Name: ________________________________________

Student # ________________________________________

1. For credit: Please redo only 2 problems between 1 through 6.
2. For extra credit: You may do the one of problems 7, 8, or 9 *which you did not do in the regular test.*
3. Indicate below which problems you have done.

My redo problems are: ________________________________________

# PHY215, fall 2006

## Modern Physics and Thermodynamics

Exam #2, Round Two. Due Monday, November 13, 2006

Please show all of your work. If you need more space, use the back and indicate clearly what problem is being continued. If you still need more space...ask for another sheet and clearly include your name and what problem is begin continued.

## Constants

1 calorie = 4.186 J
1 atmosphere = $1.01 \times 10^5$ Pa
Gas Constant: $R = 8.3145$ J/mol·K
Bolzmann's Constant: $k = 1.38 \times 10^{-23}$ J/L
Sefan-Boltzmann's constant: $\sigma = 5.67 \times 10^{-8}$ W/m$^2$K$^4$
Avagadro's Number: $N_A = 6.023 \times 10^{23}$ mol$^{-1}$
Speed of Light: $c = 3 \times 10^8$ m/s
Charge of the electron: $-e = -1.6 \times 10^{-19}$ C
Mass of the electron: $m_e = 9.1094 \times 10^{-31}$kg = 511 keV/c$^2$
Mass of the proton: $m_p = 1.6726 \times 10^{-27}$kg = 938.3 MeV/c$^2$
Mass of the neutron: $m_n = 1.6749 \times 10^{-27}$kg = 939.6 keV/c$^2$
Mass of the alpha particle: $m_\alpha = 3727.4$ MeV/c$^2$
Planck's Constant: $h = 6.63 \times 10^{-34}$J-s = $4.14 \times 10^{-15}$ eV-s
...times $c$: $hc = 1.9864 \times 10^{-25}$J-m = 1239.8 eV-nm
Reduced $h$: $h/2\pi = \hbar = 1.0546 \times 10^{-34}$J-s = $6.5821 \times 10^{-16}$ ev-s
...times $c$: $\hbar c = 3.162 \times 10^{-28}$J-m = 197.33 eV-nm
Electrostatic constant: $\dfrac{1}{4\pi\epsilon_0} = 8.9876 \times 10^9$ N-m$^2$-C$^{-2}$
...times $e^2$: $\dfrac{e^2}{4\pi\epsilon_0} = 2.3071 \times 10^{-28}$ J-m = $1.4400 \times 10^{-9}$eV-m
Bohr radius: $a_0 = \dfrac{\hbar}{m_e c\alpha} = 0.5292 \times 10^{-10}$ m
Fine structure constant: $\alpha = \dfrac{e^2}{4\pi\epsilon_0 \hbar c} = 1/137.036$

Formulae

$$\begin{aligned}
\text{reduced mass: } \mu &= \frac{mM}{m+M} \\
\text{mean velocity for an ideal gas: } < v > &= \frac{4}{\sqrt{2\pi}}\sqrt{\frac{kT}{m}}
\end{aligned}$$

Integrals

$$\begin{aligned}
\int \sin x dx &= -\cos x \\
\int \cos x dx &= \sin x \\
\int \sin^2 x dx &= \frac{1}{2}x - \frac{1}{2}\sin 2x \\
\int x \sin^2 x dx &= \frac{x^2}{4} - \frac{x \sin 2x}{4} - \frac{\cos 2x}{8} \\
\int x^2 \sin^2 x dx &= \frac{x^3}{6} - \left(\frac{x^2}{4} - \frac{1}{8}\right)\sin 2x - \frac{x \cos 2x}{4} \\
\int e^{-ax} dx &= -\frac{1}{a}e^{-ax}
\end{aligned}$$

**1. (5 pts)** Thomson's "Plum Pudding" model of the atom imagined a "pudding" of positive charge interspersed with "plums" of particulate electrons. It could not explain what experiment done by his old student, Rutherford, and why? A sketch might help.

**2. (total for problem: 10 pts)** The cosmic ray particle, the "muon" ($\mu$) has a rest energy of 106 MeV. It can be produced in the lab and actually be captured by a proton to form a "muonic atom" in which the $\mu$ takes the place of an electron in an otherwise hydrogen-looking atom. So, the bound system is one of proton-muon.

**a. (2 pts)** Show that the reduced mass of the $\mu - p$ system is 95.2 MeV/c$^2$.

**b. (5 pt)** What is the smallest radius for the "orbiting" muon according to the Bohr model?

**c. (3 pts)** What is the binding energy of the muon-proton system in the lowest Bohr orbit compared to that of "normal" hydrogen atom?

**3. (5 pts)** Air is mostly Nitrogen. On a warm summer day, we'll assume that $T = 37°C$. Treating the molecule as a part of an ideal gas leads to a mean molecular speed of $< v >= 484.2$ m/s. What is the DeBroglie wavelength of $N_2$ and how does it compare to its own diameter, which is about 1nm?

**4. (5 pts)** A proton is confined in a uranium nucleus of diameter $16 \times 10^{-15}$m. Assume that its motion is non-relativistic, what is the minimum kinetic energy in keV according to the uncertainty principle if the nucleus is thought of as a one-dimensional "box."

**5. (total for problem: 10 pts)** A wavefunction has the value $\psi = A \sin x$ between 0 and $2\pi$ and zero elsewhere.

**a. (5 pts)** What is the normalization constant, $A$?

**b. (5 pts)** Sketch the wavefunction and the probability density on the same graph. don't worry about an absolute vertical scale, but show the relative sizes of the two curves in your sketch.

**6. (total for problem: 10 pts)** A electron moves with a speed of $v = 10^{-4}c$ inside a one-dimensional box of length 48.5 nm. The potential is zero elsewhere and *the electron may not escape* the box.

**a. (3 pts)** Treating the electron as nonrelativistic, show that its kinetic energy is $E = 0.002555$ eV.

**b. (7 pts)** What is the approximate quantum number of the electron?

You may choose to do one of the next three problems. Important: **circle** the number of the problem you want to be graded as a part of your exam. In *addition*, you may do one of the remaining two problems for extra credit. Please put a big **X** to the left of the number of the problem you want to be considered for extra credit.

**7. (5 pts)** The normalized wave function for the ground state of hydrogen is given by $\psi_{100}(r,\theta,\phi) = \frac{1}{\sqrt{\pi a_0^3}} e^{-r/a_0}$. Show that the wave function is normalized over all space.

**8. (5 pts)** White dwarf stars have been observed with a surface temperature as hot as $200,000^{\circ}$C. What is the wavelength of the maximum intensity produced by the star?

**9. (5 pts)** A gamma ray of 700 keV energy Compton-scatters from an electron. Find the energy of the scattered photon at $110^\circ$ and the energy of the scattered electron.