

K-CHEMISTRY

AP Chemistry – Unit 1

Topic 1.1: Moles and Molar Mass (Part 2)

ANSWER KEY

21. Consider the compound butane, which has the formula C_4H_{10} . If a sample of butane contains 2.59×10^{23} atoms of hydrogen, what **mass** of butane is present?

Step 1: Calculate the number of butane molecules from hydrogen atoms.

Each butane molecule (C_4H_{10}) contains 10 hydrogen atoms.

Number of butane molecules = Number of H atoms $\div$ 10

Number of butane molecules = 2.59×10^{23} atoms $\div$ 10

Number of butane molecules = 2.59×10^{22} molecules

Step 2: Convert number of molecules to moles.

Moles of butane = Number of molecules $\div$ Avogadro's number

Moles of butane = 2.59×10^{22} molecules $\div$ (6.022×10^{23} molecules/mol)

Moles of butane = 0.0430 mol

Step 3: Calculate the molar mass of butane (C_4H_{10}).

Molar mass = $4(12.01 \text{ g/mol}) + 10(1.008 \text{ g/mol})$

Molar mass = $48.04 \text{ g/mol} + 10.08 \text{ g/mol}$

Molar mass = 58.12 g/mol

Step 4: Calculate the mass of butane.

Mass = Moles $\times$ Molar mass

Mass = 0.0430 mol $\times$ 58.12 g/mol

Mass = 2.50 g

Mass of butane = 2.50 g



Tip: When given the number of atoms of one element in a compound, you can determine the number of molecules by dividing by the number of those atoms per molecule.

22. Prevacid is used to treat gastroesophageal reflux disease (GERD). The chemical formula of Prevacid is $C_{16}H_{14}F_3N_3O_2S$.

- What is the **molar mass** of Prevacid?
- What **mass of fluorine** is in 0.75 mol of Prevacid?
- What **number of carbon atoms** is in 0.75 mol of Prevacid?
- What is the **mass** of 4.25×10^{21} molecules of Prevacid?

C × 16

H × 14

F × 3

N × 3

O × 2

S × 1

a. Calculate the molar mass of Prevacid ($C_{16}H_{14}F_3N_3O_2S$).

Molar mass = $16(12.01 \text{ g/mol}) + 14(1.008 \text{ g/mol}) + 3(19.00 \text{ g/mol}) + 3(14.01 \text{ g/mol}) + 2(16.00 \text{ g/mol}) + 32.07 \text{ g/mol}$

Molar mass = $192.16 \text{ g/mol} + 14.11 \text{ g/mol} + 57.00 \text{ g/mol} + 42.03 \text{ g/mol} + 32.00 \text{ g/mol} + 32.07 \text{ g/mol}$

Molar mass = 369.37 g/mol

b. Calculate the mass of fluorine in 0.75 mol of Prevacid.

Mass of F = $0.75 \text{ mol} \times 3 \text{ F atoms/molecule} \times 19.00 \text{ g/mol}$

Mass of F = $0.75 \text{ mol} \times 57.00 \text{ g F/mol}$

Mass of F = 42.75 g

c. Calculate the number of carbon atoms in 0.75 mol of Prevacid.

Number of C atoms = $0.75 \text{ mol} \times 16 \text{ C atoms/molecule} \times 6.022 \times 10^{23} \text{ atoms/mol}$

Number of C atoms = $0.75 \text{ mol} \times 16 \times 6.022 \times 10^{23} \text{ atoms/mol}$

Number of C atoms = $7.23 \times 10^{24} \text{ atoms}$

d. Calculate the mass of 4.25×10^{21} molecules of Prevacid.

Moles of Prevacid = $4.25 \times 10^{21} \text{ molecules} \div (6.022 \times 10^{23} \text{ molecules/mol})$

Moles of Prevacid = $7.06 \times 10^{-3} \text{ mol}$

Mass = $7.06 \times 10^{-3} \text{ mol} \times 369.37 \text{ g/mol}$

Mass = 2.61 g

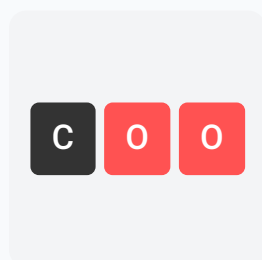
a. Molar mass of Prevacid = 369.4 g/mol

- b. Mass of fluorine = 42.8 g
 c. Number of carbon atoms = 7.23×10^{24} atoms
 d. Mass of 4.25×10^{21} molecules = 2.61 g

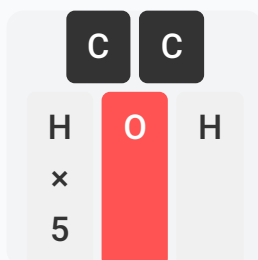
💡 Interesting fact: Prevacid (lansoprazole) is a proton pump inhibitor that decreases the amount of acid produced in the stomach, helping to treat conditions like GERD and ulcers.

23. Consider the following space-filling models for dry ice, ethanol, and caffeine. What **amount (moles)** is represented by each of the following samples?

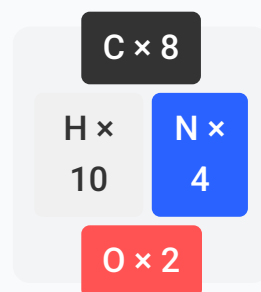
- a. 1.50 g of dry ice
 b. 2.72×10^{21} molecules of ethanol
 c. 20.0 mg of caffeine



Dry ice (CO_2)



Ethanol ($\text{C}_2\text{H}_5\text{OH}$)



Caffeine ($\text{C}_8\text{H}_{10}\text{N}_4\text{O}_2$)

a. Calculate moles of dry ice (CO_2).

Molar mass of CO_2 = $12.01 \text{ g/mol} + 2(16.00 \text{ g/mol}) = 44.01 \text{ g/mol}$

Moles of CO_2 = $1.50 \text{ g} \div 44.01 \text{ g/mol} = 0.0341 \text{ mol}$

b. Calculate moles of ethanol ($\text{C}_2\text{H}_5\text{OH}$ or $\text{C}_2\text{H}_6\text{O}$).

Moles of $\text{C}_2\text{H}_6\text{O}$ = Number of molecules $\div$ Avogadro's number

Moles of $\text{C}_2\text{H}_6\text{O}$ = $2.72 \times 10^{21} \text{ molecules} \div (6.022 \times 10^{23} \text{ molecules/mol})$

Moles of $\text{C}_2\text{H}_6\text{O}$ = $4.52 \times 10^{-3} \text{ mol}$

c. Calculate moles of caffeine ($\text{C}_8\text{H}_{10}\text{N}_4\text{O}_2$).

Molar mass of $\text{C}_8\text{H}_{10}\text{N}_4\text{O}_2 = 8(12.01) + 10(1.008) + 4(14.01) + 2(16.00)$

Molar mass = $96.08 + 10.08 + 56.04 + 32.00 = 194.20 \text{ g/mol}$

Moles of caffeine = $20.0 \text{ mg} \div 194.20 \text{ g/mol} = 0.0200 \text{ g} \div 194.20 \text{ g/mol} = 1.03 \times 10^{-4} \text{ mol}$

a. Dry ice: 0.0341 mol

b. Ethanol: $4.52 \times 10^{-3} \text{ mol}$

c. Caffeine: $1.03 \times 10^{-4} \text{ mol}$



Interesting facts:

- Dry ice is solid CO_2 that sublimates directly from solid to gas at -78.5°C
- Caffeine is the world's most widely consumed psychoactive substance

24. What **number of atoms of nitrogen** are present in 5.00 g of each of the following?

- glycine, $\text{C}_2\text{H}_5\text{O}_2\text{N}$
- magnesium nitride
- calcium nitrate
- dinitrogen tetroxide

a. Glycine ($\text{C}_2\text{H}_5\text{O}_2\text{N}$)

Step 1: Calculate the molar mass of glycine.

Molar mass = $2(12.01) + 5(1.008) + 2(16.00) + 14.01 = 75.07 \text{ g/mol}$

Step 2: Calculate moles of glycine.

Moles of glycine = $5.00 \text{ g} \div 75.07 \text{ g/mol} = 0.0666 \text{ mol}$

Step 3: Calculate number of N atoms.

Number of N atoms = $0.0666 \text{ mol} \times 1 \text{ N atom/molecule} \times 6.022 \times 10^{23} \text{ atoms/mol}$

Number of N atoms = $4.01 \times 10^{22} \text{ atoms}$

b. Magnesium nitride (Mg_3N_2)

Step 1: Calculate the molar mass of Mg_3N_2 .

$$\text{Molar mass} = 3(24.31) + 2(14.01) = 100.95 \text{ g/mol}$$

Step 2: Calculate moles of Mg_3N_2 .

$$\text{Moles of } \text{Mg}_3\text{N}_2 = 5.00 \text{ g} \div 100.95 \text{ g/mol} = 0.0495 \text{ mol}$$

Step 3: Calculate number of N atoms.

$$\text{Number of N atoms} = 0.0495 \text{ mol} \times 2 \text{ N atoms/formula unit} \times 6.022 \times 10^{23} \text{ atoms/mol}$$

$$\text{Number of N atoms} = 5.96 \times 10^{22} \text{ atoms}$$

c. Calcium nitrate ($\text{Ca}(\text{NO}_3)_2$)

Step 1: Calculate the molar mass of $\text{Ca}(\text{NO}_3)_2$.

$$\text{Molar mass} = 40.08 + 2[14.01 + 3(16.00)] = 40.08 + 2(62.01) = 164.10 \text{ g/mol}$$

Step 2: Calculate moles of $\text{Ca}(\text{NO}_3)_2$.

$$\text{Moles of } \text{Ca}(\text{NO}_3)_2 = 5.00 \text{ g} \div 164.10 \text{ g/mol} = 0.0305 \text{ mol}$$

Step 3: Calculate number of N atoms.

$$\text{Number of N atoms} = 0.0305 \text{ mol} \times 2 \text{ N atoms/formula unit} \times 6.022 \times 10^{23} \text{ atoms/mol}$$

$$\text{Number of N atoms} = 3.67 \times 10^{22} \text{ atoms}$$

d. Dinitrogen tetroxide (N_2O_4)

Step 1: Calculate the molar mass of N_2O_4 .

$$\text{Molar mass} = 2(14.01) + 4(16.00) = 28.02 + 64.00 = 92.02 \text{ g/mol}$$

Step 2: Calculate moles of N_2O_4 .

$$\text{Moles of } \text{N}_2\text{O}_4 = 5.00 \text{ g} \div 92.02 \text{ g/mol} = 0.0543 \text{ mol}$$

Step 3: Calculate number of N atoms.

$$\text{Number of N atoms} = 0.0543 \text{ mol} \times 2 \text{ N atoms/molecule} \times 6.022 \times 10^{23} \text{ atoms/mol}$$

$$\text{Number of N atoms} = 6.54 \times 10^{22} \text{ atoms}$$

a. Glycine: 4.01×10^{22} N atoms

b. Magnesium nitride: 5.96×10^{22} N atoms

c. Calcium nitrate: 3.67×10^{22} N atoms

d. Dinitrogen tetroxide: 6.54×10^{22} N atoms



Note: Even though we have the same mass (5.00 g) of each compound, the number of nitrogen atoms varies because each compound has a different molar mass and a different number of nitrogen atoms per formula unit.

25. Ascorbic acid, or vitamin C ($\text{C}_6\text{H}_8\text{O}_6$), is an essential vitamin. What is the **molar mass** of ascorbic acid? If a typical tablet contains 500.0 mg of vitamin C, what **amount (moles)** of vitamin C is contained in 10 tablets? What **number of vitamin C molecules** is in eight tablets?

Step 1: Calculate the molar mass of vitamin C ($\text{C}_6\text{H}_8\text{O}_6$).

Molar mass = $6(12.01 \text{ g/mol}) + 8(1.008 \text{ g/mol}) + 6(16.00 \text{ g/mol})$

Molar mass = $72.06 \text{ g/mol} + 8.06 \text{ g/mol} + 96.00 \text{ g/mol}$

Molar mass = 176.12 g/mol

Step 2: Calculate the amount (moles) of vitamin C in 10 tablets.

Mass of vitamin C in 10 tablets = $10 \times 500.0 \text{ mg} = 5000 \text{ mg} = 5.000 \text{ g}$

Moles of vitamin C = $5.000 \text{ g} \div 176.12 \text{ g/mol} = 0.02839 \text{ mol}$

Step 3: Calculate the number of vitamin C molecules in 8 tablets.

Mass of vitamin C in 8 tablets = $8 \times 500.0 \text{ mg} = 4000 \text{ mg} = 4.000 \text{ g}$

Moles of vitamin C = $4.000 \text{ g} \div 176.12 \text{ g/mol} = 0.02271 \text{ mol}$

Number of molecules = $0.02271 \text{ mol} \times 6.022 \times 10^{23} \text{ molecules/mol}$

Number of molecules = $1.368 \times 10^{22} \text{ molecules}$

Molar mass of vitamin C = 176.1 g/mol

Amount of vitamin C in 10 tablets = 0.0284 mol

Number of vitamin C molecules in 8 tablets = $1.37 \times 10^{22} \text{ molecules}$



Health fact: Humans cannot synthesize vitamin C and must obtain it from their diet. A deficiency in vitamin C leads to scurvy, a disease that was common among sailors on long voyages without access to fresh fruits and vegetables.

26. The molecular formula of acetylsalicylic acid (aspirin), one of the most commonly used pain relievers, is $\text{C}_9\text{H}_8\text{O}_4$.

- Calculate the **molar mass** of aspirin.
- A typical aspirin tablet contains 500. mg $\text{C}_9\text{H}_8\text{O}_4$. What **amount (moles)** of $\text{C}_9\text{H}_8\text{O}_4$ molecules and what **number of molecules** of acetylsalicylic acid are in a 500.-mg tablet?

a. Calculate the molar mass of aspirin ($\text{C}_9\text{H}_8\text{O}_4$).

Molar mass = $9(12.01 \text{ g/mol}) + 8(1.008 \text{ g/mol}) + 4(16.00 \text{ g/mol})$

Molar mass = $108.09 \text{ g/mol} + 8.06 \text{ g/mol} + 64.00 \text{ g/mol}$

Molar mass = 180.15 g/mol

b. Calculate the amount (moles) of aspirin in a 500. mg tablet.

Moles of aspirin = $500. \text{ mg} \div 180.15 \text{ g/mol} = 0.500 \text{ g} \div 180.15 \text{ g/mol} = 0.00277 \text{ mol}$

Calculate the number of aspirin molecules in a 500. mg tablet.

Number of molecules = $0.00277 \text{ mol} \times 6.022 \times 10^{23} \text{ molecules/mol}$

Number of molecules = $1.67 \times 10^{21} \text{ molecules}$

a. Molar mass of aspirin = 180.2 g/mol

b. Amount of aspirin in a 500. mg tablet = 0.00277 mol

Number of aspirin molecules = $1.67 \times 10^{21} \text{ molecules}$



Medical history: Aspirin was first isolated from willow bark in 1828. It is one of the most widely used medications globally, with an estimated 40,000 tonnes (44,000 tons) consumed each year.

27. Chloral hydrate ($\text{C}_2\text{H}_3\text{Cl}_3\text{O}_2$) is a drug formerly used as a sedative and hypnotic. It is the compound used to make "Mickey Finns" in detective stories.

- a. Calculate the **molar mass** of chloral hydrate.
- b. What **amount (moles)** of $\text{C}_2\text{H}_3\text{Cl}_3\text{O}_2$ molecules are in 500.0 g chloral hydrate?
- c. What is the **mass in grams** of 2.0×10^{22} molecules of chloral hydrate?
- d. What **number of chlorine atoms** are in 5.0 g chloral hydrate?
- e. What **mass of chloral hydrate** would contain 1.0 g Cl?
- f. What is the **mass** of exactly 500 molecules of chloral hydrate?

a. Calculate the molar mass of chloral hydrate ($\text{C}_2\text{H}_3\text{Cl}_3\text{O}_2$).

Molar mass = $2(12.01 \text{ g/mol}) + 3(1.008 \text{ g/mol}) + 3(35.45 \text{ g/mol}) + 2(16.00 \text{ g/mol})$

Molar mass = $24.02 \text{ g/mol} + 3.02 \text{ g/mol} + 106.35 \text{ g/mol} + 32.00 \text{ g/mol}$

Molar mass = 165.39 g/mol

b. Calculate the amount (moles) of chloral hydrate in 500.0 g.

Moles = $500.0 \text{ g} \div 165.39 \text{ g/mol} = 3.023 \text{ mol}$

c. Calculate the mass of 2.0×10^{22} molecules of chloral hydrate.

Moles = $2.0 \times 10^{22} \text{ molecules} \div (6.022 \times 10^{23} \text{ molecules/mol}) = 0.0332 \text{ mol}$

Mass = $0.0332 \text{ mol} \times 165.39 \text{ g/mol} = 5.49 \text{ g}$

d. Calculate the number of chlorine atoms in 5.0 g chloral hydrate.

Moles of chloral hydrate = $5.0 \text{ g} \div 165.39 \text{ g/mol} = 0.0302 \text{ mol}$

Number of Cl atoms = $0.0302 \text{ mol} \times 3 \text{ Cl atoms/molecule} \times 6.022 \times 10^{23} \text{ atoms/mol}$

Number of Cl atoms = $5.46 \times 10^{22} \text{ atoms}$

e. Calculate the mass of chloral hydrate that would contain 1.0 g Cl.

Mass percent of Cl in chloral hydrate = $[3(35.45 \text{ g/mol}) \div 165.39 \text{ g/mol}] \times 100\% = 64.3\%$

Mass of chloral hydrate = $1.0 \text{ g Cl} \div 0.643 = 1.56 \text{ g}$

f. Calculate the mass of 500 molecules of chloral hydrate.

Moles = $500 \text{ molecules} \div (6.022 \times 10^{23} \text{ molecules/mol}) = 8.30 \times 10^{-22} \text{ mol}$

Mass = $8.30 \times 10^{-22} \text{ mol} \times 165.39 \text{ g/mol} = 1.37 \times 10^{-19} \text{ g}$

- a. Molar mass of chloral hydrate = 165.4 g/mol
- b. Amount in 500.0 g = 3.02 mol
- c. Mass of 2.0×10^{22} molecules = 5.49 g
- d. Number of Cl atoms in 5.0 g = 5.46×10^{22} atoms
- e. Mass containing 1.0 g Cl = 1.56 g
- f. Mass of 500 molecules = 1.37×10^{-19} g



Historical note: A "Mickey Finn" was a drink laced with chloral hydrate to render someone unconscious. This practice was popularized in crime fiction but is illegal and dangerous in reality.

28. Dimethylnitrosamine, $(\text{CH}_3)_2\text{N}_2\text{O}$, is a carcinogenic (cancer-causing) substance that may be formed in foods, beverages, or gastric juices from the reaction of nitrite ion (used as a food preservative) with other substances.

- a. What is the **molar mass** of dimethylnitrosamine?
- b. How many **moles** of $(\text{CH}_3)_2\text{N}_2\text{O}$ molecules are present in 250 mg dimethylnitrosamine?
- c. What is the **mass** of 0.050 mole of dimethylnitrosamine?
- d. How many **atoms of hydrogen** are in 1.0 mole of dimethylnitrosamine?
- e. What is the **mass** of 1.0×10^6 molecules of dimethylnitrosamine?
- f. What is the **mass in grams** of one molecule of dimethylnitrosamine?

a. Calculate the molar mass of dimethylnitrosamine, $(\text{CH}_3)_2\text{N}_2\text{O}$.

The formula $(\text{CH}_3)_2\text{N}_2\text{O}$ can be rewritten as $\text{C}_2\text{H}_6\text{N}_2\text{O}$.

Molar mass = $2(12.01 \text{ g/mol}) + 6(1.008 \text{ g/mol}) + 2(14.01 \text{ g/mol}) + 16.00 \text{ g/mol}$

Molar mass = $24.02 \text{ g/mol} + 6.05 \text{ g/mol} + 28.02 \text{ g/mol} + 16.00 \text{ g/mol}$

Molar mass = 74.09 g/mol

b. Calculate the moles of dimethylnitrosamine in 250 mg.

Moles = $250 \text{ mg} \div 74.09 \text{ g/mol} = 0.250 \text{ g} \div 74.09 \text{ g/mol} = 0.00337 \text{ mol}$

c. Calculate the mass of 0.050 mole of dimethylnitrosamine.

$$\text{Mass} = 0.050 \text{ mol} \times 74.09 \text{ g/mol} = 3.70 \text{ g}$$

d. Calculate the number of hydrogen atoms in 1.0 mole of dimethylnitrosamine.

$$\text{Number of H atoms} = 1.0 \text{ mol} \times 6 \text{ H atoms/molecule} \times 6.022 \times 10^{23} \text{ atoms/mol}$$

$$\text{Number of H atoms} = 3.61 \times 10^{24} \text{ atoms}$$

e. Calculate the mass of 1.0×10^6 molecules of dimethylnitrosamine.

$$\text{Moles} = 1.0 \times 10^6 \text{ molecules} \div (6.022 \times 10^{23} \text{ molecules/mol}) = 1.66 \times 10^{-18} \text{ mol}$$

$$\text{Mass} = 1.66 \times 10^{-18} \text{ mol} \times 74.09 \text{ g/mol} = 1.23 \times 10^{-16} \text{ g}$$

f. Calculate the mass of one molecule of dimethylnitrosamine.

$$\text{Mass of one molecule} = \text{Molar mass} \div \text{Avogadro's number}$$

$$\text{Mass of one molecule} = 74.09 \text{ g/mol} \div (6.022 \times 10^{23} \text{ molecules/mol})$$

$$\text{Mass of one molecule} = 1.23 \times 10^{-22} \text{ g}$$

a. Molar mass = 74.09 g/mol

b. Moles in 250 mg = 0.00337 mol

c. Mass of 0.050 mol = 3.70 g

d. Number of H atoms in 1.0 mol = 3.61×10^{24} atoms

e. Mass of 1.0×10^6 molecules = 1.23×10^{-16} g

f. Mass of one molecule = 1.23×10^{-22} g



Health note: Dimethylnitrosamine is a potent carcinogen that can form when nitrites (used as preservatives) react with amines in acidic conditions, such as in the stomach. This is one reason why there are limits on nitrite levels in processed foods.

29. Calculate the **percent composition by mass** of the following compounds that are important starting materials for synthetic polymers:

- a. $\text{C}_3\text{H}_4\text{O}_2$ (acrylic acid, from which acrylic plastics are made)
- b. $\text{C}_4\text{H}_6\text{O}_2$ (methyl acrylate, from which Plexiglas is made)
- c. $\text{C}_3\text{H}_3\text{N}$ (acrylonitrile, from which Orlon is made)

a. Calculate the percent composition of acrylic acid ($\text{C}_3\text{H}_4\text{O}_2$).

Step 1: Calculate the molar mass.

$$\text{Molar mass} = 3(12.01 \text{ g/mol}) + 4(1.008 \text{ g/mol}) + 2(16.00 \text{ g/mol})$$

$$\text{Molar mass} = 36.03 \text{ g/mol} + 4.03 \text{ g/mol} + 32.00 \text{ g/mol} = 72.06 \text{ g/mol}$$

Step 2: Calculate the percent composition.

$$\% \text{ C} = [3(12.01 \text{ g/mol}) \div 72.06 \text{ g/mol}] \times 100\% = 50.0\%$$

$$\% \text{ H} = [4(1.008 \text{ g/mol}) \div 72.06 \text{ g/mol}] \times 100\% = 5.6\%$$

$$\% \text{ O} = [2(16.00 \text{ g/mol}) \div 72.06 \text{ g/mol}] \times 100\% = 44.4\%$$

b. Calculate the percent composition of methyl acrylate ($\text{C}_4\text{H}_6\text{O}_2$).

Step 1: Calculate the molar mass.

$$\text{Molar mass} = 4(12.01 \text{ g/mol}) + 6(1.008 \text{ g/mol}) + 2(16.00 \text{ g/mol})$$

$$\text{Molar mass} = 48.04 \text{ g/mol} + 6.05 \text{ g/mol} + 32.00 \text{ g/mol} = 86.09 \text{ g/mol}$$

Step 2: Calculate the percent composition.

$$\% \text{ C} = [4(12.01 \text{ g/mol}) \div 86.09 \text{ g/mol}] \times 100\% = 55.8\%$$

$$\% \text{ H} = [6(1.008 \text{ g/mol}) \div 86.09 \text{ g/mol}] \times 100\% = 7.0\%$$

$$\% \text{ O} = [2(16.00 \text{ g/mol}) \div 86.09 \text{ g/mol}] \times 100\% = 37.2\%$$

c. Calculate the percent composition of acrylonitrile ($\text{C}_3\text{H}_3\text{N}$).

Step 1: Calculate the molar mass.

$$\text{Molar mass} = 3(12.01 \text{ g/mol}) + 3(1.008 \text{ g/mol}) + 14.01 \text{ g/mol}$$

$$\text{Molar mass} = 36.03 \text{ g/mol} + 3.02 \text{ g/mol} + 14.01 \text{ g/mol} = 53.06 \text{ g/mol}$$

Step 2: Calculate the percent composition.

$$\% \text{ C} = [3(12.01 \text{ g/mol}) \div 53.06 \text{ g/mol}] \times 100\% = 67.9\%$$

$$\% \text{ H} = [3(1.008 \text{ g/mol}) \div 53.06 \text{ g/mol}] \times 100\% = 5.7\%$$

$$\% \text{ N} = [14.01 \text{ g/mol} \div 53.06 \text{ g/mol}] \times 100\% = 26.4\%$$

a. Acrylic acid ($\text{C}_3\text{H}_4\text{O}_2$):

C: 50.0%, H: 5.6%, O: 44.4%

b. Methyl acrylate ($\text{C}_4\text{H}_6\text{O}_2$):

C: 55.8%, H: 7.0%, O: 37.2%

c. Acrylonitrile ($\text{C}_3\text{H}_3\text{N}$):

C: 67.9%, H: 5.7%, N: 26.4%

💡 **Polymer chemistry:** These monomers are the building blocks for important synthetic polymers. When polymerized, they form long chains that give plastics their useful properties.

30. In 1987 the first substance to act as a superconductor at a temperature above that of liquid nitrogen (77 K) was discovered. The approximate formula of this substance is $\text{YBa}_2\text{Cu}_3\text{O}_7$. Calculate the **percent composition by mass** of this material.

Step 1: Calculate the molar mass of $\text{YBa}_2\text{Cu}_3\text{O}_7$.

Molar mass = $88.91 \text{ g/mol} + 2(137.33 \text{ g/mol}) + 3(63.55 \text{ g/mol}) + 7(16.00 \text{ g/mol})$

Molar mass = $88.91 \text{ g/mol} + 274.66 \text{ g/mol} + 190.65 \text{ g/mol} + 112.00 \text{ g/mol}$

Molar mass = 666.22 g/mol

Step 2: Calculate the percent composition.

% Y = $(88.91 \text{ g/mol} \div 666.22 \text{ g/mol}) \times 100\% = 13.3\%$

% Ba = $[2(137.33 \text{ g/mol}) \div 666.22 \text{ g/mol}] \times 100\% = 41.2\%$

% Cu = $[3(63.55 \text{ g/mol}) \div 666.22 \text{ g/mol}] \times 100\% = 28.6\%$

% O = $[7(16.00 \text{ g/mol}) \div 666.22 \text{ g/mol}] \times 100\% = 16.8\%$

Percent composition of $\text{YBa}_2\text{Cu}_3\text{O}_7$:

Y: 13.3%

Ba: 41.2%

Cu: 28.6%

O: 16.8%



Scientific breakthrough: This high-temperature superconductor was revolutionary because it could operate using liquid nitrogen cooling (77 K), which is much less expensive than liquid helium (4 K) required for earlier superconductors.

31. The percent by mass of nitrogen for a compound is found to be 46.7%. Which of the following could be this species?



Calculate the percent nitrogen by mass for each compound:



$$\text{Molar mass} = 2(14.01 \text{ g/mol}) + 16.00 \text{ g/mol} = 44.02 \text{ g/mol}$$

$$\% \text{ N} = [2(14.01 \text{ g/mol}) \div 44.02 \text{ g/mol}] \times 100\% = 63.6\%$$



$$\text{Molar mass} = 14.01 \text{ g/mol} + 16.00 \text{ g/mol} = 30.01 \text{ g/mol}$$

$$\% \text{ N} = [14.01 \text{ g/mol} \div 30.01 \text{ g/mol}] \times 100\% = 46.7\%$$



$$\text{Molar mass} = 14.01 \text{ g/mol} + 2(16.00 \text{ g/mol}) = 46.01 \text{ g/mol}$$

$$\% \text{ N} = [14.01 \text{ g/mol} \div 46.01 \text{ g/mol}] \times 100\% = 30.4\%$$



$$\text{Molar mass} = 2(14.01 \text{ g/mol}) + 4(16.00 \text{ g/mol}) = 92.02 \text{ g/mol}$$

$$\% \text{ N} = [2(14.01 \text{ g/mol}) \div 92.02 \text{ g/mol}] \times 100\% = 30.4\%$$

The compound with 46.7% nitrogen by mass is NO (nitrogen monoxide).



Chemistry fact: NO (nitrogen monoxide) is a signaling molecule in the human body that helps regulate blood pressure by dilating blood vessels. It was named "Molecule of the Year" in 1992 by the journal Science.

32. Arrange the following substances in order of **increasing mass percent of carbon**.

- a. caffeine, $\text{C}_8\text{H}_{10}\text{N}_4\text{O}_2$
- b. sucrose, $\text{C}_{12}\text{H}_{22}\text{O}_{11}$
- c. ethanol, $\text{C}_2\text{H}_5\text{OH}$

Calculate the percent carbon by mass for each compound:

a. Caffeine ($\text{C}_8\text{H}_{10}\text{N}_4\text{O}_2$):

Molar mass = $8(12.01 \text{ g/mol}) + 10(1.008 \text{ g/mol}) + 4(14.01 \text{ g/mol}) + 2(16.00 \text{ g/mol})$

Molar mass = $96.08 \text{ g/mol} + 10.08 \text{ g/mol} + 56.04 \text{ g/mol} + 32.00 \text{ g/mol} = 194.20 \text{ g/mol}$

% C = $[8(12.01 \text{ g/mol}) \div 194.20 \text{ g/mol}] \times 100\% = 49.5\%$

b. Sucrose ($\text{C}_{12}\text{H}_{22}\text{O}_{11}$):

Molar mass = $12(12.01 \text{ g/mol}) + 22(1.008 \text{ g/mol}) + 11(16.00 \text{ g/mol})$

Molar mass = $144.12 \text{ g/mol} + 22.18 \text{ g/mol} + 176.00 \text{ g/mol} = 342.30 \text{ g/mol}$

% C = $[12(12.01 \text{ g/mol}) \div 342.30 \text{ g/mol}] \times 100\% = 42.1\%$

c. Ethanol ($\text{C}_2\text{H}_5\text{OH}$ or $\text{C}_2\text{H}_6\text{O}$):

Molar mass = $2(12.01 \text{ g/mol}) + 6(1.008 \text{ g/mol}) + 16.00 \text{ g/mol}$

Molar mass = $24.02 \text{ g/mol} + 6.05 \text{ g/mol} + 16.00 \text{ g/mol} = 46.07 \text{ g/mol}$

% C = $[2(12.01 \text{ g/mol}) \div 46.07 \text{ g/mol}] \times 100\% = 52.1\%$

Order of increasing mass percent of carbon:

Sucrose (42.1%) < Caffeine (49.5%) < Ethanol (52.1%)



Interesting observation: Even though sucrose has more carbon atoms per molecule than ethanol, its percent carbon by mass is lower because it also contains many oxygen atoms, which are heavier than hydrogen atoms.

33. Sarin is a nerve gas whose chemical formula has 2 atoms of oxygen for each molecule of sarin. If sarin is 22.8% O by mass, calculate the **molar mass** of sarin.

Step 1: Set up an equation using the percent composition information.

If sarin is 22.8% oxygen by mass, and it contains 2 oxygen atoms per molecule:

$$\text{Mass percent of O} = [2(16.00 \text{ g/mol}) \div \text{molar mass of sarin}] \times 100\% = 22.8\%$$

Step 2: Solve for the molar mass of sarin.

$$22.8\% = [2(16.00 \text{ g/mol}) \div \text{molar mass}] \times 100\%$$

$$0.228 = 32.00 \text{ g/mol} \div \text{molar mass}$$

$$\text{Molar mass} \times 0.228 = 32.00 \text{ g/mol}$$

$$\text{Molar mass} = 32.00 \text{ g/mol} \div 0.228 = 140.4 \text{ g/mol}$$

Molar mass of sarin = 140.4 g/mol



Note: Sarin ($\text{C}_4\text{H}_{10}\text{FO}_2\text{P}$) is an extremely toxic chemical weapon classified as a weapon of mass destruction by the United Nations. Its actual molar mass is 140.1 g/mol, which matches our calculation.