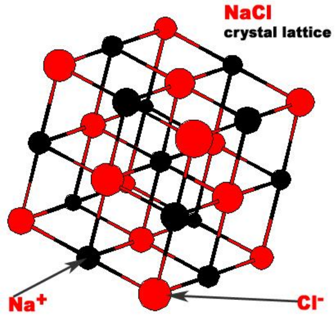
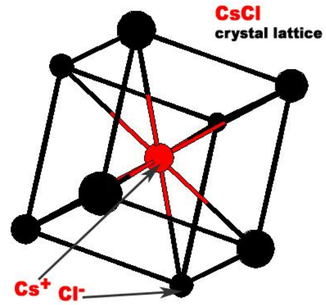
Name ____________________________ **Honors Chemistry** **___/___/___**

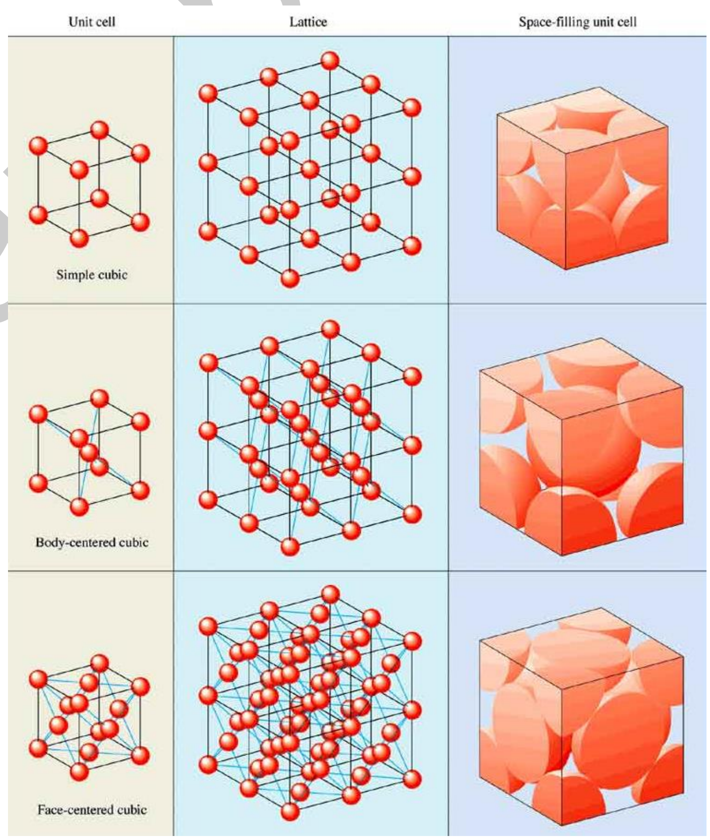
Salts & Metals
Properties of Ionic Compounds (Salts)

- Ionic compounds are composed of a cation (positively charged atom) and an anion (negatively charged atom) in an orderly arrangement. The three dimensional arrangement of atoms or ions in a crystal is referred to as **crystal lattice**. The crystal lattices of sodium chloride and cesium chloride are shown below.





- The simplest repeating unit of a crystal is known as a **unit cell**. Both NaCl and CsCl are classified as part of a cubic crystal system. The unit cells of NaCl and CsCl are different because their ions have different sizes. The structures of most binary ionic solids, such as sodium chloride, can be explained by the closest packing of spheres. Usually the smaller cation fills the holes between anions.



- The structures of crystalline solids are most commonly determined using **X-ray diffraction**.
- Three different ways that atoms can arrange themselves in a cubic crystal system are shown to the right.
- Nearly all ionic compounds are crystalline solids at room temperature.
- Most ionic compounds dissolve in water.
- Ionic compounds conduct electricity only when molten or dissolved in water. Solid ionic compounds do not conduct electricity because in order for a substance to conduct electricity it must have charged particles that can move freely. Ions in ionic compounds cannot move very much, except to vibrate.
- Ionic compounds do not have an overall net charge. They are **electrically neutral** because the amount of positive charge is equal to the amount of negative charge.
- Ionic compounds have higher melting and boiling points compared to other types of compounds (covalent compounds) because the ions in an ionic compound form strong bonds with a number of different ions due to their arrangement into crystalline structures.
- Ionic compounds are hard and brittle because their ions are arranged into unit cells which form layers. As long as the layers stay aligned, the ionic compound is hard. But, if one layer is shifted, like charges will be next to one another. The repulsive forces between like ions cause the layers to break apart.

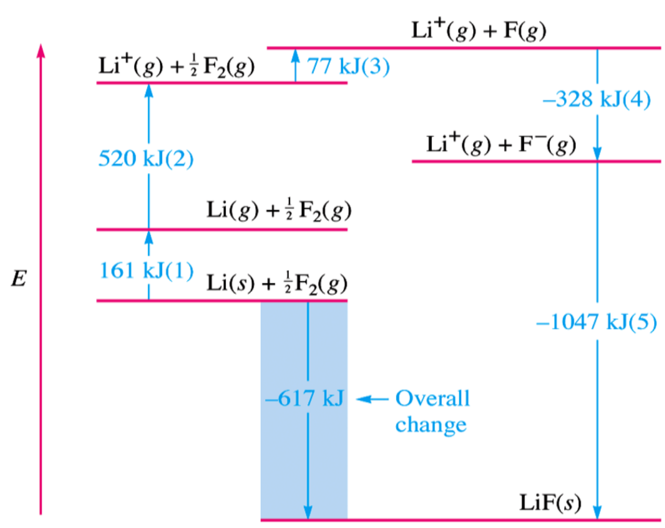
Ionic Bonds and Melting Point

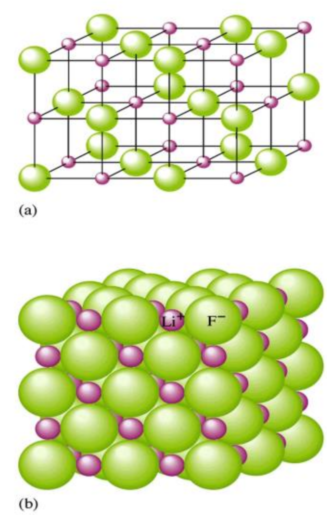
- Information about the strength of a bonding interaction is obtained by measuring the **bond or lattice energy**, which is the energy required to break the bond or the energy released when a bond is formed.
- The energy of interaction between a pair of ions can be calculated using Coulomb's law in the form:

  $E = (2.31 \times 10^{-19}\ J * nm)(\frac{Q_1 Q_2}{r})$; E has units of joules, r is the distance between the ion centers in nanometers, and Q_1 and Q_2 are the numerical ion charges.
- You will not be required to make the above calculations. You will be required to determine which of a set of ionic compounds has the highest melting point. The two factors used to determine this trend are atomic radius(r) and the magnitude to the product of their ionic charges (Q_1Q_2).
- The smaller the radius, the higher the melting point.
- The greater the magnitude of the product of the ionic charges, the higher the melting point.
- Since there is only a small difference in the atomic radius across a period, charge is the more significant factor to consider when comparing two elements in the same period.
- For example, NaCl is expected to have a lower melting point than $MgCl_2$. Mg is smaller than Na and has a greater ionic charge than Na.

Formation of Binary Ionic Compounds

- Ionic compounds (salts) form because the aggregated oppositely charged ions have a lower energy than the original elements.
- Consider the energy change associated with the following reaction: $Li(s) + ½ F_2(g) \rightarrow LiF(s)$
  - Step 1: Sublimation of solid lithium. $Li(s) \rightarrow Li(g)$ $\Delta E = 161$ kJ/mol
  - Step 2: Ionization of lithium atom. $Li(g) \rightarrow Li^+(g) + e^-$ $\Delta E = 520$ kJ/mol
  - Step 3: Dissociation of fluorine molecules. $½ F_2(g) \rightarrow F(g)$ $\Delta E = 77$ kJ/mol
  - Step 4: Formation of fluoride ions. $F(g) + e^- \rightarrow F^-(g)$ $\Delta E = -328$ kJ/mol
  - Step 5: Formation of LiF from $Li^+(g)$ and $F^-(g)$ ions. $Li^+(g) + F^-(g) \rightarrow LiF(s)$ $\Delta E = -1047$ kJ/mol
  - By adding the ΔE values, the $\Delta E_{overall} = -617$ kJ/mol of LiF. This is an exothermic reaction.

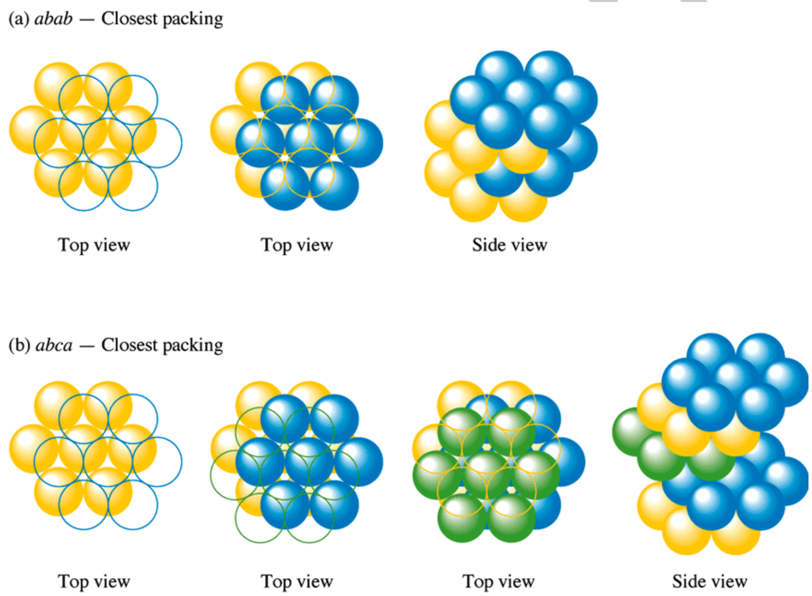




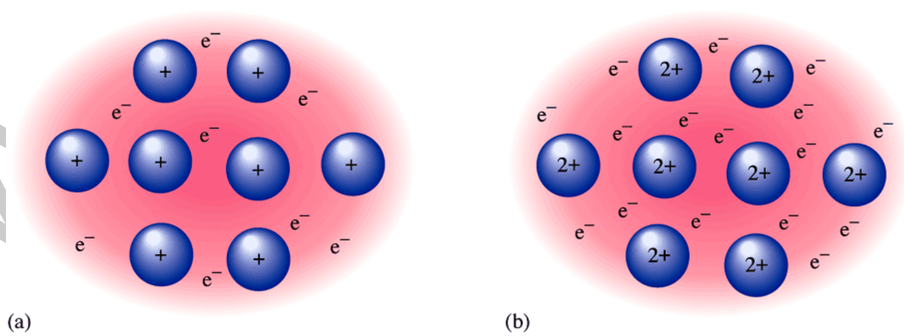
- The lattice structure of lithium fluoride is shown above. All the binary ionic compounds formed by an alkali metal(except cesium) and a halogen have the same lattice structure as lithium fluoride. It is sometimes called the sodium chloride structure.

Structure and Bonding in Metals

- Metallic bonds are formed between like metal ions.
- Metals are characterized by high thermal and electrical conductivity, malleability and ductility.
- Both metals and salts are arranged in crystals. As a result, both metals and salts have high melting and boiling points.
- A metallic crystal can be pictured as containing spherical atoms packed together and bonded to each other equally in all directions. Such an arrangement is called closest packing.
- The spheres are packed in layers in which each sphere is surrounded by six others. In the second layer the spheres do not lie directly over those in the first layer. Instead, each one occupies an indentation formed by three spheres in the first layer.
- If the third layer is positioned directly beneath the first layer, it is called **aba arrangement** or **hexagonal closest packed (hcp).**
- If the third layer is positioned so that no first layer sphere lies over one in the third layer, it is called **abc arrangement** or **cubic closest packed (ccp)** and has a face centered cubic unit cell.
- Why a particular metal adopts the structure it does is not well understood.
- Although the shapes of most metals can be changed relatively easily, most metals are durable and have high melting points. These facts indicate that the bonding in most metals is both strong and nondirectional.

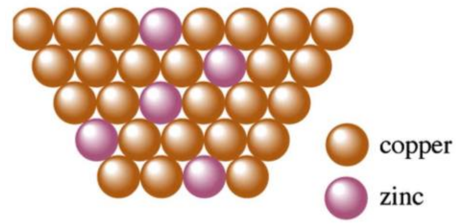


- The simplest picture that explains these observations is the electron sea model, which envisions a regular array of metal cations in a sea of valence electrons. The mobile electrons can conduct heat and electricity, and the metal ions can be easily moved around as the metal is hammered into a sheet or pulled into a wire.



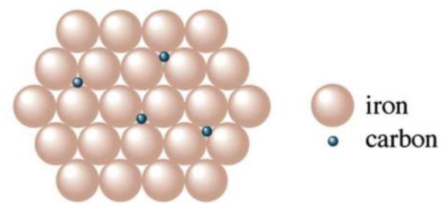
Metal Alloys

- Because of the nature of the structure of metals, other elements can be introduced into a metallic crystal relatively easily to produce a substance called an alloy.
- An **alloy is a substance that contains a mixture of elements and has metallic properties**.
- There are two types of alloys:
    - In a **substitutional alloy** some of the host metal atoms are replaced by other metal atoms similar in size. When zinc atoms replace host copper atoms, brass is formed. Brass is a substitutional alloy.
    - In an **interstitial alloy** some of the interstices (holes) in the closest packed structure are occupied by small atoms. Steel is the best known interstitial alloy. It contains carbon atoms in the holes of an iron crystal. Pure iron is relatively soft, ductile and malleable due to the absence of directional bonding. When carbon, which forms strong directional bonds, is introduced into an iron crystal, the presence of the of the directional carbon-iron bonds makes the resulting alloy harder, stronger and less ductile than pure iron.



Brass

(a)



Steel

(b)

At the completion of this assignment you will be prepared to take the following Chapter 3 on-line quizzes:

- ionic compound modified true false quiz
- ionic compounds multiple choice quiz 1
- ionic compounds multiple choice quiz 2
- metal or salt quiz

Homework: Answer each of the following questions.

1. What is a crystal lattice?
The three dimensional arrangement of atoms or ions in a crystal.

2. What is a unit cell?
The simplest repeating unit of a crystal.

3. Why are unit cells of different ionic compounds different?
Different atoms are different sizes.

4. Name three unit cells.
Simple cubic, body centered cubic, face centered cubic

5. What technique is commonly used to determine the structure of crystalline solids?
X-ray diffraction

6. In what state are most ionic compounds at room temperature?
Solid

7. When can ionic compounds conduct electricity?
Ionic compounds can conduct electricity when they are molten or dissolved in water.

8. Why can't solid ionic compounds conduct electricity?
Solid ionic compounds do not conduct electricity because in order for a substance to conduct electricity it must have charged particles that can move freely. In an ionic compound, ions are locked in place.

9. What makes ionic compounds electrically neutral?
The amount of positive charge is equal to the amount of negative charge.

10. How does the boiling point of ionic compounds compare to that of covalent compounds?
The boiling point of ionic compounds is much higher.

11. Why do ionic compounds have higher boiling points than covalent compounds?
Ionic compounds are arranged into crystal structures.

12. What makes ionic compounds hard?
Ionic compounds are arranged into crystal structures.

13. What makes ionic compounds brittle?
Ionic compounds are arranged into crystal structures. But, if one layer is shifted, like charges will be next to one another.

14. Define lattice energy.
Lattice energy is the amount of energy needed to break an ionic bond or the amount of energy released when a bond is formed.

15. For the following pairs of ionic compounds, circle which will likely have a higher melting point

a. **KI** or CsI

b. $MgCl_2$ or **$AlCl_3$**

c. Na_2S or **Na_3P**

d. **Li_3N** or Li_3P

e. **$CuCl_2$** or CuCl

16. Why do ionic compounds form?
Ionic compounds form because oppositely charged ions have a lower energy than the original elements.

17. List the five steps that must occur in the formation of NaCl from Na(s) and Cl_2(g) and indicate whether they are endothermic or exothermic.

- **Step 1: Sublimation of solid sodium. Na(s) → Na(g) endothermic**
- **Step 2: Ionization of sodium atom. Na(g) → Na^+(g) + e^- endothermic**
- **Step 3: Dissociation of chlorine molecules. ½ Cl_2(g) → Cl(g) endothermic**
- **Step 4: Formation of chloride ions. Cl(g) + e^- → Cl^-(g) exothermic**
- **Step 5: Formation of NaCl from Na^+(g) and Cl^-(g) ions. Na^+(g) + Cl^-(g) → NaCl(s) exothermic**

18. Why do most metals have high melting and boiling points?
Their atoms are arranged in to a crystalline structure.

19. What are two arrangements that metal ions are arranged into?
aba (hexagonal closest packed)
abc (cubic closest packed)

20. What is the difference in the arrangements?
aba repeats after 2 layers
abc repeats after 3 layers

21. Why are metals malleable, ductile and good conductors of heat and electricity?
Metals are malleable, ductile and good conductors of heat and electricity because they have de-localized, free-moving electrons.

22. What is an alloy?
An alloy is a mixture of elements with overall metallic properties.

23. Name two types of alloys and give an example of each.
Substitutional (brass)
Interstitial (steel)

For each of the following, determine whether the statement applies to metals, salts, both or neither.

24. **Both** They have high melting and boiling points.

25. **Both** They arranged into crystals.

26. **Metals** They conduct electricity as solids.

27. **Metals** They have free moving electrons.

28. **Metals** They are malleable and ductile.

29. **Salts** Conduct electricity only when they are molten or dissolved in water.

30. **Salts** Their bonds are formed between a cation and an anion.

31. **Both** They are generally solid at room temperature.

32. **Salts** Valence electrons are attached to only one atom.

33. **Salts** They are brittle.