General Chemistry

Lecture 5

The Mole

- The Mole is the standard unit of measurement for the amount of substances or chemical units
- A mole of a substance contains 6.02×10^{23} atoms of that substance
- 6.02×10^{23} is Avagadro's number (named after an Italian physicist)

Moles of Elements in a Formula

- 1 mole of an element contains 6.02×10^{23} atoms of that element
  - Ex) 1 mole of C contains 6.02×10^{23} atoms of C
- 1 mole of a compound contains 6.02×10^{23}
  - Ex) 1 mole of $C_6H_{12}O_6$ contains the following
    - 6 moles of C
    - 12 moles of H
    - 6 moles of O

Molar Mass

- A mole of a substance is a unit of measuring elements and compounds in a practical way using an ordinary scale
- The molar mass of an element is the quantity in grams that equals the atomic mass of an element
- To equal this quantity in grams it would take 6.02×10^{23} atoms of that element
  - Ex) 1 mole of C would equal 12.01g of the element C and would contain approximately 6.02×10^{23} atoms of carbon
- The molar mass of compounds is determined by multiplying the molar mass of each element by its subscript and adding the results
  - Ex) Li_2CO_3 – 2 moles Li x 6.94 g Li/1 mole Li = 13.8g of Li, 12.0g C/1 mole C, 3 moles O x 16.0 g O/1 mole O = 48.0g O
    molar mass of = 13.6g of Li + 12.o g C + 48.0g of O = 73.8g Li_2CO_3

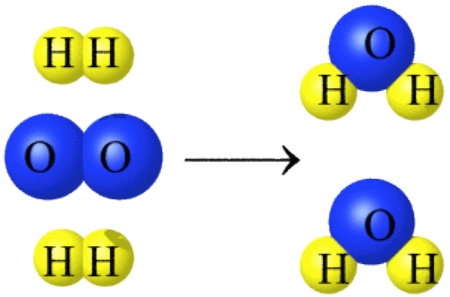
Calculations Using Molar Mass

- Molar mass is used to convert from moles of a substance to grams or from grams to moles

Chemical Equations

Chemical Properties and Chemical Change

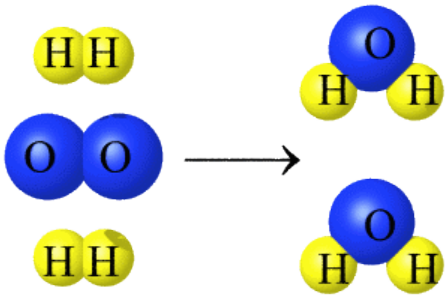
- Chemical properties describe the ability of a substance to change into a new substance
- When a chemical change occurs, the original substance is converted to one or more new substances.
  - Ex) $O_2 + 2\ H_2 \rightarrow 2H_2O$



- In a chemical equation, the formulas of the reactants are written on the left of the arrow and the formulas of the products are on the right
- If there are two or more formulas on the same side, a + sign is used
- Δ indicates heat was used
- The state (solid –s, liquid – l, or gas – g) is often indicated
- If the substance is dissolved in water (aq) is noted to indicate

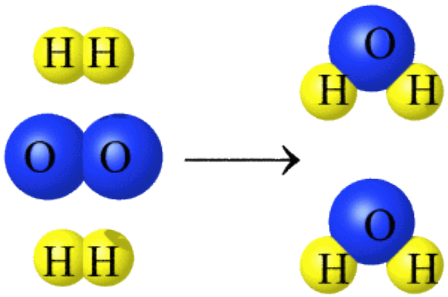
Chemical Properties and Chemical Change

- Each reaction must be written as a balanced equation, which shows the same number of atoms of each element in the reactants and products



- When chemical reactions occur, the bonds are broken and formed so that there is a difference between the reactants and products.
- However, the amount of atoms are the same on both sides of the equation
- Atoms are neither gained, lost, or changed into other types of atoms during a chemical reaction

Chemical Properties and Chemical Change



- A compound is written by giving its chemical formula. This formula lists the symbols of the elements that make it up and indicates the number of atoms of each element with a subscript
- If no subscript is given, it is understood to be 1
- $C_{12}H_{22}O_{11}$, H_20, NaCl

Types of Reactions

- A great number of reactions occur in nature
- These include
  - Combination reactions
    - $S + O_2 \rightarrow SO_2$
  - Decomposition reactions
    - $S + O_2 \rightarrow SO_2$
    - $CaCO_3 \rightarrow CaO + CO_2$
  - Replacement reactions
    - $Zn + 2HCl \rightarrow ZnCl + H_2$
  - Combustion reactions
    - $CH_4 + 2OH \rightarrow CO_2 + 2H_2O + energy$
  - Oxidation-Reduction Reaction

Oxidation, Free Radicals and Antioxidants

Oxidation - Reduction

- Oxidation and Reduction occur simultaneously and are referred to as redox reactions
- Oxidation is seen with the browning of fruit, rusting of metal, and with the patina seen on copper all when exposed to oxygen
  - Therefore early understanding of oxidation involved the introduction of oxygen to other substances
    - $2H_2 + O_2 \rightarrow 2H_2O$ – the hydrogen is oxidized and the oxygen is reduced

Oxidation - Reduction

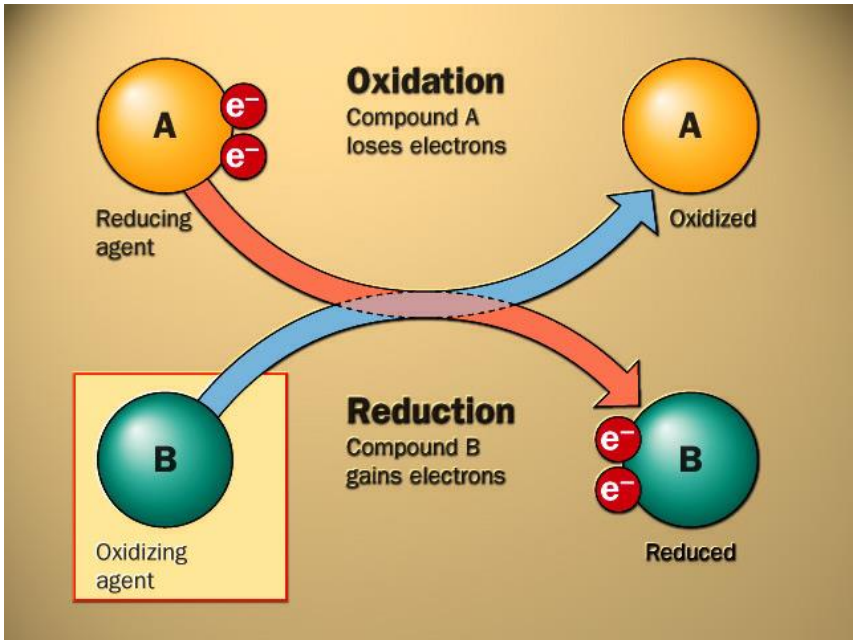
- This description was not complete enough to describe all redox reactions.
- Another way to describe oxidation and reduction is that oxidation involves the loss of hydrogen and reduction involves the gain of hydrogen through the adding or removal of hydrogen
  - $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$ – both the carbon and hydrogen are oxidized, part of the oxygen is reduced

Oxidation - Reduction

- And another way of describing redox reactions can help describe oxidation that does not involve oxygen.
- This involves the transfer of electrons.
- In this model, a substance that loses electrons is said to be oxidized while a substance that gains electrons is reduced
  - $Mg + Cl_2 \rightarrow Mg_2^+ + 2Cl^-$ - Magnesium is oxidize while the chlorine is reduced
  - This is the easiest and most important use of the term oxidation and reduction and can be remembered by the memory aid OIL RIG (Oxidation Involves Loss – Reduction Involves Gain)

Oxidation – Reduction Information for the Test

- For the test, we can define oxidation and reduction as follows
  - –Oxidation is the loss of electrons and results in the loss of hydrogen atoms together with one or two electrons or the gain of an oxygen atom or hydroxyl group
  - –Reduction is the gain of electrons and results in the gain of hydrogen atoms or loss of an oxygen atom
  - –If a substance gains electrons (and is reduced), it is referred to as an oxidizing agent

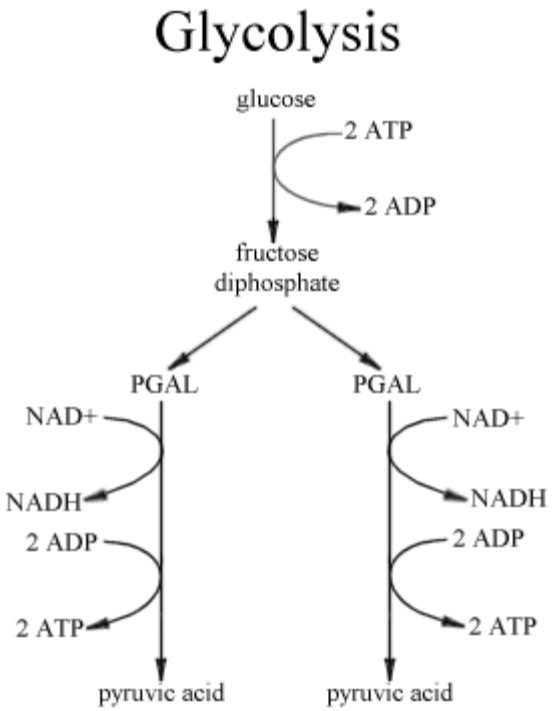


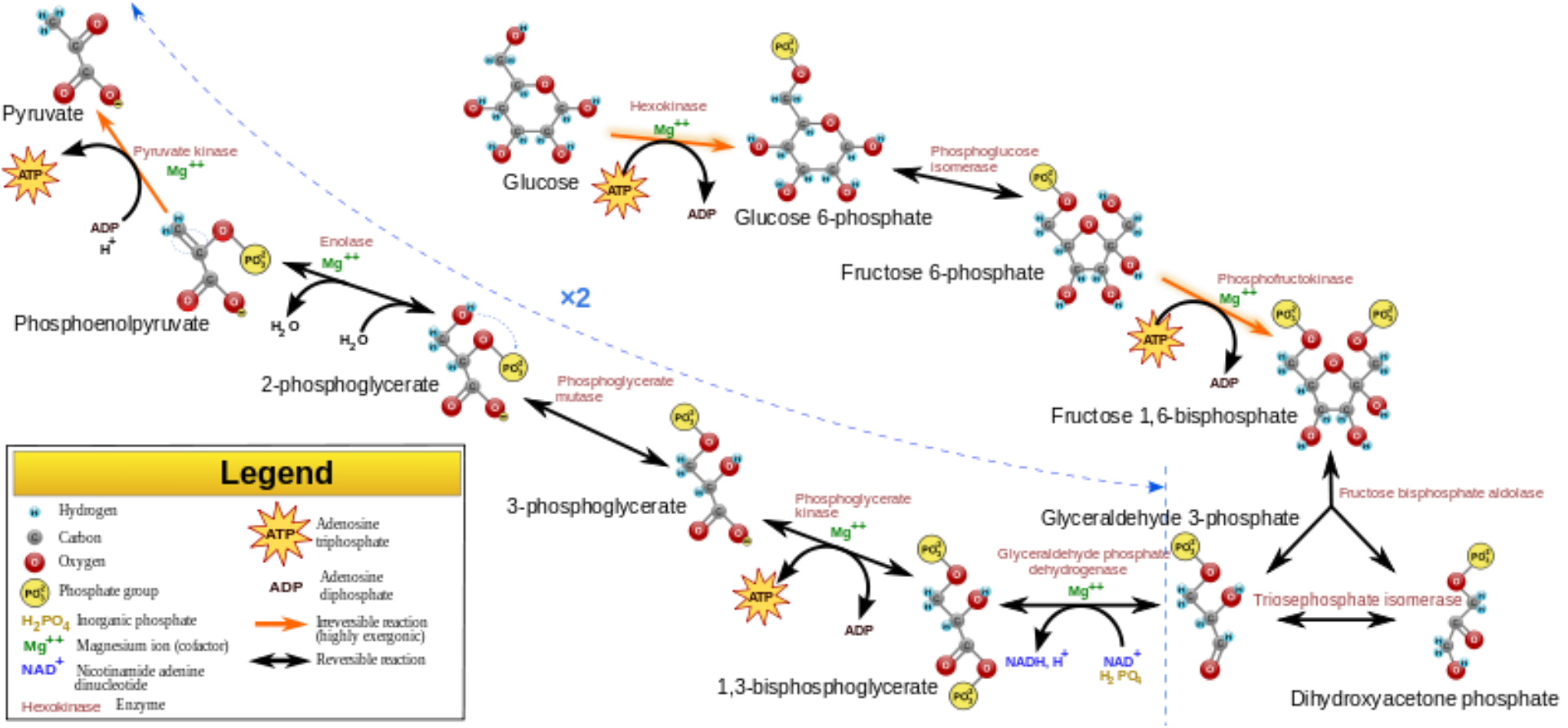
Glucose Oxidation

- These reactions are involved in the oxidation of glucose to provide energy
- Glucose oxidation is a chemical process that provides energy for an organism to carry out all of its required activities.
- During this process, glucose, a simple sugar molecule obtained from food, is broken down into carbon dioxide and water.
  - $C_6H_{12}O_6 + 6O_2 \quad 6CO_2 + 6H_2O$
- This reaction releases energy and stores it in a chemical form (ATP) for the cell to use.
- There are three separate stages of glucose oxidation:
  - Glycolysis,
  - The citric acid cycle (Krebs cycle),
  - Electron transport system (Oxidative Phosphorylation)

Glycolysis

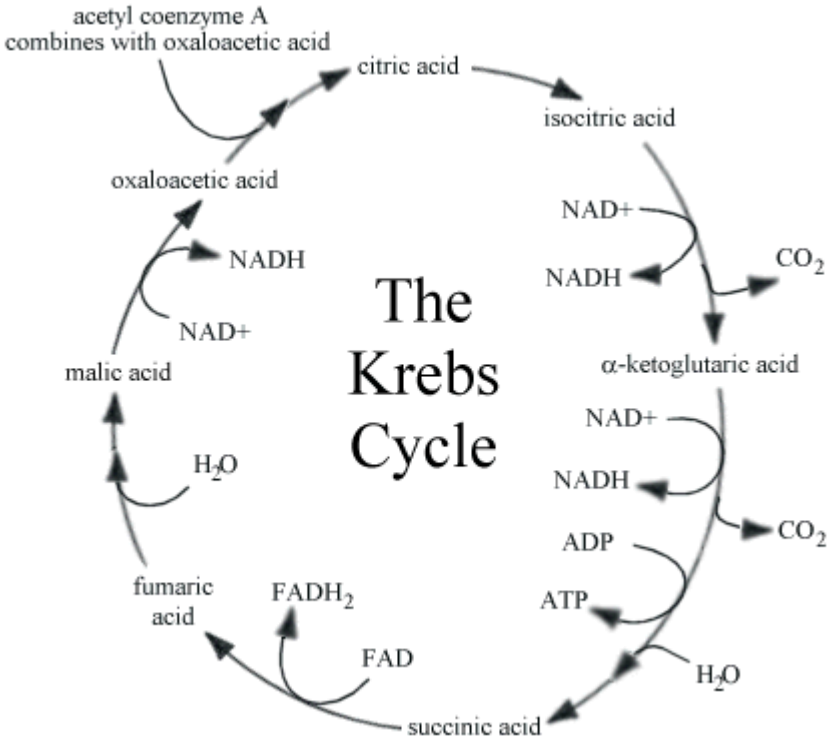
- During glycolysis, glucose molecules (six-carbon molecules) are split into two pyruvates (three-carbon molecules) during a sequence of enzyme-controlled reactions
- Glycolysis is the breakdown of glucose to two molecules of pyruvate
  - This process uses enzymes to catalyze the reactions
  - These reactions collectively use 2 ATP molecules, but create 4 ATP molecules

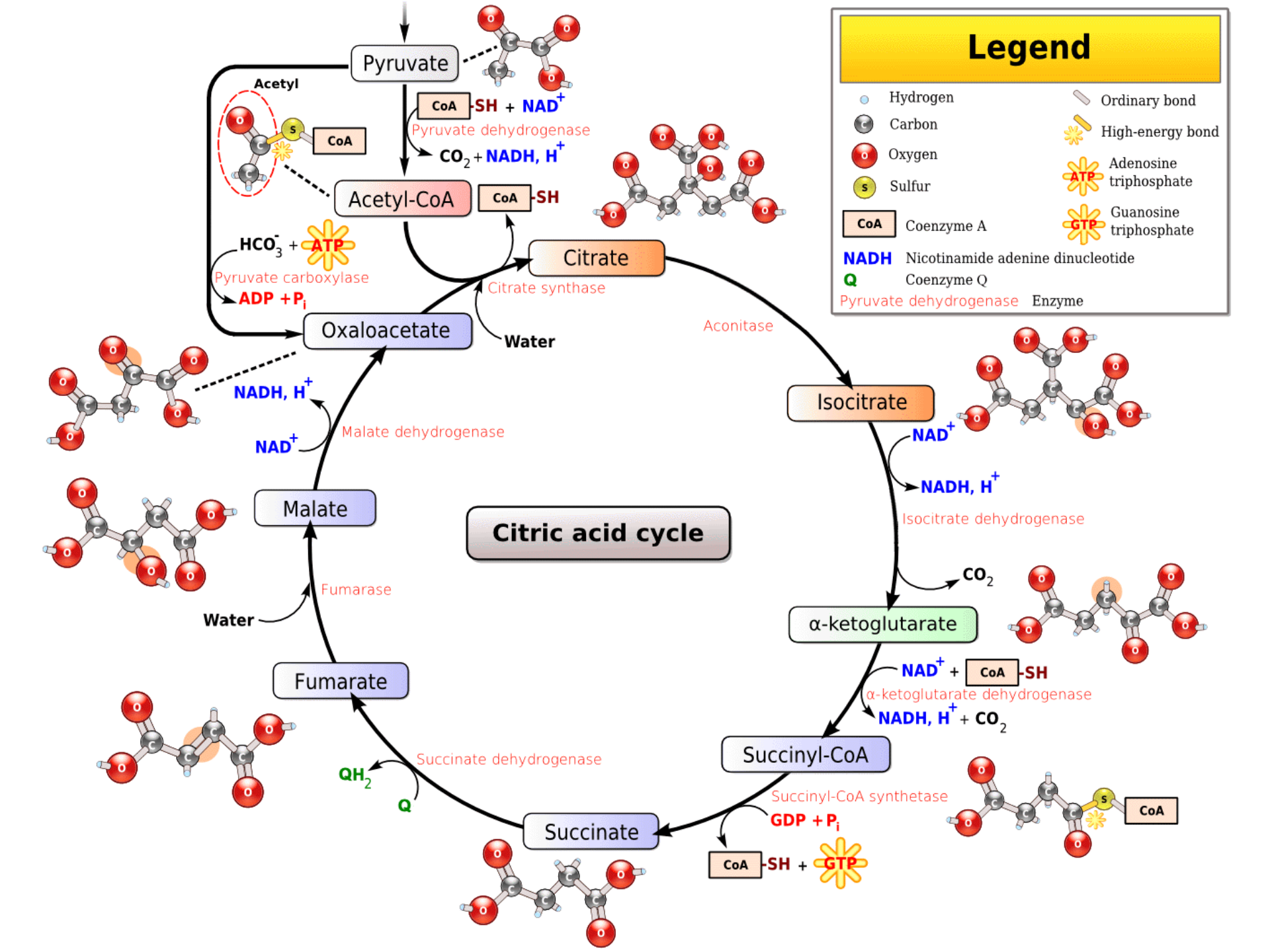



Pyruvate
Pyruvate kinase
Mg++
ATP
ADP
H+
Phosphoenolpyruvate
Enolase
Mg++
H2O
H2O
2-phosphoglycerate
×2
Phosphoglycerate mutase
3-phosphoglycerate
Phosphoglycerate kinase
Mg++
ATP
ADP
1,3-bisphosphoglycerate
Glyceraldehyde phosphate dehydrogenase
Mg++
NADH, H+
NAD+
H2PO4
Glyceraldehyde 3-phosphate
Triosephosphate isomerase
Dihydroxyacetone phosphate
Fructose bisphosphate aldolase
Fructose 1,6-bisphosphate
Phosphofructokinase
Mg++
ATP
ADP
Fructose 6-phosphate
Phosphoglucose isomerase
Glucose 6-phosphate
Hexokinase
Mg++
ATP
ADP
Glucose
Legend
Hydrogen
Carbon
Oxygen
Phosphate group
H2PO4 Inorganic phosphate
Mg++ Magnesium ion (cofactor)
NAD+ Nicotinamide adenine dinucleotide
Hexokinase Enzyme
ATP Adenosine triphosphate
ADP Adenosine diphosphate
Irreversible reaction (highly exergonic)
Reversible reaction

Krebs Cycle and Electron Transport

- Pyruvate is metabolized by the Krebs cycle (citric acid cycle), again with the assistance of enzymes
  - –These reactions metabolize pyruvate to CO_2
  - –They produces two more ATP molecules
- These reaction also produce other molecules which are used to transfer H^+ into the mitochondria to produce even more ATP
  - –32 ATP molecules are created




Legend
Hydrogen
Carbon
Oxygen
Sulfur
Ordinary bond
High-energy bond
Adenosine triphosphate
Guanosine triphosphate
CoA Coenzyme A
NADH Nicotinamide adenine dinucleotide
Q Coenzyme Q
Pyruvate dehydrogenase Enzyme
Citric acid cycle
Pyruvate
Acetyl
CoA
Acetyl-CoA
Pyruvate dehydrogenase
Pyruvate carboxylase
Citrate
Citrate synthase
Water
Oxaloacetate
Malate dehydrogenase
Malate
Fumarase
Fumarate
Succinate dehydrogenase
Succinate
Succinyl-CoA synthetase
Succinyl-CoA
α-ketoglutarate dehydrogenase
α-ketoglutarate
Isocitrate dehydrogenase
Isocitrate
Aconitase

Oxidation of Glucose

Glycolysis, Krebs Cycle, Oxidative Phosphorylation

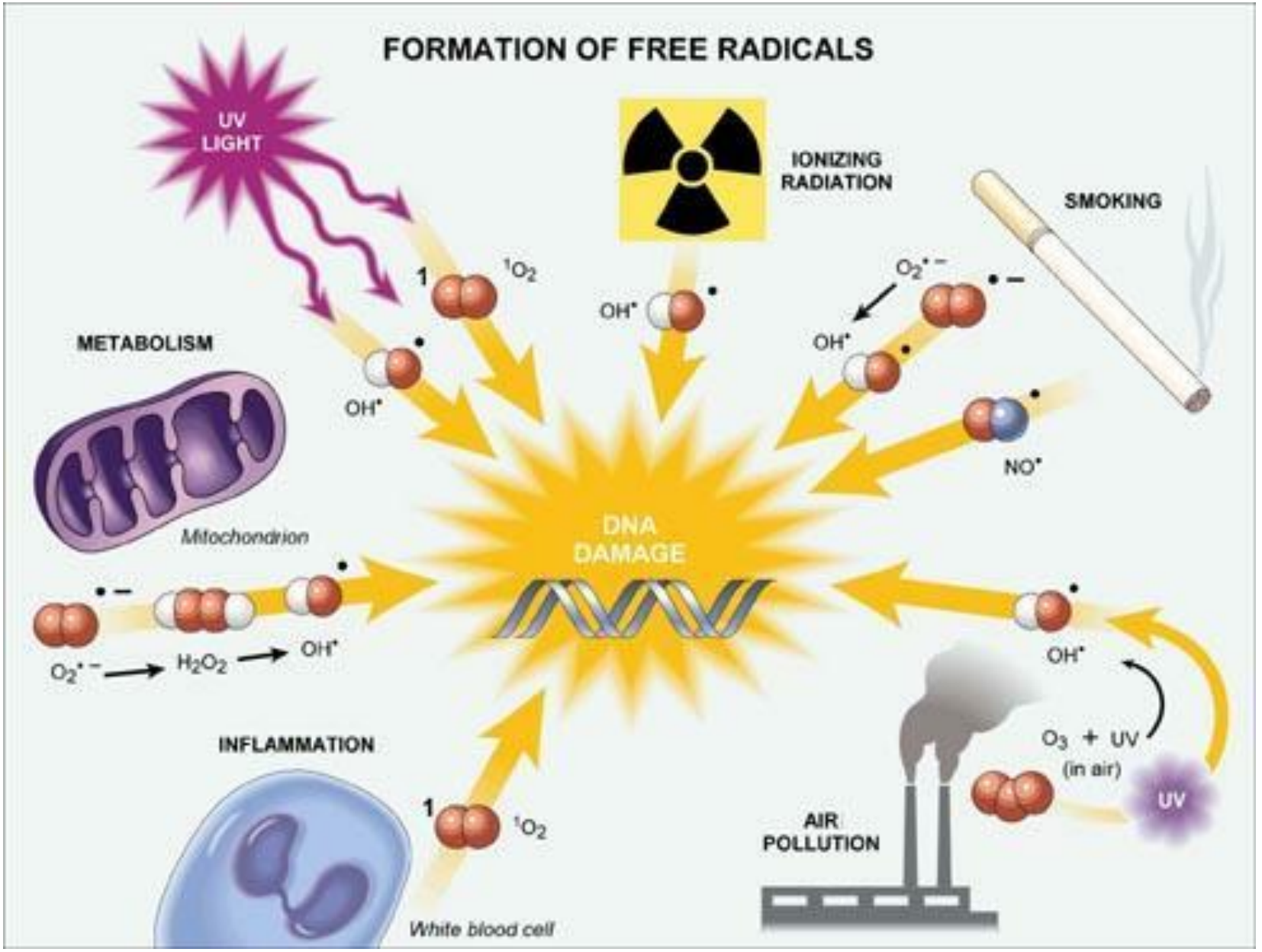
- Collectively 36 molecules of ATP are produced
- Collectively they use oxygen to 'burn' glucose and metabolize it into CO_2 and H_20
  - $C_6H_{12}O_6 + 6O_2 >> 6CO_2 + 6H_2O$

Oxidation
Free Radical Damage and Antioxidants

- Radicals are compounds that have an unpaired electron usually in the outer orbital (open electron shell)
- Free radicals are radicals that exist independently in solution or in a lipid environment
- Free radical damage is responsible for things becoming rancid or decaying and are involved in tissue damage and aging
- Radicals are created in many reaction in the body as intermediate steps and many times are not released into cells and are not harmful

Oxidation
Free Radical Damage and Antioxidants

- Other compounds can be converted to free radicals
- This occurs due to being exposed to an oxidizing agent that removes an electron from another substance or by radiation
- Free radicals are unstable and are always searching for electrons
- When the get the opportunity, they ‘steal’ and electron from another compound, thus turning it into a free radical
- This can be especially damaging to DNA or the plasma membrane of cells
- Compounds that are radicals can be written with or without the radical showing
  - Nitrogen dioxide (NO_2 - a radical in smog and cigarette smoke) may be designated as $NO_2\bullet$


FORMATION OF FREE RADICALS
UV LIGHT
IONIZING RADIATION
SMOKING
METABOLISM
Mitochondrion
DNA DAMAGE
INFLAMMATION
White blood cell
AIR POLLUTION
UV
(in air)
$^1O_2$
OH•
$O_2^{\bullet -}$
NO•
H_2O_2
O_3 + UV

Oxidation
Free Radical Damage and Antioxidants

- Antioxidants, found in large quantities in fresh fruits and vegetables can react with free radicals and stop this chain reaction
- There are several enzyme systems in the body that scavenge free radicals, but there are also important micronutrient sources such as:
  - **Vitamin E** : d-alpha tocopherol. A fat soluble vitamin present in nuts, seeds, vegetable and fish oils, whole grains (esp. wheat germ), fortified cereals, and apricots
  - **Vitamin C** : Ascorbic acid. is a water soluble vitamin present in citrus fruits and juices, green peppers, cabbage, spinach, broccoli, kale, cantaloupe, kiwi, and strawberries
  - **Beta-carotene** is a precursor to vitamin A (retinol) and is present in liver, egg yolk, milk, butter, spinach, carrots, squash, broccoli, yams, tomato, cantaloupe, peaches, and grains. (NOTE: Vitamin A has no antioxidant properties and can be quite toxic when taken in excess.)
  - Additionally, **selenium**, a trace metal that is required for proper function of one of the body's antioxidant enzyme systems, is sometimes included in this category
  - The body cannot manufacture these micronutrients so they must be supplied in the diet