Exam #: ______________________

Printed Name: ______________________

Signature: ______________________

PHYSICS DEPARTMENT

UNIVERSITY OF OREGON

Master's Final Examination
and
Ph.D. Qualifying Examination, PART I

Wednesday, September 18, 2002, 1:00 p.m. to 5:00 p.m.

The examination papers are numbered in the upper right-hand corner of each page. Print and then sign your name in the spaces provided on this page. For identification purposes, be sure to submit this page together with your answers when the exam is finished. Be sure to place both the exam number and the question number on any additional pages you wish to have graded.

There are twelve equally weighted questions, each beginning on a new page. Read all twelve questions before attempting any answers.

Begin each answer on the same page as the question, but continue on additional blank pages if necessary. Write only on one side of each page. Each page should contain work related to only one problem. If you need extra space for another problem, start a new page.

If you need to leave your seat, wait until everyone else is seated before approaching the proctor.

Calculators may be used only for arithmetic. **Calculators with stored equations or text are not allowed**. Dictionaries may be used if they have been approved by the proctor before the examination begins. **No other papers or books may be used.**

When you have finished, come to the front of the room and hand your examination paper to the proctor; first put all problems in numerical order and staple them together.

Please make sure you follow all instructions carefully. If you fail to follow instructions, or to hand your exam paper in on time, an appropriate number of points may be subtracted from your final score.

Constants

Electron charge (e)	1.60×10^{-19} C
Electron rest mass (m_e)	9.11×10^{-31} kg ($0.511\,\mathrm{MeV/c^2}$)
Proton rest mass (m_p)	1.673×10^{-27} kg ($938\,\mathrm{MeV/c^2}$)
Neutron rest mass (m_n)	1.675×10^{-27} kg ($940\,\mathrm{MeV/c^2}$)
W^+ rest mass (m_W)	$80.4\,\mathrm{GeV/c^2}$
Planck's constant (h)	$6.63 \times 10^{-34}\,\mathrm{J\cdot s}$
Speed of light in vacuum (c)	3.00×10^{8} m/s
Boltzmann's constant (k_B)	1.38×10^{-23} J/K
Gravitational constant (G)	$6.67 \times 10^{-11}\,\mathrm{N\cdot m^2/kg^2}$
Permeability of free space (μ_0)	$4\pi \times 10^{-7}$ H/m
Permittivity of free space (ϵ_0)	8.85×10^{-12} F/m
Mass of Earth (M_{Earth})	5.98×10^{24} kg
Mass of Moon (M_{Moon})	7.35×10^{22} kg
Radius of Earth (R_{Earth})	6.38×10^{6} m
Radius of Moon (M_{Moon})	1.74×10^{6} m
Radius of Mars (R_{Mars})	3.39×10^{6} m
Radius of Sun (R_{Sun})	6.96×10^{8} m
Temperature of surface of Sun (T_{Sun})	5.8×10^{3} K
Earth - Sun distance (R_{ES})	1.50×10^{11} m
Mars - Sun distance (R_{MS})	2.28×10^{11} m
Density of iron at low temperature (ρ_{Fe})	$7.88 \times 10^{3}\,\mathrm{kg/m^3}$
Classical electron radius (r_0)	2.82×10^{-15} m
Gravitational acceleration on Earth (g)	$9.8\,\mathrm{m/s^2}$
Atomic mass unit	1.66×10^{-27} kg
Specific heat of oxygen (c_V)	$21.1\,\mathrm{J/mole\cdot K}$
Specific heat of oxygen (c_P)	$29.4\,\mathrm{J/mole\cdot K}$

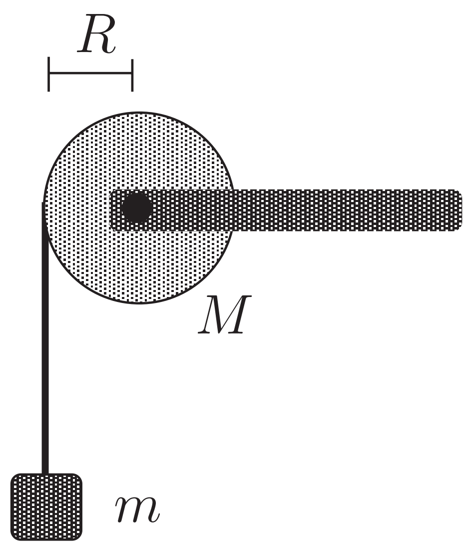
Moments of Inertia

For a hoop of mass M and radius R, about its symmetry axis: MR^2.

For a disk of mass M and radius R, about its symmetry axis: $(1/2)\,MR^2$.

For a solid sphere of mass M and radius R, about any symmetry axis: $(3/5)\,MR^2$.

Problem 1



A cord is wrapped around a uniform disk of radius R and mass M, which is mounted on an axle supported in fixed, frictionless bearings. A mass, m, is suspended from the cord.

a) Find the angular acceleration, α, of the disk.

b) Use your solution for α to show that conservation of mechanical energy holds for this system.

Problem 2

The force of interaction between two atoms of equal mass m in certain diatomic molecules can be represented as

$$F = -\frac{a}{r^2} + \frac{b}{r^3} \tag{1}$$

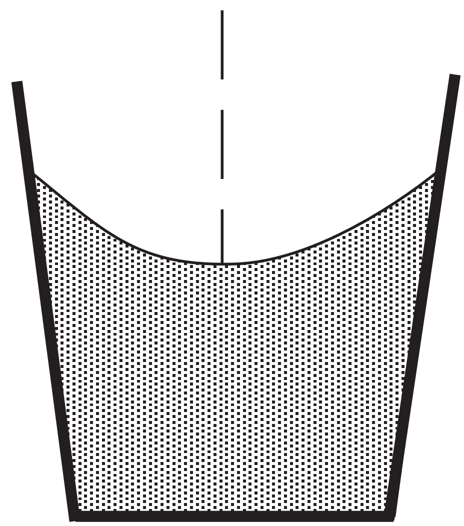
where a and b are positive constants and r is the distance between the atoms.

a) Find the equilibrium separation r_0.

b) Find the force constant k for small oscillations about this equilibrium position.

c) Find the period of small oscillations about the equilibrium separation.

Problem 3



A bucket of water spins about the vertical axis with angular velocity ω. When the water has reached a steady state, what shape does the surface of the water take? That is, find the height z of the water as a function of r, the distance from the axis.

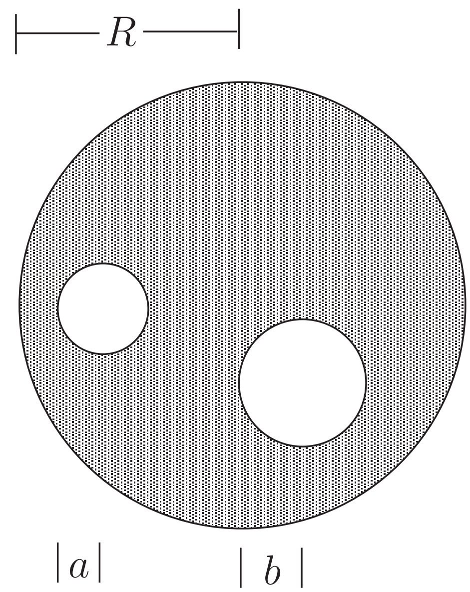
Problem 4

This question concerns Gauss's law.

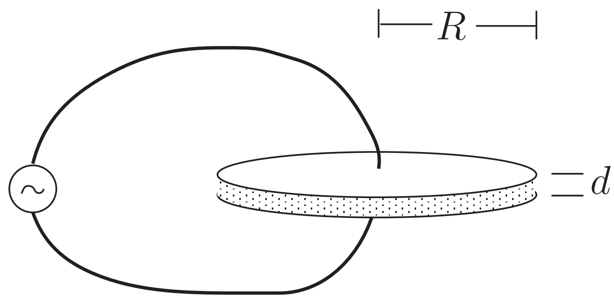
a) State Gauss's law in general terms.

b) Consider placing an amount of charge q within the bulk of a solid metal sphere. State what you know about the electric field $\vec{E}$ in the bulk of the sphere. Use this answer to show that the added charge will migrate to the sphere's surface.

c) Two spherical cavities of radii a and b, respectively, are hollowed out from the interior of a neutral metal sphere of radius R as shown below. Point charges q_a and q_b are placed at the centers of the cavities. Find the surface charge densities σ_a and σ_b on the surfaces of the two cavities and the surface charge density σ_R on the outer surface of the metal sphere.



Problem 5



A parallel plate capacitor consists of metal disks of radius R separated by a gap d. The material between the plates has conductivity σ and dielectric constant ϵ. Assume that $R \gg d$ so that fringing fields can be neglected. The plates are connected to a generator which provides an oscillating emf given by $V(t) = V_0 \sin(\omega t)$.

a) Find the displacement current I_d and the conduction current I_c between the capacitor plates.

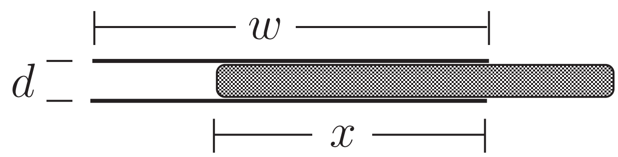
b) What is the magnetic field between the plates? Make a sketch that shows the direction of the magnetic field.

c) Determine the direction of the electromagnetic energy flow in the space between the capacitor plates. Find the total power associated with this energy flow.

Problem 6

Square parallel plates of width w and separation d are charged to a potential difference V and then isolated. The separation is much smaller than the width: $d \ll w$. The charges on the two plates are equal in magnitude and opposite in sign.

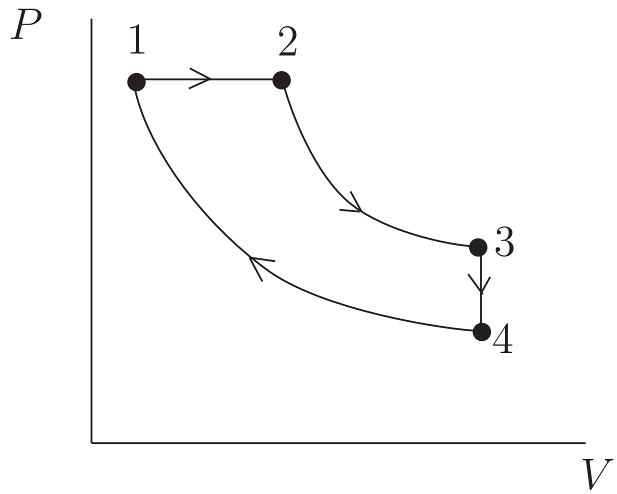
a) Calculate the charge Q on one of the plates.



b) A dielectric sheet with dielectric constant $\epsilon = \epsilon_0 \epsilon_t$, width w and thickness d is inserted between the plates to a distance x (with $x < w$). Calculate the capacitance C and the energy E of the system.

c) Find the direction and the magnitude of the force on the dielectric.

Problem 7



Consider a heat engine running on the cycle shown above. One mole of ideal gas with specific heats $C_V = 2R$ and $C_P = 3R$ starts at point 1 with initial temperature, volume, and temperature T_1, V_1, and P_1 respectively. The four steps in the cycle are all reversible. This problem concerns only the first step, which consists of an isobaric (constant pressure) expansion to $V = 4V_1$.

a) Calculate the work done on the gas in going from 1 to 2.

b) Calculate the heat absorbed by the gas in going from 1 to 2.

Problem 8

A system of N independent particles are in equilibrium at temperature T. Each particle has three energy levels, which have energies ϵ_1, ϵ_2, and ϵ_3, and degeneracies 1, 2, and 1 respectively.

a) Write an expression for the fraction of particles in each energy level.

b) Find the heat capacity of the system.

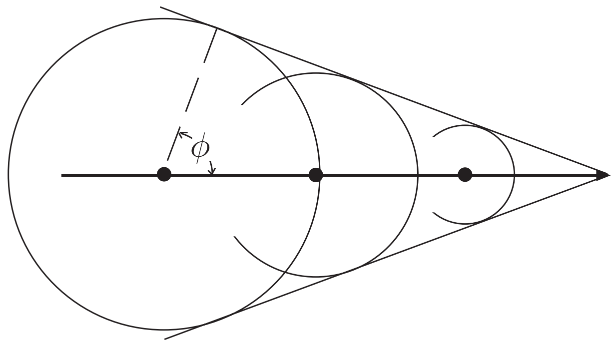
Problem 9

Calculate the numerical value of the mean temperature of Mars assuming that both the sun and Mars are perfect black bodies. (Assume that Mars rotates on its axis sufficiently fast that the difference between day and night temperatures is not too great.)

Problem 10

A particle with mass m, confined to move in the x-direction only, is in the fourth-lowest energy eigenstate of a box with perfectly reflecting walls located at $x = -a$ and $x = +a$. (That is, the particle is in an infinite square-well potential.) At time $t = 0$, the walls are suddenly removed, so that the particle becomes free. Find the probability distribution for the particle's momentum immediately following the removal of the walls. Make a sketch of this probability distribution and label the characteristic scales of its features, explaining them qualitatively where you can.

Problem 11



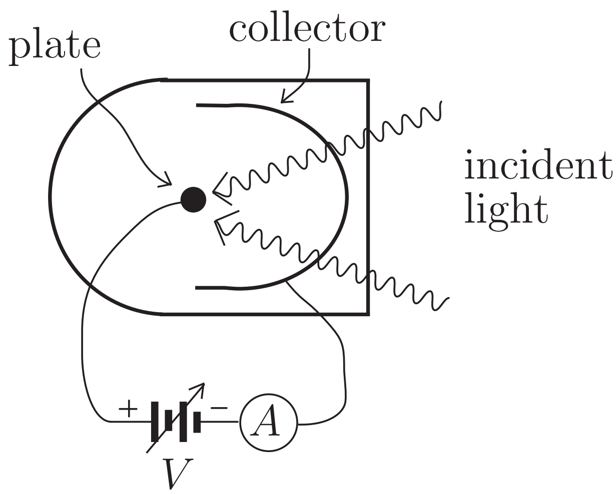
When an electric charge moves through a medium at a speed greater than the wave velocity of light in the medium, c/n, the charge will radiate. This is Cerenkov radiation, illustrated by the application of Huygen's principle in the figure above.

a) For a beam of protons of kinetic energy 340 MeV passing through a sheet of extra dense flint glass with n = 1.88, what would be the angle of emission, ϕ (see the diagram) of the Cerenkov radiation?

b) Determine the threshold kinetic energy for Cerenkov radiation in the flint glass, that is, the energy below which the protons would not emit radiation.

Problem 12

The apparatus shown schematically below is used to study photoelectrons emitted when monochromatic light of wavelength λ strikes the device's plate electrode. The plate has a work function, W. An adjustable retarding voltage, V, can be applied between the plate and a "collector" electrode to suppress the collection of the electrons. The intensity, I, of the light source can also be varied. The current from the electrons reaching the collector is measured by an ammeter, denoted by the "A" in a circle.



a) Originally one used arguments based on classical mechanics and the wave nature of light to analyze the expected results from such an experiment. Based upon these classical ideas, predict the expected relationship between the kinetic energy of the photo-excited electrons and the intensity and wavelength of the light. Explain your predictions.

b) Succinctly describe an experiment with the above apparatus that can test one of your predictions. Describe which variables would be held constant, which would be varied, and what you would expect to observe based on classical physics. Draw a graph to illustrate your description. Discuss how the outcome of the experiment would support or refute your chosen prediction.