 points) Determine an expression for the induction voltage through the loop when it rotates with an angular frequency ω.
c) (2 point) Calculate the maximum induction voltage if the loop from a) is rotating with f = 30 Hz.
d) (4 points) This simple generator setup represents an LR circuit. Assuming that the self-inductance of the loop is L = 0.10 H, what is the amplitude of the sinusoidal current in the circuit after steady sinusoidal oscillation has been established?

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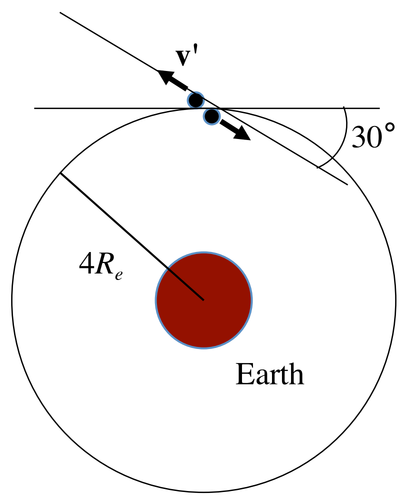
Problem 5. Two objects of equal mass have circular orbits around Earth. They orbit in the same plane and with the same radius $r = 4R_e$ but move in opposite directions. They collide with an elastic response, leading to $30°$ inward/outward deflections, as indicated by the post-collision velocity vector **v'** in the sketch. [The impact parameter b of the collision is very small relative to R_e.]

What are the minimum and maximum radii of the orbits after the collision?



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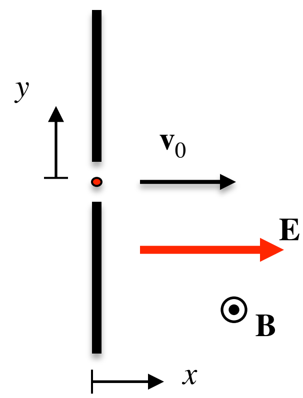
Problem 6. An electron moves through a gap in a surface with velocity $\mathbf{v}_0 = v_0\,\mathbf{e}_x$ and $v_0 << c$. It is then subject to forces from uniform electric and magnetic fields, $\mathbf{E} = E_x\,\mathbf{e}_x$ and $\mathbf{B} = B_z\,\mathbf{e}_z$.



a) (2 points) Determine an expression for the acceleration of the electron.

b) (8 points) What is the electron's velocity as a function of time $\left[v_x(t) \text{ and } v_y(t)\right]$, starting from $t = 0$ when the electron passes through the surface at $x = 0$ and ending when the trajectory returns to $x = 0$? (You do not need to determine the time at which the electron returns to $x = 0$.)