The University of Georgia
Department of Physics and Astronomy

Graduate Qualifying Exam — Part II

10 August 2016

Instructions:

- Attempt all problems. You *must* show your work and/or clearly explain your answers in order to be able to earn a passing grade for a problem.
- Start each problem on a new sheet of paper. Write the problem number on the top left of each page, and your pre-arranged **prelim ID** number (but *not* your name) on the top right of each page. Leave margins for stapling and photocopying.
- This is a closed-book exam. You are permitted to bring one page of notes (equations, definitions, physical constants, etc.) per exam day. You must hand in this page of notes with the exam each day.
- You may use a calculator, but *only* for arithmetic functions (i.e., not for referring to notes stored in memory, doing symbolic algebra, etc.).

Part II has five problems, numbered 6–10.

Problem 6: (three parts)

(a) Find the eigenvalues and eigenspinors of the S_y operator in the standard z basis for a spin-1/2 particle.

(b) If you measured S_y on a particle in the general state $|\chi\rangle = a|+\rangle + b|-\rangle$, what values might you get, and what is the probability of each? (Check that the probabilities add up to 1.)

(c) If you measured S_y^2, what values might you get, and with what probabilities?

Problem 7: (one part)

A well insulated container is divided in half by a thin barrier. In the left half of the container is an ideal gas of N particles at some temperature T; the right half of the container is empty. The barrier breaks, doubling the volume of the gas from V_0 to $2V_0$. What is the increase in entropy of the system resulting from this adiabatic expansion of the gas? (An **adiabatic** process is one in which no heat is added to or removed from the system.)

Problem 8: (two parts)

Consider the molecules HCl and DCl, where D denotes the deuterium or "heavy hydrogen" atom, $D = {}^2H$.

(a) Explain why the bond length R_0 and bond force constant k should be about the same for DCl as for HCl.

(b) The spacing of adjacent vibrational energy levels in HCl is $\hbar\omega_c \simeq 0.37$ eV. What is the corresponding energy level spacing in DCl? (You might consider treating the Cl atom as fixed.)

Problem 9: (three parts)

(a) A π^0 meson is an unstable particle that is produced in high-energy particle collisions. It has a mass-energy equivalent of about 135 MeV, and it exists for an average lifetime of only 8.7×10^{-17} s before decaying into two gamma rays. Using the uncertainty principle, estimate the fractional uncertainty $\Delta m/m$ in its mass determination.

(b) The neutron has a mass-energy equivalent of about 940 MeV. Neutrons emitted in nuclear reactions can be slowed down via collisions with matter. They are referred to as thermal neutrons once they come into thermal equilibrium with their surroundings. The average kinetic energy $3kT/2$ of a thermal neutron is approximately 0.04 eV. Calulate the de Broglie wavelength of a thermal neutron with this average kinetic energy.

(c) How does the de Broglie wavelength from the previous part compare with the characteristic atomic spacing in a crystal, which is of the order of 1 angstrom (10^{-10} m, i.e., the Bohr radius)? Would you expect thermal neutrons to exhibit diffraction effects when scattered by a crystal? Explain.

Problem 10: (two parts)

A cylinder contains 3.00 moles of helium gas at a temperature of 300 K.

(a) How much heat must be transfered to the gas to increase its temperature to 500 K if it is heated at constant volume?

(b) How much thermal energy must be transfered to the gas at constant pressure to raise the temperature to 500 K?

It might help to know the physical data $C_V = 12.5$ J/(mol K) and $C_P = 20.8$ J/(mol K) for helium.