Combustion reaction problems

1. methane (CH₄) + oxygen → carbon dioxide + water
   \[ \text{CH}_4 + \text{2O}_2 \rightarrow \text{CO}_2 + 2\text{H}_2\text{O} \]

2. ethane (C₂H₆) + oxygen → carbon dioxide + water
   \[ 2\text{C}_2\text{H}_6 + 7\text{O}_2 \rightarrow 4\text{CO}_2 + 6\text{H}_2\text{O} \]

3. propane (C₃H₈) + oxygen → carbon dioxide + water
   \[ \text{C}_3\text{H}_8 + 5\text{O}_2 \rightarrow 3\text{CO}_2 + 4\text{H}_2\text{O} \]

4. butane (C₄H₁₀) + oxygen → carbon dioxide + water
   \[ 2\text{C}_4\text{H}_{10} + 13\text{O}_2 \rightarrow 8\text{CO}_2 + 10\text{H}_2\text{O} \]

5. pentane (C₅H₁₂) + oxygen → carbon dioxide + water
   \[ \text{C}_5\text{H}_{12} + 8\text{O}_2 \rightarrow 5\text{CO}_2 + 6\text{H}_2\text{O} \]

6. hexane (C₆H₁₄) + oxygen → carbon dioxide + water
   \[ 2\text{C}_6\text{H}_{14} + 19\text{O}_2 \rightarrow 12\text{CO}_2 + 14\text{H}_2\text{O} \]

7. ethene (C₂H₄) + oxygen → carbon dioxide + water
   \[ \text{C}_2\text{H}_4 + 3\text{O}_2 \rightarrow 2\text{CO}_2 + 2\text{H}_2\text{O} \]

8. ethyne (C₂H₂) + oxygen → carbon dioxide + water
   \[ 2\text{C}_2\text{H}_2 + 5\text{O}_2 \rightarrow 4\text{CO}_2 + 2\text{H}_2\text{O} \]

9. benzene (C₆H₆) + oxygen → carbon dioxide + water
   \[ 2\text{C}_6\text{H}_6 + 15\text{O}_2 \rightarrow 12\text{CO}_2 + 6\text{H}_2\text{O} \]
Stoichiometry questions

a. \( \text{H}_2 + \text{Cl}_2 \rightarrow 2 \text{HCl} \) (needs balanced)

How many grams of HCl can be produced if 7.25 g of Cl\(_2\) is reacted with an unlimited supply of H\(_2\)?

\[
\begin{array}{c|c|c|c}
7.25 \text{ g Cl}_2 & 1 \text{ mol Cl}_2 & 2 \text{ mol HCl} & 36.46 \text{ g HCl} \\
\hline
70.90 \text{ g Cl}_2 & 1 \text{ mol Cl}_2 & 1 \text{ mol HCl} & = 7.46 \text{ g HCl}
\end{array}
\]

b. \( 2\text{Al} + \text{Fe}_2\text{O}_3 \rightarrow \text{Al}_2\text{O}_3 + 2\text{Fe} \) (needs balanced)

How many grams of Fe can be produced when 10.0 g of Al is reacted with an excess (unlimited) supply of Fe\(_2\)O\(_3\)?

\[
\begin{array}{c|c|c|c}
10.0 \text{ g Al} & 1 \text{ mol Al} & 2 \text{ mol Fe} & 55.85 \text{ g Fe} \\
\hline
26.98 \text{ g Al} & 2 \text{ mol Al} & 1 \text{ mol Fe} & = 20.7 \text{ g Fe}
\end{array}
\]

c. \( \text{Pb(CH}_3\text{COO})_2 + \text{H}_2\text{S} \rightarrow \text{PbS} + 2\text{CH}_3\text{COOH} \) (needs balanced)

How many grams of PbS is produced when 5.00 g of H\(_2\)S is reacted with an excess (unlimited) supply of Pb(CH\(_3\)COO)\(_2\)?

\[
\begin{array}{c|c|c|c|c}
5.00 \text{ g} & 1 \text{ mol H}_2\text{S} & 1 \text{ mol PbS} & 239.27 \text{ g} \\
\hline
34.09 \text{ g H}_2\text{S} & 1 \text{ mol H}_2\text{S} & 1 \text{ mol PbS} & = 35.1 \text{ g PbS}
\end{array}
\]
Limiting reagent and yield problems

1. Balanced equation:

\[ \text{C}_3\text{H}_8 \ + 5 \text{ O}_2 \ \longrightarrow \ 3 \text{ CO}_2 \ + 4 \text{ H}_2\text{O} \]

a) O\text{}_2

b) 0.065 mol CO\text{}_2

c) 1.56 g H\text{}_2\text{O}

d) 13.86 g C\text{}_3\text{H}_8

2a) Al\text{}_2\text{(SO}_3\text{)}_3

b) 0.068 mol Al\text{(OH)}_3

c) 12.85 g Na\text{}_2\text{SO}_3

d) 1.84 g Na\text{OH}

3. Balanced equation:

\[ 4 \text{ Al}_2\text{O}_3 \ + 9 \text{ Fe} \ \longrightarrow \ 3 \text{ Fe}_3\text{O}_4 \ + 8 \text{ Al} \]

a) Fe

b) 0.16 mol Al

c) 14.12 g Fe\text{}_3\text{O}_4

d) 17.13 g Al\text{}_2\text{O}_3
Solid calcium carbonate, CaCO₃, is able to remove sulphur dioxide from waste gases by the reaction:

\[
\text{CaCO}_3 + \text{SO}_2 + \text{other reactants} \rightarrow \text{CaSO}_3 + \text{other products}
\]

In a particular experiment, 255 g of CaCO₃ was exposed to 135 g of SO₂ (limiting) in the presence of an excess amount of the other chemicals required for the reaction.

a) What is the theoretical yield of CaSO₃? 253 g CaSO₃

b) If only 198 g of CaSO₃ was isolated from the products, what was the percentage yield of CaSO₃ in this experiment? 78.3%

---

### Titration problems

1) \( \text{HCl} + \text{NaOH} \rightarrow \text{NaCl} + \text{H}_2\text{O} \)

\[
\frac{M_A V_A}{n_A} = \frac{M_B V_B}{n_B}
\]

**Note:** \( n_A \) and \( n_B \) are the # of moles from the balanced equation.

\[
M_A = \frac{M_B V_B n_A}{V_A n_B} = \frac{(0.45 \text{ M})(83 \text{ mL})(1)}{(235 \text{ mL})(1)} = 0.16 \text{ M HCl}
\]

3) \( \text{H}_2\text{SO}_4 + 2 \text{ NaOH} \rightarrow \text{Na}_2\text{SO}_4 + 2 \text{ H}_2\text{O} \)

\[
\frac{M_A V_A}{n_A} = \frac{M_B V_B}{n_B}
\]

\[
M_A = \frac{M_B V_B n_A}{V_A n_B} = \frac{(0.75 \text{ M})(38 \text{ mL})(1)}{(155 \text{ mL})(2)} = 0.092 \text{ M H}_2\text{SO}_4
\]

5) \( \text{HCl} + \text{NaOH} \rightarrow \text{NaCl} + \text{H}_2\text{O} \)

\[
\frac{M_A V_A}{n_A} = \frac{M_B V_B}{n_B}
\]

\[
M_B = \frac{M_A V_A n_B}{V_B n_A} = \frac{(0.30 \text{ M})(12.5 \text{ mL})(1)}{(285 \text{ mL})(1)} = 0.013 \text{ M NaOH}
\]
Ideal gas law problems

7) If I have 21 moles of gas held at a pressure of 78 atm and a temperature of 900 K, what is the volume of the gas?

\[ PV = nRT \]
\[ V = \frac{nRT}{P} = \frac{21 \text{ mol} \cdot 0.0821 \frac{\text{L} \cdot \text{atm}}{\text{mol} \cdot \text{K}} \cdot 900\text{K}}{78 \text{ atm}} \]
\[ V = 19.89 \text{ L} \]

9) If I have 2.4 moles of gas held at a temperature of 97 °C and in a container with a volume of 45 liters, what is the pressure of the gas?

\[ PV = nRT \]
\[ P = \frac{nRT}{V} = \frac{2.4 \text{ mol} \cdot 0.0821 \frac{\text{atm} \cdot \text{L}}{\text{mol} \cdot \text{K}} \cdot 370\text{K}}{45\text{L}} \]
\[ P = 1.62 \text{ atm} \text{ or } P = 164.06 \text{ kPa} \]

10) If I have an unknown quantity of gas held at a temperature of 1195 K in a container with a volume of 25 liters and a pressure of 560 atm, how many moles of gas do I have?

\[ PV = nRT \]
\[ n = \frac{RT}{PV} = \frac{0.0821 \frac{\text{atm} \cdot \text{L}}{\text{mol} \cdot \text{K}} \cdot 1195\text{K}}{560 \text{ atm} \cdot 25\text{L}} \]
\[ n = 0.007008 \text{ mol} \]

12) If I have 72 liters of gas held at a pressure of 3.4 atm and a temperature of 225 K, how many moles of gas do I have?

\[ PV = nRT \]
\[ n = \frac{RT}{PV} = \frac{0.0821 \frac{\text{atm} \cdot \text{L}}{\text{mol} \cdot \text{K}} \cdot 225\text{K}}{72\text{L} \cdot 3.4\text{atm}} \]
\[ n = 0.07546 \text{ mol} \]

Combines gas law problems

1) If I initially have a gas at a pressure of 12 atm, a volume of 23 liters, and a temperature of 200 K, and then I raise the pressure to 14 atm and increase the temperature to 300 K, what is the new volume of the gas? 30 L
3) A gas that has a volume of 28 liters, a temperature of 45 °C, and an unknown pressure has its volume increased to 34 liters and its temperature decreased to 35 °C. If I measure the pressure after the change to be 2.0 atm, what was the original pressure of the gas? 2.5 atm

8) If I have 2.9 L of gas at a pressure of 5.0 atm and a temperature of 50 °C, what will be the temperature of the gas if I decrease the volume of the gas to 2.4 L and decrease the pressure to 3.0 atm? 160 K

Partial pressure problems

6. A rigid container with a volume of 5.60 L holds 71.0 g Cl₂ gas (MM = 70.906 g/mol) and 4.00 g He gas (MM = 4.0026 g/mol). If the total pressure is 760 mm Hg, what is the partial pressure of both gases?

\[
\frac{71.0}{70.906} = 1.00 \text{ mol Cl}_2
\]

\[
\frac{4.00}{4.0026} = 1.00 \text{ mol He}
\]

\[
760 / 2 = 380 \text{ mm Hg} = P_{\text{Cl}_2} = P_{\text{He}}
\]

4. A 12.2 L metal tank at STP contains three gases: oxygen, helium, and nitrogen. If the partial pressures of the three gases in the tank are 35.0 atm of O₂, 5.0 atm of N₂, and 25.0 atm of He, how many moles of each gas are present inside of the tank?

\[
35.0 (12.2) = n (0.0821) (273) \rightarrow \frac{n_{O_2}}{n_{N_2}} = 19.1 \text{ mol}
\]

\[
5.0 (12.2) = n (0.0821) (273) \rightarrow \frac{n_{N_2}}{n_{He}} = 2.72 \text{ mol N}_2
\]

\[
25.0 (12.2) = n (0.0821) (273) \rightarrow n_{He} = 13.6 \text{ moles}
\]

Photon problems

1. What is the wavelength of the line in the Balmer series of hydrogen that is composed of transitions from the n=5 to the n=2 level? (R = 1.097 x 10⁷ m⁻¹ and 1 nm = 10⁻⁹ m)

   a) 339 nm
   b) 563 nm
   c) 434 nm
   d) 467 nm

\[
\frac{1}{\lambda} = R \left( \frac{1}{n_k^2} - \frac{1}{n_r^2} \right) = 1.097 \times 10^7 \left( \frac{1}{2^2} - \frac{1}{5^2} \right)
\]

\[
\frac{1}{\lambda} = 2.30 \times 10^4 \quad \lambda = 4.34 \times 10^{-7} \text{ m}
\]
Example Problem 6.4

When a hydrogen atom undergoes a transition from $E_3$ to $E_1$, it emits a photon with $\lambda = 102.6$ nm. Similarly, if the atom undergoes a transition from $E_3$ to $E_2$, it emits a photon with $\lambda = 656.3$ nm. Find the wavelength of light emitted by an atom making a transition from $E_2$ to $E_1$.

\[
\frac{kE_3}{\lambda} = \frac{(6.626 \times 10^{-34} \text{ J s})(2.998 \times 10^8 \text{ m s}^{-1})}{102.6 \text{ nm}} \times \frac{10^9 \text{ nm}}{1 \text{ m}} = 1.936 \times 10^{-18} \text{ J}
\]

\[
\lambda = 656.3 \text{ nm}
\]

\[
\frac{kE_2}{\lambda} = \frac{(6.626 \times 10^{-34} \text{ J s})(2.998 \times 10^8 \text{ m s}^{-1})}{656.3 \text{ nm}} \times \frac{10^9 \text{ nm}}{1 \text{ m}} = 3.027 \times 10^{-19} \text{ J}
\]

\[
\lambda = 102.6 \text{ nm}
\]

\[
E_{2\rightarrow1} = E_{3\rightarrow1} - E_{3\rightarrow2} = 1.936 \times 10^{-18} \text{ J} - 3.027 \times 10^{-19} \text{ J} = 1.633 \times 10^{-18} \text{ J}
\]

\[
\frac{k}{E_{2\rightarrow1}} = \frac{(6.626 \times 10^{-34} \text{ J s})(2.998 \times 10^8 \text{ ms}^{-1})}{1.633 \text{ nm} \times 10^{-18} \text{ J}} = 1.216 \times 10^{-7} \text{ m}
\]

Example 2

Calculating the Energy and Wavelength of Electron Transitions in a One-electron (Bohr) System

What is the energy (in joules) and the wavelength (in meters) of the line in the spectrum of hydrogen that represents the movement of an electron from Bohr orbit with $n = 4$ to the orbit with $n = 6$? In what part of the electromagnetic spectrum do we find this radiation?

Solution

In this case, the electron starts out with $n = 4$, so $n_1 = 4$. It comes to rest in the $n = 6$ orbit, so $n_2 = 6$. The difference in energy between the two states is given by this expression:

\[
\Delta E = E_1 - E_2 = 2.179 \times 10^{-18}\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)
\]

\[
\Delta E = 2.179 \times 10^{-18}\left(\frac{1}{4^2} - \frac{1}{6^2}\right) \text{ J}
\]

\[
\Delta E = 2.179 \times 10^{-18}\left(\frac{1}{16} - \frac{1}{36}\right) \text{ J}
\]

\[
\Delta E = 7.566 \times 10^{-20} \text{ J}
\]
This energy difference is positive, indicating a photon enters the system (is absorbed) to excite the electron from the $n = 4$ orbit up to the $n = 6$ orbit. The wavelength of a photon with this energy is found by the expression $E = \frac{hc}{\lambda}$. Rearrangement gives:

$$\lambda = \frac{hc}{E} = \left(6.626 \times 10^{-34} \text{ J s}\right) \times \frac{2.998 \times 10^{8} \text{ m s}^{-1}}{7.566 \times 10^{-30} \text{ J}} = 2.626 \times 10^{-6} \text{ m}$$

From Figure 2 in Chapter 6.1 Electromagnetic Energy, we can see that this wavelength is found in the infrared portion of the electromagnetic spectrum.

**Check Your Learning**

What is the energy in joules and the wavelength in meters of the photon produced when an electron falls from the $n = 5$ to the $n = 3$ level in a He$^+$ ion ($Z = 2$ for He$^+$)?

**Answer:**

$6.198 \times 10^{-19}$ J; $3.205 \times 10^{-7}$ m

4. The ionization energy of the hydrogen atom in its ground state is 13.6 eV. What is the energy of the n=4 state?

a) 3.40 eV
b) 0.850 eV
c) -3.40 eV
d) 0.850 eV

$$E_n = -\frac{13.6 \text{ eV}}{n^2} = -\frac{13.6}{4^2} = -0.85 \text{ eV}$$

3. The Paschen series of hydrogen corresponds to electron transitions from higher levels to $n=3$.

From what level do electrons come that produce a wavelength of 1282 nm?

a) 4
b) 7
c) 5

d) 6

$$\frac{1}{\lambda} = R \left(\frac{1}{n_e^2} - \frac{1}{n_u^2}\right)$$

$$\frac{1}{n_u^2} = \frac{1}{n_e^2} - \frac{1}{\lambda R} = \frac{1}{3^2} - \frac{1}{\left(\frac{2.86 \times 10^{-4}}{(1.09 \times 10^7)}\right)(1.09 \times 10^7)}$$

$$\frac{1}{n_u^2} = 0.040 \quad n_u^2 = 25 \quad n = 5$$
Periodic table problems

1. Which atom in each pair has the larger atomic radius?
   a) Li or K b) Ca or Ni c) Ga or B d) O or C e) Cl or Br
   f) Be or Ba g) Si or S h) Fe or Au

---

Ionization Energy

- **Ionization energy** - the energy required to remove an electron from a gaseous atom, forming a cation.
  - Formation of $X^+$ is the first ionization energy, $X^{2+}$ would be the second ionization energy, etc.

$$X(g) \rightarrow X^+(g) + e^-$$

- The more strongly held an electron is, the higher the ionization energy must be.
- As valence electrons move further from the nucleus, they become easier to remove and the first ionization energy becomes smaller.

---

4. Which element in each pair has a larger ionization energy?
   a) Na or O b) Be or Ba c) At or F d) Cu or Ra e) I or Ne
   f) K or V g) Ca or Fr h) W or Se