The University of Georgia
Department of Physics and Astronomy

Prelim Exam
August 17, 2020

Part I (problems 1, 2, 3, and 4)
9:00 am – 1:00 pm

Instructions:

- Start each problem on a new sheet of paper. Write the problem number on the top left of each page and your pre-arranged prelim ID number (but **not** your name) on the top right of each page. Leave margins for stapling and photocopying.

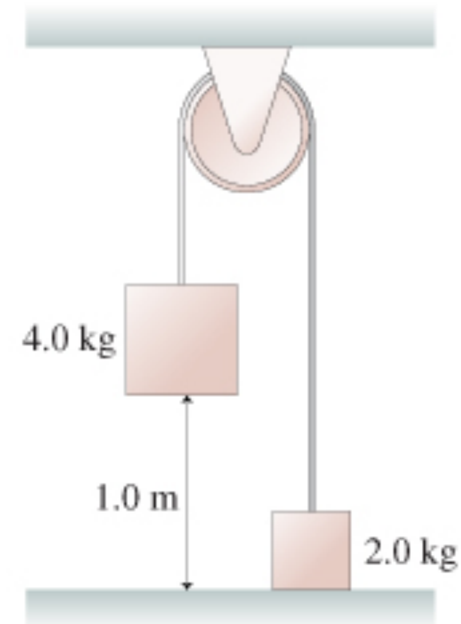
- Put your answers only on one side of the paper. Please **do not** write on the back side.

- If not advised otherwise, derive the mathematical solution for a problem from basic principles or general laws (Newton's laws, Maxwell's equations, Schrodinger's equation, etc.).

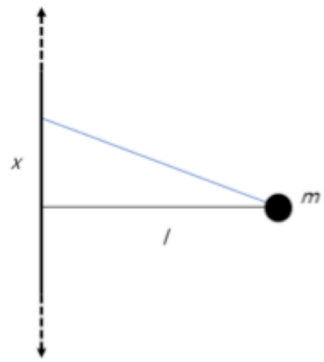
- You may use a calculator for basic operations only (i.e., not for referring to notes stored in memory, symbolic algebra, symbolic and numerical integration, etc.) The use of cell phones, tablets, and laptops is not permitted.

Problem 1

The two blocks in the figure are connected by a massless rope that passes over a pulley. The pulley is 12 cm in diameter and has a mass of 2.0 kg. As the pulley turns, friction at the axle exerts a torque of magnitude 0.50 Nm. If the blocks are released from rest, how long does it take the 4.0 kg block to reach the floor?



Problem 2



A particle of mass m is placed a distance l away from an infinitely long straight wire with mass density σ kg/m. Show that the force on the particle is $F = 2G\sigma m/l$. Do this in two ways.

(a) Integrate along the wire the contribution to the force.

(b) Integrate along the wire the contributions to the potential, and then differentiate to obtain the force.

(Hint) For the second part, the potential due to the infinite wire is infinite. To escape the difficulty of handling infinite potential, you can let the wire have a large but finite length. Then find the potential and force, and then let the length go to infinity.

Problem 3

A hollow spherical shell contains charge density $\rho = k/r^2$ for $a \le r \le b$, where k is a constant, a is the inner radius of the shell, and b is the outer radius of the shell.

(a)
Use Gauss's law for electrostatics to determine the electric field in the region $r < a$.

(b)
Use Gauss's law for electrostatics to determine the electric field in the region $a \le r \le b$.

Problem 4

A current $\boldsymbol{I}$ flows down a long straight wire of radius $\boldsymbol{a}$.

(a) If the wire is made of linear material with susceptibility χ_m, and the current is distributed uniformly, what is the magnetic field a distance $\boldsymbol{s}$ from the axis?

(b) Find all bound currents (i.e., the surface bound current and the volume bound current).

(c) What is the net bound current flowing down the wire?

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Part II (problems 5 and 6)
2:00 pm – 4:00 pm

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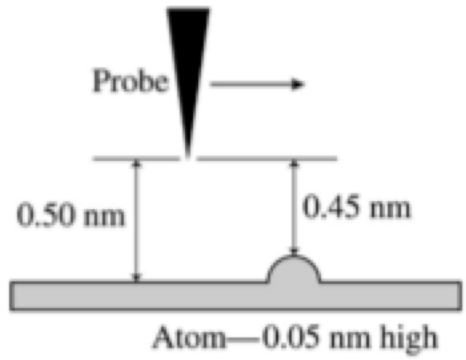
Problem 5



(a) What is the probability that an electron will tunnel through a 0.50 nm air gap from a metal to a STM (scanning tunneling microscope) probe if the work function is 4.0 eV?

(b) The probe passes over an atom that is 0.050 nm "tall." By what factor does the tunneling current increase? (Assume the tunneling current is proportional to the tunneling probability.)

(c) If a 10% current change is reliably detectable, what is the smallest height change the STM can detect?

Problem 6

The "half-infinite well" refers to the following potential energy function:

$$U(x) = \begin{cases} \infty, & x < 0 \quad \text{(Region I)} \\ 0, & 0 < x < L \quad \text{(Region II)} \\ U_0, & L < x \quad \text{(Region III)} \end{cases}$$

(a) State the boundary conditions that must be satisfied by bound-state solutions of the Schrödinger equation (i.e., $E < U_0$) for the half-infinite well.

(b) Derive the energy quantization condition for bound states of the half-infinite well:

$$\sqrt{E}\cot\left(\sqrt{\frac{2mE}{\hbar^2}}L\right) = -\sqrt{U_0 - E}\,.$$