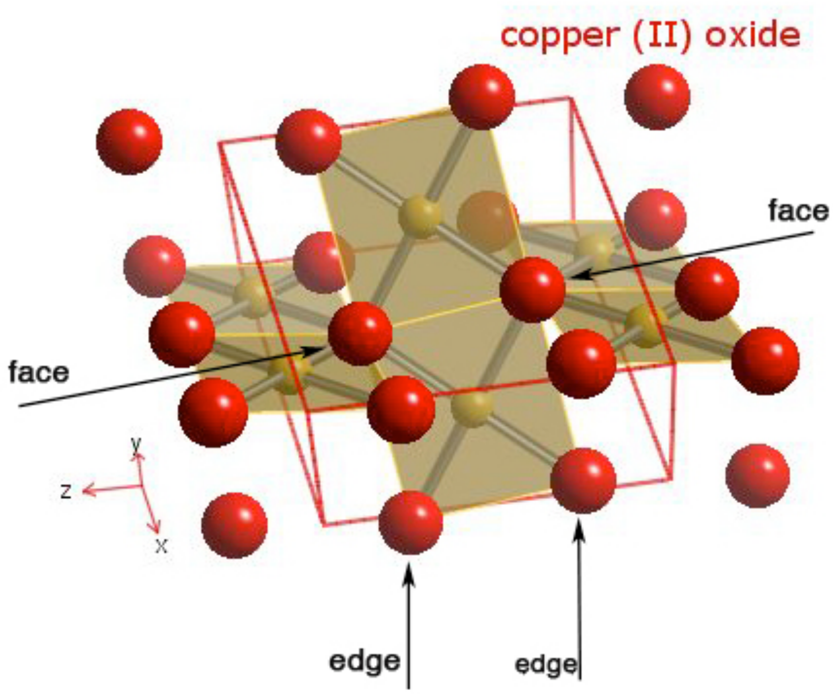
CHEM104
Chapter 13
Worksheet

Copper, like most transition metals, can have more than one oxidation state in compounds, different oxidation states even when combining with the same element.

In this worksheet you will investigate several copper oxide compounds,

1. The unit cell of cupric oxide is shown below. Use it to determine:
   a) the empirical formula
   b) Z, the number of molecules

NOTE: there are two additional red atoms on the bottom face of the unit cell that are not visible in this picture.



Cu = 2 (inside) + 4x ½ (side faces) = 4 Cu atoms
O = 8 (edges) + 4x ½ (top/bottom faces) = 4 O atoms

Z = 4 , empirical formula CuO

2. There are three possible copper oxide compounds— Cu_2O, CuO and Cu_2O_3 .
(a) What are the Cu oxidation states in each ionic solid?

Cu_2O— Cu(1+)
CuO — Cu(2+)
Cu_2O_3 — Cu(3+); O(2-) in all three.

(b) Which of these copper oxide compounds— Cu_2O, CuO and Cu_2O_3 — are thermodynamically stable? Which is the ***most*** stable?
You are encouraged to use your class notes as well as the Web Elements site for any thermodynamic data needed for your calculations.
You may assume the lattice energy of Cu_2O_3 is the same as that of Al_2O_3 (which is a valid assumption because the ionic radii of the Cu and Al ions are nearly identical).

Thermodynamic data (in units of kJ/mol everywhere)

Lattice energies (WebElements)
Cu_2O : -3273 kJ/mol
CuO : -4135 kJ/mol
Cu_2O_3 : -15,600 kJ/mol

Cu(s) Sublimation enthalpy = atomization enthalpy (Web Elements) = +338

Cu ionization enthalpies: (Webelements)
Cu(I) **+746**
Cu(II) +746 + 1958 = **+2704**
Cu(III) +746 + 1958 + 3554 = **+6258**

O2 bond dissoc enthalpy (lecture notes) 493 per mole O2
O electron attachment enthalps (lecture notes) +639 kJ/mol O atoms

---

Calculation of formation enthalpies:

Cu_2O :
$\Delta H_f = 2(\Delta H_{sub} + \Delta H_{IE}^{1}) + \Delta H_{BD} + \Delta H_{EA} + \Delta H_{lattice}$
$= 2\ (338 + 746) + ½(493) + 639 + (-3273)$
ΔH_f = -220 kJ/mol

CuO :
$\Delta H_f = \Delta H_{sub} + \Delta H_{IE}^{1,2} + \Delta H_{BD} + \Delta H_{EA} + \Delta H_{lattice}$
$= 338 + 2704 + ½(493) + 639 + (-4135)$
ΔH_f = -208 kJ/mol

Cu_2O_3 :

$\Delta H_f = 2(\Delta H_{sub} + \Delta H_{IE}^{1,2,3}) + \Delta H_{BD} + \Delta H_{EA} + \Delta H_{lattice}$

$= 2\ (338 + 6258)\ + 3/2\ (493) + 3(639) + (-15{,}600)$

$\Delta H_f = +\ 248$ kJ/mol

Interpretations:

Cu_2O : -220 kJ/mol – this is a stable solid, slightly more sstable than CuO

CuO : -208 kJ/mol – this is a stable solid

Cu_2O_3 : + 248 kJ/mol – thisi is an UNSTABLE solid; it will not form.