

EP 317 MIDTERM TEST (4 WRITTEN PROBLEMS)

Instructor: Yansun Yao

13:00 ~ 14:20, February 23rd, 2016

ANSWER ALL **FOUR** QUESTIONS.

TOTAL MARKS ARE **30**.

MARKS PER EACH QUESTION ARE INDICATED.

Physical Constants:

Elementary charge: $e = 1.602 \times 10^{-19} \text{ C}$

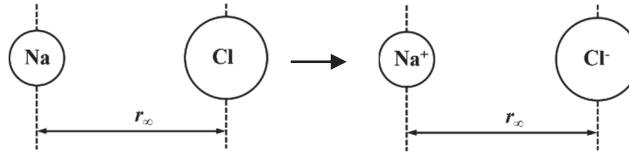
Permittivity of free space: $\epsilon_0 = 8.85 \times 10^{-12} \text{ C}^2 \text{ N}^{-1} \text{ m}^{-2}$

Avogadro's number: $N_A = 6.022 \times 10^{23} \text{ mol}^{-1}$

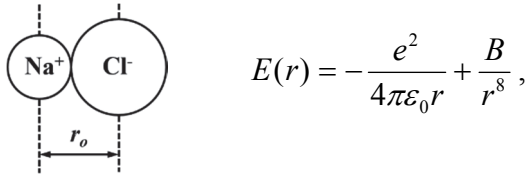
Wiedemann-Franz-Lorenz coefficient: $C_{\text{WFL}} = 2.44 \times 10^{-8} \text{ W } \Omega \text{ K}^{-2}$

1. Bonding. The ionization energy of Na is 5.14 eV and the electron affinity of Cl is 3.61 eV.

(a) How much energy is required to form a Na^+ and Cl^- ion pair, where Na^+ and Cl^- are infinitely separated (r_∞), from neutral Na and Cl atoms? **(2 marks)**



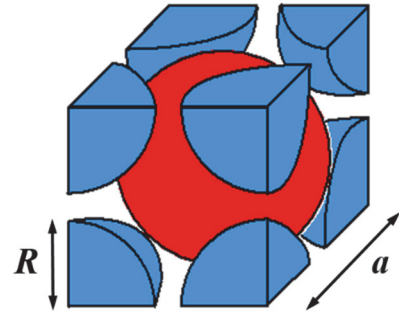
(b) The interatomic interaction energy of an isolated $\text{Na}^+ - \text{Cl}^-$ pair as a function of atomic separation r can be written as the sum of an attractive term and a repulsive term,



where $B = 6.972 \times 10^{-96} \text{ J m}^8$. Calculate the equilibrium separation (r_0) of this ion pair. **(4 marks)**

2. Crystal structure. Magnesium (Mg) has a body centered cubic (BCC) structure. Assuming the Mg atom are solid spheres with radius R that touch each other.

(a) Given that the density of Mg is $1.74 \times 10^3 \text{ kg m}^{-3}$, and the atomic mass of Mg is 24.31 g mol^{-1} , calculate the BCC lattice constant a . (2 mark)



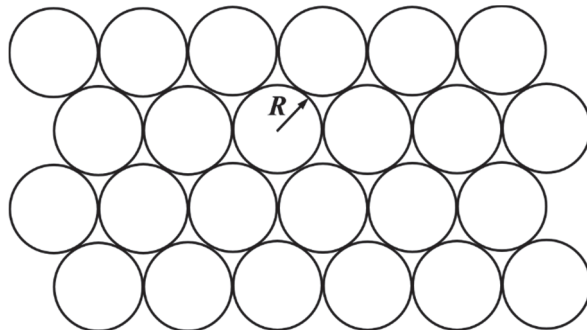
(b) **Draw** the (110) plane and **determine** the fraction (%) of the (110) plane occupied by atoms, i.e.,

$$\frac{\text{area of the plane occupied by atoms}}{\text{total area of the plane}}$$

(3 marks).

(c) The (110) plane is not close packed. A closed-packed plane is shown in the figure below. Determine the fraction (%) of this plane occupied by atoms. (3 marks)

Hint: you can identify a 2-dimensional unit cell and work in the unit cell.



3. Electrical and thermal conductivity. Electron drift mobility in silver has been measured to be $56 \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1}$ at $27 \text{ }^\circ\text{C}$ (300 K). The atomic mass and density of Ag are given as $107.87 \text{ g mol}^{-1}$ and 10.50 g cm^{-3} , respectively.

(a) Assuming that each Ag atom contributes exactly one free electron, calculate the resistivity of Ag at $27 \text{ }^\circ\text{C}$. **(3 marks)**

(b) Calculate the thermal conductivity of pure silver at $27 \text{ }^\circ\text{C}$. If you did not obtain an answer for (a), use a value of $2.0 \times 10^{-8} \text{ } \Omega \text{ m}$. **(3 marks)**

(c) Calculate the thermal conductivity of silver that contains 10 vol. % of porosity (air) at $27 \text{ }^\circ\text{C}$. If you did not obtain an answer for (b), use a value of $366 \text{ W m}^{-1} \text{ K}^{-1}$. **(3 marks)**

4. Gallium Arsenide (GaAs). Gallium as an element has a valence of 3. Arsenic as an element has a valence of 5. See below the positions of Ga and As in the periodic table of the elements,

The Periodic Table of the Elements

					2 He Helium 4.003
5 B Boron 10.811	6 C Carbon 12.0107	7 N Nitrogen 14.00674	8 O Oxygen 15.9994	9 F Fluorine 18.9984032	10 Ne Neon 20.1797
13 Al Aluminum 26.981538	14 Si Silicon 28.0855	15 P Phosphorus 30.973761	16 S Sulfur 32.066	17 Cl Chlorine 35.4527	18 Ar Argon 39.948
31 Ga Gallium 69.723	32 Ge Germanium 72.61	33 As Arsenic 74.92160	34 Se Selenium 78.96	35 Br Bromine 79.904	36 Kr Krypton 83.80
49 In Indium 114.818	50 Sn Tin 118.710	51 Sb Antimony 121.760	52 Te Tellurium 127.60	53 I Iodine 126.90447	54 Xe Xenon 131.29
81 Tl Thallium 204.3833	82 Pb Lead 207.2	83 Bi Bismuth 208.98038	84 Po Polonium (209)	85 At Astatine (210)	86 Rn Radon (222)

- (1) Assuming sp^3 hybridization, predict a cubic structure of crystalline GaAs. (2 marks)
- (2) In the structure you predicted, how many As atoms does each Ga atom bond to? (2 mark)
- (3) Both elemental Ga and elemental As are metallic. Do you expect the GaAs structure you predicted to be metallic, or semiconducting? Briefly explain the reasons. (3 marks)