Exam # ____

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DEPARTMENT OF PHYSICS

UNIVERSITY OF OREGON

Ph.D. Qualifying Exam

Part III: Modern, and Applied Physics

Room 115, Lawrence Hall

Friday, September 26, 1997, 11 a.m. to 3 p.m.

• The examination papers are numbered in the upper right hand corner of each page. Sign your name and print it 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. Your exam number is already on the question sheets. Be sure to place both the exam number and the question number on any pages you wish to have graded.

• There are six equally weighted questions, each beginning on a new page.

• Read all six questions before attempting any answers.

• Begin each answer on the same page as the question, but continue on 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 on 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 which can store 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.

• Please make sure you follow all instructions carefully. If you fail to follow instructions, or to stop working on the exam when the time is up, an appropriate number of points may be subtracted from your final score. When you have finished, remain in your seat and a proctor will collect your exam.

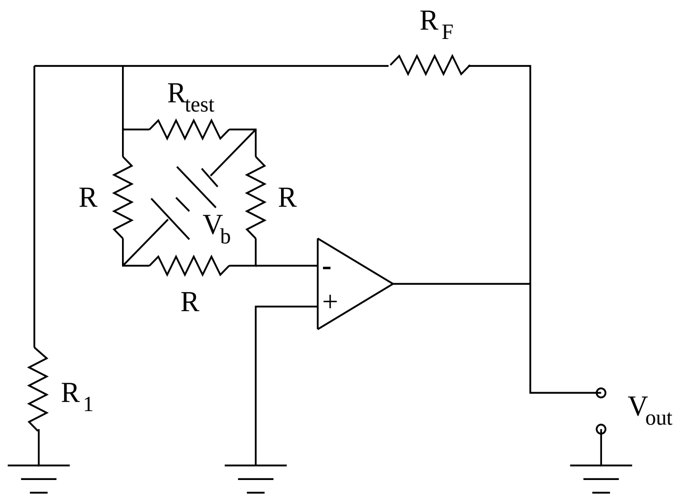
1. There is good evidence that cosmic ray protons observed on earth come from far away, from outside of our galaxy. This raises the question of how high the energy of a proton can be in order to travel such a long way without losing its energy in the process

$$p + \gamma \to p + e^+ + e^-$$

where the photons γ are from the 3 K cosmic microwave background radiation (i.e., a thermal gas of photons that permeates the universe and has a temperature of about 3 K as observed from the earth). Considering that the above process can happen only if there is enough energy available in the (p, γ) center-of-momentum frame to create the $e^+ - e^-$ pair, estimate the threshold proton energy $E_p^{\text{threshold}}$ (in eV) in the rest frame of the earth for the above reaction to occur with a 3 K photon.

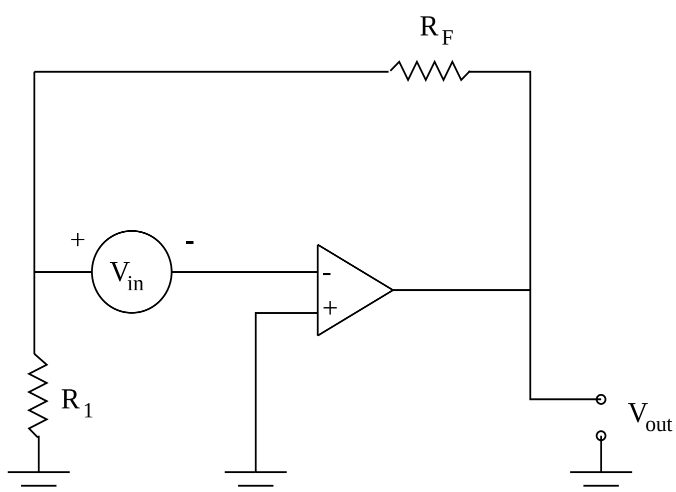
hint: $k_B \approx 10^{-4}\,\text{eV/K}$

2. An ideal operational amplifier is used to measure small fractional resistance changes δ in a resistance thermometer, as shown below. The resistance of the thermometer is $R_{\text{test}} = R(1+\delta)$.



a) Give two properties of an ideal operational amplifier that make it suitable for this purpose.

b) Noticing that the circuit can be represented by the equivalent circuit shown, determine the voltage V_{out} in terms of the voltage V_{in}.



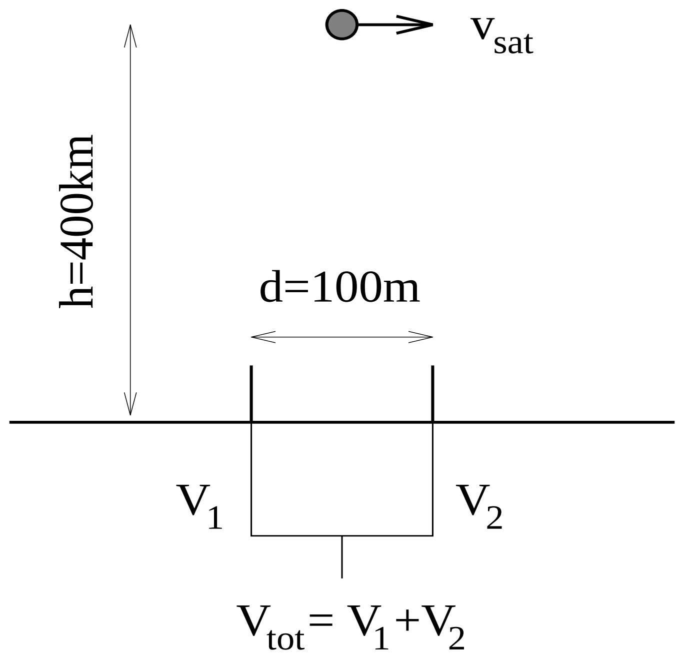
c) Now find V_{in}, and also V_{out}, as functions of δ.

d) To reduce unwanted high–frequency noise, the circuit is to be modified to reduce the high–frequency gain. Indicate, without any calculation, how this can be achieved with a single capacitor.

3. A satellite orbiting earth is continuously transmitting microwaves of wavelength $\lambda = 0.15\,\text{m}$. When the satellite is above the ground station, which has two antennae separated by a distance $d = 100\,\text{m}$, and is located in the plane of the orbit, the amplitude of the total signal, $V_1 + V_2$, that is received by the two antennae oscillates with a period $\tau = 0.156\,\text{s}$. The satellite's altitude above the ground station is $h = 400\,\text{km}$. From these data, approximately determine the satellite's velocity.

hint: (1) Neglect the curvatures of the earth and of the satellite's orbit.

(2) Neglect the transverse Doppler effect.



4. In particle physics experiments, charged particles can sometimes be identified using time–of–flight measurements of the particle masses. In this problem you are asked to explore the precision of this technique.

From standard kinematics, the rest mass of a relativistic particle with momentum p that travels a distance d in a time τ can be expressed as

$$m = \frac{p}{c}\left[(c\tau/d)^2 - 1\right]^{1/2} \quad ,$$

where the rest mass m is expressed in units of MeV/c^2, and momentum has units of MeV/c.

a) In most experiments the usefulness of the time–of–flight technique is limited by the precision of the timing measurement. Given that the standard deviation σ_τ of the time–of–flight τ is much less than the mean of τ, find the standard deviation of the rest mass measurement. Neglect any uncertainty in p and d. Express your answer in terms of σ_τ, p, d, the speed of light c, and the rest mass of the particle m.

b) Consider particles with $p = 500\,\mathrm{MeV}/c$ and a travel distance $d = 1\,\mathrm{m}$. If the distribution of the measured travel times is approximately Gaussian with a standard deviation of 200 ps, find the approximate values of the mass resolution for pions ($m_\pi \approx 140\,\mathrm{MeV}/c^2$), kaons ($m_K \approx 494\,\mathrm{MeV}/c^2$), and protons ($m_p \approx 938\,\mathrm{MeV}/c^2$). Is the timing resolution sufficiently good to separate pions, kaons, and protons?

c) Which of the reconstructed mass distributions (pions, kaons, or protons) will be most nearly Gaussian in the regions near their respective peaks? Which will be least Gaussian? Justify your answer.

5. The resistivity ρ of a metal is the ratio of the applied electric field strength E to the induced current density j: $\rho = E/j$.

Consider the following model for a metal: The metal contains a gas of free electrons. Under the action of the applied field the electrons accelerate until they undergo a collision with an impurity or with a lattice vibration (phonon). The distribution of electron velocities immediately after a collision is isotropic.

a) Express the resisitivity ρ in terms of the electron number density n, the electron mean velocity $< v >$ between collisions, the collision mean–free path ℓ, the electron charge $-e$, and the electron mass m.

b) For a metal with $n = 5 \times 10^{22}\,\mathrm{cm}^{-3}$ and $\ell = 100\mathring{A}$ at a temperature $T = 300\,\mathrm{K}$, estimate ρ in $\mu\Omega\mathrm{cm}$.

6. An atom with mass m in its electronic ground state is moving non–relativistically with velocity $\vec{v}$, when a visible photon traveling in the same direction as the atom is incident on it. The photon's frequency is near the frequency of one of the atom's allowed electronic transitions. If the atom is at rest, that frequency is ω_0. If the atom absorbs the photon, the atom recoils.

a) Give an expression for the Doppler shift of the resonance absorption frequency (in rad/s) due to the atom's initial motion.

b) Find the recoil velocity of the atom if it absorbs the photon.

c) Find the shift, due to the recoil, of the resonance frequency for absorption of the photon compared to the case where the atom is held fixed at rest.

hint: Write the frequency shift as the Doppler shift plus another term.

d) Assume that the atom is subject to a constant–power beam of light traveling in the same initial direction as the atom. If the spectrum of the light is broad and centered near the atom's resonance absorption frequency, the atom will be accelerated as a consequence of many absorption and re–emission events. Consider the average contributions to this acceleration from absorption and spontaneous emission processes. Assuming that the atom can absorb and spontaneously emit one photon during a time τ, find an approximate expression for the atom's average acceleration. Use the result to estimate the value of acceleration of a sodium atom (atomic weight = 23 g/mole, $\tau \approx 10$ ns) that absorbs yellow light.