Exam #: ______________________

Printed Name: ______________________

Signature: ______________________

PHYSICS DEPARTMENT

UNIVERSITY OF OREGON

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

Wednesday, September 19, 2001, 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.

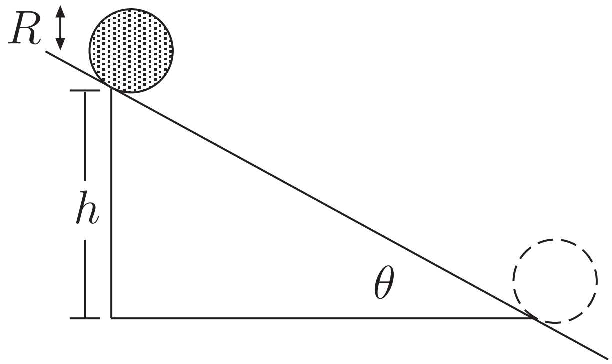
Constants

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)	$6.38 \times 10^{6}\,\mathrm{m}$
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)	$29.4\,\mathrm{J/mole\cdot K}$

Integrals

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

$$\int_{0}^{\infty} \frac{dx}{x}\, x^{n}\, e^{-x} = \Gamma(n)$$



Problem 1

A solid cylinder of mass M and radius R is initially at rest at the top of an incline whose surface makes an angle θ with the horizontal. The top of the incline is at height h, the bottom at height zero.

a) The cylinder rolls without slipping down the incline. Find the speed of the cylinder's center of mass when it reaches the bottom of the incline.

b) The cylinder is replaced at the top of the incline and the surface conditions are changed so that it now slides without friction down the incline without rotating. Find the speed of its center of mass at the bottom of the incline. Is the final speed greater or smaller than in part a) or is it the same? Explain briefly which of these one would expect before doing a calculation.

Problem 2

A particle of mass m moving in a straight line with velocity v_0 enters a medium which subjects it to a drag force $F = -c/v^2$, where c is a constant.

a) Find the time for the particle to stop in terms of m, v_0 and c.

b) Find the distance in which the particle stops in terms of m, v_0 and c.

Problem 3

Consider the equation for hydrostatic equilibrium for the atmosphere near the surface of the earth,

$$\frac{dp}{dz} = -g\rho, \tag{1}$$

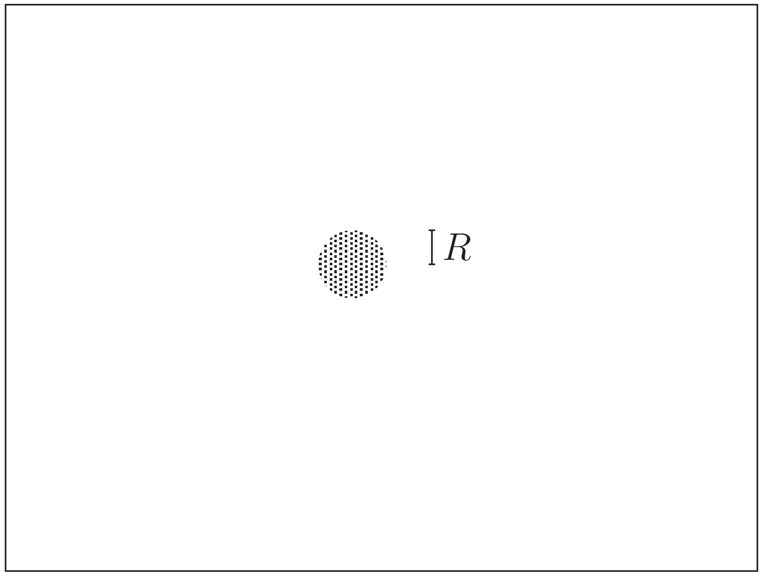
where p is the pressure in the air, ρ is its density, z is the height, and g is the acceleration of gravity.

a) Begin by drawing a cylinder of air, defining your coordinates, and showing the forces acting on the cylinder. From that diagram, show that Eq. (1) must hold.

b) Using Eq. (1) and assuming that the atmosphere is an ideal gas, show that if the temperature of the atmosphere were independent of height, then the dependence of atmospheric pressure on height would be exponential in nature.

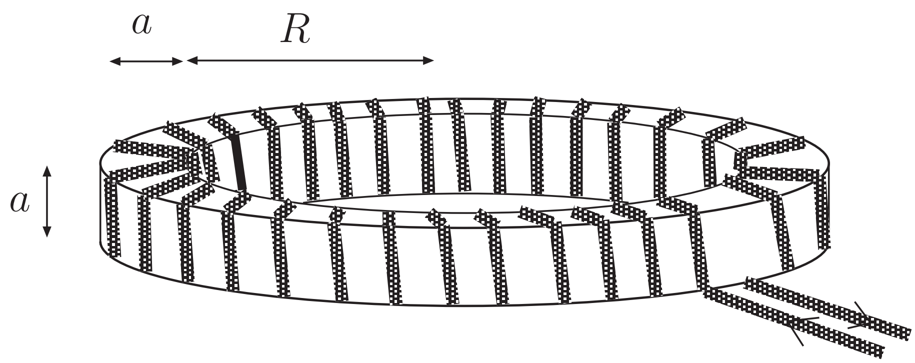
Problem 4

The electric field strength near the surface of the earth is (approximately) 110 V/m at an altitude of 100 m and 25 V/m at an altitude of 1000 m. Calculate the average electric charge density in the atmosphere between these heights.



Problem 5

At time $t = 0$ a charge Q_0 is uniformly spread over the interior of a small sphere of radius R made of a material that obeys Ohm's law with electrical conductivity $\sigma = 10\ \text{ohm}^{-1}\text{m}^{-1}$. The small sphere is part of a large block of the same material. Calculate the time dependence of the charge contained within the small sphere. If the material were copper, would the charge dissipate more quickly or less quickly?



Problem 6

An iron ring is uniformly wrapped with $N = 300$ turns of wire carrying current $I = 4$ A. The ring has the shape obtained by rotating a square of side $a = 0.8$ cm about an axis a distance $R = 7$ cm from the nearest side of the square. That is, the ring occupies the volume specified in cartesian coordinates by $0 < z < a$, $R < \sqrt{x^2 + y^2} < R + a$. Assume that iron exhibits an approximately linear relation between magnetization and applied field, as specified by relative permeability $\mu_r \equiv \mu/\mu_0 = 200$.

a) Calculate the magnetic field H and the magnetic induction B in the ring as a function of the distance r from the axis.

b) Calculate the inductance L of the ring.

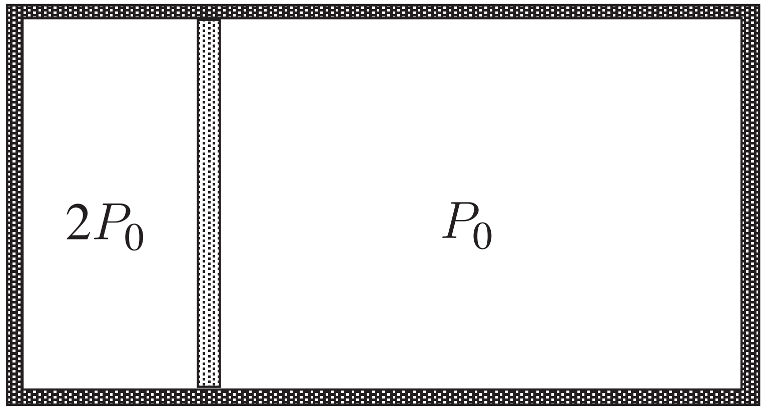
Problem 7

Consider two macroscopic systems consisting, respectively, of a mass M_A of a substance A with specific heat C_A and a mass M_B of a substance B with specific heat C_B. The systems start with initial temperatures T_A and T_B respectively. Suppose that the two systems are placed in contact and thermally isolated from the outside world and that heat is allowed to slowly pass between them until they reach a common final temperature, T_f. The volumes and particle numbers of each system remain fixed throughout this process and the specific heats C_A and C_B are temperature independent..

a) Find the final temperature T_f.

b) What is the entropy change of each system? You may express your answer in terms of T_f as well as T_A and T_B.

c) Show that your answer to part b) is consistent with the second law of thermodynamics, $\Delta S > 0$.



Problem 8

Consider a thermally insulated horizontal cylinder closed at both ends. A frictionless, heat-conducting piston divides the volume into two unequal parts. The piston is initially clamped so that the volume to the left of it is V_0 and that to the right is $3V_0$. The left-hand side contains an idea gas at temperature T_0 and pressure $2P_0$. The right-hand side contains an ideal gas of the same composition and the same temperature T_0, but at a pressure P_0.

a) What is the relationship between temperature, pressure, and volume of an ideal gas? Write down this expression for the left-hand and right-hand regions.

The piston is now released and allowed to reach equilibrium. Assume that the final, equilibrium temperature is still T_0.

b) What is the final pressure on each side of the piston (in terms of P_0)?

c) What are the final volumes on each side of the piston (in terms of V_0)?

d) Is the assumption that the final temperature is T_0 valid? Justify your answer.

Problem 9

The coefficient of thermal conductivity, κ, for a moderate temperature gradient is defined by

$$Q_z = \kappa \frac{\partial T}{\partial z}. \tag{2}$$

where Q_z is the flux of thermal energy in the $+\hat{z}$ direction. Estimate κ for a dilute gas using elementary kinetic theory arguments. Express it in terms of the gas quantities n (molecular number density), $\bar{v}$ (mean speed), ℓ (mean free path), and c (heat capacity per molecule).

Problem 10

A homogeneous monochromatic light beam with wavelength $\lambda = 0.4 \times 10^{-7}$ m impinges perpendicularly on a material with a work function of 2.0 eV. The beam intensity is $I = 3.0 \times 10^{-9}$ W/m^2.

a) Calculate the number of photoelectrons emitted per square meter per second, assuming a quantum efficiency of 100%.

b) Calculate the energy left behind in the material per square meter per second.

c) Calculate the kinetic energy of each photoelectron.

Problem 11

A 1 kg mass is hanging on a spring with a spring constant of 25 N/m. The spring is stretched 2 cm and released, resulting in undamped simple harmonic motion. Consider this oscillator from the point of view of quantum mechanics. What is its quantum number? Explain why mechanical oscillators like this do not appear to have a quantized nature.

Problem 12

An electron is accelerated from rest through a potential drop of 0.13 MV and then travels at a constant velocity.

a) How long does it take for the electron (after reaching its final velocity) to travel between two points that are 8.4 m apart in the laboratory rest frame.

b) How long does this take in the electron rest frame?

c) What is the distance between the two points as measured in the electron rest frame.