PHYSICS DEPARTMENT

UNIVERSITY OF OREGON

<u>Master's Final Examination</u>
and
<u>Ph.D. Qualifying Examination, PART I</u>

Monday, March 28, 2005, 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

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Electron charge (e)	1.60×10^{-19} C
Electron rest mass (m_e)	9.11×10^{-31} kg $(0.511 \,\text{MeV}/c^2)$
Proton rest mass (m_p)	1.673×10^{-27} kg $(938 \,\text{MeV}/c^2)$
Neutron rest mass (m_n)	1.675×10^{-27} kg $(940 \,\text{MeV}/c^2)$
W^+ rest mass (m_W)	$80.4 \,\text{GeV}/c^2$
Planck's constant (h)	6.63×10^{-34} 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)	6.67×10^{-11} 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 Sun (R_Sun)	6.96×10^8 m
Earth - Sun distance (R_ES)	1.50×10^{11} m
Density of iron at low temperature (ρ_Fe)	7.88×10^3 kg/m^3
Classical electron radius (r_0)	2.82×10^{-15} m
Gravitational acceleration on Earth (g)	9.8 m/s^2
Atomic mass unit	1.66×10^{-27} kg
Specific heat of oxygen (c_V)	21.1 J/mole$\cdot$K
Specific heat of oxygen (c_P)	29.4 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 or cylinder 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: $(2/5)\,MR^2$.

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

Problem 1
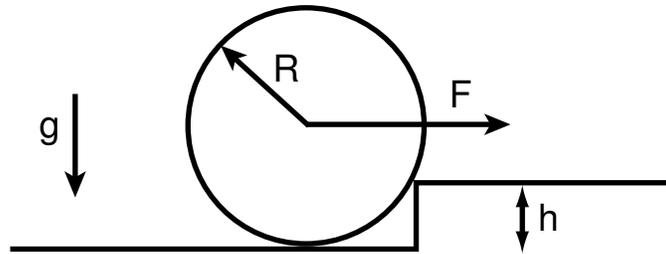
A wheel of radius R and mass M rests on the ground with its axle parallel to a curb of height $h < R$. In order to start the wheel over the curb, what minimum force F, parallel to the ground, must be applied to the axle?

Problem 2

A boat traveling with an initial velocity of v_0 shuts off its engine at time $t_0 = 0$ and at position $x_0 = 0$. The force of friction acting on the boat is proportional to the boat's velocity, v, with a constant of proportionality b.

a) Determine the boat's velocity as a function of time starting at $t_0 = 0$.

b) Solve for the distance traveled x as a function of time starting at $t_0 = 0$.

Problem 3

Consider five objects in a race. The objects start at the same height and roll down an inclined plane without slipping. Determine the order in which they finish the race. The objects are as follows:

1. a solid sphere of radius $2R$,

2. a solid sphere of radius R,

3. a spherical shell of radius R,

4. a solid cylinder of radius R,

5. a hoop of radius R.

Problem 4

A capacitor is formed by two thin, concentric, metallic spherical shells with radii a (inner) and b (outer). The shells are charged with $+Q$ (inner) and $-Q$ (outer), where Q is a positive charge.

a) Give an expression for the electric field $\vec{E}(\vec{r})$ everywhere.

b) Calculate the potential difference between the two shells.

c) Find an expression for the capacitance of the system.

d) Find an expression for the total field energy contained in the space between the two shells by integrating over the field energy density.

Problem 5
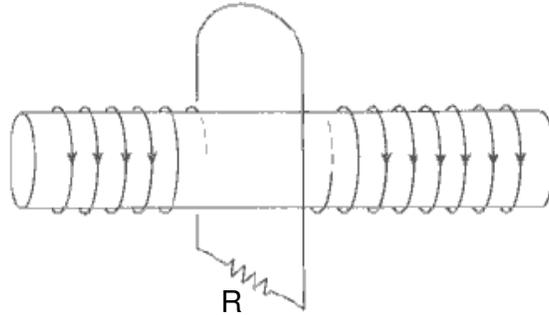
A solenoid of radius a, wound with N turns per unit length, is surrounded by a loop of wire with resistance R as shown.

a) If the current in the solenoid is increasing at a constant rate $dI/dt = k$, what current flows in the loop?

b) Explain whether the current in the loop is flowing in the same direction or the opposite direction with respect to the current in the solenoid.

c) If the current I in the solenoid is held constant, but the solenoid is pulled out of the loop and reinserted in the opposite direction, how much charge passes through the resistor?

Problem 6

An electron, initially at rest, is accelerated through a potential of 1000 V and enters a region with a uniform magnetic field of magnitude 10^{-3} Tesla. Assume the direction of the electron entering the field region is $+\hat{y}$ and the magnetic field is in the $-\hat{z}$ direction as indicated by the crosses in the figure below. Two parallel plates, separated by 5 cm, can be energized with a voltage difference V_b to produce a uniform electric field in the $\hat{x}$ direction.

a) First, consider the case when there is no electric field ($V_b = 0$). Sketch the motion of the electron and find the radius of the electron's trajectory.

b) Second, consider what happens when the electric field is switched on. What voltage potential V_b between the plates would be required to make the electron travel in a straight line?
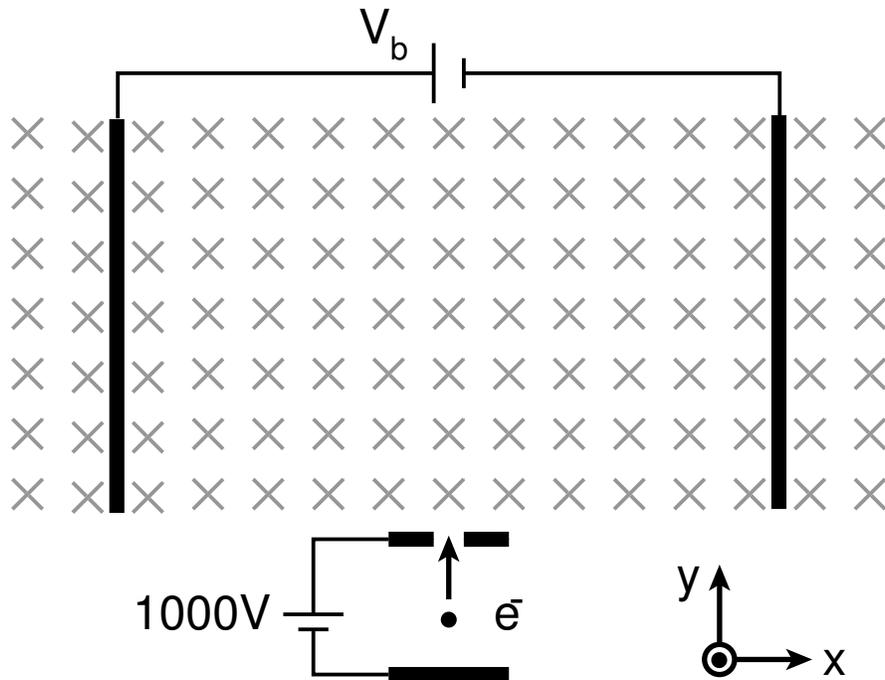
Problem 7

You just passed the patent agent's bar exam. Your first client would like to patent a new type of heat engine called Engine X. The engine has a work output W of 100 J/cycle and it operates between heat reservoirs maintained at the boiling and freezing temperatures of water. The inventor claims a thermodynamic efficiency of $\epsilon_x = 0.75$.

a) How much heat Q_H would Engine X extract from the high-temperature reservoir per cycle?

b) How much heat Q_L would Engine X transfer to the low temperature reservoir per cycle?

c) What would be the entropy change per cycle for the entire system?

d) Will you take the case? In other words, can this engine work as the inventor claims? Explain.

Problem 8
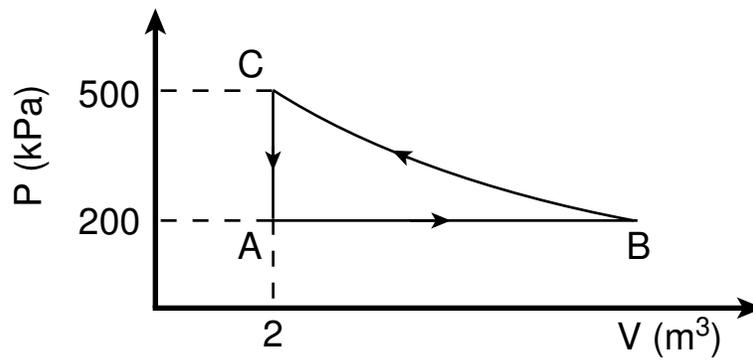
A constant amount of an ideal monatomic gas undergoes the cyclic process $ABCA$ in the PV diagram shown above. The path BC is isothermal.

a) Calculate the volume at point B.

b) Calculate the work done by the gas during one complete cycle beginning and ending at A.

c) In terms of work and heat, what is the net result of this process?

Problem 9

Imagine a particle that can be in only two states with energies $E_0 = 0$ eV and $E_1 = 0.05$ eV. Initially, the degeneracy of each state is assumed to be 1. The particle is in equilibrium with a reservoir at 300 K.

a) Calculate the probability for this particle to be in each of the two states.

b) Calculate the mean energy of the particle.

c) Now assume that the degeneracy of the upper state is 2. How does this affect your answers to a) and b)? Explain.

Problem 10

In the photoelectric effect experiment, it is found that a stopping potential of 1.0 V is needed to stop all the current when incident light of wavelength 260 nm is used and a stopping potential of 2.3 V is needed for light of wavelength 207 nm.

a) From these data determine Planck's constant (in Js).

b) Determine the work function of the metal (in eV).

c) What is the minimum photon energy necessary to eject an electron from the metal?

Problem 11

The surface temperature of the Sun is 6000 K. The sunlight striking the Earth's surface has a power per unit area of 1300 W/m^2.

a) What is the typical energy of a photon emitted from the Sun?

b) Estimate (to within an order of magnitude) the number of photons per second from the Sun that strike the circular, 10 meter diameter aperture of the Keck telescope.

c) How far away in astronomical units (A.U.) from the Earth could a star identical to the Sun be and still be detected by the Keck telescope, assuming that at least 1 photon/second has to reach the aperture. (Reminder: 1 A.U. is defined as the distance from the Earth to the Sun).

Problem 12

A rocket of proper length $L_0 = 30$ meters moves past a space station (A) at speed $v = 0.8c$ as shown. When the nose of the rocket (A') coincides with the station (A), clocks in both rocket and station are set to zero and a pulse of light is emitted from point A' towards B'.
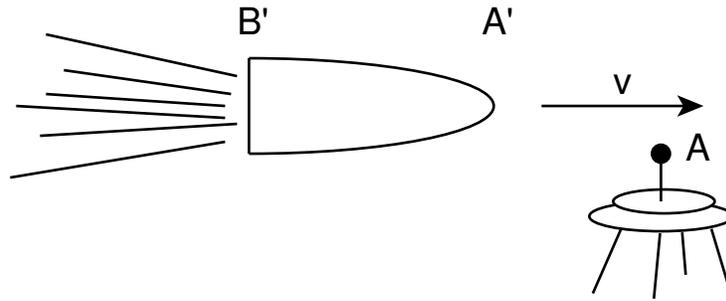
a) Determine the time t'_B at which the light is detected at B' according to the clock in the rocket.

b) Determine the time t_B at which the light is detected at B' according to the clock in the space station.