

STUDY GUIDE – CHAPTER 3
ENERGY IN CHEMICAL REACTIONS

1) EXPLAIN QUALITATIVELY THE LAW OF CONSERVATION OF ENERGY

- Energy is the ability to do **work** or effect **change**. Energy is usually represented by the symbol "**E**". The unit of measurement for energy is the **joule**, represented by the symbol **J**.
- The law of conservation of energy can be expressed in different ways:
 - I. **Energy can be neither created nor destroyed; it can only be transferred or transformed.**
 - II. **In an isolated system, the total amount of energy remains constant.**

SAMPLE PROBLEMS

1) Which of the following statements is a correct definition of the concept of energy?

- A) Energy is the cause of motion.
- B) Energy is the ability to do work.
- C) Energy is the ability to effect change.
- D) Energy is the ability to do work or effect a change.**

2) Which of the following statements is not consistent with the law of conservation of energy?

- A) Energy can neither be created nor destroyed.
- B) Energy can only be transferred or transformed.
- C) The total amount of energy in an isolated system always remains constant.
- D) The total amount of energy in a non isolated system always remains constant.**

2) DESCRIBE HEAT AS A MANIFESTATION OF ENERGY

- **Thermal energy** results from the degree of **agitation** of the particles of a substance or from their **random** movement. It depends on two factors:
 - the **temperature** present in a substance
 - the **number of particles** of the substance.
- **Heat** is the transfer of thermal energy between two environments with different temperatures.
- Heat always passes from the **warmer** environment to the **cooler** environment.

SAMPLE QUESTIONS

1) Which of the following statements is a complete definition of “thermal energy”?

- A) **Thermal energy is the energy contained in a substance, determined by the number of particles in it and their temperature.**
- B) Thermal energy is the total energy contained in an environment.
- C) Thermal energy is the energy contained in a substance, determined by the temperature.
- D) Thermal energy is the energy contained in a substance, determined by the number of particles in it.

2) Which one of the following sentences is TRUE?

- A) **A 40 kg radiator at 60°C gives off more heat than a burning candle at 120°C. There is more thermal energy because the mass of the radiator is so much bigger)**
- B) A plate of edible soup gives off more heat than a plate of boiling soup.
- C) A cup of boiling water gives off more heat than a tub filled with water at 50°C.
- D) A cup of cold tea gives off more heat than a cup of hot tea.

3) Which of the following statements is a correct definition of “heat”?

- A) Heat is the transfer of thermal energy between two environments with different masses.
- B) **Heat is the transfer of thermal energy between two environments with different temperatures.**
- C) Heat is the energy contained in a substance, determined by the temperature.
- D) Heat is the energy contained in a substance determined by the number of particles in it.

4) *How does heat pass in media with different temperatures?*

- A) Heat always passes from the cooler to the warmer environment.
- B) Heat always passes from the substance with a higher mass to the substance with a smaller mass.
- C) Heat always passes from the warmer to the cooler environment.**
- D) Heat always passes from the substance with a lower temperature to the substance with a higher temperature.

5) *Complete the table below by indicating whether each of the variations in temperature or in the number of particles causes an increase or a decrease in thermal energy.*

Variation	Increase or decrease in thermal energy
The number of particles goes from 200 g to 60 g.	decrease
The temperature goes from 15°C to -15°C.	decrease
The number of particles goes from 25 g to 100g	increase
The temperature goes from 10°C to 100°C.	increase

6) *Which of the following objects gives off more heat and why?*

- a) A 50 kg block of ice at -20°C or a 250 kg block of ice at the same temperature?

THE 250 KG BLOCK OF ICE WILL GIVE OFF MORE HEAT BECAUSE IT HAS MORE PARTICLES INSIDE.

- b) Burning completely a 25 g candle or a 50 g candle?

THE 50 g CANDLE WILL GIVE OFF MORE HEAT BECAUSE IT HAS MORE PARTICLES INSIDE

- c) The Dead Sea or the Mediterranean Sea?

MEDITERRANEAN SEA IS A MUCH BIGGER BODY OF WATER THEREFORE IT STORES MORE ENERGY.

3) *DESCRIBE THE RELATIONSHIP BETWEEN HEAT AND TEMPERATURE*

- Heat is a **form of energy**. Heat depends on the **speed** of the particles and on their mass, which is the **number of particles**.
- Temperature takes into account only the **speed particles** of a substance or their degree of agitation. Temperature measures heat.
- Temperature is usually expressed in degrees Celsius (°C), and heat, in joules (J).

SAMPLE QUESTIONS

- 1) Which of the following statements correctly describes the difference between heat and temperature?
- A) **Temperature takes into account only the speed of particles of a substance or their degree of agitation. Heat depends on the speed of the particles and on their mass.**
- B) Temperature takes into account only the speed of particles of a substance or their degree of agitation. Heat depends on the temperature.
- C) Heat takes into account only the speed of particles of a substance or their degree of agitation. Temperature depends on the speed of the particles and on their mass.
- D) Heat takes into account only the speed of particles of a substance or their degree of agitation. Temperature depends on the mass of the particles.

2) Below are situations in which the concepts of *heat* and *temperature* are involved:

- 1) The degree of agitation of the molecules decreases when the substance is cooled. **TEMPERATURE**
- 2) Today it's 25°C outside. **TEMPERATURE**
- 3) Ice melts in the water. **HEAT**
- 4) The optimal temperature for making French fries is between 375°F and 400°F. **TEMPERATURE**
- 5) Human body temperature is about 37°C. **TEMPERATURE**

Which of the following represents a correct description of the above concepts?

- A) **1 – temperature; 2 – temperature; 3 - heat; 4 – temperature; 5 – temperature**
- B) 1 – heat; 2 –temperature; 3- heat; 4 – temperature; 5 – temperature
- C) 1 – temperature; 2 –heat; 3- heat; 4 – temperature; 5 – temperature
- D) 1 – heat; 2 –temperature; 3- heat; 4 – heat; 5 – temperature

3) **DEFINE THE ENERGY EFFICIENCY OF A DEVICE OR SYSTEM AS THE PROPORTION OF ENERGY CONSUMED THAT IS TRANSFORMED INTO EFFECTIVE WORK (amount of useful energy / amount of energy consumed x100)**

- In an isolated system, the total amount of energy remains constant. In a **non-isolated** system, energy is **dispersed** in the environment.
- The energy efficiency of a machine or a system is the **percentage of energy** consumed that was transformed into useful energy.
- Energy efficiency is calculated using the equation below, and the result is expressed as a **percentage**.

$$\text{EnergyEfficiency} = \frac{\text{AmountOfUsefulEnergy}}{\text{AmountOfEnergyConsumed}} \times 100\%$$

SAMPLE PROBLEMS

- 1) To perform work equal to 3600 J, a machine consumes 14 000 J. *What is the energy efficiency of this machine?*

<p>Given:</p> <p><i>Energy consumed=14 000 J</i></p> <p><i>Useful energy = 3600 J</i></p>	<p>Solution:</p> <p><i>Energy efficiency = $\frac{\text{amt.of useful energy}}{\text{amt.of energy consumed}} \times 100\%$</i></p> <p><i>$E = \frac{U}{C} \times 100 = \frac{3600 \text{ J}}{14000 \text{ J}} \times 100 = 60\%$</i></p>	
<p>Required: <i>Energy efficiency=?</i></p>	<p>Answer: <i>The energy efficiency of this machine is 60%</i></p>	

- 2) *Calculate the amount of useful energy of a car if its energy efficiency is 70% and the amount of energy consumed is 3200 J.*

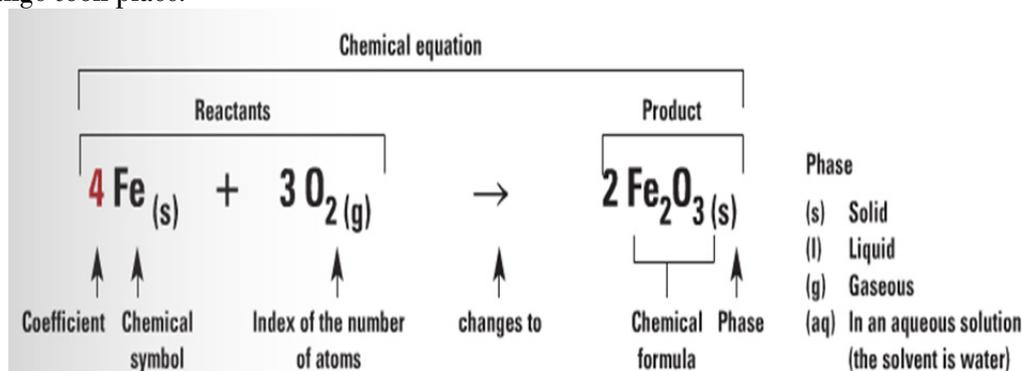
<p>Given:</p> <p><i>energy efficiency=70%=0.7</i></p> <p><i>energy consumed =3200 J</i></p>	<p>Solution:</p> <p><i>Energy efficiency = $\frac{\text{amt.of useful energy}}{\text{amt.of energy consumed}} \times 100\%$</i></p> <p><i>$U = E \times C = 0.7 \times 3200 = 2240 \text{ J}$</i></p>	
<p>Required: <i>Useful energy=?</i></p>	<p>Answer: <i>The amount of useful energy is 2240J</i></p>	

- 3) *Calculate the amount of energy consumed by an electronic device that produces 410 kJ of energy and has an efficiency of 75%.*

<p>Given:</p> <p><i>useful energy =410 kJ</i></p> <p><i>energy efficiency=75%=0.75</i></p>	<p>Solution:</p> <p><i>Energy efficiency = $\frac{\text{amt.of useful energy}}{\text{amt.of energy consumed}} \times 100\%$</i></p> <p><i>$C = \frac{U}{E} = \frac{410 \text{ kJ}}{0.75} = 546.7 \text{ kJ}$</i></p>	
<p>Required: <i>Energy consumed?</i></p>	<p>Answer: <i>The amount of energy consumed is 546.7 kJ</i></p>	

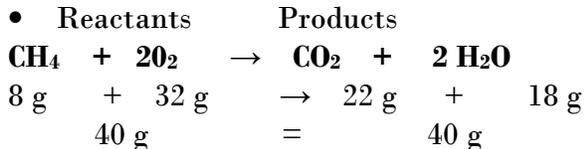
4) EXPLAIN THE LAW OF CONSERVATION OF MASS DURING A CHEMICAL REACTION

- Chemical changes occur when the **bonds** between reactants (initial substances) are broken to form new **products** (final substances), whose characteristic properties are **different**.
- A chemical change, or chemical reaction, can be represented by a **chemical equation**, which shows how the change took place.



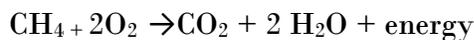
The law of conservation of mass states that ***in a chemical change the mass of the reactants is equal to the mass of the products. Another way of explaining this concept is that mass is not created, nor destroyed.***

Example:

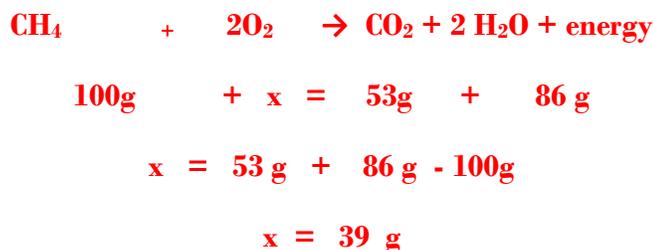


SAMPLE PROBLEMS

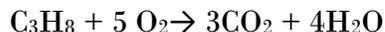
1) The following chemical equation represents the combustion of methane gas (CH₄)



100 g of methane reacts completely with a certain amount of oxygen. During the reaction, 53 g of CO₂ and 86 g of water are produced. ***What was the mass of the oxygen?***



2) The following chemical equation represents the combustion of propane gas (C₃H₈).



58 g of propane reacts completely with a certain amount of oxygen. During the reaction, 32 g of CO₂ and 43 g of water are produced. *What was the mass of the oxygen?*

A) 133 g

B) 17 g

C) 26 g

D) 15 g

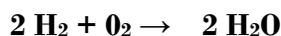


$$58\text{g} + x = 32\text{g} + 43\text{g}$$

$$x = 32\text{g} + 43\text{g} - 58\text{g}$$

$$x = 17\text{g}$$

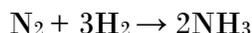
3) Given the following equation:



If 8 g of hydrogen reacts completely with 64 g of oxygen, *what will be the mass of water formed?*

$$\text{Answer: } 8\text{g} + 64\text{g} = 72\text{g}$$

4) The following equation describes the synthesis of ammonia:



If 56 g of nitrogen (N₂) is combined with hydrogen (H₂) and 68 g of ammonia (2NH₃) is produced, what mass of hydrogen was used?



$$56\text{g} + x = 68\text{g}$$

$$x = 68\text{g} - 56\text{g}$$

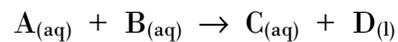
$$x = 12\text{g}$$

Answer: The mass of hydrogen used is 12g

5) In the course of an experiment, you react a solution of sodium iodide, NaI_(aq) with a solution of lead nitrate, Pb(NO₃)_{2(aq)}. The mass of the reactants prior to the experiment is 32.35 g. Following the experiment you find that the mass of the products is also 32.35 g. *What law is demonstrated by this experiment?*

THE LAW OF CONSERVATION OF MASS

- 6) On mixing two aqueous solutions, you observe from the products that a neutralization reaction has occurred. The equation and results below illustrate this chemical reaction.



$$35 \text{ g} + ? \text{ g} \rightarrow 75 \text{ g} + 56 \text{ g}$$

Apply the Law of Conservation of Mass to find the amount of reactant B that must have been present.

Answer:

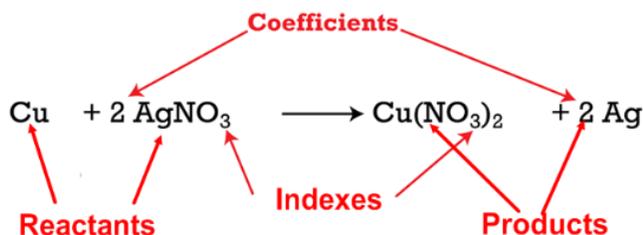
$$35 \text{ g} + X = 75 \text{ g} + 56 \text{ g}$$

$$X = 75 \text{ g} + 56 \text{ g} - 35 \text{ g}$$

$$X = 96 \text{ g}$$

5) BALANCE CHEMICAL EQUATIONS

- Balancing chemical equation is another way of ensuring that the law of conservation of mass is respected. Mass is not created, nor destroyed, therefore all reacting atoms must be found on the product side, of course as part of different molecules.
- When the equation is balanced, the number of atoms of each element must be the same in the *reactants* (reagents) and the *products*.
- These rules must be followed to balance a chemical equation:
 - only *coefficients* may be added;
 - the *indexes* in the chemical formulas of compounds cannot be changed;
 - do not write the coefficient 1; it is *understood*;
 - coefficients must be *whole numbers* reduced to the *lowest term*;



Ex. 1:



- even though the atoms have been arranged in different compounds, the number of atoms of each element remains the same on each side of the equation

	Reactants	Products
Na	1	1
O	1	1
H	2	2
Cl	1	1

Ex. 2



	Reactants	Products
Zn	1	1
H	2	2
Cl	2	2

In the example above, the equation has been balanced by using 2 HCl in the reactants.

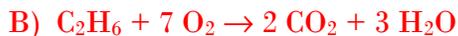
SAMPLE PROBLEMS

- 1) Which of the following chemical equations is consistent with the law of conservation of mass?

To solve problems like this one, you always need to count the number of atoms on every side of the equation. Draw a table with two columns: one for the atoms in the reactant side, one for the atoms in the product side. Count each of them and write their number. If for every element the two numbers are equal, the equation is balanced.



Number of atoms before the reaction	Number of atoms after the reaction
H $3 \times 2 + 2 \times 3 = 12$	H $12 \times 2 = 24$
S 3	S 3
O $4 \times 3 + 2 \times 3 = 18$	O $4 \times 3 + 12 \times 1 = 24$
Al 2	Al 2



Number of atoms before the reaction	Number of atoms after the reaction
C 2	C 2
H 6	H 6
O $7 \times 2 = 14$	O $2 \times 2 + 3 \times 1 = 7$



Number of atoms before the reaction	Number of atoms after the reaction
Fe 2	Fe 4
O 6	O 6
C 3	C 3



Number of atoms before the reaction	Number of atoms after the reaction
N 8	N $6 + 2 = 8$
H $8 \times 3 = 24$	H $6 \times 4 = 24$
Cl $3 \times 2 = 6$	Cl $6 \times 1 = 6$

- A) $3 \text{H}_2\text{SO}_4 + 2 \text{Al}(\text{OH})_3 \rightarrow \text{Al}_2(\text{SO}_4)_3 + 12 \text{H}_2\text{O}$
B) $\text{C}_2\text{H}_6 + 7 \text{O}_2 \rightarrow 2 \text{CO}_2 + 3 \text{H}_2\text{O}$
C) $\text{Fe}_2\text{O}_3 + 3 \text{CO} \rightarrow 4 \text{Fe} + 3 \text{CO}_2$
D) $8 \text{NH}_3 + 3 \text{Cl}_2 \rightarrow 6 \text{NH}_4\text{Cl} + \text{N}_2$

2) Identify the missing substance in the following balanced equation:



- a) NaCO **b) Na₂CO₃** c) NaCO₃ d) 2NaCO₃

3) Consider the chemical reactions represented by the equations below. *Which one represents an equation in which the law of conservation of matter is respected?*

- A) $2 \text{NO} + \text{O}_2 \rightarrow \text{NO}_2$
B) **$2 \text{Na} + 2 \text{H}_2\text{O} \rightarrow 2 \text{NaOH} + \text{H}_2$**
C) $\text{H}_3\text{PO}_4 + \text{KOH} \rightarrow \text{K}_3\text{PO}_4 + 3 \text{H}_2\text{O}$
D) $3 \text{HBr} + \text{Fe}(\text{OH})_3 \rightarrow \text{FeBr}_3 + 6 \text{H}_2\text{O}$

4) In neutralizing sulfuric acid, H₂SO₄, with caustic soda, NaOH, sodium sulfate, Na₂SO₄, and water are produced. *Which equation represents this chemical reaction?*

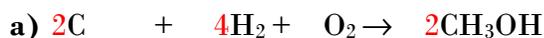
- A) **$\text{H}_2\text{SO}_4 + 2 \text{NaOH} \rightarrow \text{Na}_2\text{SO}_4 + 2 \text{H}_2\text{O}$**
B) $\text{Na}_2\text{SO}_4 + 2 \text{H}_2\text{O} \rightarrow \text{H}_2\text{SO}_4 + 2 \text{NaOH}$
C) $\text{H}_2\text{SO}_4 + \text{NaOH} \rightarrow \text{Na}_2\text{SO}_4 + 2 \text{H}_2\text{O}$
D) $\text{Na}_2\text{SO}_4 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{SO}_4 + 2 \text{NaOH}$

5) Consider the chemical reactions represented by the equations below. *Which one represents a neutralization equation in which the law of conservation of matter is respected?*

The law of conservation of mass is respected if the equation is balanced. The number of atoms of each type is the same on the reactant and the product side. B is also a balanced equation, but IT IS NOT a neutralization reaction. In a neutralization reaction an acid and a base are represented on the left side of the equation and a salt and water are represented on the right.

- A) $2 \text{NO} + \text{O}_2 \rightarrow \text{NO}_2$
B) $2 \text{Na} + 2 \text{H}_2\text{O} \rightarrow 2 \text{NaOH} + \text{H}_2$
C) **$\text{H}_3\text{PO}_4 + 3 \text{KOH} \rightarrow \text{K}_3\text{PO}_4 + 3 \text{H}_2\text{O}$**
D) $3 \text{HBr} + \text{Fe}(\text{OH})_3 \rightarrow \text{FeBr}_3 + 6 \text{H}_2\text{O}$

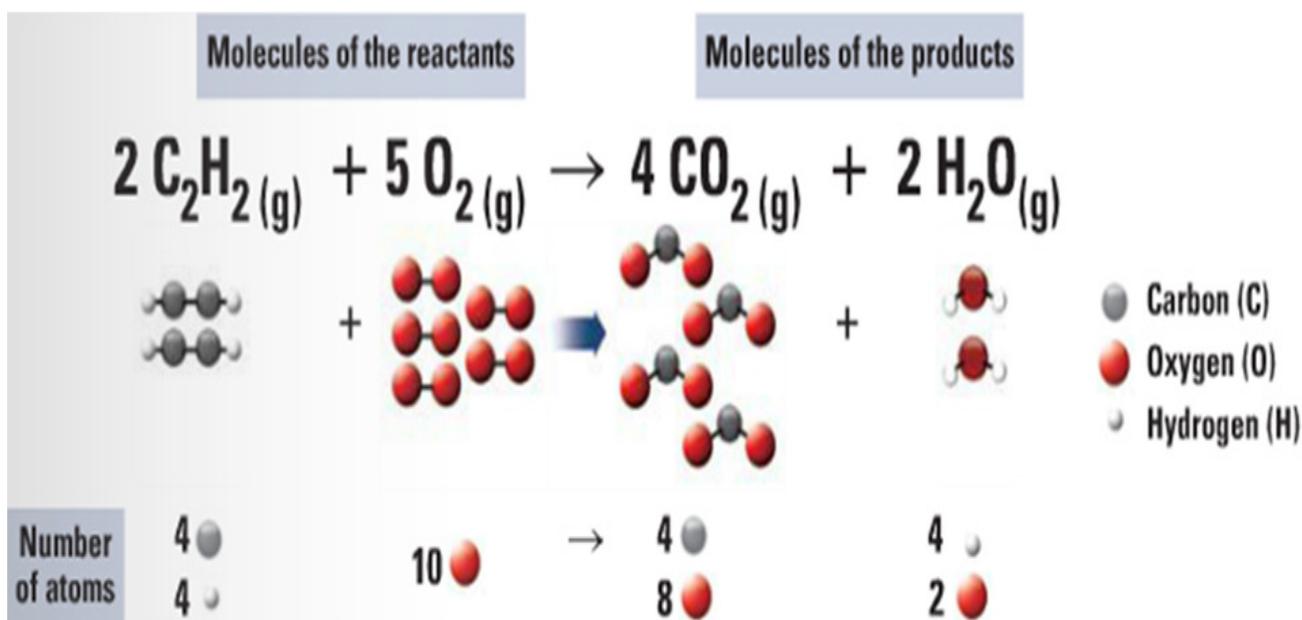
6) Balance each of the following chemical equations:



6) REPRESENT THE CONSERVATION OF MASS USING THE PARTICLE MODEL

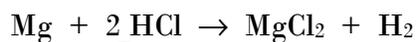
- Another way of ensuring that the law of conservation of mass is respected, is counting and drawing all atoms involved in chemical reactions
- *Mass is not created, nor destroyed*, therefore all reacting atoms must be found on the product side, of course as part of different molecules.

Example: the combustion of acetylene (C₂H₂)



SAMPLE PROBLEMS

- 1) A strip of magnesium (Mg) reacts with concentrated hydrochloric acid (HCl) to produce magnesium chloride (MgCl₂) and hydrogen gas (H₂). The balanced equation for this reaction is as follows:

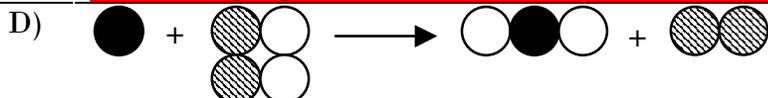
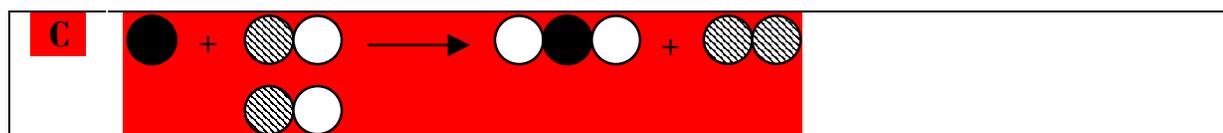
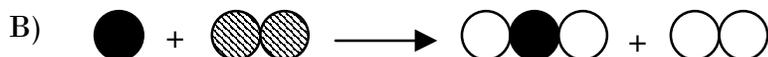
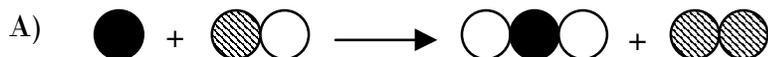


: Magnesium

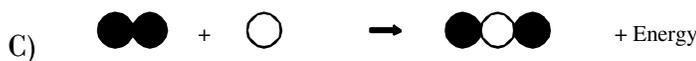
: Hydrogen

: Chlorine

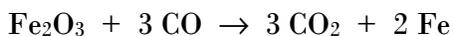
If we refer to the legend above, *which of the following models correctly represents this balanced equation?*



2) Carbon burns in the presence of oxygen, O_2 , to form carbon dioxide, CO_2 . The carbon atom is represented by \bullet and the oxygen atom by \circ . *Which model represents this chemical reaction?*

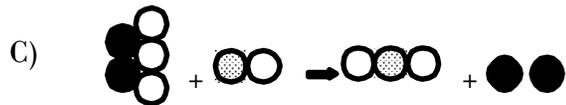
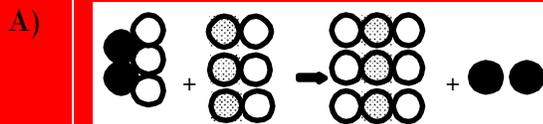


3) Hematite is a mineral that contains iron oxide (Fe_2O_3). In order to extract iron (Fe) from hematite, carbon monoxide (CO) is reacted with the mineral at a very high temperature. The balanced equation for the reaction is:



Which of the models illustrated below represents this reaction?

Iron : \bullet Carbon : \circ Oxygen : \circ



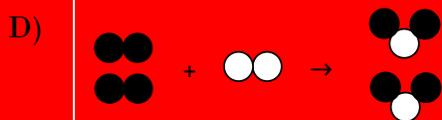
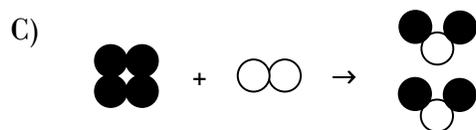
- 4) During a chemical reaction, two molecules of hydrogen gas, H_2 , react with one molecule of oxygen gas, O_2 , to produce two molecules of water, H_2O . The balanced chemical equation for this reaction is as follows:



Below are four proposed models of the balanced chemical equation for this reaction. They were constructed using the following symbols:

Hydrogen: ● Oxygen: ○

Which of these models represents the balanced chemical equation for this reaction?



- 5) John neutralizes hydrobromic acid (HBr) with potassium hydroxide (KOH) and obtains potassium bromide (KBr) and water.

- 1) *Write the balanced chemical equation for the reaction.*
- 2) *Represent the reaction using the particle model.*

1) Reaction :



2) Legend :

K : ● O : ○ H : ○ Br : ●

