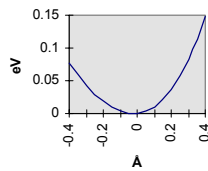


State Any Assumptions You Need To Make – Show All Work – Circle Any Final Answers
Use Your Time Wisely – Work on What You Can – Be Sure to Write Down Equations
Feel Free to Ask Any Questions

For all problems, use $c = 2.998 \times 10^8 \text{ m/s}$; $h = 6.626 \times 10^{-34} \text{ J}\cdot\text{s}$; $\hbar = 1.055 \times 10^{-34} \text{ J}\cdot\text{s}$.

The Hartree and Fock Reunion Tour (50,000 points)

1.) In Computer Assignment 3, Problem A, we moved the central lithium ion in our LiCl crystal simulation around and plotted the Energy versus position. Not only does this suggest that the central lithium *wants* to be in the middle between all those chlorine ions, but this resembles the potential well of a Simple Harmonic Oscillator[†]. In fact, this *is* the potential well that the central lithium ion sits in. Hartree-Fock calculations do not take temperature into account. As the temperature rises from absolute zero ($T = 0 \text{ K}$), thermal energy is added and the central lithium ion sits higher in the well and oscillates back and forth. Clearly, if we treat this as a 1-D quantum S.H.O., we can see from this simple chart that for $E = 0.0750 \text{ eV}$, there is a maximum displacement $-A = -0.400 \text{ \AA}$. Since $E = \frac{1}{2} kA^2$ and $\omega = \text{sqrt}(k/m)$, and lithium-7 has a mass of $7.016004 \times 1.66 \times 10^{-27} \text{ kg}$, (a) find the value of the spring constant k .



(b) Find the value of the angular frequency ω .

(c) For a quantum oscillator, $E = (n + \frac{1}{2}) \hbar\omega$, find what n corresponds to $E = 0.0750 \text{ eV}$.

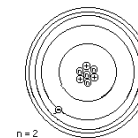
(d) If this is thermal motion, then this energy also corresponds to $E = k_B T$, where $k_B = 8.617 \times 10^{-5} \text{ eV/K} = 1.381 \times 10^{-23} \text{ J/K}$ is the Boltzmann constant. What temperature does $E = 0.0750 \text{ eV}$ represent? Is this reasonable?

[†] The energies from CA-3 have been converted to eV and normalized so that the bottom of the well is zero. The two sides are not symmetric because the computer assignment was done in the x direction and the x - y direction.

What? More Fun with Lithium? How Could This Test Get Worse? (50,000 points)



2.) A positive lithium Li^{2+} ion consists of a single electron in orbit around a nucleus with three protons and four neutrons. (a) Find the radius of the first *four* orbitals for this *hydrogenic* lithium. *Hint: Once you have the first one, the next are easy to calculate.*



(b) Find the energies of the first *four* orbitals for this *hydrogenic* lithium.

(c) Visible light runs between 400 nm ($4.00 \times 10^{-7} \text{ m}$) and 750 nm ($7.50 \times 10^{-7} \text{ m}$). All the transitions to or from $n = 1$ in lithium are likely to be in the UV. Do any of the transitions $4 \rightarrow 2$, $3 \rightarrow 2$ or $2 \rightarrow 1$ have energies in visible light?

(d) The actual mass-to-volume ratio of lithium is $\rho_{Li} = 530 \text{ kg/m}^3$. Given that $6.941 \text{ grams} = 0.006941 \text{ kg} = 1.000 \text{ mole}$ of lithium, and that $1 \text{ mole} = 6.02 \times 10^{23}$, find the volume of one lithium atom. Compare this to the volume found from a cube with sides ($2 \times r_2$), where r_2 is the radius of the $n = 2$ hydrogenic lithium orbit.

(e) For this next part, let's consider sodium (Na), simply because the numbers are in the book. The ionization energy (or first ionization potential) of Na is 5.138 eV (p.328 Serway M&M). The photoelectric effect work function for Na is 2.28 eV (p. 74). Define what each energy represents and give a plausible physics explanation as to why the work function is so much less than the ionization energy, when both involve removing an electron.

The Relativistic 1040 – And You Think Taxes Are Hard Now... (50,000 points)

3.) Bill Gates XI, President of MicroMcDisneySoft, and the great-great-great-great-great-grandson of the original Microsoft Bill Gates, is on the planet Neptune. Light takes four hours ($14,400 \text{ sec}$) to travel from Neptune to Earth. (a) How far is Neptune from Earth? *For our purposes, Neptune and Earth are at rest with respect to each other.*

It is 9pm and Bill's taxes are due on Earth at Midnight. The IRS is just waiting to fine him 5% for being late. But Bill jumps onto a starship and heads to Earth at $\beta = 0.95$. $\gamma = 3.20$. His lawyers tell him that his watch won't say it's Midnight when he gets to Earth. What time will Bill get near Earth (b) from the IRS's point of view and (c) from his point of view? *Ignore any time to start or stop the starship. Bill will be filing his taxes electronically, of course.*

Bill's starship has a rest mass of $135,000 \text{ kg}$. Find its (d) momentum and (e) kinetic energy, as seen by the IRS.

Nuclear Physics: Not Too Clear and Not Too Fizzy (50,000 points)

4.) Consider a fusion situation which does the following: (I) Two hydrogen-1 nuclei combine to form a hydrogen-2. (II) A hydrogen-1 combines with a hydrogen-2 to form a hydrogen-3 and a gamma ray. (III) Two hydrogen-3 nuclei combine to form a helium-4 and two protons. (a) Write down each of these three nuclear reactions, including as much detail as necessary to balance the equations.

(b) For the total reactions of types I, II and III needed to form the helium-4 in step III in part (a), use the following information to find out how much energy is released by the conversion of mass to energy.

1_0n neutron	1.008665 <i>u</i>	2_1H deuteron	2.014102 <i>u</i>	4_2He helium	4.002603 <i>u</i>
1_1H proton	1.007825 <i>u</i>	3_1H triton	3.016050 <i>u</i>	1 <i>u</i> converts to	931.5 MeV

(c) Copper-64 can undergo either a β^+ or a β^- decay. Write down both nuclear reactions completely.

(d) Nuclear fission of uranium-235 begins by the nucleus absorbing a neutron and the resulting unstable nucleus breaks typically into two pieces plus two to three neutrons and releasing about 200 MeV of energy. The larger piece is most likely to have an atomic mass of around $A = 140$. Write down a plausible fission reaction that will release two or three neutrons. Don't worry if the isotopes you pick are not in Appendix B.