33-131 Exam 2, Tuesday 2000 Oct. 24

Name____**Section**______

- **Read all problems carefully before attempting to solve them.**
- **Your work must be legible, and the organization must be clear.**
- **Correct answers without adequate explanation will be counted wrong.**
- **Incorrect explanations mixed in with correct explanations will be counted wrong.**
- **Make explanations complete but brief. Do not write a lot of prose.**
- **Include diagrams!**
- **Show what goes into a calculation, not just the final number:** $\frac{(8\times10^{-3})(5\times10^{6})}{(2\times10^{-5})(4\times10^{4})} = 5\times10^{4}$
- **Give physical units with your results.**

If you cannot do some portion of a problem, invent a symbol for the quantity you can't calculate (explain that you're doing this), and do the rest of the problem.

Problem Score

1 (25 pts):________

2 (15 pts):________

3 (10 pts):________

4 (50 pts):________

5 (3 pts):________

Total: ________

Problem 1 (25 pts) You observe photon emissions from a collection of quantum objects, each of which is known to have just four quantized energy levels. The collection is kept at a high temperature, and you detect emitted photons using a detector sensitive to photons in the energy range from 2.5 eV to 30 eV. With this detector, you observe photons emitted with energies of 3 eV, 6 eV, 8 eV, and 9 eV, but no other energies.

(a, 15 pts) It is known that the ground state energy of one of these objects is –10 eV. Propose a possible arrangement of energy levels. Explain in detail, using a diagram.

(b, 5 pts) You obtain a second detector that is sensitive to photon energies in the energy range from 0.1 eV to 2.5 eV. What additional photon energies do you observe to be emitted? Explain briefly.

(c, 5 pts) You cool the collection of objects to a very low temperature and send a beam of photons with a wide range of energies through the material. Using both detectors to determine the absorption spectrum, what are the photon energies of the dark lines? Explain briefly.

Problem 2 (15 pts) An electron is traveling at a speed of $0.95c$. An electric force of 1.6×10^{-13} N is applied in the direction of motion while the electron travels a distance of 2 m. What is the new speed of the electron?

Problem 3 (10 pts) You drop a single coffee filter from a tall building, and it takes 52 seconds to reach the ground. Next you drop a stack of 3 of these coffee filters. About how long will they take to hit the ground? Explain briefly, including any approximations or simplifying assumptions you had to make.

Problem 4 (50 pts) An alpha particle (the nucleus of a helium atom, containing two protons and two neutrons) moving with momentum p is shot toward a carbon-12 nucleus (containing six protons and six neutrons) that is moving with the same momentum p toward the alpha particle. The speeds are nonrelativistic.

(a, 10 pts) For this process, as a function of the separation r between the alpha particle and the carbon-12 nucleus, plot K_1+K_2 (the sum of the kinetic energies of the two nuclei), plot the potential energy, and plot the sum of the kinetic energies and the potential energy. Label each of the three plots clearly.

(b, 37 pts) What is the minimum momentum p necessary so that the alpha particle and carbon-12 nucleus come in contact, so that a nuclear reaction can occur? (This reaction produces oxygen-16.) The radius of a nucleus is approximately $(1.3\times10^{-15}\ \text{m})A^{1/3}$, where A is the total number of protons and neutrons. Briefly explain your analysis.

(c, 3 pts) What is the kinetic energy of the alpha particle in part (a), in MeV (1 MeV = 10^6 eV)?

Problem 5 (3 pt bonus question)

If you get a total score greater than 100, we round down to 100; since this problem is only worth 3 bonus points, don’t attempt it unless you have finished all the other problems and checked your work.

Estimate very roughly the energy of the lowest-energy photon emitted by a diatomic molecule in a transition between two vibrational energy levels.

Fundamental Principles and Definitions

$\Delta E = W + Q$

work = $\vec{F} \bullet \vec{r} = Fr\cos\theta = F_x r_x + F_y r_y + F_z r_z$ joules (constant force) work = $\sum \vec{F} \bullet \Delta\vec{r}$ (variable force)

$\vec{F} = -\left[\frac{\partial U}{\partial x}\hat{\imath} + \frac{\partial U}{\partial y}\hat{\jmath} + \frac{\partial U}{\partial z}\hat{k}\right]$ power = $\vec{F} \bullet \vec{v}$

Specific Results and Data

spring energy = $\frac{1}{2}k_s s^2 + U_0$ electric energy = $\frac{1}{4\pi\varepsilon_0}\frac{Q_1 Q_2}{r}$, $\frac{1}{4\pi\varepsilon_0} = 9\times10^9$ N·m²/C²

gravitational energy = $\frac{-GMm}{r}$; change can be approximately $\Delta(mgy)$

thermal energy: average energy of atoms in an object proportional to temperature of the object

oscillator: $E_N = N\left(\hbar\sqrt{\frac{k_s}{m}}\right)$; classically $\omega = \sqrt{\frac{k_s}{m}}$ hydrogen atom: $E_N = -\frac{13.6\text{ eV}}{N^2}$

$E = \frac{mc^2}{\sqrt{1-\frac{v^2}{c^2}}} = mc^2 + K$; $K \approx \frac{p^2}{2m}$ if $v \ll c$ $E^2 - (pc)^2 = (mc^2)^2$

air resistance: $F \propto v^2$

$G = 6.7\times10^{-11}$ N·m²/kg² $g = 9.8$ N/kg $\hbar = 1.05\times10^{-34}$ J•s $c = 3\times10^8$ m/s

1 eV = 1.6×10^{-19} J Avogadro's number = 6×10^{23} proton or positron charge: $e = 1.6\times10^{-19}$ coulomb

$m_{\text{proton}} \approx m_{\text{neutron}} \approx m_{\text{hydrogen atom}} = 1.7\times10^{-27}$ kg $m_{\text{electron}} = 9\times10^{-31}$ kg