

Chapter 5

Problems

Problem 5.1 (Two very similar questions)

Gypsum is a soft [mineral](#) composed of [calcium sulfate dihydrate](#). It is widely mined and is used as a [fertilizer](#) and as the main constituent in many forms of [plaster](#), [blackboard/sidewalk chalk](#), and [drywall](#). What is the correct formula for calcium sulfate dihydrate? (Wikipedia)

(Hint: dihydrate implies two molecules of water for one formula unit of calcium sulfate)

- *(a). $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$
- (b). $\text{Ca}_2\text{SO}_4 \cdot 2\text{H}_2\text{O}$
- (c). $\text{Ca}(\text{SO}_4)_2 \cdot 2\text{H}_2\text{O}$
- (d). $\text{Ca}_2(\text{SO}_4)_3 \cdot 2\text{H}_2\text{O}$
- (e). $\text{Ca}_3(\text{SO}_4)_2 \cdot 2\text{H}_2\text{O}$

Answer

Calcium is in Group 2A of the Periodic Table (alkaline earth metals). These metals form ions with a charge of +2. The charge on a sulfate ion is -2. Thus, in one unit of calcium sulfate, there is one calcium ion (Ca^{2+}) and one sulfate ion (SO_4^{2-}).

Problem 5.1 (Alternate)

Magnesium sulfate is used both externally (as **Epsom salt**) and internally. In the [UK](#), a medication containing magnesium sulphate and [phenol](#), called "drawing paste", is claimed to be useful for small boils or localized infections, and removing splinters. Internal uses include: replacement therapy for [magnesium deficiency](#), treatment of acute and severe [arrhythmias](#), and as a [bronchodilator](#) in the treatment of [asthma](#). (Wikipedia).

What is the correct formula for magnesium sulfate?

- *(a). MgSO_4
- (b). Mg_2SO_4
- (c). $\text{Mg}(\text{SO}_4)_2$
- (d). $\text{Mg}_2(\text{SO}_4)_3$
- (e). $\text{Mg}_3(\text{SO}_4)_2$

Answer

Magnesium is in Group 2A of the Periodic Table (alkaline earth metals). These metals form ions with a charge of +2. The charge on a sulfate ion is -2. Thus, in one unit of magnesium sulfate, there is one magnesium ion (Mg^{2+}) and one sulfate ion (SO_4^{2-}).

Problem 5.2

What is the generic formula for a halide of an alkali metal?

- (a). MX_2
- (b). M_2X
- ☒ (c). MX
- (d). MX_3
- (e). M_3X

Answer

Alkali metals (Group 1A of the Periodic Table) form ions with a charge of +1 (M^+). Halide ions are derived from halogens (Group 7A of the Periodic Table) form ions with a charge of -1 (X^-). Thus, in one unit of an alkali metal halide, there is one positive ion (M^+) and one negative ion (X^-).

Problem 5.3

Together with other iron compounds, the compound with the formula FeSO_4 is used to fortify foods and to treat and prevent [iron deficiency anemia](#). (Wikipedia) What is the correct name for this compound?

- (a). Iron sulfate
- ☒ (b). Iron (II) sulfate
- (c). Iron (III) sulfate
- (d). Iron (I) sulfate (I)
- (d). Iron (II) sulfate (II)

Answer

The charge on a sulfate ion is -2. Thus, to make a unit of FeSO_4 neutral, the charge on the positive ion is +2, i.e., the species is (Fe^{2+}). Since transition metals (such as iron) can exhibit charges that can vary (+2 or +3 for Fe), the charge is specified in parentheses using Roman numerals. In FeSO_4 , the charge is +2. Hence, the correct name is iron (II) sulfate.

Problem 5.4

Under the generic name "algedrate", aluminum hydroxide is used as an [antacid](#) in humans and animals (mainly cats and dogs). (Wikipedia) What is the correct formula for this compound?

- (a). AlOH
- (b). Al_2OH
- (c). $\text{Al}(\text{OH})_2$
- ☒ (d). $\text{Al}(\text{OH})_3$
- (e). Al_3OH

Answer

Aluminum (Group 3A of the Periodic Table) forms ions with a charge of +3 (Al^{3+}). A hydroxide ion has a charge of -1 (OH^-). Thus, in one unit of aluminum hydroxide, there is one aluminum ion (Al^{3+}) and three hydroxide ions.

Problem 5.6

For which of the following compounds, the empirical and molecular formulas are identical?
(Select all that apply)

- (a). Hydrogen peroxide, a mild antiseptic (molecular formula H_2O_2)
- *(b). Methane, the major component of natural gas (molecular formula CH_4)
- *(c). Ammonia, used in fertilizers (molecular formula NH_3)
- *(d). Propane, used as a fuel for barbeques and portable stoves (molecular formula C_3H_8)
- (e). Octane, the major component of gasoline (molecular formula C_8H_{18})

Answer

An **empirical formula** indicates the types of atoms present and the **simplest whole-number ratio** of atoms (or ions) in the compound. A **molecular formula** indicates the **actual numbers** of the atoms (or ions) in the compound. Please see the table below.

Compound	Molecular Formula	Empirical Formula
Hydrogen peroxide	H_2O_2	HO
Methane	CH_4	CH_4
Ammonia	NH_3	NH_3
Propane	C_3H_8	C_3H_8
Octane	C_8H_{18}	C_4H_9

Problem 5.7 (Fill in the blanks)

Dry air has the following major components: Nitrogen, oxygen, argon and carbon dioxide.

- (a). In the Lewis structure for O_2 , there is a _____ bond.
- (b). In the Lewis structure for N_2 , there is a _____ bond.
- (c). In the Lewis structure for CO_2 , the carbon-oxygen bonds are _____ bonds.

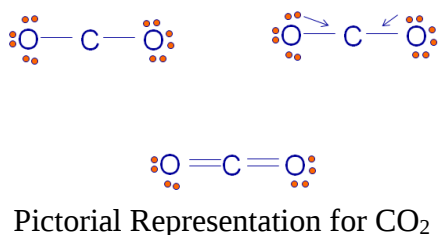
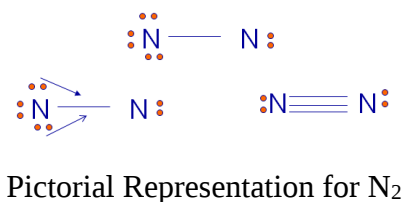
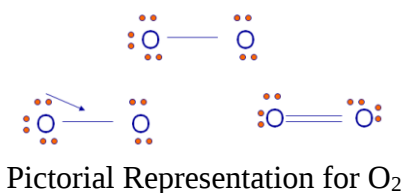
Answer

- (a). In the Lewis structure for O_2 , there is a double bond.
- (b). In the Lewis structure for N_2 , there is a triple bond.
- (c). In the Lewis structure for CO_2 , the carbon-oxygen bonds are double bonds

The steps are:

1. Determine the total number of valence (outer shell) electrons.
2. Draw a skeleton structure of the molecule or ion, arranging the atoms around a central atom. Connect each atom to the central atom with a single bond (one electron pair).
3. Distribute the remaining electrons as lone pairs on the terminal atoms (except hydrogen), completing an octet around each atom.
4. Place all remaining electrons on the central atom.

5. Rearrange the electrons of the outer atoms to make multiple bonds with the central atom in order to obtain octets wherever possible.



Problem 5.8

The compound with the formula NO is a signaling molecule in physiological processes.

- (a). (Fill in the blanks) The name of this compound is _____.
- (b). (True or false) The compound NO obeys the Octet Rule.

Answer

(a). **Nitrogen monoxide**

(b). **False;** NO contains an odd number of electrons (11 valence electrons), and thus can't obey the Octet Rule.

Problem 5.9

Carbon monoxide (CO) is found in fumes produced any time you burn fuel in cars or trucks, small engines, stoves, lanterns, grills, fireplaces, gas ranges, or furnaces. CO can build up indoors (where the amount of air is limited) and poison people and animals who breathe it. (CDC)

The Lewis structure for CO is similar to that for _____.

- (a). O₂
- * (b). N₂
- (c). NO
- (d). H₂

Answer

CO and N₂ contain the same number of atoms and the same number of valence electrons. Hence, their Lewis structures both contain a triple bond.

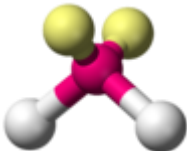
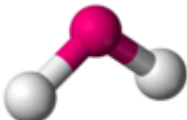
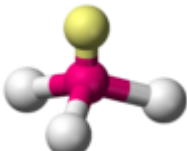
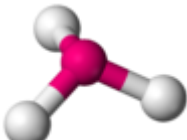
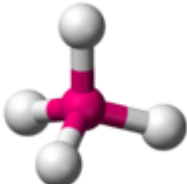
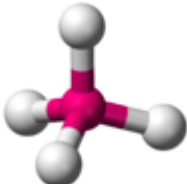
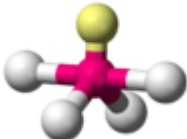
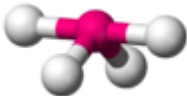
Problem 5.10

Which of the following molecules has a tetrahedral **molecular** structure?

- (a). H_2O
- (b). NH_3
- *(c). CH_4
- (d). SF_4

Answer (Images from Wikipedia)

We carefully distinguish between electron-pair geometry (that includes lone pairs, in yellow in the table below) and molecular structure (that excludes the lone pairs).

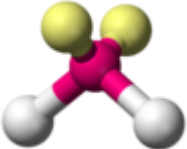
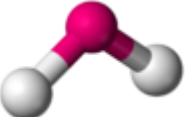
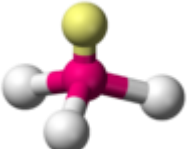
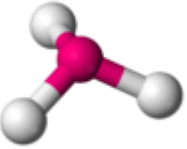
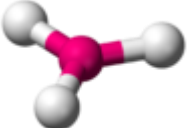
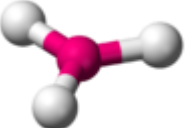
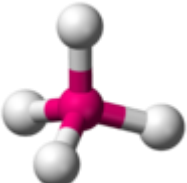
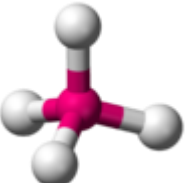
Molecule	Electron-pair geometry	Molecular Structure
H_2O	 Tetrahedral	 Bent
NH_3	 Tetrahedral	 Pyramid
CH_4	 Tetrahedral	 Tetrahedral
SF_4	 Trigonal bi-pyramid	 See-saw

Problem 5.11

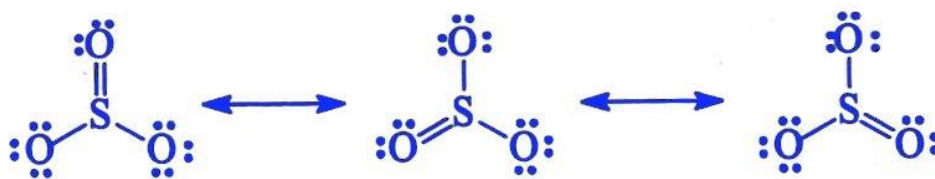
Which of the following molecules has bond angles of 120 degrees?

- (a). H_2O
- (b). NH_3
- (c). CO_2
- *(d). SO_3
- (e). CH_4

Answer (Images from Wikipedia)

Molecule	Electron-pair geometry	Molecular Structure	Bond Angles
H_2O	 Tetrahedral	 Bent	Less than 109.5°
NH_3	 Tetrahedral	 Pyramid	Less than 109.5°
CO_2	 Linear	 Linear	180°
SO_3	 Trigonal Planar	 Trigonal Planar	120°
CH_4	 Tetrahedral	 Tetrahedral	109.5°

Resonance structures for SO_3 are shown below.



Problem 5.12

Which of the following molecules is/are polar? Select all that apply.

(a). CO_2

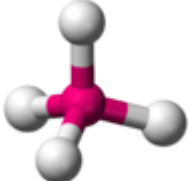
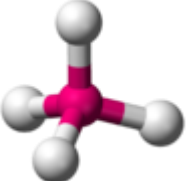
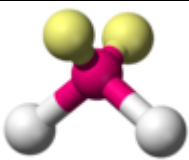
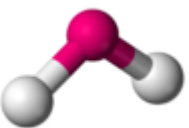
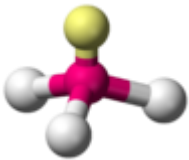
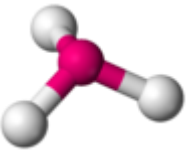
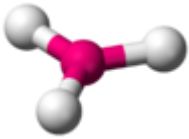
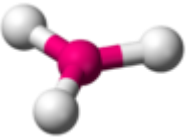
(b). CCl_4

*(c). H_2O

*(d). NH_3

(e). BF_3

Answer (Images from Wikipedia)

Molecule	Electron-pair geometry	Molecular Structure	Polar/Nonpolar
CO_2	 Linear	 Linear	Nonpolar
CCl_4	 Tetrahedral	 Tetrahedral	Nonpolar
H_2O	 Tetrahedral	 Bent	Polar
NH_3	 Tetrahedral	 Pyramid	Polar
BF_3	 Trigonal Planar	 Trigonal Planar	Nonpolar

Problem 5.13

Which of the following molecules is the most polar?

- *(a). HF
- (b). HCl
- (c). HBr
- (d). HI
- (e). HAt

Answer

All of these molecules have polar covalent bonds. The larger the electronegativity difference between the atoms, the greater is the polarity.

The values of electronegativity are:

Element	Electronegativity
H	2.1
F	4.0
Cl	3.0
Br	2.8
I	2.5
At	2.2

Thus, the H-F bond is the most polar.

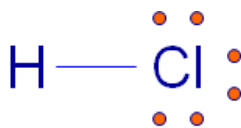
Problem 5.14

Fill in the blanks.

Stomach acid (or gastric juice) mostly consists of hydrochloric acid (HCl). In HCl, the formal charge on H is _____ and the formal charge on Cl is _____.

Answer

The Lewis structure for HCl is shown below.



Formal charge = # valence shell electrons (free atom) – # lone pair electrons – 1/2 # bonding electrons

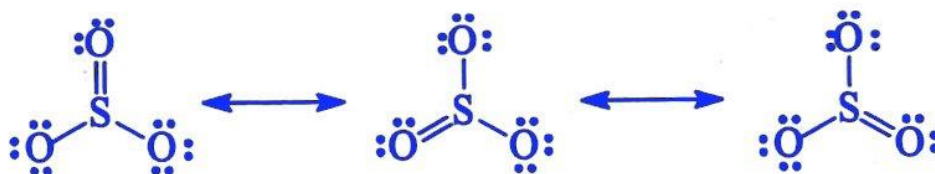
$$\text{H} - \text{Formal charge} = 1 - 0 - 1/2(2) = 0$$

$$\text{Cl} - \text{Formal charge} = 7 - 6 - 1/2(2) = 0$$

We note that the sum of formal charges on atoms in a molecule is 0.

Problem 5.15

The resonance structures of the compound SO_3 (which is a significant component of acid rain) are shown below.



(a). Fill in the blank. The name of the compound is _____.

(b). (True or false). One of the bonds in SO_3 is shorter than the other two.

Answer

(a). The name of the compound is sulfur trioxide.

(b). False. The structure of SO_3 is an *average* of the three resonance structures. All the S-O bonds are identical, and longer than a double bond but shorter than a single bond.