University of Alabama
Department of Physics and Astronomy

PH 102-2 / LeClair Spring 2008

Problem Set 12: Review, Mostly

Instructions:

- Answer all questions below. Show your work for full credit.
- Due before 5pm, 25 Apr 2008. There is no late penalty for this homework.
- Problem sets may turned in *via* email or hard copy
- Hard copies may be left in Dr. LeClair's mailbox (Gallalee 206) or office (Bevill 228)
- You may collaborate, but everyone must turn in their own work

1. 10 points. In the 1996 movie *Eraser*, a corrupt business Cyrez is manufacturing a handheld rail gun which fires aluminum bullets at nearly the speed of light. Let us be optimistic and assume the actual velocity is $0.75\,c$. We will also assume that the bullets are tiny, about the mass of a paper clip, or $m = 5 \times 10^{-4}\,\text{kg}$.

(a) What is the relativistic kinetic energy of such a bullet? **(b)** What *rest mass* would have to be completely converted to energy to supply this kinetic energy? Note that 1 kg of TNT has an equivalent energy content of about $4 \times 10^9\,\text{J}$.

2. 10 points. Two identical point charges $+q$ are located on the y axis at $y = +a$ and $y = -a$. **(a)** What is the electric potential for an arbitrary point (x,y)?

(b) A circular ring of charge of radius a has a total positive charge Q distributed uniformly around it. The ring is in the $x=0$ plane with its center at the origin. What is the electric field (both magnitude and direction) along the x axis at an arbitrary point $x=b$ due to the ring of charge? *Hint: Consider the total charge Q to be made up of many pairs of identical charges placed on opposite points on the ring.*

3. 10 points. The purely electrostatic crystallization energy for a mole of crystalline solid can be found by considering the electrostatic potential energy of a lattice of ionic charges. We found that it could be expressed as a factor M times the electrostatic energy of a single pair of ions:

$$E_{\text{cryst}} = -\frac{N_A z^2 e^2 M}{4\pi\epsilon_0 r}$$

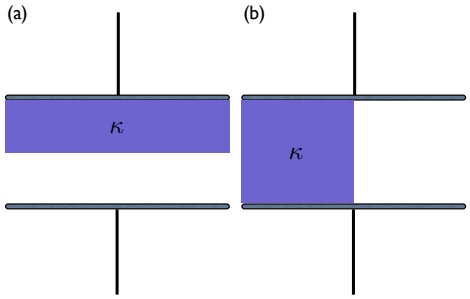
where N_A is Avogadro's number, z is the charge per ion in the crystal, r is the distance between ions in the crystal, and M is the Madelung constant for the lattice as discussed in the notes. The values of M, z, and r for several common solids crystallizing in the rocksalt (NaCl) structure are given below.

Compound	**chg/ion**	M	r (pm)
LiF	e	1.748	201.4
LiCl	e	1.748	257.0
LiBr	e	1.748	275.1
NaCl	e	1.748	282
NaBr	e	1.748	289.9

Note that $1\,\text{pm} = 10^{-12}\,\text{m}$. As it turns out, the energy of crystallization determined from electrostatics is essentially the same energy required to separate a mole of solid into a gas of its ions - we need additionally only a small correction factor to account

for the repulsion of the ions at small distances due to quantum effects.

(a) Calculate the crystallization energy, **in electron volts**, for the compounds in the table above. Which compound is the "most stable?"
(b) Lime, CaO, is know to have the same structure as NaCl (and thus the same Madelung constant) and the edge length of the unit cell for CaO is 481 pm. Thus, Ca-O distance is 241 pm. Evaluate the energy of crystallization, E_{cryst} for CaO.
(c) Calculate the crystallization energy for MgO, for which $z=2$ and $r=286\,\text{pm}$.



4. A parallel plate capacitor has a capacitance C when there is vacuum between the plates. The gap between the plates is half filled with a dielectric with dielectric constant κ in two different ways, as shown below. Calculate the effective capacitance, in terms of C and κ, for both situations. *Hint: try breaking each situation up into two equivalent capacitors.*

5. 10 points. The battery in your car stores about $10^3\,\text{W}\cdot\text{h}$ worth of energy at a potential difference of 12 V. One day while doing yard work, you decide to run your 200 W car stereo without the engine running. In order to start your car, you need to deliver 500 A at 7.2 V for at least 1 sec. How long can you run your stereo before you can no longer start the car?

6. 10 points. How many different resistance values can be constructed from a $2\,\Omega$, $4\,\Omega$, and a $6\,\Omega$ resistor? (You only have one of each.) Show how you would get each resistance value either individually or by combining them.

7. 10 points. An electron is moving at a speed of $0.01c$ on a circular orbit of radius 10^{-10} m.

(a) What is the strength of the resulting magnetic field at the center of the orbit? (The numbers given are typical, in order of magnitude, for an electron in an atom.)

(b) If the nucleus of the atom (at the center of the orbit) consists of a single proton, what would its precession frequency be? *Hint: from the nucleus' point of view, it orbiting the electron in a circular path.* Recall $\omega=qB/m$ and $\omega=2\pi f$.

In fact, this is a crude estimate of the hydrogen proton resonance frequency. We are off by a factor of about 2.8, having neglected all of quantum physics.

8. 10 points. A hydrogen atom initially in its ground state ($n=1$) absorbs a photon and ends up in the state for which $n=3$. If the atom eventually returns to the ground state, what photon energies could the atom emit?

9. 10 points. Initially, the radioactive decay rate of a particular group of nuclei is 300 counts per second. After 5 minutes, the decay rate drops to about 38 counts per second.

(a) What approximately is the half life of this nucleus?
(b) What will be the approximate decay rate (in counts per second) after 2.5 *additional* minutes?

10. 10 points. Calculate the binding energy *in MeV* of a deuteron (the atom ${}^2_1\text{H}$), given that its atomic mass is 2.014102 u. Note that $m_{p^+}=1.007825\,\text{u}$, and $m_{n^0}=1.00866\,5\text{u}$.