PHYSICS DEPARTMENT PRINCETON UNIVERSITY

GRADUATE GENERAL EXAMINATION

Tuesday, January 9, 2001 - 9:00 am - 12:00 noon

Part IV.

This part of the General Examination poses SIX questions, TWO on Relativity and FOUR on General and Atomic Physics. You must do ONE relativity problem and TWO General and Atomic questions.

Work each problem in a separate examination booklet. Be sure to label each booklet with your name, the section name, and the problem number.

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Part IV. Section A. Relativity

1. How much will the recession velocity of an extragalactic source change over the course of a year?

Assume both we and the source are comoving with the expansion of the universe (*i.e.,* the comoving distance is fixed) and that the universe today has a ratio of matter density to critical density equal to $\Omega_m < 1$ (and no cosmological constant or other form of energy density).

a) Express the change in recession velocity in terms of H_0, Ω_m and the red shift of the source z_s.

b) For $z_s \approx 1$, estimate the change in recession velocity after one year. The Hubble constant today is $H_0 \approx (10^{10}\,\mathrm{yr})^{-1}$.

c) Comment on whether this is detectable.

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Part IV. Section A. Relativity (continued)

2. A standard freshman physics problem goes something like this:

Suppose the Earth is a uniform nonrotating sphere with a hole along a diameter ($d = 1.2 \times 10^7$ m). A 1 kg mass is dropped into the hole. Ignoring air resistance, what happens? (Assume that all the electric and magnetic moments of the mass are zero.)

Of course, the answer is that the mass oscillates forever and the period of oscillation is the same as that of a satellite in orbit at the Earth's surface, about 85 minutes.

But that does not take into account gravitational radiation:

a) What is the frequency of the radiation?

b) Estimate the time for the damping of oscillations.

Newton's constant is $G \sim 7 \times 10^{-11}\ \mathrm{m}^3/\ \mathrm{kg\,s}^2$

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Part IV. Section B. General and Atomic Physics

1. When an electron (or positronium atom) is injected with nearly zero energy into liquid helium, a bubble quickly forms around it. This phenomenon (which also occurs in liquid hydrogen, liquid neon and possibly in solid helium) lowers the mobility of the electron to a value similar to that for a positive ion.

   Estimate the numerical value of the radius of the bubble at zero pressure and temperature $\ll$ 1K.

   Hint: An energy argument may be useful.

2. An incandescent light bulb has a fine tungsten wire. Assume that the bulb dissipates 40 W at 120 V. The resistivity of tungsten is 1.5×10^{-6} Ω-m. Given that you want to make the color of the light output of the bulb as close to natural sunlight as possible, calculate the length and radius of the wire, assuming that the wire is a cylinder.

3. The hydrogen molecule has two electrons occupying the same spatial wavefunction. The states occupied by the hydrogen nuclei can be characterized by their orbital angular momentum L and their spin S. States with odd L are termed *ortho* states and states with even L are termed *para* states. Compute the percentage of hydrogen molecules in the lowest *para* state at room temperature in zero magnetic field.

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Part IV. Section B. General and Atomic Physics (continued)

4. Your mission is to find the unknown values of a resistor and capacitor using the equipment in the hall outside Jadwin A10: an oscilloscope, a signal generator with a 600 ohm output impedance, and a breadboard circuit which you can wire up any way you want.

Your writeup should describe very briefly your approach, sketch the circuit used and your results. Expect the value of the resistor to be between 10 and 10,000 ohms, and the value of the capacitor to be between 0.001 and 1 microfarad. Your measurement should be good to 10%.