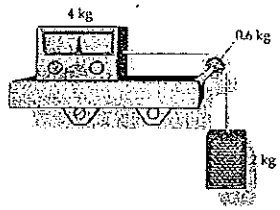
Prelim. Exam
August 28, 2006

Classical Mechanics

M-1



From her elevated DJ booth at a dance club, Caroline is lowering a 2-kg speaker using a 0.6-kg disk of radius 8 cm as a pulley, as shown in the figure. The speaker wire runs straight up from the speaker, over the pulley, and then horizontally across the table. She attaches the wire to the 4-kg amplifier on her tabletop, and then turns to get the other speaker. The table, however, is nearly frictionless, and the whole system begins to move when she lets go.

(a) What is the net torque about the center of the pulley?

(b) What is the total angular momentum of the system 3.5 s after release?

(c) What were the net torque about the center of the pulley for the case in which the coefficient of friction between the table and the 4-kg amplifier were 0.25?

M-2

A straight, smooth tunnel is dug through a spherical planet whose mass density ρ_0 is constant. The tunnel passes through the center of the planet and is perpendicular to the planet's axis of rotation, which is fixed in space. The planet rotates with an angular velocity ω such that objects in the tunnel have no acceleration relative to the tunnel.

(a) Find ω.

(b) What would happen to objects in the tunnel if the planet rotates at smaller angular velocity?

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Thermodynamics

TH-1

On a cold day you can warm your hands by rubbing them together.

(a) Assume that the coefficient of friction between your hands is 0.5, that the normal force between your hands is 35 N, and that you rub them together at an average speed of 35 cm/s. What is the rate at which heat is generated?

(b) Assume further that the mass of each of your hands is approximately 350g, that the specific heat of your hands is about 4 kJ/kg·K, and that all the heat generated goes into rasing the temperature of your hands.
How long must you rub your hands together to produce a 5-C° increase in their temperature?

TH-2

Helium gas (γ=1.67) is initially at a pressure of 16 atm, a volume of 1 L, and a temperature of 600 K. It is expanded isothermally until its volume is 4 L and is then compressed at constant pressure until its volume and temperature are such that an adiabatic compression will return the gas to its original state.

(a) Sketch this cycle on a *PV* diagram.

(b) Find the volume and temperature after the isobaric compression.

(c) Find the work done during each cycle.

(d) Find the efficiency of the cycle.

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Quantum Mechanics / Modern Physics

QM-1

A square well extends from $x=-a$ to $x=a$. For simplicity, consider the potential outside the well to be infinity.

(a) Write down the Schroedinger Equation for this problem for a (spinless) particle trapped in the well.

(b) Show that there exist two classes of solutions: symmetric and antisymmetric wave functions.

(c) What happens if a thin, high wall is erected at $x=0$? Which class of solutions is still correct?

QM-2

The positron is a particle identical to the electron except that it carries a positive charge of e. Positronium is the bound state of an electron and positron.

(a) Calculate the energies of the five lowest energy states of positronium using the reduced mass $\mu=m_e m_p/(m_e+m_p)$ in the energy solution $E_n = -\frac{me^4}{2\hbar^2 n^2} = -\frac{13.6\text{eV}}{n^2}$.

(b) Do transition between any of the levels found in part (a) fall in the visible range of wavelengths? If so, which transitions are these?

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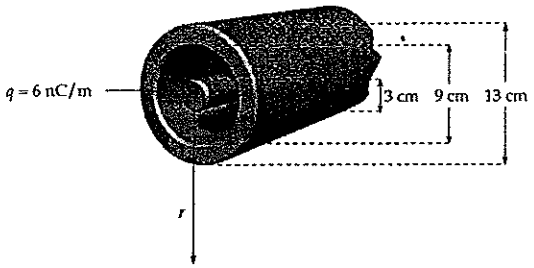
Electricity & Magnetism

EM-1

The figure shows a portion of an infinitely long, concentric cable in cross section (coax cable). The inner conductor carries a charge of 6 nC/m; the outer conductor is uncharged.



(a) Show that the electric field due to an infinitely long, uniformly charged cylindrical shell of radius R carrying a surface charge density σ is given by

$E_r = 0$ for $r<R$ and $E_r = \dfrac{\sigma R}{\varepsilon_0 r} = \dfrac{\lambda}{2\pi\varepsilon_0 r}$ for $r>R$ (where $\lambda = 2\pi R\sigma$ is the charge per unit length).

(b) Find the electric field for all values of r, where r is the distance from the axis of the cylindrical system.

(c) What are the surface charge densities on the inside and the outside surfaces of the outer conductor?

EM-2

Two coils that are separated by a distance equal to their radius and that carry equal currents such that their axial fields add are called Helmholtz coils. A feature of Helmholtz coils is that the resultant magnetic field between the coils is very uniform.

Let R=10 cm, I=20 A, and N=300 turns for each coil. Place one coil in the yz plane with its center at the origin and the other in a parallel plane at x=10 cm.

(a) Calculate the resultant field B_x at x=5 cm, x=7 cm, x=9 cm, and x=11cm.

(b) Use your result and the fact that B_x is symmetric about the midpoint of the coils to sketch B_x versus x.