Exam #: ________________________

Printed Name: ________________________

Signature: ________________________

PHYSICS DEPARTMENT

UNIVERSITY OF OREGON

Master's Final Examination

and

Ph.D. Qualifying Examination, PART I

Monday, April 1, 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)	$1.60 \times 10^{-19}\,\mathrm{C}$
Electron rest mass (m_e)	$9.11 \times 10^{-31}\,\mathrm{kg}$ ($0.511\,\mathrm{MeV/c^2}$)
Proton rest mass (m_p)	$1.673 \times 10^{-27}\,\mathrm{kg}$ ($938\,\mathrm{MeV/c^2}$)
Neutron rest mass (m_n)	$1.675 \times 10^{-27}\,\mathrm{kg}$ ($940\,\mathrm{MeV/c^2}$)
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)	$3.00 \times 10^{8}\,\mathrm{m/s}$
Boltzmann's constant (k_B)	$1.38 \times 10^{-23}\,\mathrm{J/K}$
Gravitational constant (G)	$6.67 \times 10^{-11}\mathrm{N\cdot m^2/kg^2}$
Permeability of free space (μ_0)	$4\pi \times 10^{-7}\,\mathrm{H/m}$
Permittivity of free space (ϵ_0)	$8.85 \times 10^{-12}\,\mathrm{F/m}$
Mass of earth (M_E)	$5.98 \times 10^{24}\,\mathrm{kg}$
Equatorial radius of earth (R_E)	$6.38 \times 10^{6}\,\mathrm{m}$
Radius of sun (R_S)	$6.96 \times 10^{8}\,\mathrm{m}$
Temperature of surface of sun (T_S)	$5.8 \times 10^{3}\,\mathrm{K}$
Earth - sun distance (R_{ES})	$1.50 \times 10^{11}\,\mathrm{m}$
Density of iron at low temperature (ρ_{Fe})	$7.88 \times 10^{3}\,\mathrm{kg/m^3}$
Classical electron radius (r_0)	$2.82 \times 10^{-15}\,\mathrm{m}$
Gravitational acceleration on Earth (g)	$9.8\,\mathrm{m/s^2}$
Atomic mass unit	$1.7 \times 10^{-27}\,\mathrm{kg}$
Specific heat of oxygen (c_V)	$21.1\,\mathrm{J/mole\cdot K}$
Specific heat of oxygen (c_P)	$29.4\,\mathrm{J/mole\cdot K}$

Stirling's Formula

$$\ln(x!) = x\ln(x) - x - \ln\left(\sqrt{2\pi x}\right) + \mathcal{O}(1/x)$$

Integrals

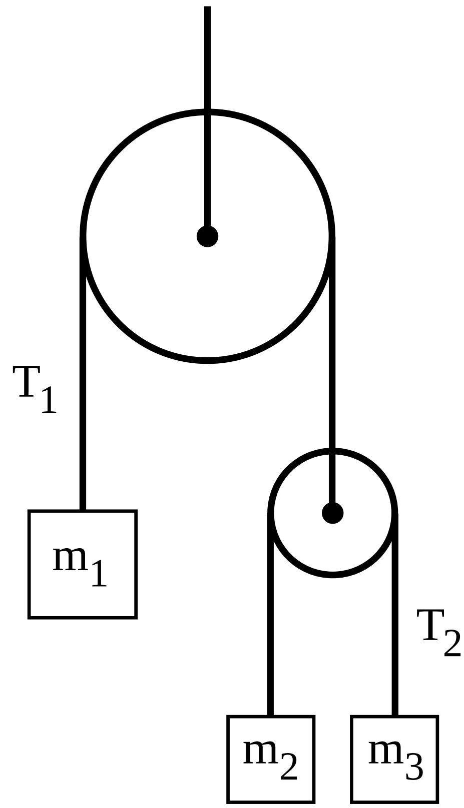
$$\begin{aligned} \int_{-\infty}^{\infty} dx\, x^{2n}\, e^{-ax^2} &= \frac{1 \times 3 \times 5 \times \cdots \times (2n-1)}{2^n\, a^n}\sqrt{\frac{\pi}{a}} \\ \int_0^{\infty} \frac{dx}{x}\, x^n\, e^{-x} &= \Gamma(n) \end{aligned}$$

Problem 1

The double Atwood machine pictured below has frictionless, massless pulleys and cords. Determine the following quantities (assuming $m_1 \neq m_2 \neq m_3$):

a) the acceleration of masses m_1, m_2, and m_3,

b) the tensions T_1 and T_2 in the cords.



Problem 2

Ruchardt's tube is an apparatus that uses mechanics to measure the ratio of specific heats ($\gamma = \mathrm{C_p}/\mathrm{C_v}$) for a gas. The apparatus is a long glass tube with cross-sectional area A connected to a large gas volume. A steel ball of mass m fits precisely into the long tube. When the ball in the tube is at equilibrium, the pressure in the enclosed gas volume, V_{eq}, is given by

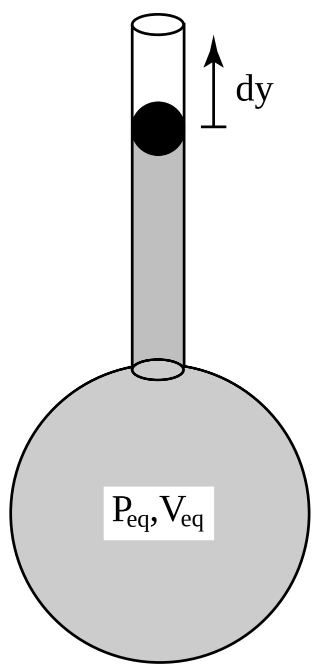
$$P_{\mathrm{eq}} = P_0 + mg/A,$$

where P_0 is the external pressure.

When the ball in the tube is perturbed away from the equilibrium position by a small distance dy there is a total volume change dV and pressure change dP due to adiabatic compression of the gas in the volume. (Assume dP and dV are much smaller than the equilibrium pressure and volume P_{eq} and V_{eq}). The relation between the gas pressure and volume is

$$PV^{\gamma} = \text{constant}.$$

Show that the perturbed ball will undergo simple harmonic motion and solve for the period of the motion in terms of γ, m, A, P_{eq}, and V_{eq}.

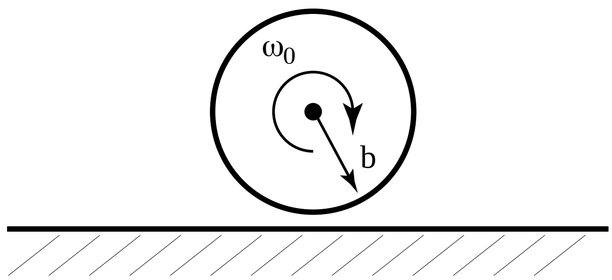


Problem 3

A uniform sphere of mass m and radius b is set spinning at angular frequency ω_0 about a horizontal axis. The sphere is initially in a position infinitesimally above a horizontal table, and then the sphere is allowed to come into contact with the table. The sphere feels a gravitational acceleration g and there is a coefficient of friction μ between the sphere and the table. The moment of inertia of a uniform sphere is given by $I = \frac{2}{5}mb^2$.

a) How much time will elapse before the sphere starts to roll without slipping?

b) What is ω when the ball first starts to roll without slipping?



Problem 4

a) Given an infinite sheet of electric charge with charge per unit area σ, determine the electric field E as a function of distance r away from the sheet.

b) Given an infinite line of electric charge with charge per unit length λ, determine the electric field E as a function of distance r away from the line.

c) Compute the corresponding potentials $\Phi(r)$ in cases a) and b).

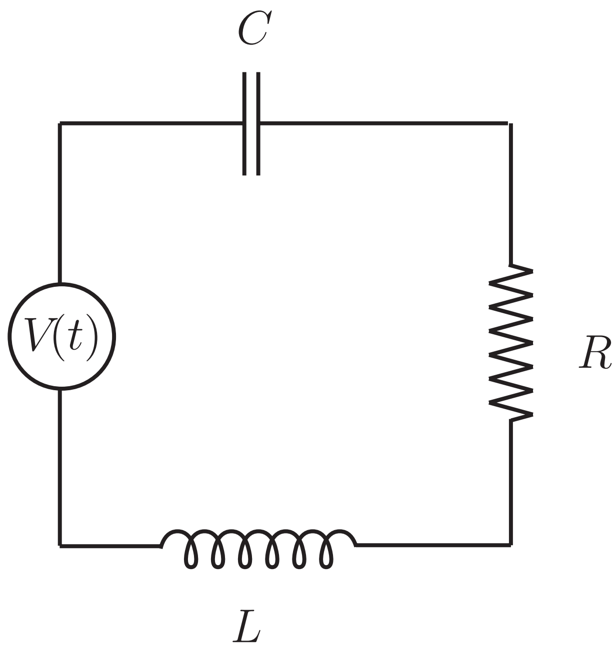
Problem 5

A damped RLC circuit is driven by a voltage of the form $V(t) = V_0(1 - e^{-at})$, where V_0 and a are positive constants. In this particular circuit, the value of the damping resistor has been chosen to be $R = La$ and the capacitance C has been chosen to be $C = 1/(4La^2)$, where L is the value of the inductance. Let the charge on the capacitor be $q(t)$.

a) Write a differential equation describing the time dependence of $q(t)$.

b) Find a solution of the form $q(t) = A + Be^{-at}$ and determine the values of A and B.

c) Sketch a graph of the behavior of q as a function of time.



Problem 6

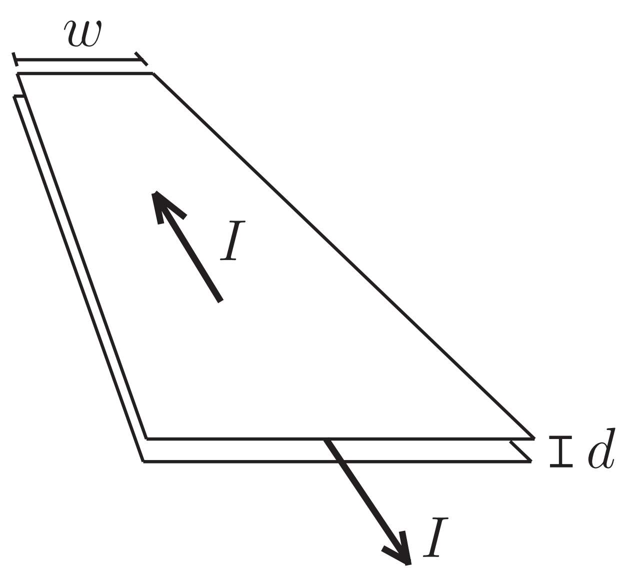
Part of a certain circuit board is a long transmission line. It consists of two parallel plate conductors of width w and separation d. The space between the two conductors is filled with air. Assume $w \gg d$ so that the effects of fringe fields at the edges of the conductors can be ignored.

An important parameter of the circuit board is the characteristic impedance Z of the transmission line. To find Z, the capacitance and inductance of the line need to be known.

a) Treating the transmission line as a parallel plate capacitor, find c, its capacitance per unit length.

b) A current I flows through both the bottom and the top plates of the transmission line. The currents flowing through the two plates have the same magnitude but opposite direction. Find the magnitude and direction of the magnetic field between the plates.

c) The inductance L of a conductor is given by the ratio Φ/I, where Φ is the magnetic flux generated by a current I. Find l, the inductance per unit length of the transmission line.



Problem 7

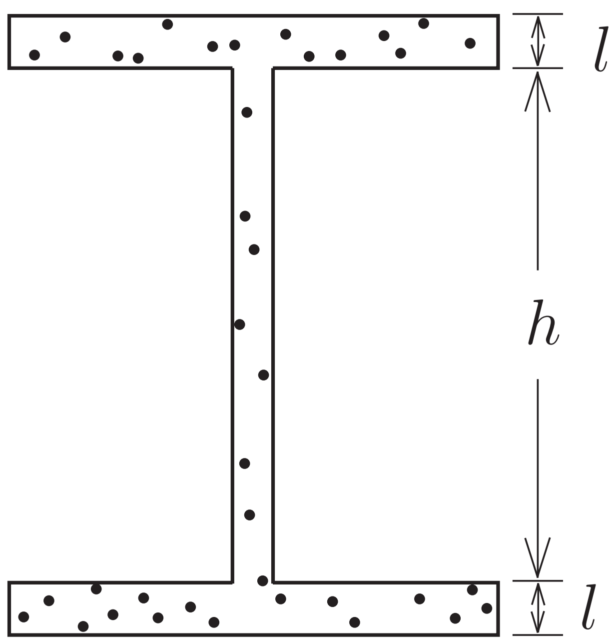
N atoms, each of mass m, of an ideal monatomic gas occupy a volume consisting of two identical chambers connected by a narrow tube, as illustrated below. There is a gravitational field with acceleration g directed downward in the figure. The gas is in thermal equilibrium at temperature T.

The height h of the upper chamber above the lower chamber is much greater than the height l of either chamber. The volume of the tube is negligible compared with that of the chambers. Assume that $mgl \ll k_B T$, but *not* that there is any particular relation between mgh and $k_B T$. Treat the system classically and the atoms as having no internal degrees of freedom.

a) Calculate the number of atoms in the upper chamber in terms of N, m, g, h, and T.

b) Calculate the total energy (kinetic and potential) of the system in terms of the same parameters.

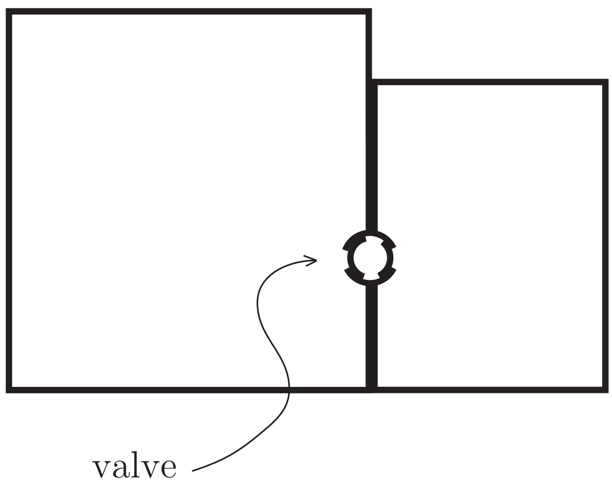
c) From the total energy obtain an expression for the specific heat of the system as a function of the temperature.



Problem 8

a) Find the work done on an ideal gas during an isothermal change of volume from V_A to V_B.

b) Next, suppose an isolated system consists of two vessels containing identical ideal gases at the same temperature T and with equal numbers of particles N, but at different pressures P_1 and P_2. A valve is opened so gas can flow between the vessels. Find the pressure of the connected vessels.



Problem 9

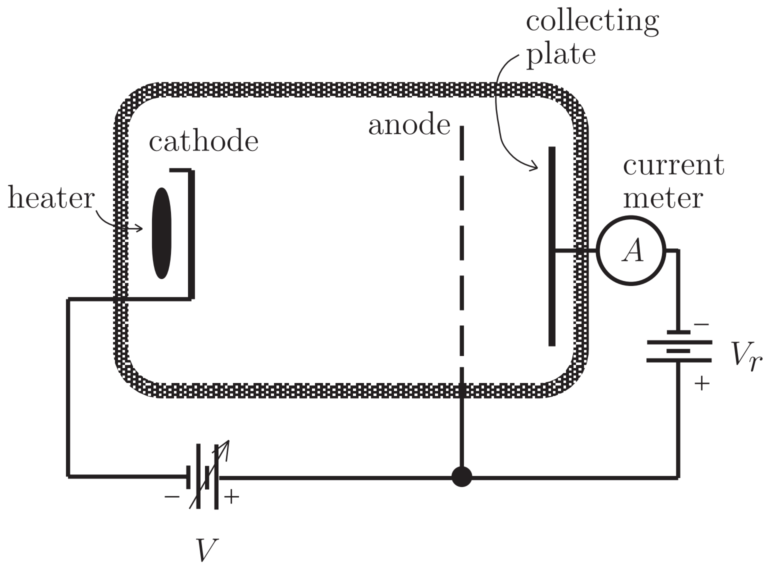
Stephan's law relates the total energy E radiated by a black body per unit area per unit time to the temperature T of the black body,

$$E = \sigma T^4.$$

Picture the earth and sun as black body radiators. Use Stephan's law to estimate the steady state temperature of the earth, assuming that the temperature is constant over the entire surface of the earth and that all of the energy input to the earth comes from the sun. Use the data given at the beginning of the test.

Is your answer too high or too low compared to reality? What effects might account for the difference?

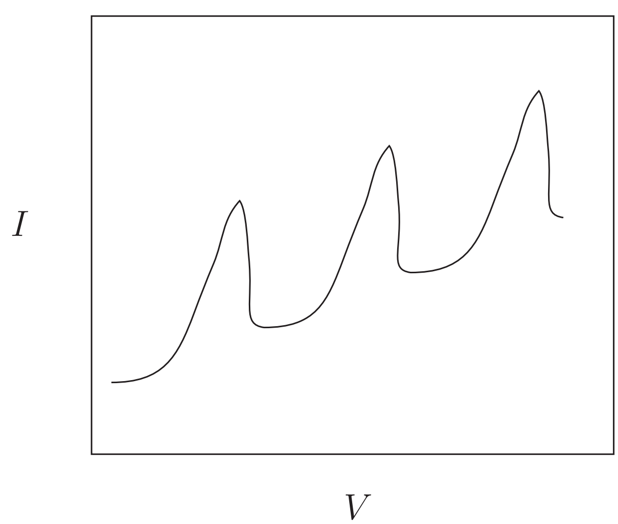
Problem 10



The apparatus depicted above was used in 1914 to study the collisions of electrons with atoms. The chamber is filled with mercury vapor at low pressure. Electrons are emitted thermally at the heated cathode on the left. A variable voltage, V, is applied between the cathode and a slotted anode. Another voltage of opposite polarity, V_r, is applied between the anode and an electron collecting plate. The current, I, between the cathode and the collecting plate is measured by a meter.

a) What is the purpose of applying the voltage V between the cathode and the anode? Why is the anode slotted? What is the purpose of the voltage V_r that is applied between the anode and the collecting plate?

b) A typical plot of the current I versus the voltage V for this experiment is sketched below. What is the significance of the peaks in the plot? Why they are regularly spaced?



Problem 11

An electromagnetic wave pulse of frequency f is traveling in vacuum in the x direction at constant velocity v.

a) If we measure f over the finite time interval Δt that it takes the pulse to pass, explain why the frequency will be uncertain by an amount Δf that is given approximately by

$$\Delta f \, \Delta t \geq 1.$$

b) Using this expression, derive the relationship between the uncertainties Δx and Δp in the position and momentum of the wave pulse.

Problem 12

Consider the construction of a "matter/antimatter drive" for a spaceship, the *Enterprise*. Suppose that, in a small time interval Δt a mass ΔM of fuel is utilized. Compute the momentum boost ΔP for each of the following two options:

Option A. The fuel ΔM consists of $\Delta M/2$ of matter and $\Delta M/2$ of antimatter. All of the fuel is annihilated into photons which are reflected directly out the back of the *Enterprise*.

Option B. The fuel ΔM consists of $\Delta M/4$ of matter and $\Delta M/4$ of antimatter plus an additional mass $\Delta M/2$ of matter. The $\Delta M/4$ of matter and $\Delta M/4$ of antimatter fuel is annihilated and the energy released is used to accelerate the remaining $\Delta M/2$ of matter, which is ejected in the backward direction.