NAME_____

University of Maryland
Department of Physics

Physics 132   **Dr. E. F. Redish**

Spring 2013   **Final Exam**   **17.V.13**

(200 points)

Instructions:

Do not open this examination until the proctor tells you to begin. Read these instructions while waiting.

1. When the proctor tells you to begin, **write your name at the top of every page that has a place for it including this one.** (This is essential since exam booklets will be separated for grading.)

    The first problem booklet contains the short-answer problems. Do your work for these problems (1-6) on the pages for those problems. Write your answers for those problems in the appropriate boxes at the right of each problem.

2. The second booklet contains long-answer problems. Do your work for each of these (I-VI) on the page for that problem. (Work on other pages will not be looked at.) If you need more pages, ask a proctor for a blank page, label it with your name and the problem number, and insert it into the exam behind the page to which it refers when you hand it in.

3. On all the problems *except short answers*, your answers will be evaluated at least in part on how you got them. **No credit may be given for answers that do not show how you got them**. Partial credit will be granted for correct steps shown, even if the final answer is wrong.

4. Write clearly and logically so we can understand what you are doing and give you as much partial credit as you deserve. We cannot give credit for what you are thinking – only for what you show.

5. If on a multi-step problem you can't do one part, don't give up. Go on to the next part anyway. If necessary, define a name for anything you couldn't find and express your answer in terms of it.

6. If you try one approach and then decide on another, cross out the one you have decided is wrong. If your paper has both correct and incorrect approaches the grader will <u>not</u> choose between them. You will not receive credit when contradictory statements are present, even if one is correct.

7. All calculations should be done to the appropriate number of significant figures.

8. At the end of the exam, write and sign the honor pledge in the space below: "I pledge on my honor that I have not given or received any unauthorized assistance on this examination.

You may find some of the following equations and values useful

$k_C = 9 \times 10^9$ N-m^2/C^2 $G = \frac{2}{3} \times 10^{-10}$ N-m^2/kg^2

$N_A = 6.02 \times 10^{23}$ molecules/mole $N_W = 7 \times 10^9$ ppl

$c = 3 \times 10^8$ m/s $e = 1.6 \times 10^{-19}$ C

$k_B T = 1/40$ eV/molecule $RT = 2.4$ kJ/mole

$$\lambda = \sqrt{\frac{\kappa k_B T}{k_C q^2 c_0}}$$

$$\omega_0 = \sqrt{\frac{k}{m}}$$

$$\Delta V = \frac{k_B T}{q} \ln\left(\frac{c_2}{c_1}\right)$$

$$\omega_0 = \sqrt{\frac{g}{L}}$$

For room temperature and q = charge on one electron, $\dfrac{k_B T}{q} = 25$ meV and $\dfrac{k_B T}{k_C q^2} = 1.7\ \mu$m

*** Good Luck ***

Problems 1-6 are multiple-choice/short-answer questions. Write your answers in the boxes provided next to the questions. Give <u>all answers that are correct</u> (but you will lose points for each incorrect answer given). If none are correct, write N and briefly indicate what a correct answer would look like. Explanations are not required on this part of the exam.

Nitric oxide (NO) is a simple molecule, but it plays important roles in a variety of biological processes ranging from neurotransmission to playing a role in the immune system. It was named "Molecule of the Year" by the journal, *Science* in 1992.* In the first three problems, we will consider whether there is a significant probability of finding NO in an excited vibrational state as a result of its interaction with other molecules at body temperature. We'll do this in three parts. As a first step, we'll analyze the vibrational oscillations using a classical model to get the angular frequency of the vibration, ω_0. In the second, we'll use the discrete (quantum) spectrum corresponding to the parameter ω_0 to consider whether the excited energy levels are occupied with any significant probability. And in the third, we'll analyze the photon transitions between the levels.

Note that each part can be done independently of the others, so if you get stuck on one, don't hesitate to go on to the others.

   * *http://en.wikipedia.org/wiki/Biological_functions_of_nitric_oxide*

1. (15 pts) An oscillating diatomic molecule can be thought of (at least for small vibrations) as two atoms connected by a spring as shown in the top of the figure at the right. Oxygen has an atomic number of 16 Daltons and nitrogen has an atomic number of 14 Daltons. For simplicity, we will treat these as if they were two atoms of the same mass – 15 Daltons.
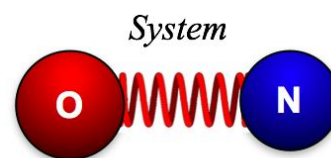
Some consideration of the Newton's law equations for masses and springs shows that the oscillation of a system consisting of two masses of mass m connected by a spring with spring constant k is described the same equation as a single mass with mass $m/2$ connected by a spring with spring constant k. So we can use this system (with $m \sim 15$ Daltons) as a model of our diatomic vibrations.
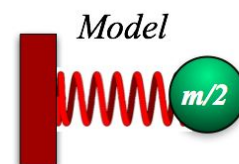
1.1 (5 pts) What value should we take for the mass of our model mass on the spring in kg?

    A. 2.5×10^{-23} kg
    B. 2.5×10^{-26} kg
    C. 1.25×10^{-23} kg
    D. 1.25×10^{-26} kg
    E. Something else (give it on your answer sheet)

1.2 (5 pts) Using the symbols as defined in the problem description, what will be the frequency, f, of the oscillation of the system in our classical model?

    A. $f = \sqrt{\dfrac{k}{m}}$

    B. $f = \sqrt{\dfrac{2k}{m}}$

    C. $f = \dfrac{1}{2\pi}\sqrt{\dfrac{k}{m}}$

    D. $f = \dfrac{1}{2\pi}\sqrt{\dfrac{2k}{m}}$

    E. Something else (give it on your answer sheet)

Name_____

1.3 (5 pts) We haven't specified the amplitude of our oscillation but we've given the frequency. This is because:

    A. The frequency is quoted for a "standard" amplitude (1 unit).
    B. For a classical simple harmonic oscillator the frequency does not depend on the amplitude.
   C. This was an error. We need to specify the amplitude before we can figure out the frequency.
    D.

, we know that the relative probability of a molecule in a medium at temperature, T, being excited has the

2. (10 pts) Real molecules have to be treated by quantum, not classical mechanics. Although the classical treatment gives a correct description of the parameters involved and of the potential energy, there are differences. In the classical treatment, any energy is allowed, in the quantum treatment, only particular energy levels are allowed, as shown in the figure at the right.

The lowest level permitted (the ground state, E_0) is not at the bottom of the well but a little up from it. For a simple harmonic oscillator, the spacing between neighboring allowed levels is $\Delta E = hf$. According to our study of thermodynamics form

$$\frac{P(E)}{P(E_0)} = e^{-\Delta E/\varepsilon}$$

where $\Delta E = E - E_0$ and ε is a parameter that has units of energy and depends on T.
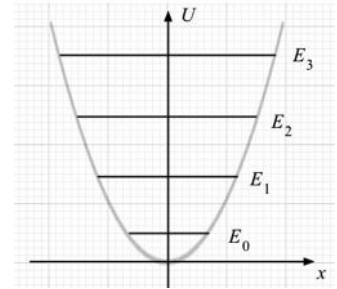
2.1 (5 pts) If we are using ΔE to represent the excitation energy of a single diatomic molecule, and the molecule is in a human body at normal body temperature of 37 °C, what value should we take for ε?

    A. 3.1 meV
    B. 25 meV
    C. 28 meV
    D. 0.03 kJ
    E. 2.4 kJ
    F. 2.7 kJ
    G. Something else (give it on your answer sheet).

2.2 (5 pts) If the value of hf for our diatomic molecule is ~ 0.22 eV, and the energy of the ground state is 0.11 eV, what is the probability of finding it in a living human body in its first excited state?

    A. ~1
    B. ~1 x 10^{-2}
    C. ~4 x 10^{-4}
    D. ~8 x 10^{-4}
    E. Something else (give it on your answer sheet).

3. (5 pts) If the diatomic molecule NO has the vibrational states shown in the figure for problem 2 with $hf = 220$ meV, approximately what wavelength of light do you need to illuminate it with in order to excite it from its ground state to the state E_2?

    A. 1.40 μm
    B. 2.80 μm
    C. 2.8 nm
    D. 5.6 nm

E.   Something else (give it on your answer sheet)

4. (20 points) Below are shown four equations and five descriptions of a physical system. For each equation select which physical system (in an idealized model) could be appropriately described by that equation.

4.1 $x(t) = A\sin(\omega t + \phi)$

4.2 $y(x,t) = A\sin(kx)\cos(\omega t)$

4.3 $y(x,t) = A\sin\left(\dfrac{2\pi}{\lambda}[x - vt]\right)$

4.4 $y(x,t) = A\sin(kx + \omega t)$

A.   A transverse traveling wave on a long taut spring traveling in the positive x direction.
B.   A transverse traveling wave on a long taut spring traveling in the negative x direction
C.   A hanging mass oscillating around it's equilibrium position.
D.   A standing wave on a long taut spring.

E.   None of these physical systems corresponds to this equation.

5. (20 pts) In the figure at the right are shown four charges aligned on a grid. The top two are positive and the bottom two are negative, but all have the same magnitude, q.
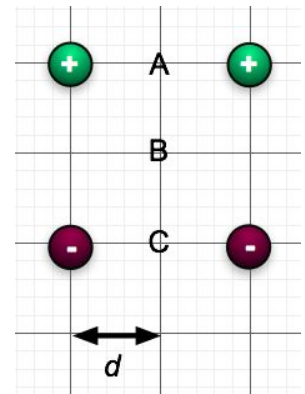
5.1 (5 pts) A test charge placed at one of the three positions A, B, or C would measure an electrostatic potential that is equal to a pure number times one of the following factors which we will call V_0. Which of these factors is appropriate to use for specifying the electrostatic potential measured by a test charge?

A. $\dfrac{k_c q^2}{d}$

B. $\dfrac{k_c q^2}{d^2}$

C. $\dfrac{k_c q}{d}$

D. $\dfrac{k_c q}{d^2}$

E.   None of these has the right dimensions to be used.

5.2 (15 pts) For each of the points A, B, and C specify which of the expressions numbered 1-8 on the right would correctly give the electrostatic potential created by the four charges shown at that point.

5.2.1 A

5.2.2 B

5.2.3 C

1. $+V_0$
2. $-V_0$
3. $+2V_0$
4. $-2V_0$
5. $+4\ V_0$

5. $-4V_0$
6. $+(2-2/\sqrt{5})V_0$
7. $-(2-2/\sqrt{5})V_0$
8. 0

9. None of these are correct.

6. (30 pts) Each of the problems in this part has a description of an object and an optical device (lens or mirror). A sketch is shown below. For each case, indicate in the appropriate box on your answer sheet whether

- the image is real (R), virtual (V), or no image is formed (N) ;

- the image is on the same side of the device as the object (S) or the opposite side (O). If there is no image put a null mark (ϕ)

- if an image is formed, on which side of the system must the observer be in order to see it, left (-) or right (+)?

For each problem you should therefore give three answers (for example : V O +). For the mirrors the center is shown. For the lenses, the focal points are shown. The radius of curvature of the mirrors is R, the focal length of the lenses is f.

i. An object on the right side of a spherical mirror, a distance $s > R$ from the mirror. The mirror is concave towards the object.

ii. An object on the right side of a spherical mirror, a distance $s < R/2$ from the mirror. The mirror is convex towards the object.

iii. An object on the left side of a spherical mirror, a distance $R > s > R/2$ from the mirror. The mirror is concave towards the object.

iv. An object on the right side of a convex lens, a distance $s > f$ from the lens.

v. An object on the left side of a convex lens, a distance $s < f$ from the lens

(a)

(b)

(c)

(d)

(e)
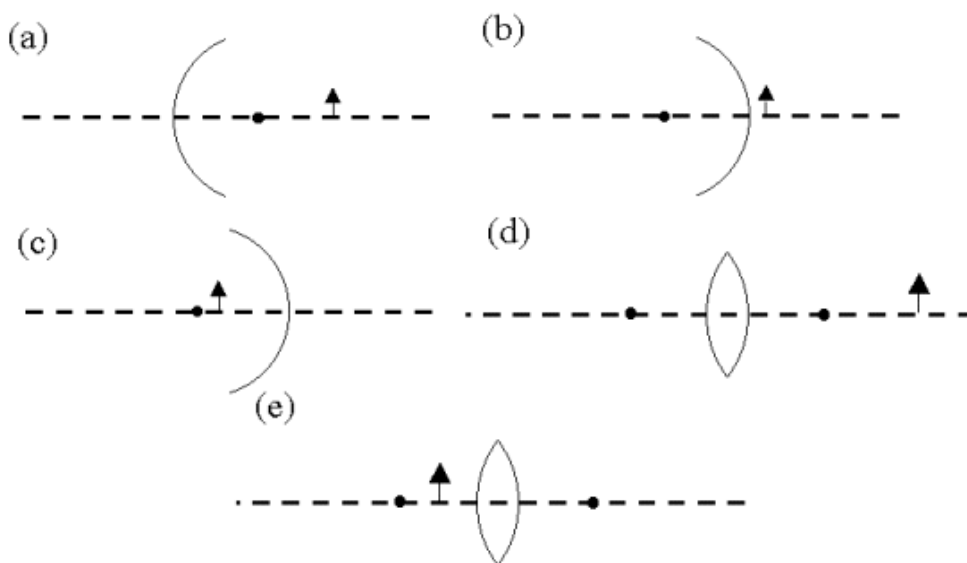
Go on to the second part
of the exam (in the other booklet).