Chapter 17:
HOW CHEMICALS REACT
This lecture will help you understand:

- Chemical Equations
- Counting Atoms and Molecules by Mass
- Reaction Rates
- Catalysts
- Energy and Chemical Reactions
- Chemical Reactions Are Driven By Entropy
Chemical Equations

During a chemical reaction, one or more new compounds are formed as a result of the rearrangement of atoms.

Reactants $\rightarrow$ Products

$2 \text{H}_2(g) + 1 \text{O}_2(g) \rightarrow 2 \text{H}_2\text{O}(g)$ (balanced)
Chemical Equations

*Law of Mass Conservation:* No atoms are gained or lost during any reaction.
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The number of times atoms appear before the arrow must be equal to the number of times they appear after the arrow.
In total, how many atoms are represented by the following schematic for a chemical reaction?

A. 2
B. 5
C. 6
D. 12
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Explanation:
The atoms of the reactants are the SAME atoms of the products, except in a different configuration.
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“conventional” equation format

All you see here are six different atoms!
Is this reaction balanced?

A. Yes
B. No
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A. Yes
B. No
How many “diatomic” molecules are represented?

A. 1  
B. 2  
C. 3  
D. 4
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A. 1
B. 2
C. 3
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Explanation:
The diatomic molecule shown with the products is actually the same molecule shown to the left with the reactants. What happened here is that this molecule didn’t react.
How many “diatomic” molecules are represented?

A. 1  
B. 2  
C. 3  
D. 4  

Explanation:
The diatomic molecule shown with the products is actually the same molecule shown to the left with the reactants. What happened here is that this molecule didn’t react.
Is the following chemical equation balanced?

\[ 1 \text{CH}_4 + 2 \text{O}_2 \rightarrow 2 \text{H}_2\text{O} + 1 \text{CO}_2 \]

A. No, because the molecules have changed.
B. Yes, because the coefficients on each side add up to the same number.
C. No, because there are more oxygen atoms in the products.
D. Yes, because the same atoms appear before and after.
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Counting Atoms and Molecules By Mass

• Chemists need a way to mathematically express a chemical equation.
Counting Atoms and Molecules By Mass

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• Periodic table gives the formula mass of the elements.
Counting Atoms and Molecules By Mass

The mass of one carbon atom is approximately 12 amu.
The mass of one oxygen molecule is approximately 32 amu.

A carbon atom is \( \frac{12}{32} \), or \( \frac{3}{8} \), as massive as an oxygen molecule.

Number of carbon atoms = Number of oxygen molecules

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Counting Atoms and Molecules By Mass

• Avogadro’s number relates the mass to the number of molecules.
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Counting Atoms and Molecules By Mass

2 \ce{H_2} + 1 \ce{O_2} \rightarrow 2 \ce{H_2O}

2 moles
which is
4 g
which is
12.04 \times 10^{23} \text{ molecules}

1 mole
which is
32 g
which is
6.02 \times 10^{23} \text{ molecules}

2 moles
which is
36 g
which is
12.04 \times 10^{23} \text{ molecules}
How many moles are in 45.5 grams of chlorine gas?

A. 0.55 moles
B. 0.64 moles
C. 1.28 moles
D. 1.34 moles
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A. 0.55 moles  
B. 0.64 moles  
C. 1.28 moles  
D. 1.34 moles

*Hint:* Chlorine gas is a diatomic, Cl₂.
How many moles are in 45.5 grams of chlorine gas?

A. 0.55 moles
B. 0.64 moles
C. 1.28 moles
D. 1.34 moles

Explanation:
One mole of chlorine, Cl₂, is 71 grams. So 45.5 grams is 45.5/71 = 0.64 moles.
How many grams of water are produced from 1.25 moles of methane?

\[
1 \text{ CH}_4 + 2 \text{ O}_2 \rightarrow 2 \text{ H}_2\text{O} + 1 \text{ CO}_2
\]

A. 11.25 grams  
B. 22.5 grams  
C. 45 grams  
D. 90 grams
How many grams of water are produced from 1.25 moles of methane?

\[ 1 \text{ CH}_4 + 2 \text{ O}_2 \rightarrow 2 \text{ H}_2\text{O} + 1 \text{ CO}_2 \]

A. 11.25 grams
B. 22.5 grams
C. 45 grams
D. 90 grams

**Explaination:**

1 mole of methane will produce 2 moles of water, so 1.25 moles of methane will produce 2.5 moles of water.

Do you understand that one mole of water is 18 grams? If so, then you should see that 2.5 moles is 45 grams.
How many moles of carbon dioxide are produced from 50 grams of methane?

\[
1 \text{CH}_4 + 2 \text{O}_2 \rightarrow 2 \text{H}_2\text{O} + 1 \text{CO}_2
\]

A. 0.78 moles
B. 1.57 moles
C. 3.13 moles
D. 6.26 moles
How many moles of carbon dioxide are produced from 50 grams of methane?

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C. 3.13 moles  
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Explanation:
First convert the 50 grams of methane to moles of methane. Because there is a 1:1 ratio of methane to carbon dioxide, this is the same number of moles of carbon dioxide that will be formed. Convert this number of moles to grams knowing that 1 mole of carbon dioxide is 44 grams.
Reaction Rates

Reaction rate: The speed with which products form from the reactants.
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Affected by

- Concentration
- Temperature
- Catalyst
Reaction Rates

Reaction rate: The speed with which products form from the reactants.

Affected by
- Concentration
- Temperature
- Catalysts

Premise:
Reactant molecules have to make physical contact with each other in order to transform into products.
Reaction Rates

Reaction rate: The speed with which products form from the reactants.

Affected by

- Concentration

The more concentrated a sample of nitrogen and oxygen, the greater the likelihood that N₂ and O₂ molecules will collide and form nitrogen monoxide.
Reaction Rates

Reaction rate: The speed with which products form from the reactants.

Affected by

- Temperature

Slow-moving molecules may collide without enough force to break the bonds. In this case, they cannot react to form product molecules.
Catalysts

Reaction rate: The speed with which products form from the reactants.

Affected by

- Catalysts

Reactant molecules must gain a minimum amount of energy, called the activation energy, $E_{act}$, in order to transform into product molecules.
Catalysts

Reaction rate: The speed with which products form from the reactants.

Affected by

- Catalysts

A catalyst has the effect of lowering the activation energy, which allows for the reaction to proceed at a quicker rate.
Carefully examine the following reaction sequence of the catalytic formation of ozone, O₃, from molecular oxygen, O₂. Which chemical is behaving as the catalyst?

\[
\begin{align*}
\text{O}_2 & + 2 \text{ NO} \rightarrow 2 \text{ NO}_2 \\
2 \text{ NO}_2 & \rightarrow 2 \text{ NO} + 2 \text{ O} \\
2 \text{ O} + 2 \text{ O}_2 & \rightarrow 2 \text{ O}_3
\end{align*}
\]

A. Nitrogen dioxide, NO₂
B. Nitrogen monoxide, NO
C. Atomic oxygen, O
D. Oxygen, O₂
Carefully examine the following reaction sequence for the catalytic formation of ozone, O\textsubscript{3}, from molecular oxygen, O\textsubscript{2}. Which chemical compound is behaving as the catalyst?

\[ \text{O}_2 + 2 \text{NO} \rightarrow 2 \text{NO}_2 \]
\[ 2 \text{NO}_2 \rightarrow 2 \text{NO} + 2 \text{O} \]
\[ 2 \text{O} + 2 \text{O}_2 \rightarrow 2 \text{O}_3 \]

A. Nitrogen dioxide, NO\textsubscript{2}
B. **Nitrogen monoxide, NO**
C. Atomic oxygen, O
D. Oxygen, O\textsubscript{2}

**Explanation:**
The NO reacts with O\textsubscript{2} to form O, which reacts with O\textsubscript{2} to form O\textsubscript{3}. In other words, the NO gets this reaction going. As another clue, note how NO is regenerated after the second reaction.
Energy and Chemical Reactions

Exothermic reaction: A chemical reaction that results in the net production of energy.

reactants $\rightarrow$ products $+$ energy
Exothermic reaction: A chemical reaction that results in the net production of energy.

Reactants $\rightarrow$ Products $+$ Energy

Endothermic reaction: A chemical reaction in which there is a net consumption of energy.

Energy $+$ Reactants $\rightarrow$ Products
# Energy and Chemical Reactions

<table>
<thead>
<tr>
<th>Bond</th>
<th>Bond Energy (kJ/mole)</th>
<th>Bond</th>
<th>Bond Energy (kJ/mole)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H—H</td>
<td>436</td>
<td>N—N</td>
<td>159</td>
</tr>
<tr>
<td>H—C</td>
<td>414</td>
<td>O—O</td>
<td>138</td>
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<tr>
<td>H—N</td>
<td>389</td>
<td>Cl—Cl</td>
<td>243</td>
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<tr>
<td>H—O</td>
<td>464</td>
<td>C=O</td>
<td>803</td>
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<td>H—F</td>
<td>569</td>
<td>N=O</td>
<td>631</td>
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<tr>
<td>H—S</td>
<td>339</td>
<td>O=O</td>
<td>498</td>
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<tr>
<td>H—Cl</td>
<td>431</td>
<td>C≡C</td>
<td>837</td>
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<tr>
<td>C—C</td>
<td>347</td>
<td>N≡N</td>
<td>946</td>
</tr>
</tbody>
</table>

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Use the bond energies below to determine whether the following reaction is exothermic or endothermic:

\[ \text{H}_2 + \text{Cl}_2 \rightarrow 2 \text{HCl} \]

- H-H (bond energy: 436 kJ/mol)
- Cl-Cl (bond energy: 243 kJ/mol)
- H-Cl (bond energy: 431 kJ/mol)

A. Exothermic, with more than 50 kJ of energy released.
B. Endothermic, with more than 50 kJ of energy absorbed.
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\[-679 \text{ kJ/mol (absorbed)} + 862 \text{ kJ/mol (released)} = 183 \text{ kJ/mol} \]

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\[ \begin{align*} 
\text{H}_2 & \quad 436 \text{ kJ/mol} \quad 243 \text{ kJ/mol} \quad 679 \text{ kJ/mol} \quad \text{(absorbed)} \\
\text{Cl}_2 & \quad 431 \text{ kJ/mol} \\
2 \text{HCl} & \quad 862 \text{ kJ/mol} \quad \text{(released)} \\
\end{align*} \]

\[ \Delta = 862 - 679 = 183 \text{ kJ/mol released} \]

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Chemical Reactions Are Driven By Entropy

It is the natural tendency of energy to disperse from where it is concentrated to where it is dilute.
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Examples

A hot pan radiates heat
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Examples

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- Gasoline combusts into smaller molecules
Chemical Reactions Are Driven By Entropy

It is the natural tendency of energy to disperse from where it is concentrated to where it is dilute.

Examples

A hot pan radiates heat
Gasoline combusts into smaller molecules
Marbles bouncing on the floor come to a stop
Chemical Reactions Are Driven By Entropy

It is the natural tendency of energy to disperse from where it is concentrated to where it is dilute.

*Entropy:* The term used to describe the degree to which energy has become dispersed.
Chemical Reactions Are Driven By Entropy

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*Entropy:* The term used to describe the degree to which energy has become dispersed.

Reactions that result in an increase in entropy (energy dispersal) tend to occur on their own.
Which type of chemical reaction leads to a greater dispersal of energy?

A. Exothermic  B. Endothermic
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A. Exothermic  
B. Endothermic
Chemical Reactions Are Driven By Entropy

• Exothermic reactions tend to be self-sustaining, because they lead to large increases in entropy.
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• Exothermic reactions tend to be self-sustaining because they lead to large increases in entropy.

Example: A campfire
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• Endothermic reactions tend to require the continual input of energy.
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  *Example:* A campfire

- Endothermic reactions tend to require the continual input of energy.

  *Example:* Photosynthesis