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Biology Department

Grade 11

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Unit 5
Energy transformation

5.1 Respiration

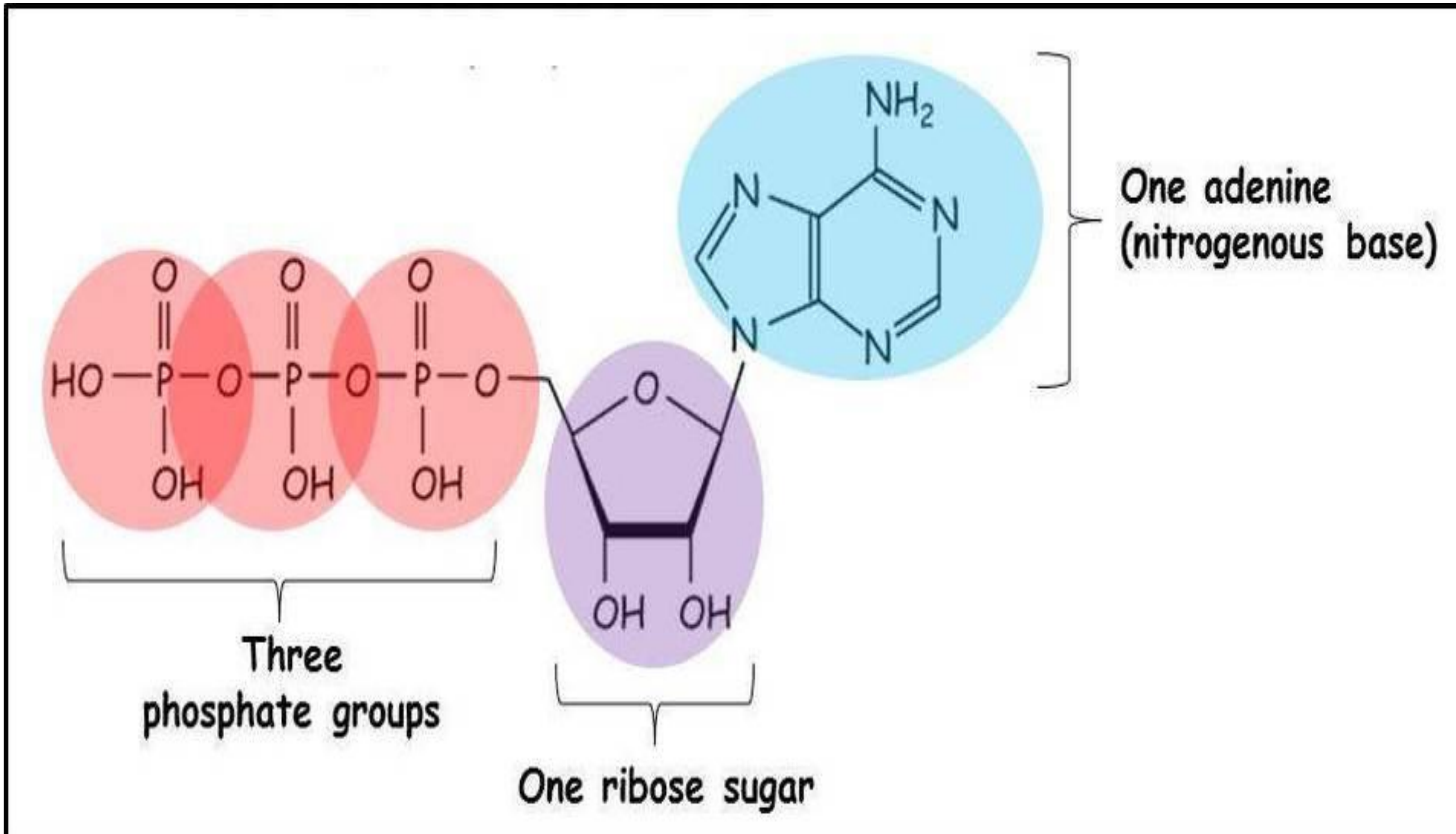
- Respiration is a **biochemical process** in which chemical **energy** in organic molecule is released by **oxidation**
- Many organic molecule can be respired. Such molecule are called **respiratory substrates.**
- The respiratory substrate includes **carbohydrates, lipids and proteins**
- The chemical energy released by oxidation of respiratory substrate is then made available to living cell in the form of **Adenosine triphosphate (ATP).**
- ATP is a molecule found in living organisms. It is the main source of usable energy for the activity of the cell.

The structure of ATP

- The full name for ATP is **Adenosine Tri-Phosphate**
- ATP molecule based on **adenine nucleotides** with **two extra phosphate** groups.
- It is described as a **phosphorylated nucleotide**
- When the third phosphate of ATP split, energy is released and adenosine diphosphate is produced (ADP).

- **ATP made up of:**
  1) **Adenine** (nitrogenous base)
  2) **Ribose** (pentose sugar)
  3) **Three phosphate group**
- **Adenine and ribose** sugar make **adenosine** (a type of nucleoside)
- Adenosine and 3 phosphate group make ATP

Structure of ATP….

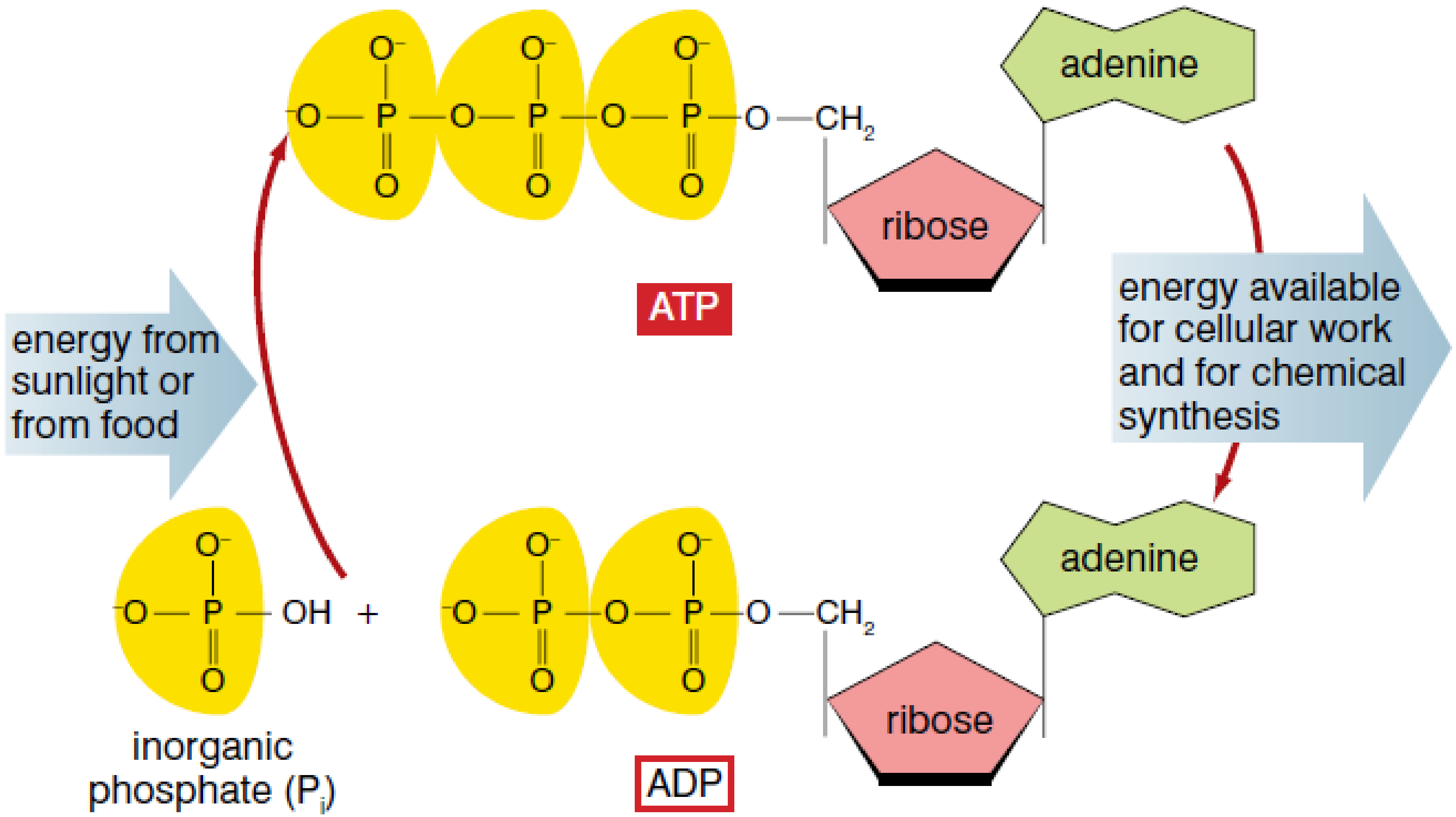


Inter-conversation of ATP and ADP

- ATP is an ideal energy storage molecule (energy currency of a cell)
- Energy to form **ATP** come from **sunlight and food**
- So, ATP is formed in both photosynthesis and in cellular respiration
- The **conversion of ATP into ADP** and inorganic phosphate(Pi) results in **release energy.**
- Likewise, the **conversion of ADP and ATP** absorption of the **same amount of energy.**

$$\text{ATP} + H_2O \underset{\text{Condensation}}{\overset{\text{Hydrolysis}}{\rightleftharpoons}} \text{ADP} + \text{Pi} + \text{Energy}$$

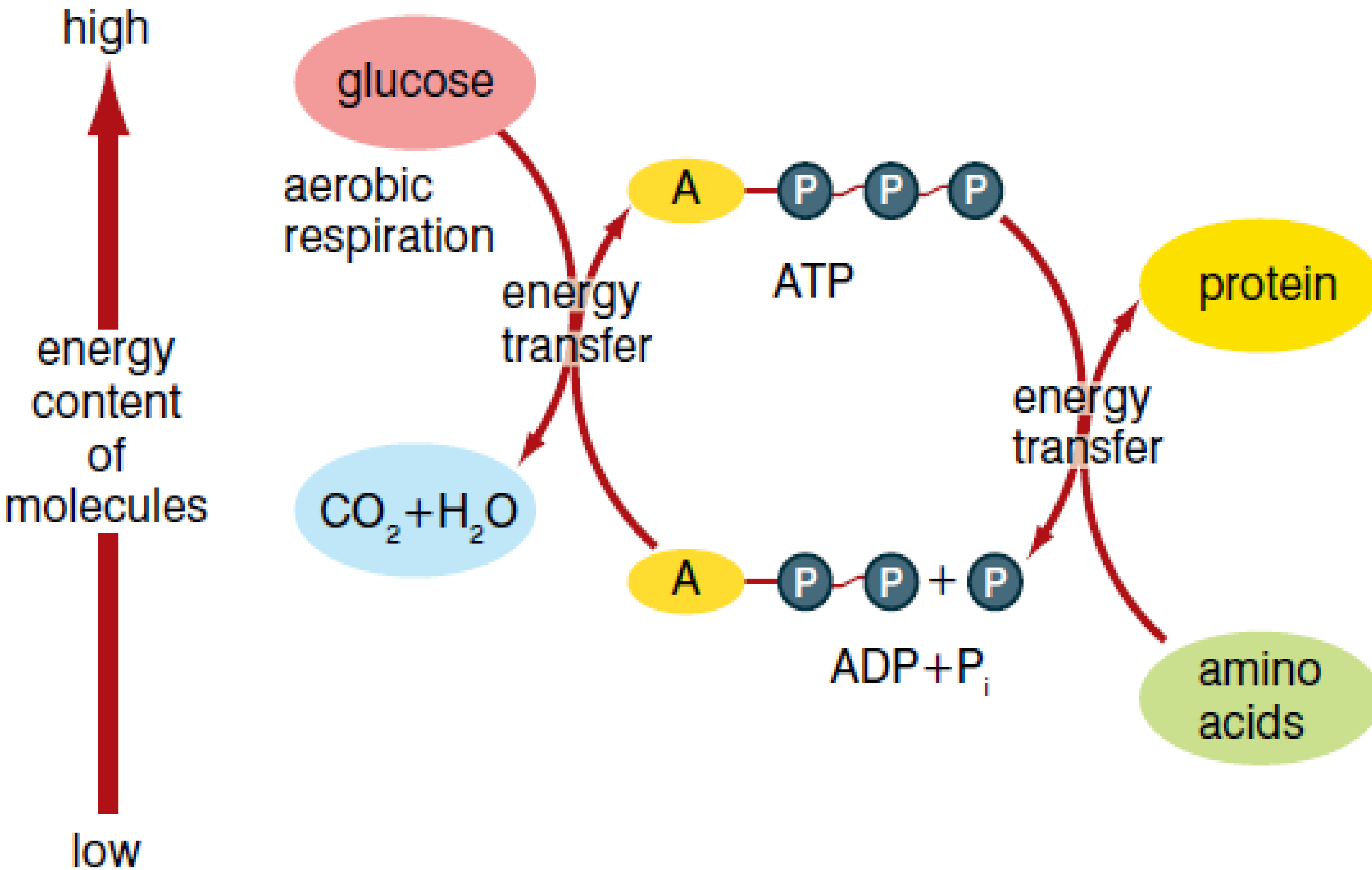
The inter-conversion of ADP and ATP



Energy coupling

- Sunlight energy cannot be used directly by plants to ‘drive’ the synthesis of proteins or any other molecules.
- ATP is used to transfer energy to the relevant cellular process such as production of proteins from amino acids.
- The synthesis of protein and glucose molecule are the source of energy to cellular process
- **Energy coupling:** the transfer of energy from one reaction to another to drive the second reaction
- The Production of ATP is coupled with the reactions that transfer energy.

Energy coupling…



ATP is adapted to transfer energy in cellular process:

1) **Releases energy in small amounts** that are closely matched to the amounts of energy required for cellular reactions
2) **Released energy from the molecule quickly.** Energy release in a single step hydrolysis reaction
3) **ATP is able to move** around within the cell easily, but cannot leave the cell
4) **It is found in all living cell:** universal energy carrier

Examples; cellular processes require energy from ATP

- the synthesis of macromolecules – such as proteins
- active transport across a plasma membrane
- muscle contraction
- conduction of nerve impulses
- The initial reactions of respiration

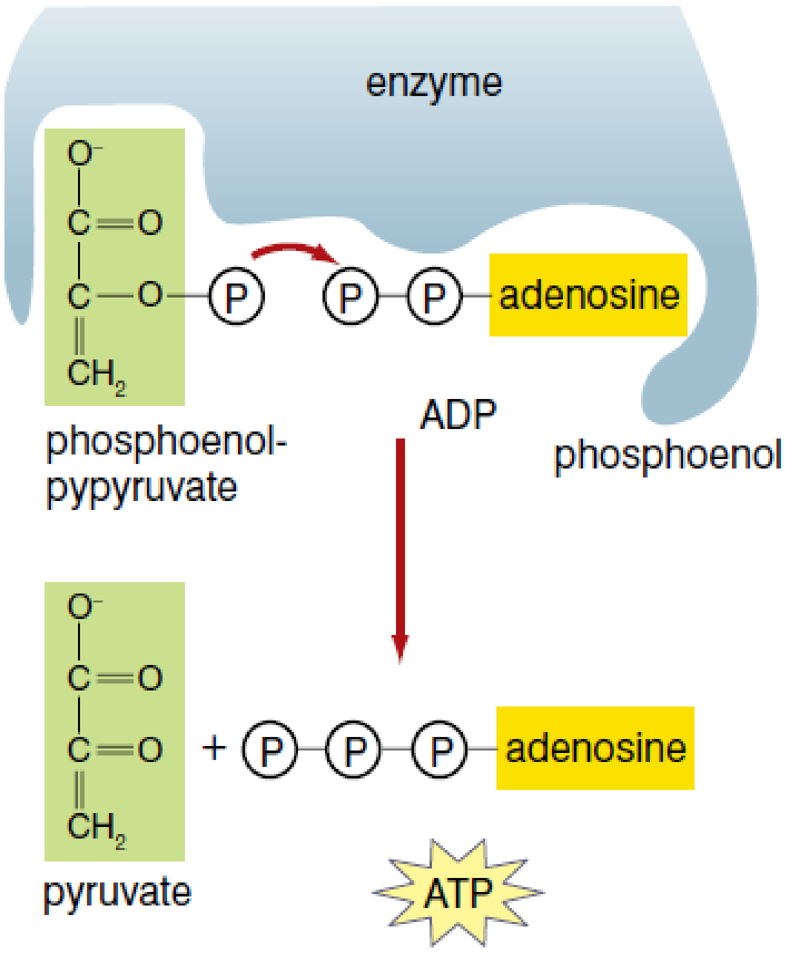
ATP produced in a cell

- The process of making ATP in the cells is basically the same.
- It involves joining of ADP and Pi to form ATP using an input of energy.
- The formation of ATP involves an enzyme called **ATP synthase.**
- ATP synthase is found in membranes of a mitochondrion and chloroplast.
- In both photosynthesis and aerobic respiration, ATP synthase catalyze ATP production.
- **R**espiration can produce ATP in two main pathways:
  1) **Aerobic respiration**–requires the presence of oxygen, and
  2) **Anaerobic respiration**-take place in the absence of oxygen.

Aerobic respiration

1. Substrate level phosphorylation.

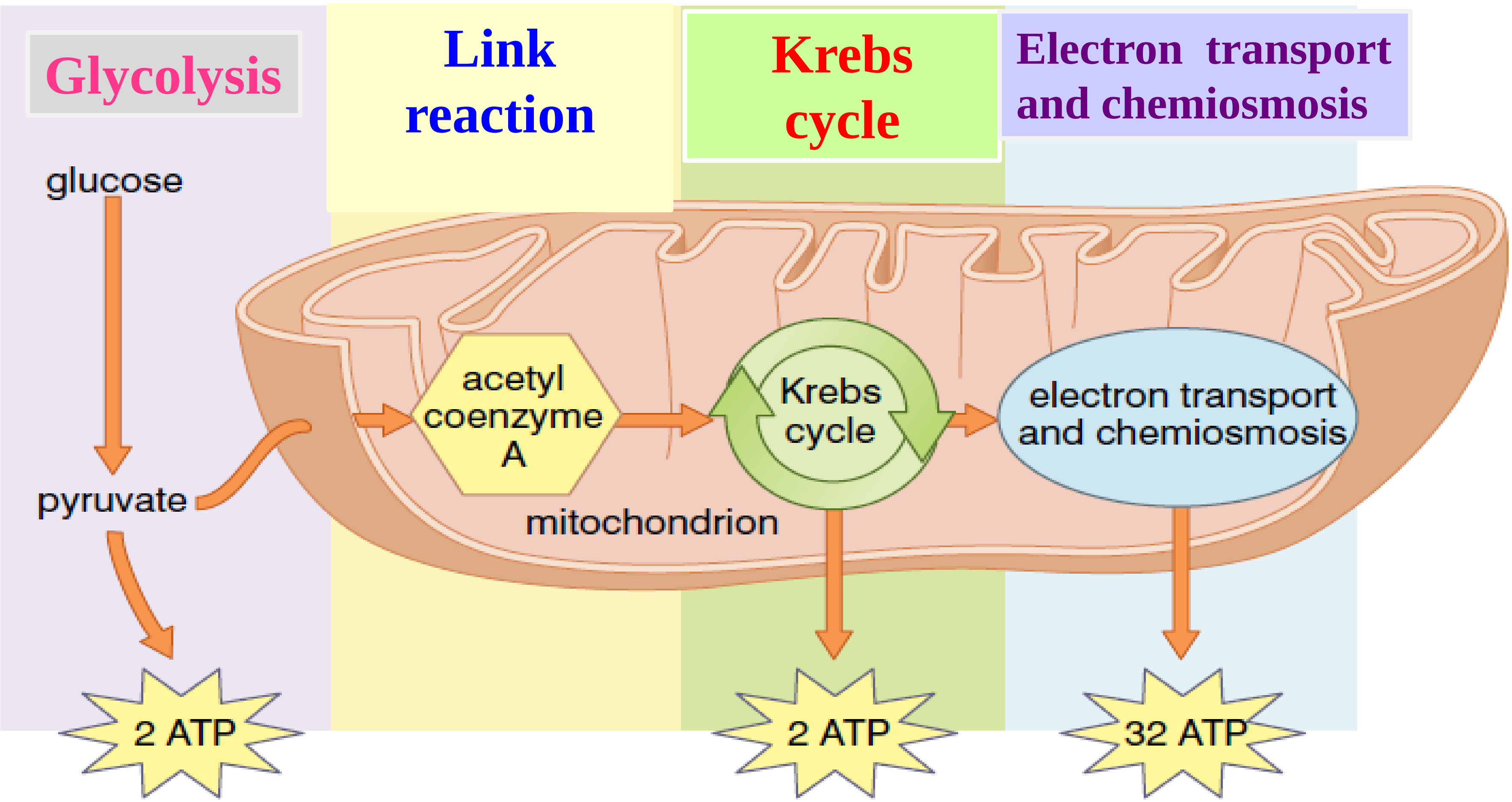
- ATP is synthesis directly from the transfer of Pi group to ADP
- Phosphate containing compound transfer phosphate group directly to ADP, forming ATP
- For example phosphoenol pyruvate transfers a phosphate group directly to ADP.
- An Enzyme ATP synthase not involved
- It produce **10% ATP (4 ATP)** produced in aerobic respiration per glucose molecule.



2. Oxidative phosphorylation

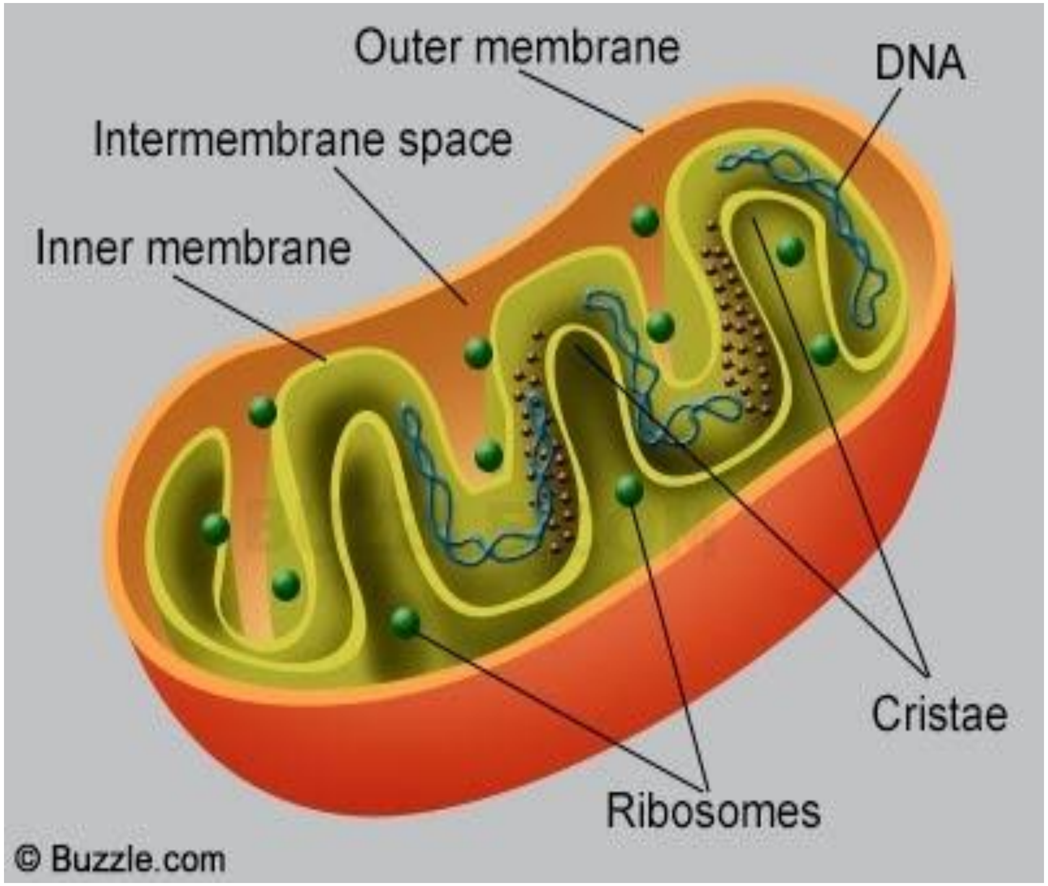
- ATP production as a result of the transfer of electron from NADH or FADH2 to oxygen by a serious of electron carrier.
- It takes place in mitochondria and **involves ATP synthetase enzyme**.
- **90%** (**34ATP**) of ATP produce by oxidative phosphorylation per glucose molecule
- Two molecules are important in the transfer hydrogen ions
  - **Nicotinamide Adenine Dinucleotide (NAD)**
  - **Flavine Adenine Dinucleotide (FAD)**
- Both are capable of accepting hydrogen ions.
  - NADH (reduced NAD) → NAD^+ (NAD oxidized)
  - FADH (reduced FAD) → FAD (FAD oxidised)

The entire phase of respiration of glucose takes place in four stages.



Mitochondria is the site of aerobic respiration

- *Glycolysis takes place in the cytosol of cytoplasm*
- ***Link reaction and Krebs cycle** takes place in **matrix of mitochondria***
- *Electron transport chain takes place in the cristae of mitochondria*



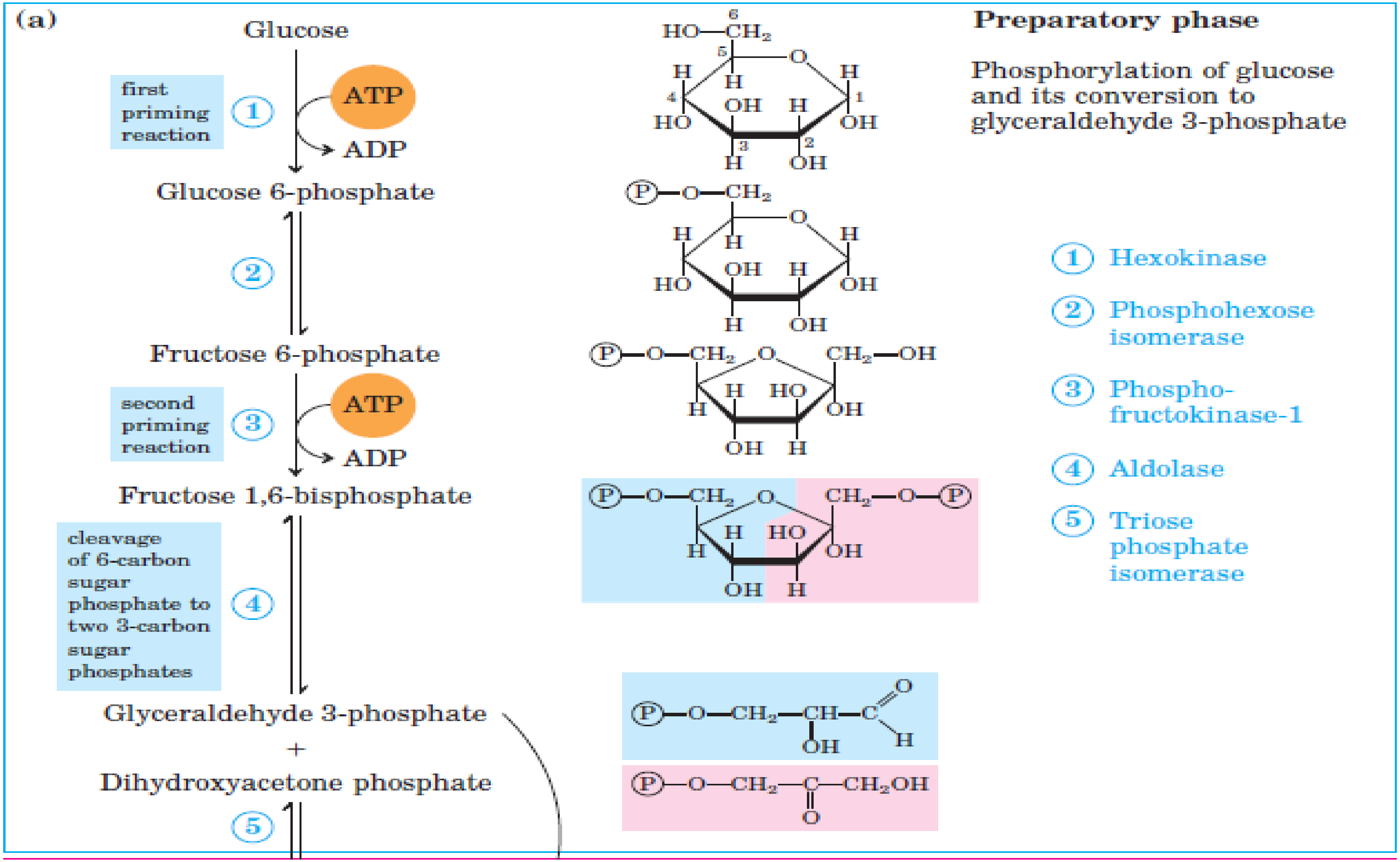
Glycolysis

- The term glycolysis derived from the Greek words,
  - **Glycos**=Sugar,
  - **lysis**=Splitting, therefore it is splitting of glucose
- Glycolysis is common to both aerobic and anaerobic respiration
- It does not require the presence of oxygen. The only energy releasing process in an aerobic respiration
- So glycolysis is anaerobic **breakdown of glucose to 3-carbon atom pyruvate**
- Pyruvate can enter the mitochondria for aerobic respiration
- It takes place in the cytosol of cytoplasm.

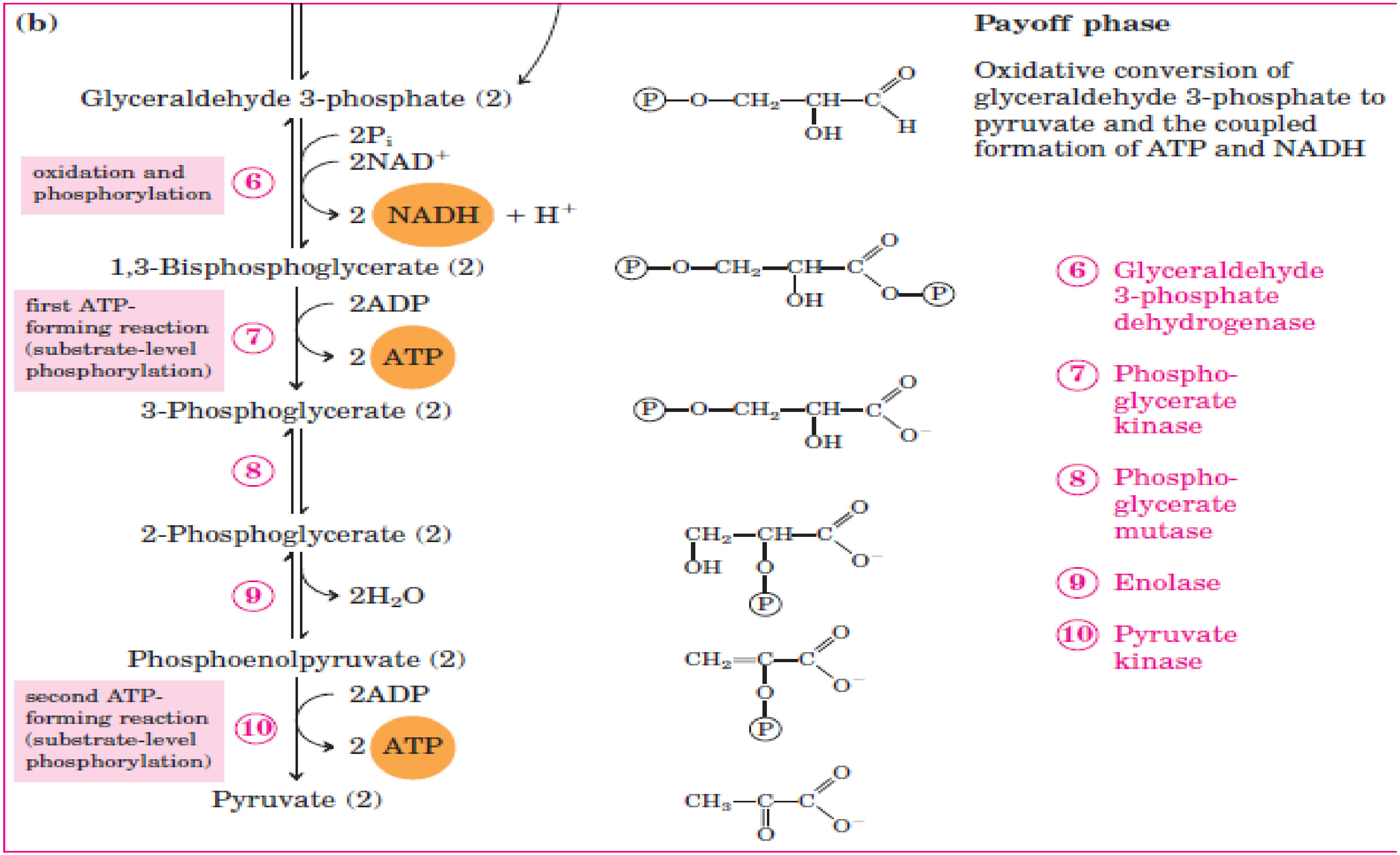
Glycolysis…

- **Glycolysis does not take place inside the mitochondria because:**
  - Glucose is large molecule that cannot diffuse through the mitochondrial membranes.
  - Absence of carrier proteins to transport glucose molecule across the membranes.
- In glycolysis pathway, 2 molecule of ATP are used for the phosphorylation of glucose in first stage.
- Therefore, a net of **two molecule of ATP** synthesised and **two molecule of reduce NAD** (**NADH**) are produce per glucose molecule.
- **Generally in glycolysis**
  - **Input** of glycolysis is **glucose, NAD^+, ADP** and Pi
  - **Output pyruvate, 4 ATP** total **(2 net ATP)** and **2 NADH**

Glycolysis preparatory reaction

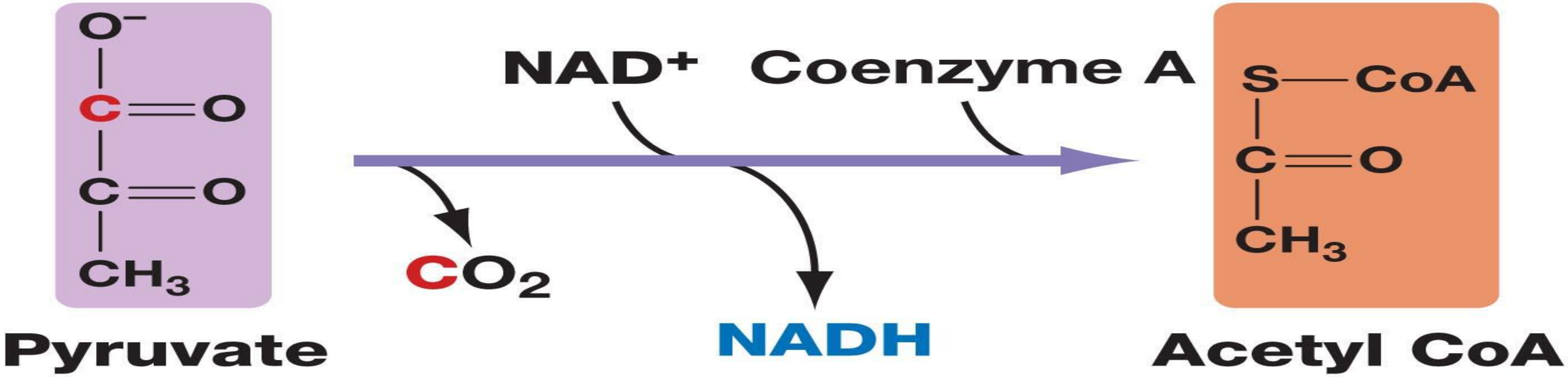


Glycolysis payoff reaction



2. Link reaction /conversion of pyruvate to acetyl Co A/

- Link reaction is the stage between glycolysis and Krebs cycle
- **Takes place** in the **matrix of mitochondria**
- **Two pyruvate** transported into matrix of mitochondria
- **3-carbon compound pyruvat**e converted into **2 carbon acetyl CoA**



In the link reaction

- **Decarboxylation:** removing of carbon dioxide from the molecule
  - Decarboxylation of pyruvate results in formation of 2 carbon compound acetyl
- **Dehydrogenation**: removing hydrogen from a molecule
  - Hydrogen transfer to NAD^+ and produce reduced NAD^+ / NADH/.
- A sulfur containing coenzyme A binds to the acetyl **to form acetyl CoA**
  - **Input** molecule **2 Pyruvate, NAD**
  - **Output 2CO_2, 2acetyl CoA and 2NADH**
  - The overall reaction ⟶ 2pyruvate+2NAD + 2CoA 2acetyl CoA +2NADH + 2CO_2

Krebs cycle /citric acid cycle/

- Also known as **tricarboxylic acids (TCA)** or **citric acid cycle.**
- It is a serious of chemical reaction that convert acetyl CoA into carbon dioxide, water and energy
- Takes place in the matrix of the mitochondria in eukaryotic cell.
- It is oxygen dependent reaction.
- **In Krebs cycle per glucose molecule**
  - **4-carbon dioxide** is released
  - **6 Reduced NAD (NADH**) produced
  - **2-Reduced FAD (FADH2).**
  - **2-Guanosine triphosphate (GTP) =ATP** synthesised through Substrate level phosphorylation of

Krebs cycle….

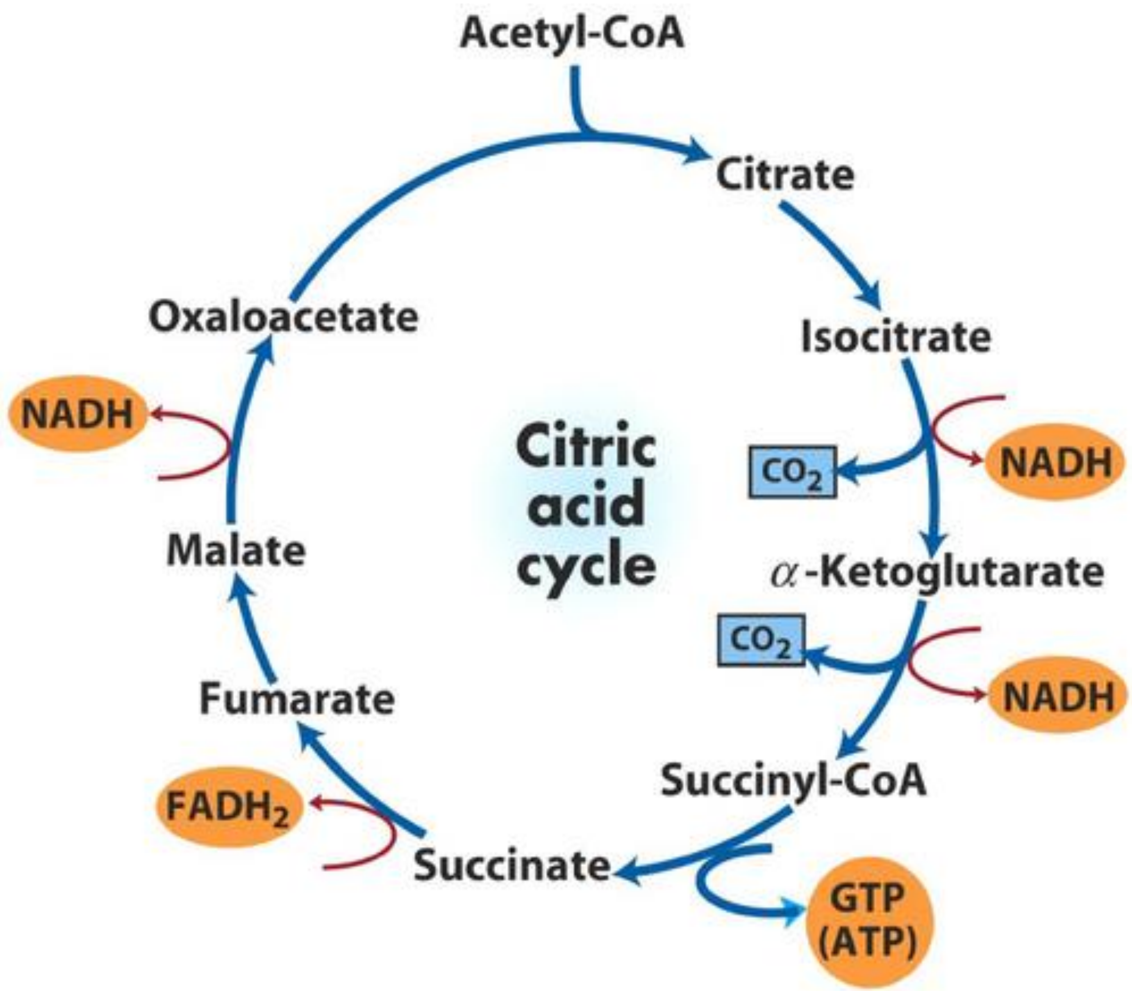
In Krebs cycle from one glucose molecule

Input

- 2 acetyl CoA,
- 2ADP + Pi
- NAD,
- FAD

Output

- 6NADH,
- 2FADH
- 2GTP=ATP

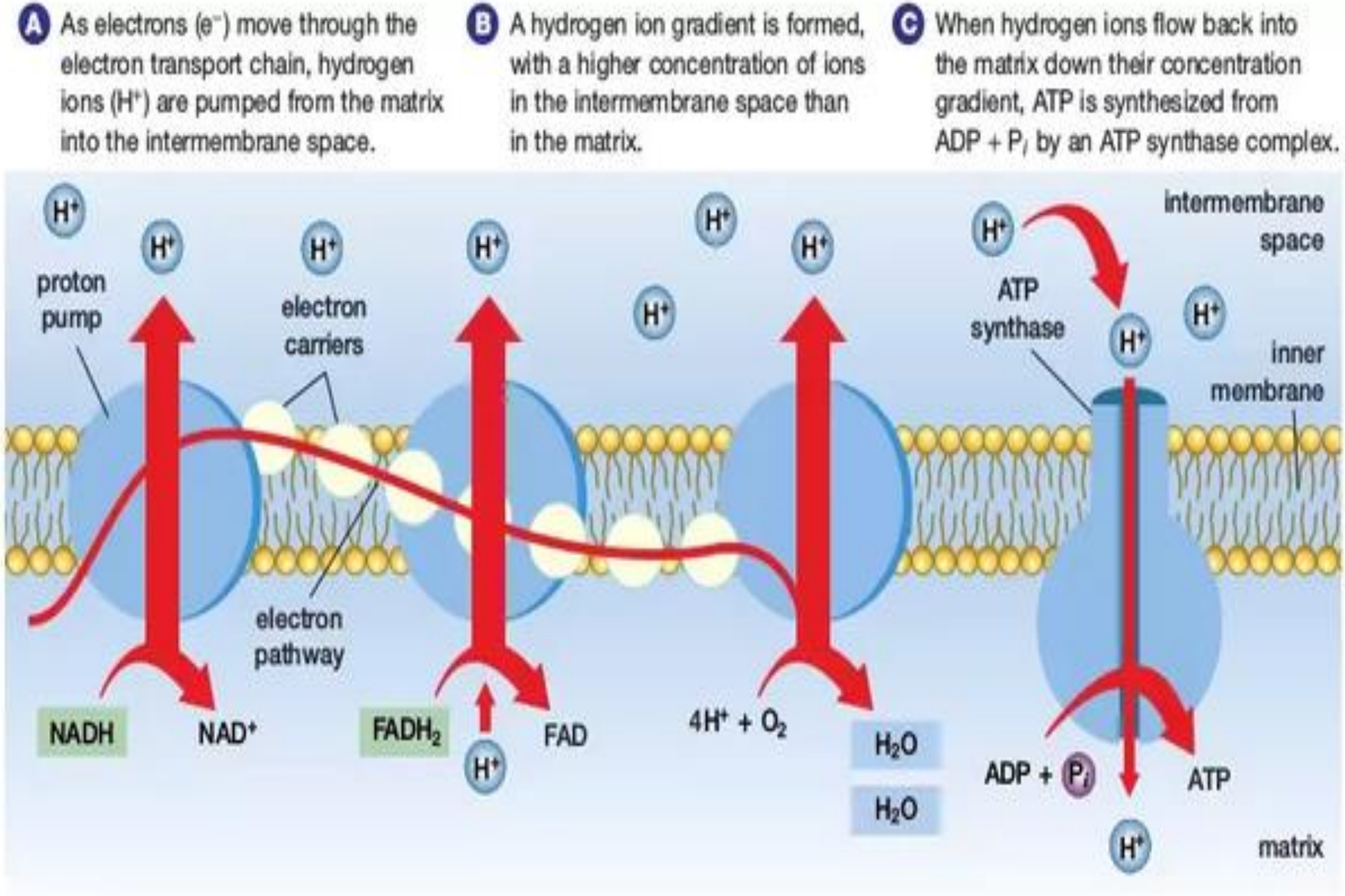


Electron transport chain (ETC) and chemiosmosis

- The **electron transport chain** and **chemiosmosis together** make up **oxidative phosphorylation.**
- The reactions take place **inner mitochondrial membrane /cristae/.**
- The **molecules that act as electron carriers in the electron transport chain are:**
  - **NAD dehydrogenase**
  - **Ubiquinone**
  - **Cytochromes (Cytochrome b-c1, Cytochromes c, Cytochrome oxidase)**
- Three of the electron carrier such as
  - **NAD dehydrogenase (**Oxidise /dehydrogenate/ reduce NAD**)**
  - **Ubiquinone (**Oxidise /dehydrogenate/ reduce FAD**)**
  - **Cytochrome b-c1 complex pump proton** from matrix of mitochondrion to the inter-membrane space

Electron transport….

- Due to the pumping action **protons accumulate in the inter-membrane space** creating a higher concentration than in the matrix
- As results, **protons diffusing** down concentration gradient through the ATP synthase molecule.
- The diffuse of proton makes the **synthesis ATP** from ADP and Pi.
- The diffusion of hydrogen ions through the ATP synthase is **chemiosmosis.**
- **The oxidation of one molecule of**
  - **Reduce NAD (NADH)** six protons passing through ATP synthase and three molecules of ATP produced
  - **Reduce FAD (FADH2)** four protons passing through ATP synthase and two molecules of ATP produced
- Eventually electron accept by **oxygen** to produce water molecule. Because of this, oxygen is known as the **terminal electron acceptor**.


A As electrons (e^-) move through the electron transport chain, hydrogen ions (H^+) are pumped from the matrix into the intermembrane space.
B A hydrogen ion gradient is formed, with a higher concentration of ions in the intermembrane space than in the matrix.
C When hydrogen ions flow back into the matrix down their concentration gradient, ATP is synthesized from ADP + P_i by an ATP synthase complex.
intermembrane space
proton pump
electron carriers
ATP synthase
inner membrane
electron pathway
NADH
NAD^+
$FADH_2$
FAD
$4H^+ + O_2$
H_2O
H_2O
ADP + P_i
ATP
matrix
H^+

Process	input	Output	Substrate level phosphorylation	Oxidative level phosphorylation
➢ **Glycolysis**	➢ Glucose	➢ 2 Pyruvate ➢ 2NADH ➢ 4ATP	➢ 4ATP total 2 ATP net	➢ 2NADH=2× 3=**6ATP**
➢ **Link reaction**	➢ 2 Pyruvate	➢ $2CO_2$ ➢ 2Acetyl CoA ➢ 2NADH	➢ --	➢ 2NADH=2× 3=**6ATP**
➢ **Krebs cycle**	➢ 2 Acetyl CoA	➢ $4CO_2$ ➢ 2GTP=2ATP ➢ 6NADH ➢ 2FADH	➢ 2GTP=2ATP	➢ 6NADH=6× 318 **ATP** ➢ =2FADH=2× 2= **4 ATP**
Total ATP production per glucose molecule is **38**, However, in practice **2 ATP** is used to **drive proton pump**. So the actual ATP production per **glucose molecule is 36**			➢ **4AT**P	**34 ATP**

II. Anaerobic respiration

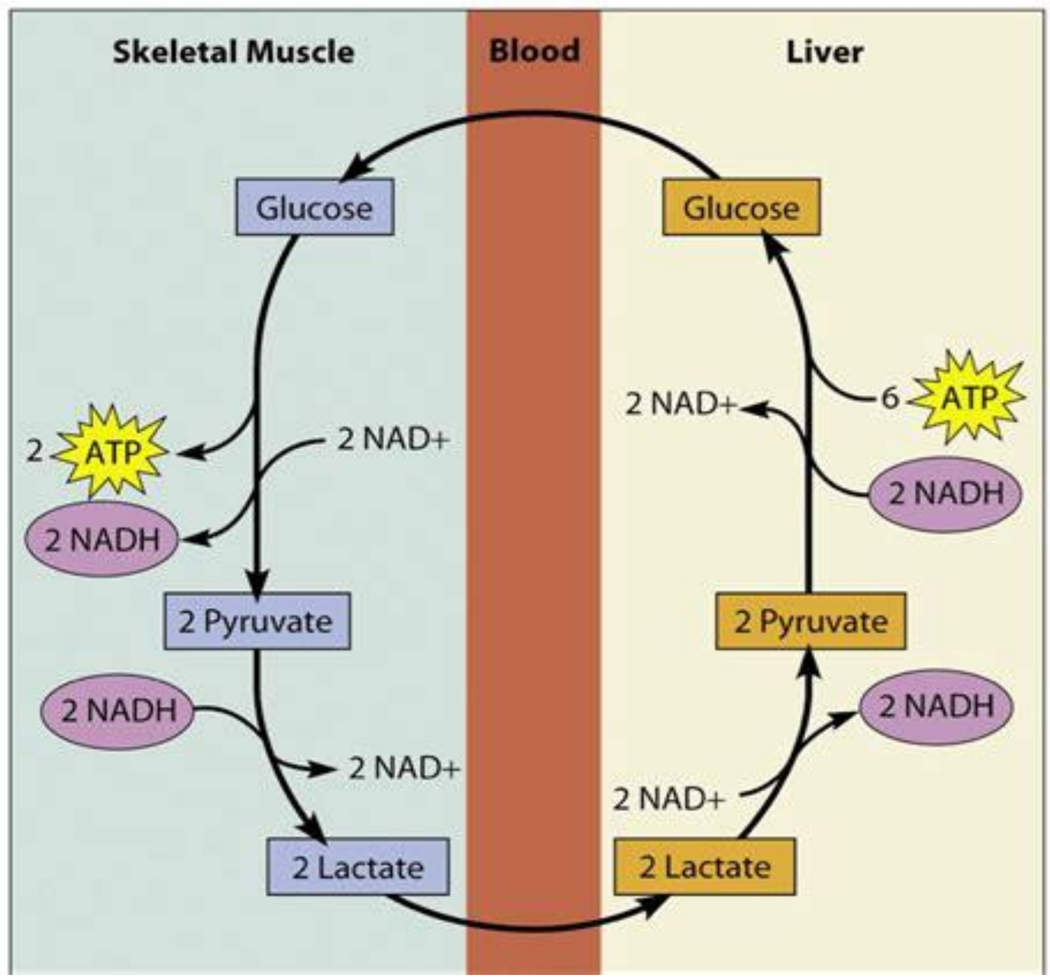
- Take place in the **cytoplasm** of a cell
- The process does not require **oxygen**
  - Oxidative phosphorylation do not occur
  - Final electron acceptor and formation of water cannot take place
  - In the absence of oxygen link reaction, Krebs cycle and electron transport chain stops
- Only glycolysis continues in anaerobic respiration
- NADH produced during glycolysis supply hydrogen to reduced pyruvate
- Only 2ATP formed from one glucose

Anaerobic respiration in animal cell (Lactate fermentation)

- During heavy exercise the **muscle cell** respire anaerobically
- Pyruvate reduce by NADH to form lactate
- ATP used in sprints and short distance runs in nearly all generated anaerobically
- Produce a waste product called **lactic acid**
- The **accumulation of lactic acid** during exercise cause **muscular fatigue**
- **Lactic acid** formed can be used to **regenerate glucose** or completely metabolized as an **energy source in the liver**
- A summary of anaerobic respiration in animal cells
  - Glucose ⟶ Lactate (lactic acid) + 2ATP
  - $C_6 H_{12}O_6 \longrightarrow 2C_3H_6O_3 + 2ATP$

Cori cycle

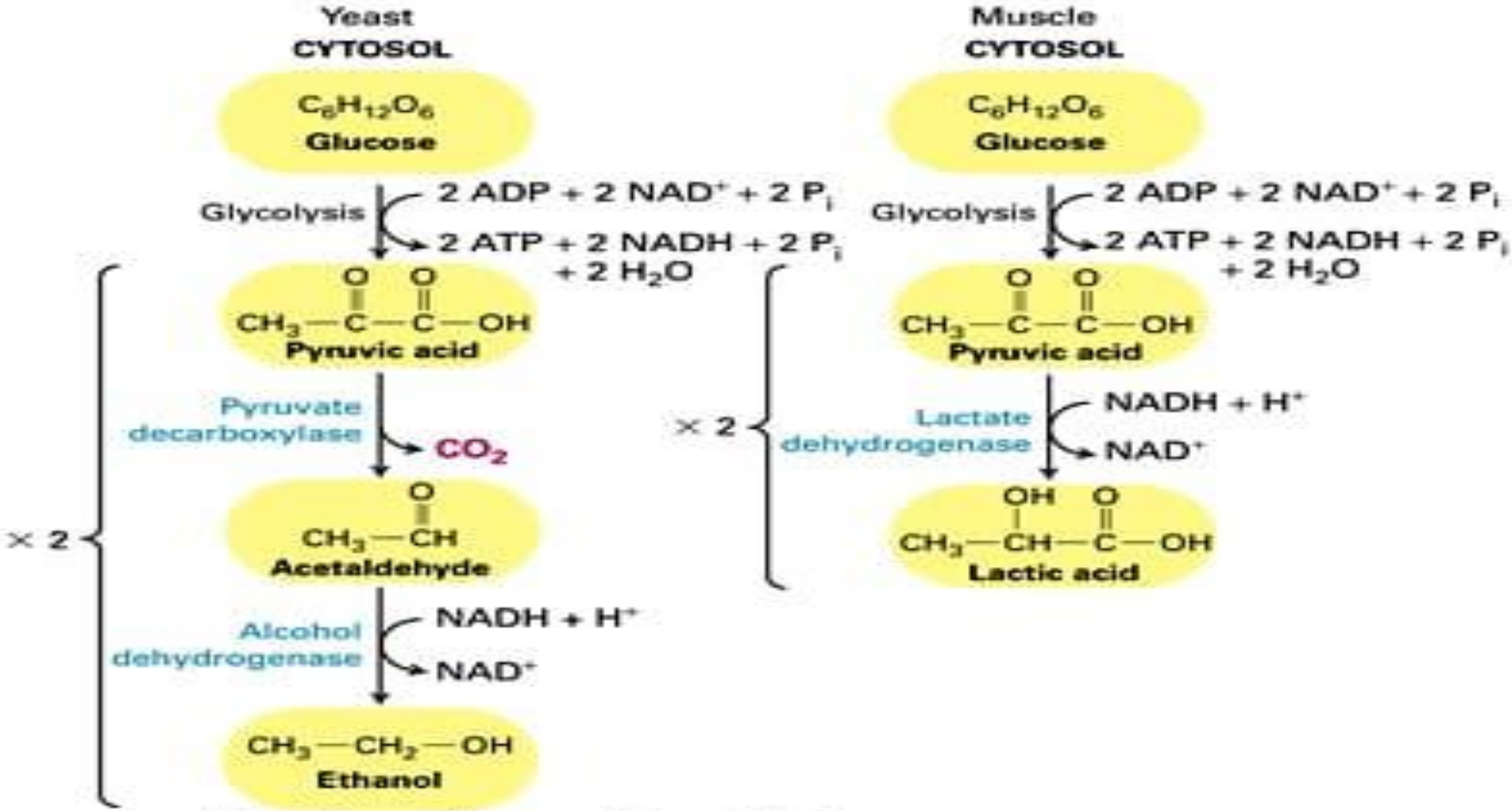
- **Cori cycle** is the **metabolic pathway of carbohydrates**, that **links** lactate formation in muscle tissue to glucose formation in the liver
- **Involves two organ** the contraction **muscle** and **liver**
- Works in **anaerobic condition**
- Helps the human body produce additional energy to muscle in stress condition



Anaerobic respiration in yeast cell (Alcoholic fermentation)

- Yeast cell produce ethanol and carbon dioxide when ferment glucose.
- Anaerobic respiration in yeast result in making alcoholic drinks
- A summary of anaerobic respiration in yeast cells
  - $C_6H_{12}O_6 \longrightarrow 2C_2H_5OH + {}_2CO_2 + 2ATP$
  - Glucose $\longrightarrow$ Ethanol (alcohol) + carbon dioxide +2ATP

ANAEROBIC METABOLISM (FERMENTATION)



Overall reactions of anaerobic metabolism:

Glucose + 2 ADP + 2 P_i $\longrightarrow$ 2 ethanol + 2 CO_2 + 2 ATP + 2 H_2O

Glucose + 2 ADP + 2 P_i $\longrightarrow$ 2 lactate + 2 ATP + 2 H_2O

Some use of fermentation industry

Process	Organisms				
	Propani-Bacteria	**Lactobacillus streptococcus**	**Yeast**	**Clostridium**	**Escherichia coli**
Fermentation product	Propionic Acid	Lactic acid	CO_2 Ethanol	Acetone isopropecine	Acetic acid
Industrial product	To make Swiss cheese	Cheddar-Cheese Yoghurt	Wine beer	Nile polish remover	Vinegar

Protein catabolism

- The metabolism of proteins, lipids and carbohydrates ‘converges’ on the Krebs cycle.
- Protein first hydrolysis into amino acids.
- Excess amino acids used to make new protein or be source of cellular respiration
- **Amino acids** first undergo **deamination** /removal of amino group/
- The **remaining carbon skeleton** of the amino acids **converted into pyruvate, acetyl CoA** and other **Krebs cycle** components
- **For example,**
  - the amino acid leucin converted into acetyl CoA,
  - alanine converted into acetyl CoA
  - praline converted into α-ketogluterate

Lipid catabolism

- Lipids digests into glycerol and fatty acids
- Glycerol phosphorylated and converted into glyceraldehyde-3-phosphate (G3P) and join glycolysis
- Fatty acids transported into mitochondrial matrix and undergo β-oxidation and converted into Acetyl CoA
- In **β-oxidation** if **2n carbon** oxidize generate;
  - **n-1 cycle**
  - **n-1NADH**
  - **n-1 FADH**
  - **n-acetyl CoA**

E.g. How many ATP yield form palmitic acids /a 16 carbon fatty acid /

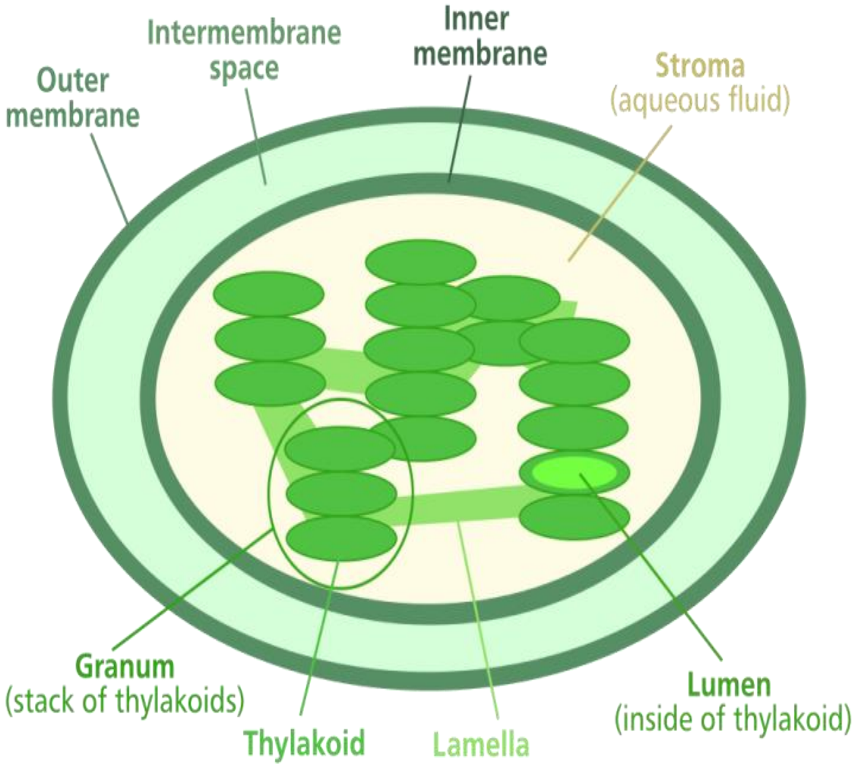
- As the **rule β-oxidation 2n carbon** of fatty acid requires;
  - **n-1 cycle** of oxidation and yields **n-1 NADH, n-1 FADH** and **n-acetyl CoA**
- 8-1=**7cycle gives 7 NADH**, **7 FADH** & **8 Acetyl CoA**
  - **7NADH** gives **7×3ATP=21ATP**
  - **7FADH**gives**7×2ATP**=**14ATP**
  - **8 acetyl CoA** gives 8×12ATP=**96ATP** (since 1acetyl CoA enter Krebs cycle gives 12 ATP)
- **Total ATP production from 16 carbon fatty acids 21+14+96=131 ATP**
- **For activation** of oxidation process **2ATP are required** therefore the net **ATP gain is 131-2=129ATP**

5.2 Photosynthesis

- **Photosynthesis** formed from two wards; **photo** and **synthesis**
  - **Photo= means light**
  - **synthesis** means **joining together**.
- So, photosynthesis is the joining of carbon dioxide and water with the energy of the sun into carbohydrate
- **Photosynthesis** is the process by which **green plants convert** inorganic compound such as **CO_2 and H_2O into organic compounds** by using **chlorophyll** and **light energy** from the sun within the chloroplast.
- Photosynthesis is a process by which light energy is converted into chemical energy of sugar and other organic compound.
- **Transduced** is **conversion of energy** from one form to another
- **Transduction** take place in **light dependent reaction**

Structure and function of a chloroplast

- Each chloroplast has **outer** and **inner membrane** separated by **Intermembrane space**.
- Chloroplast has **third membrane system**, the **thylakoid** that are flat, saclike structures suspended in the stroma
  - The thylakoid arranged in the stack called **grana**
  - The grana contain **photosynthetic pigments** and the system converting ADP to **ATP.**
- **Stroma** contain enzyme for carbon dioxide fixation

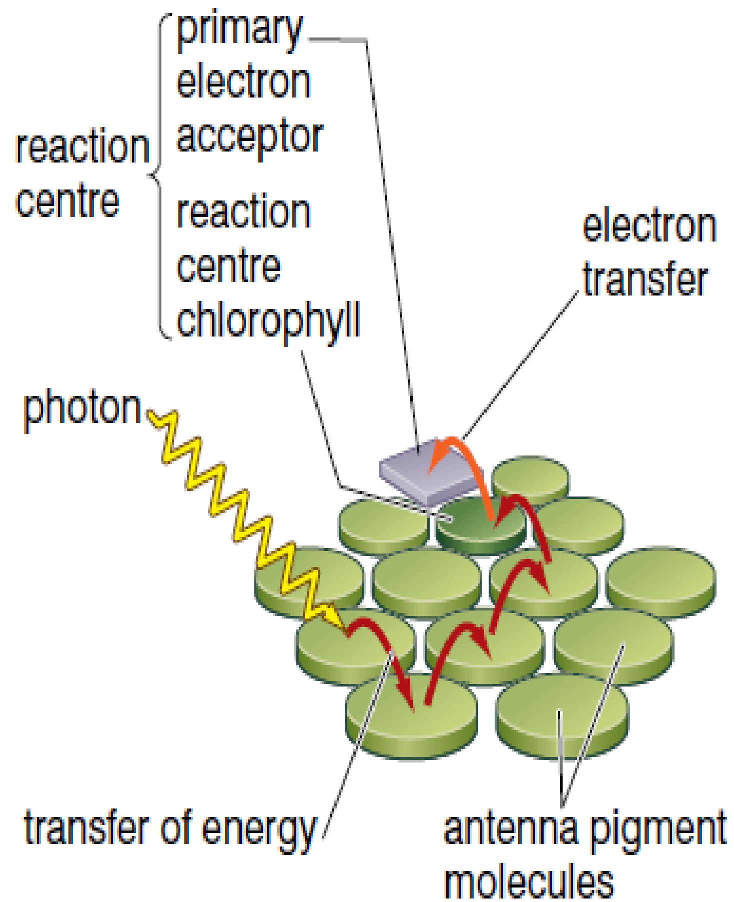


Contd.

- **Chloroplas**t have **photosynthetic pigments**, which enable them to absorb sunlight
- The **main photosynthetic pigment** is called **chlorophyll**.
- Chlorophylls **absorb red** and **blue** light and **reflect green** light
- Chlorophyll and other photosensitive pigment molecules are arranged in **photosystems**

The structure of photosystem

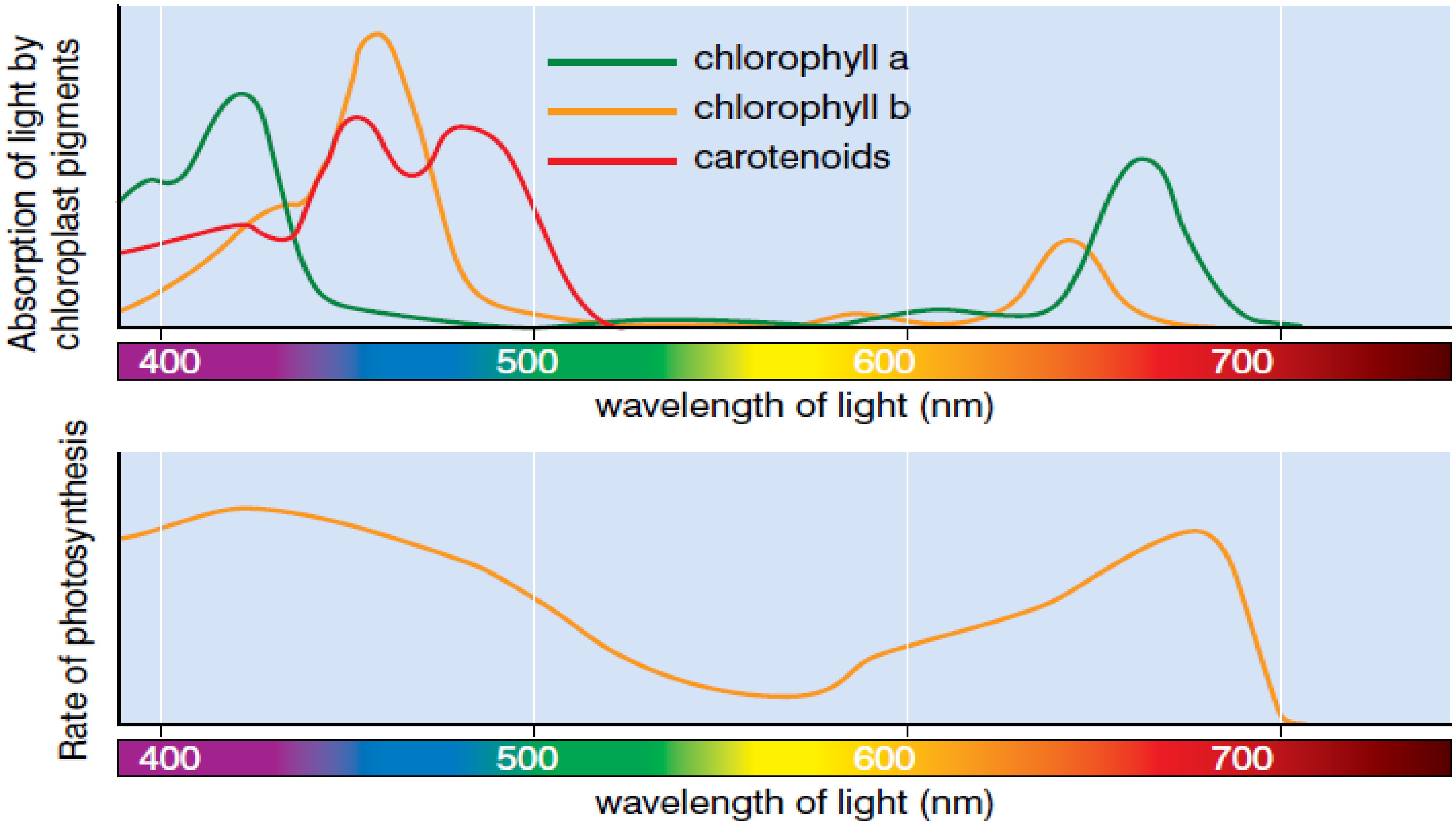
- **Photosystems** biochemical mechanism by which chlorophyll absorbs light energy.
- The molecules of **photosystems** and the **electron transport chains** are fixed in the membranes of the **thylakoids.**
- There are **two different photosystems**, each **sensitive to light of a different wavelength** and linked to a different electron transport chain.
- A **photosystem** consists a **reaction center molecule** and an **antenna complex**



Cond.

- **Reaction center molecule** where light-dependent reactions begin
- The cluster of photosynthetic pigment is called **antenna complex**
- Pigments in the **antenna complex** can absorb different wavelengths of light.
- Antenna complex consists of **chlorophyll a, chlorophyll b** and **carotenoids.**
- The **reaction center molecule** is always **chlorophyll a.**
- The range of wavelengths each molecule absorbs is its **absorption spectrum**.
- **Action spectrum** the photosynthesis effectiveness of each wavelength

Absorption and action spectrum



Phase of photosynthesis

Light-dependent reactions

- Light dependent reaction take place in the **thylakoid of chloroplast**
- Chlorophyll absorbs radiant energy of sunlight
- Chlorophyll release energized electron
- **The energized election is used to make ATP** and **NADPH**
  - ATP a source energy for the reactions
  - Reduced NADP /NADPH/ a source hydrogen ions for a reduction reaction.
- **Split water molecule** into hydrogen and oxygen **/photolysis of water/**
  - Oxygen gas is released in to the atmosphere came from water molecule

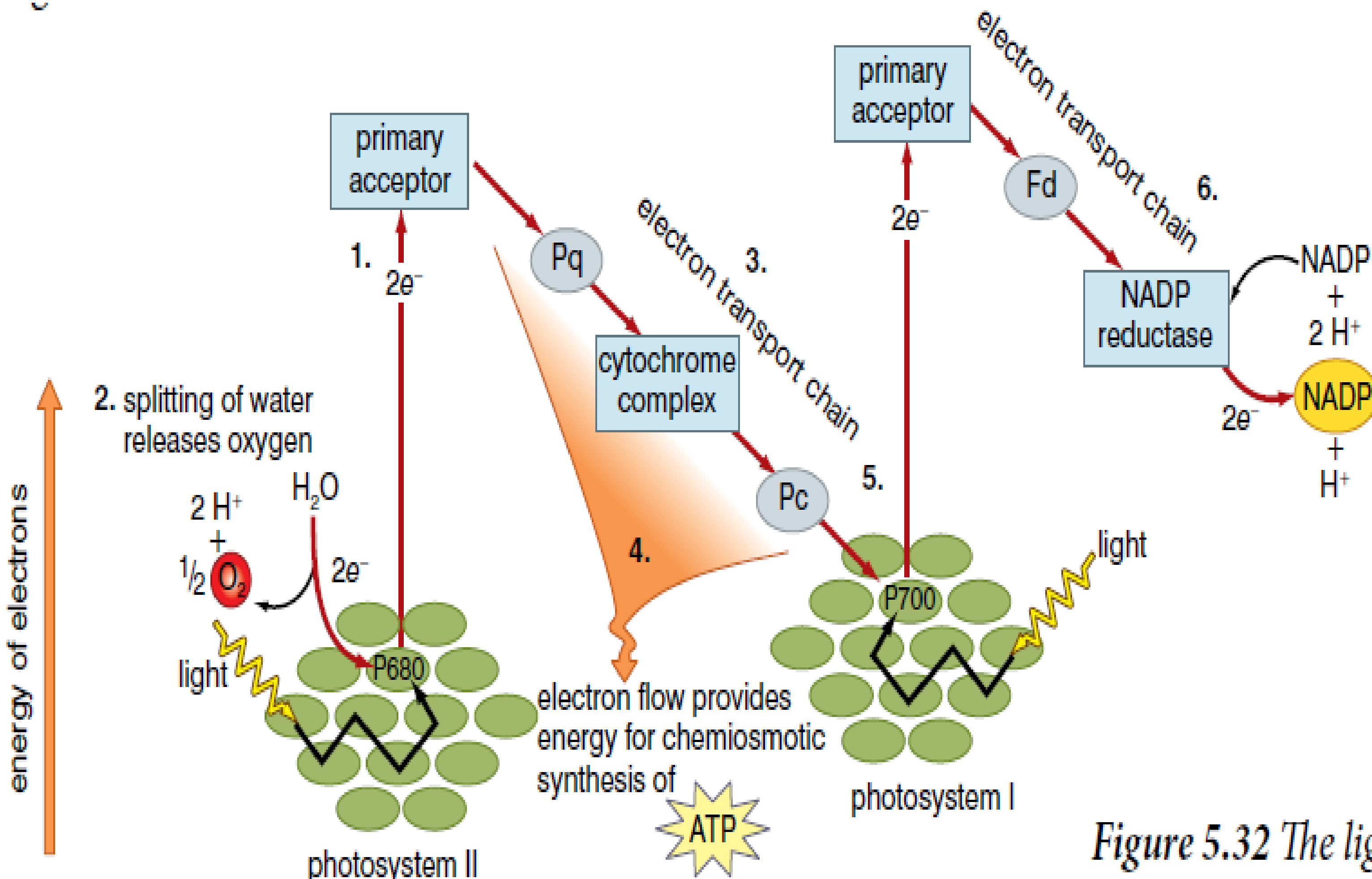


Figure 5.32 The light-dependent reactions of photosynthesis

Major events in light dependent reaction

1) Light energy is trapped in **photosystem II (p680)** are excited energized electrons to the higher energy level in photons of light

   - Energized electrons received by **primary electron acceptor**.

2) Energized electrons cause water molecule split into hydrogen ion and oxygen gas called **photolysis of water** /$2H_2O \rightarrow O2 + 4H^{+} + 4e^{-}$/

3) The primary electron acceptor passes the electrons to electron transport chains include **Plastoquinone ('Pq'). Cytochromes, Plastocyanin (Pc) (**the last carrier in the chain**)**.

Major events in light dependent reaction….

4) The energy loss during electron transport chain coupled with the **pumping of proton** from **stroma of chloroplast to thylakoid interior** which result in the accumulation of proton inside thylakoid

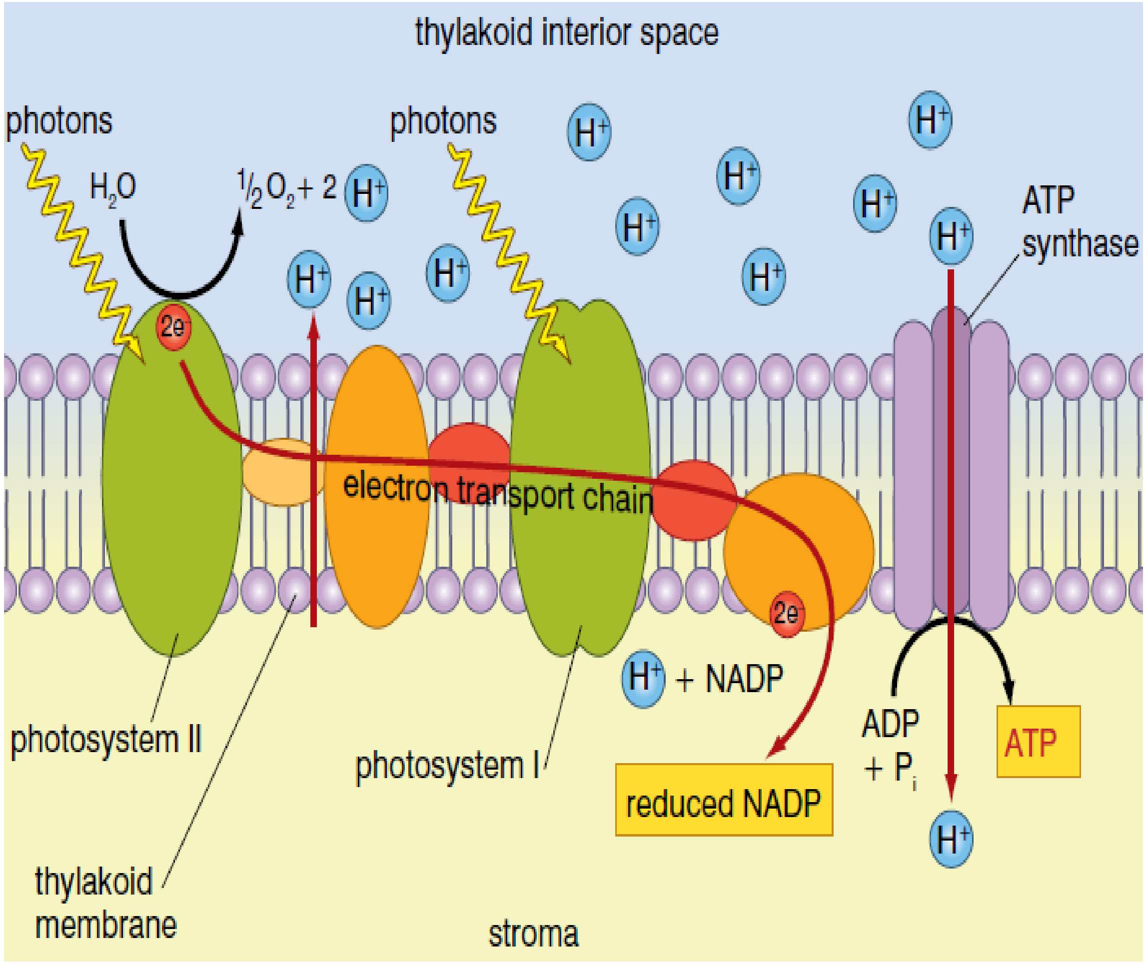
- This results in, **concentration gradient** creates between the **thylakoid interior** and **the stroma** of the chloroplast
- **Protons move down concentration gradient** (**thylakoid to stroma**), through ATP synthase, causing **chemiosmotic syntheses of ATP**

5) Electrons in chlorophyll molecules in photosystem **I (p700)** excited and escape from the molecule.

- The electrons passed down the second electron transport chain **ferredoxin (Fd)** and **NADP reductase**.
- At the end of ETC the electron react with the proton and NADP in the stroma of the chloroplast to form **reduced NADP (NADPH).**

Arrangement of molecule in photosynthetic unit

- **Photosynthetic unit** an arrangement of molecules capable of carrying out all the reactions in the light-dependent stage of photosynthesis
- **photosynthetic unit can carry out:**
  - **photolysis of water**
  - **synthesis of ATP**
  - **synthesis of reduced NADP**



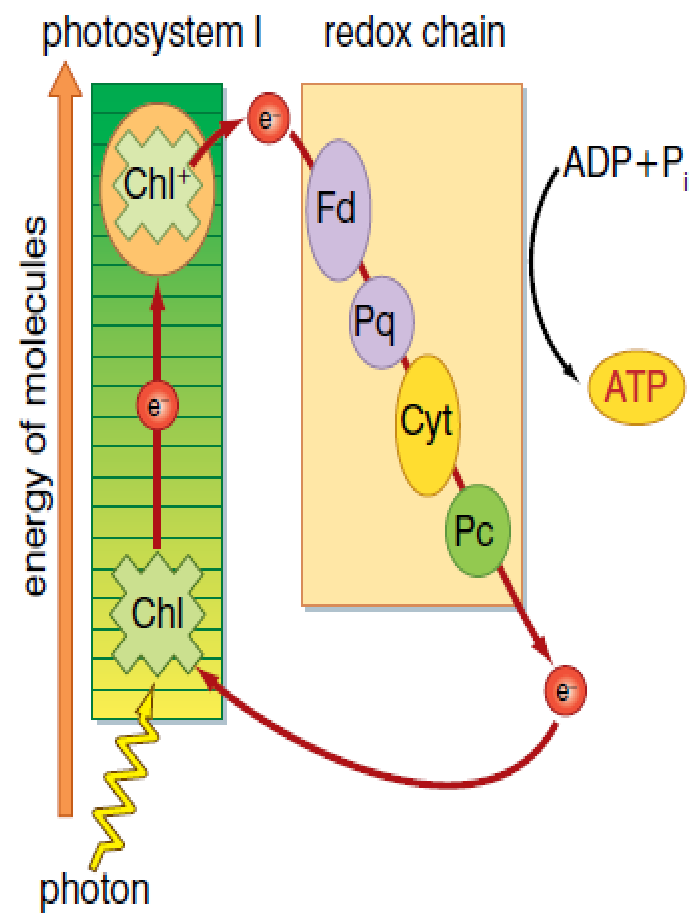
Cyclic and noncyclic photophosphorylation

1. *Non-cyclic photophosphorylation*

- Electron do not come back to the chl. molecule
- First **electron donor is water**
- Involves **photolysis of water**
- **Both PS I and PS II** involves
- **ATP via PsII** and **NADPH via PsI** produced
- The **final electron acceptor is NADP**
- **Oxygen is evolved** as a byproduct
- **It is a non-cyclic photophosphorylation.** Because:
  1. Phosphorylation (formation of ATP) is light-dependent
  2. Electrons lost from the chlorophyll is not recycled

2. Cyclic photophosphorylation

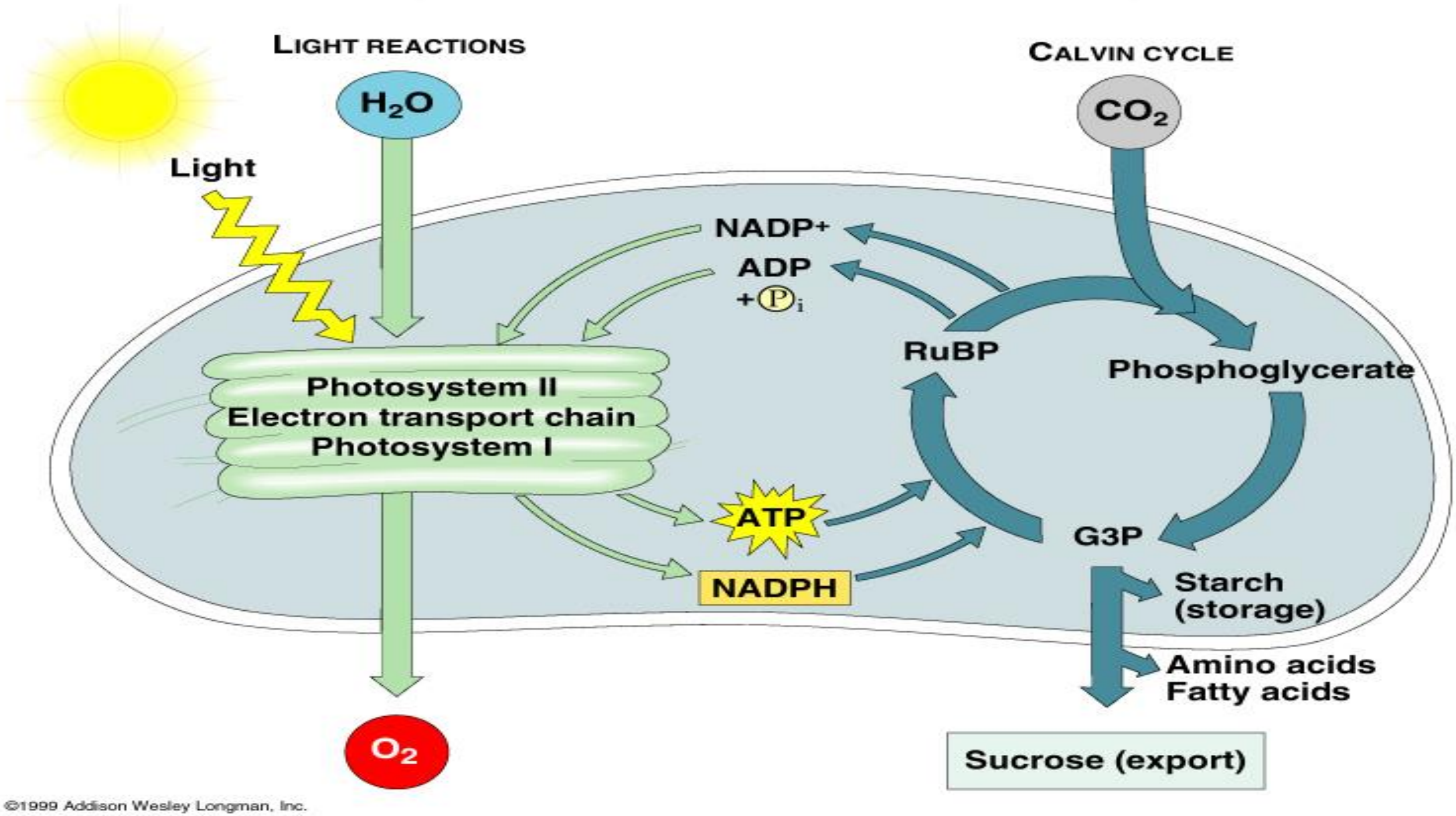
- **Electron return back to chlorophyll molecule.**
- Involves **photosystem I only**
- **Only ATP produced**
  - **No photolysis** of water
  - **No reduced NADP** are formed
  - **Oxygen is not** evolved
- **Cyclic photophosphorylation** only happens when sugars cannot be synthesized for some reason, such as lack of carbon dioxide



Light-independent reactions /Carbohydrate synthesized/

- **Independent of light**
- Chemical reactions **take place in the stroma** of the chloroplasts.
- **Reduction of carbon dioxide** to glucose
- CO_2 from the atmosphere combine **with hydrogen from NADPH** to form glucose.
- **ATP produce** in light dependent reaction used as a source of energy

Light dependent | **Light independent**



Calvin cycle /C3 pathway/

- The light independent reaction also called **Calvin cycle**
- Named after Melvin Calvin, who discover the process in1960
- The process **use up ATP** and **NADPH** from light reaction
- The process **reduce gaseous carbon dioxide** into sugar
- **NADPH is a reducing power** and **ATP as a source of energy**

Three stages of Calvin cycle

1. Fixation

- **CO_2** react with **5-carbon** molecule called ribulose diphosphate **(RUBP)** to form a molecule of three carbon compound **3-phosphoglycrate (3-GP)**
- The reaction **catalyzed** by **Rubisco (**Ribulose diphosphate carboxylase oxygnase**)**
- Rubisco catalyze the addition of carbon dioxide and oxygen.

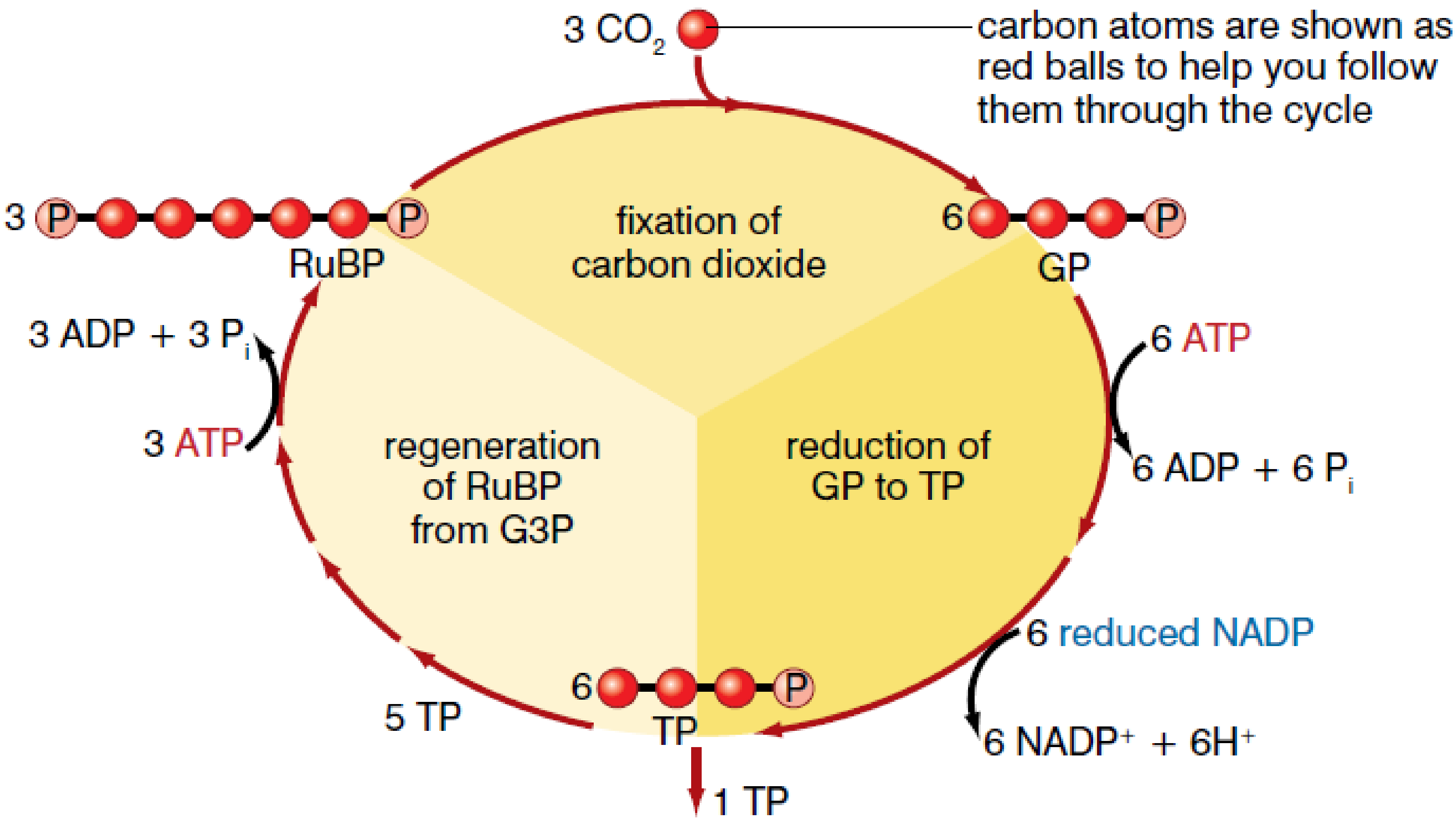
2. Reduction

- In this phase **ATP and NADPH** produce in light independent reaction is **utilized** to produce **triose phosphate (TP, (Glyceraldehyde 3-phosphate (G3P)**
- To **convert** phosphoglycrate /**3GP/ to TP(G3P)** use **hydrogen ion** from **reduce NADP** and **energy from ATP**
- This step is **called reduction** because NADPH donates electrons to 3GP to creates TP (G3P)
- In the light-independent reactions, reduced **NADP is used to reduce GP to TP**/**G3P**/

3. Regeneration of RUBP

- As **3CO_2** enter the cycle,
  - **6TP** (glyceraldehyde 3- phosphate/ are made,
  - **1TP**(G3P) enter the bio chemical pathway to produce glucose
  - **5TP** (G3P) recycled to **regenerate RUBP** using ATP as a source of energy. The regeneration process require 3 molecule of ATP
- 6**CO_2** enter the cycle would give an output of **two** molecules of **triose phosphate** (**TP**) enough to make one molecule of glucose

Calvin cycle



Type of photosynthesis

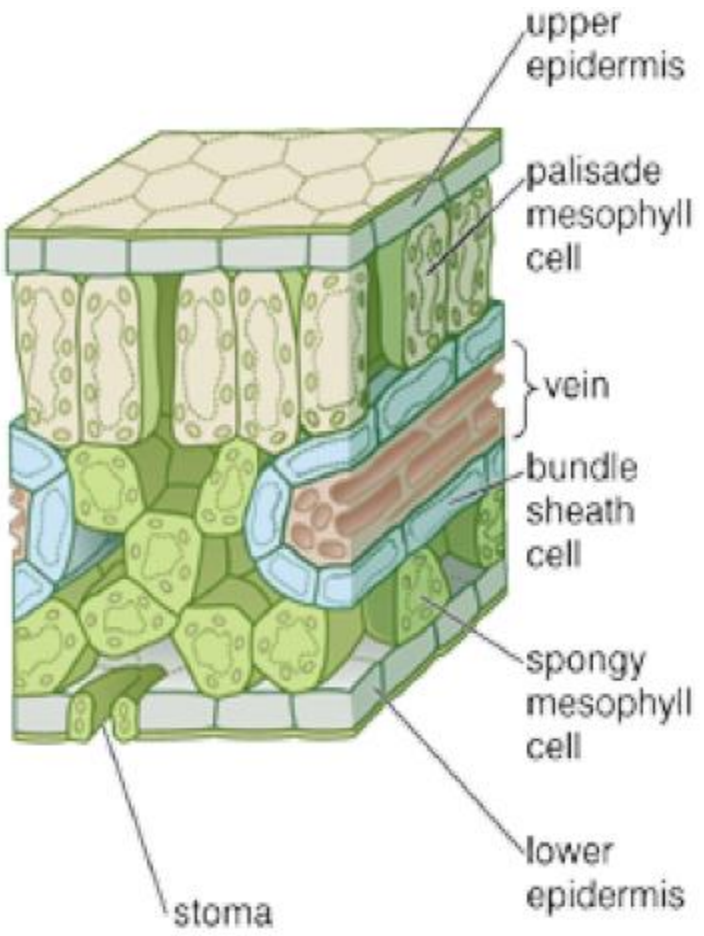
- There are three basic type of photosynthesis based on the mechanism plant employ to form carbohydrates.
  1) C3 photosynthesis
  2) C4 photosynthesis
  3) CAM (crassulacean acid metabolism)

C3 photosynthesis and photorespiration

- It is **called C3 photosynthesis** because the **first compound** formed in the light independent reactions of the Calvin cycle contains three carbons **GP.**
- Takes place in plants living in **temperate environments**
- More efficient than C4 and CAM plants **under cool, moist conditions and normal light**.
- **Example of C3 plant rice, wheat, soybean, peas and carrots**
- **CO_2 fixes** with RuBP using the **enzyme RUBISCO**.
- **RUBISCO can bind to both CO2 and O2.**
  - **High CO2, Low O2, favors carboxylase** activity **(continue in Calvin cycle)**
  - **Low CO2, high O2 favors oxygnase** activity results in **photorespiration**

Adaptation of C3 plants for photosynthesis

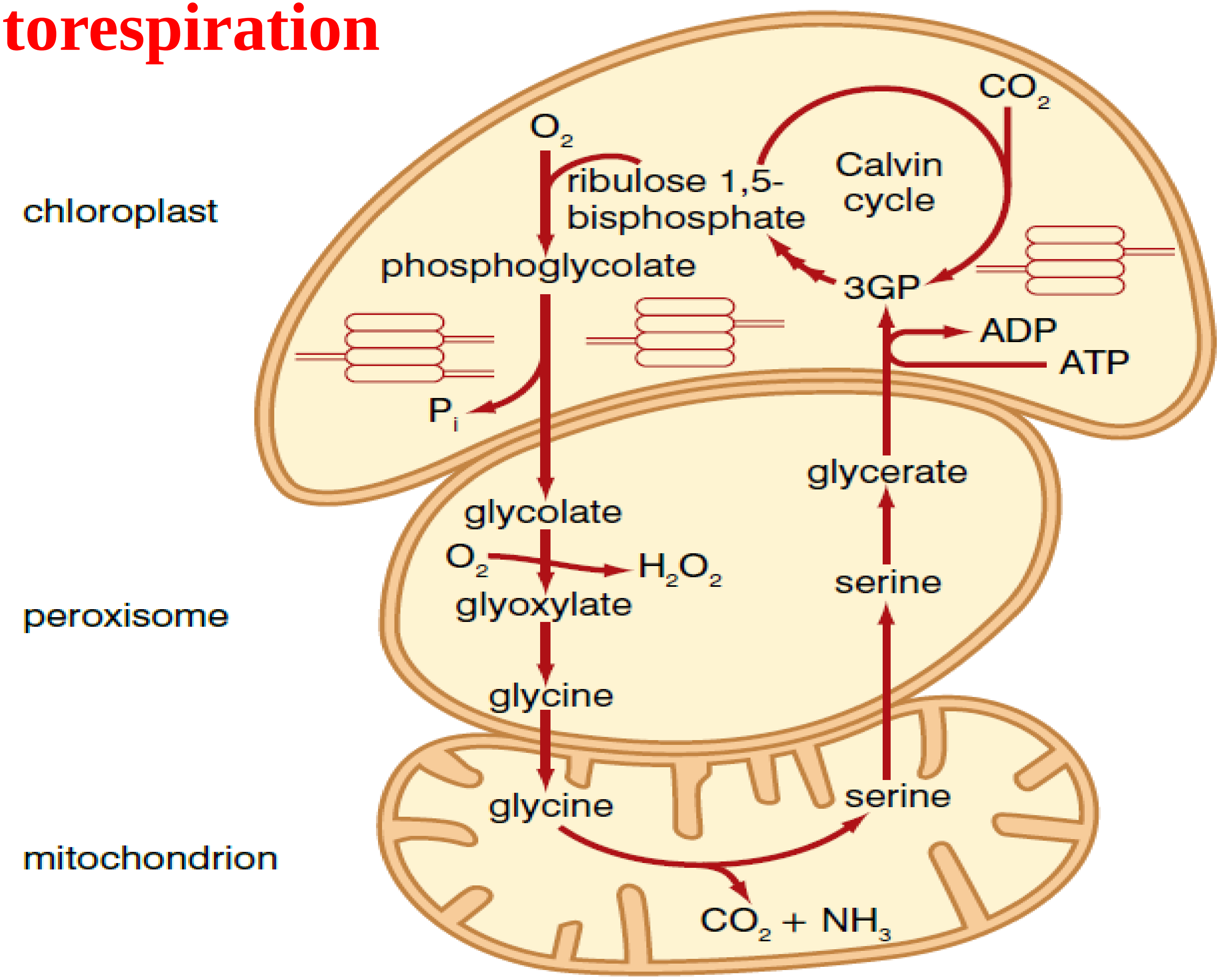
- **Broad leaves** to absorb much sunlight as possible.
- **Spongy mesophyll has air spaces** that allow easy diffusion of gases
- **Bundle sheath** cell do **not have chloroplast**
- **Stomata open during the day** to allow the entry of carbon dioxide.
- **CO_2 fixes** with RuBP using the **enzyme RUBISCO**.
- In **C3 photosynthesis, fixation** of CO_2 to organic compound and the **Calvin cycle** both occur in the **mesophyll cell.**



Photorespiration in C3-photosynthesis

- **Problem with C3 pathway** under high light intensity and high temperatures (tropics plants)
- During **high light intensity** plant close their stomata to conserve water
- If the stomata closed **CO_2 intake reduced** & **builds up O_2, results in photorespiration**
  - In photorespiration the enzyme **Rubisco binds with oxygen**, not carbon dioxide.
  - RuBP is oxidised to **one molecule of glycerate phosphate (3GP)** (not two) and a molecule of **phosphoglycolate**.
- **Photorespiration** reduces overall plant productivity because CO_2 is released in the process
- **Chloroplast, mitochondria** and **peroxisome** involve in photorespiration

Photorespiration



Photorespiration reduces the efficiency of photosynthesis because;

1) Photorespiration **diverts reduction of carbon to carbohydrate to oxidation of carbon**, which is the reverse of photosynthesis
2) It need **resynthesized ribulose biphosphate**
3) **Additional ATP is used** in the resynthesize of RuBP.
4) Need waste energy to removed phosphoglycolate

C4 photosynthesis

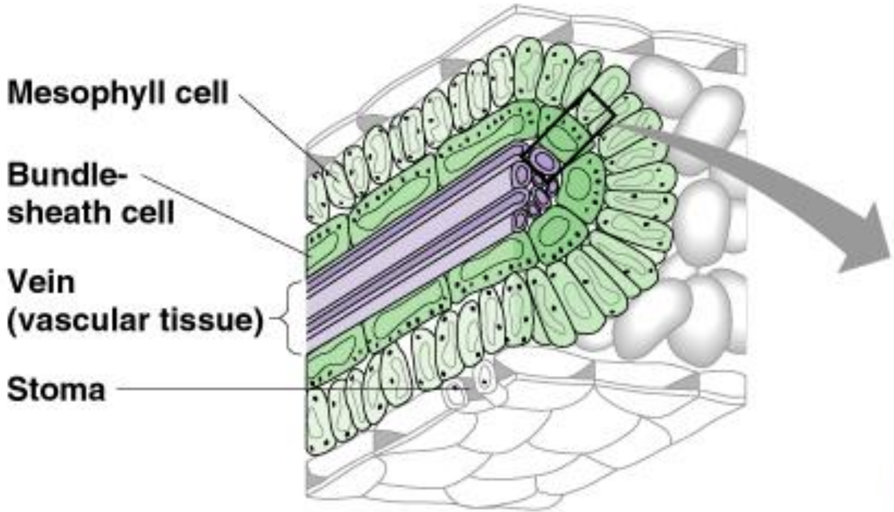
- The first product of carbon dioxide fixation is 4-carbons **oxaloacetic acid.**
- Plant that utilize this pathway are called **C4 plants**
- In **C4 photosynthesis**, the **carbon fixation** and **the Calvin cycle** takes place in different cell
- Phosenolpyruvate /PEP/ is carbon dioxide acceptor
- Carbon **fixation into PEP in mesophyll** call and **Calvin cycle in bundle sheath cell**
- **C4 plant** mostly **found in tropical region**
- **Maize, crabgrass, sorghum** and **sugar cane** example of C4 photosynthesis

The structure C4 plant leaf

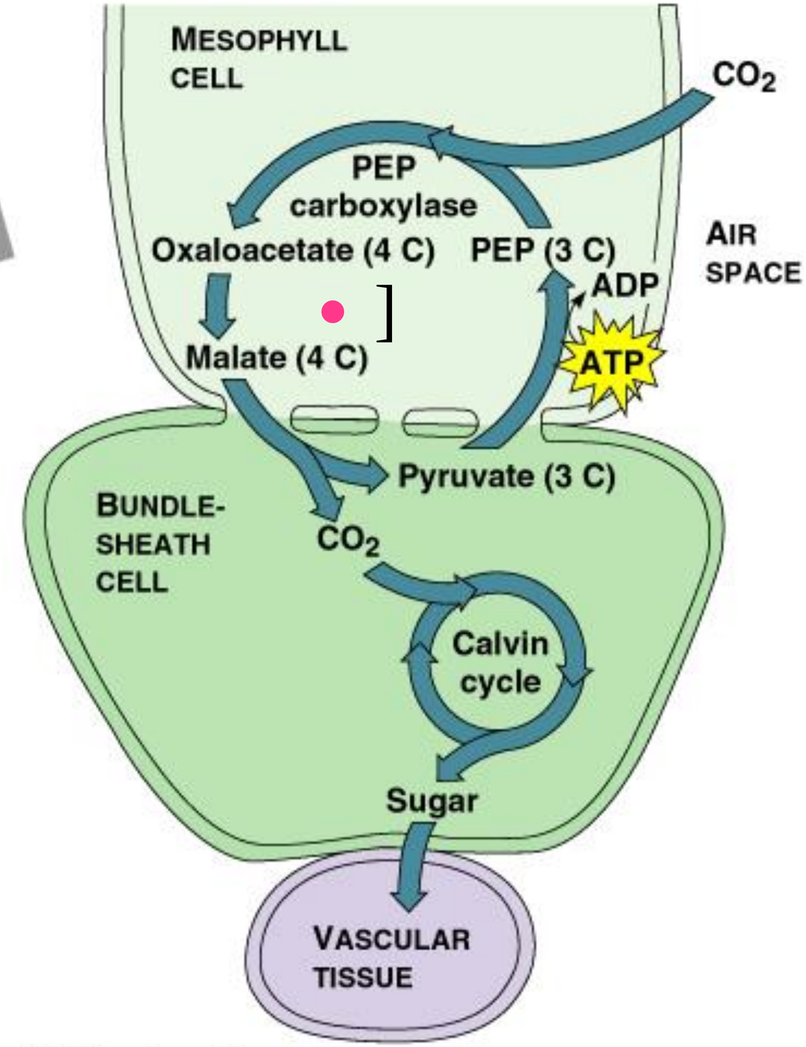
- **Mesophyll cells have chloroplasts with thylakoids** and so can carry out the light-dependent reactions.
- **The bundle sheath cell contain chloroplasts, but lack thylakoid**
  - The light-dependent reactions cannot occur bundle sheath cell due to the lack of thylakoid
  - So, oxygen is not produced in bundle sheath cell.
  - This helps to prevent Photorespiration
  - Calvin cycle take place in bundle sheath cell cells.

The following reactions take place C4 plant:

1) **Carbon dioxide reacts with a 3-carbon compound called phosphoenol pyruvate /PEP/ to form the 4 carbon compound oxaloacetate**
   - PEP carboxylase/**pepc**/ catalyses the reaction of carbon dioxide with PEP in the mesophyll cells.
2) **Oxaloacetate is converted into another C4 compound malate**
   - Malate passes from the mesophyll cell into a bundle sheath cell.
   - CO_2 for Calvin cycle derived from malic acid,
   - C4-plant obtain CO_2through an indirect process rather than through the stomata.
3) **In the bundle sheath cell, malate is converted to pyruvate and a molecule of carbon dioxid**e.
   - CO_2 starts the reactions of the Calvin cycle by binding with RuBP
   - Pyruvate is converted back to Phosphoenolpyruvate /PEP/ by using 2 molecule of ATP.



(a) C_4 leaf anatomy



(b) The C_4 pathway

- **C4 photosynthesis is most efficient in conditions of:**
  - Low carbon dioxide concentration
  - High light intensity
  - High temperature

CAM (crassulacean acid metabolism) plant

- **CAM plant use PEP carboxylase** to collect carbon dioxide during night and store carbon dioxide as malate.
- It is a most **significant pathway** in **succulent plants**
- CAM photosynthesis is effective in **desert area**
- In CAM photosynthesis, the carbon fixation and the Calvin cycle are **separated in time.**
- fixation of carbon dioxide into PEP during night and Calvin cycle during the day
- **Cacti, pineapple** are **example of C4 plant**

Cycle of CAM photosynthesis

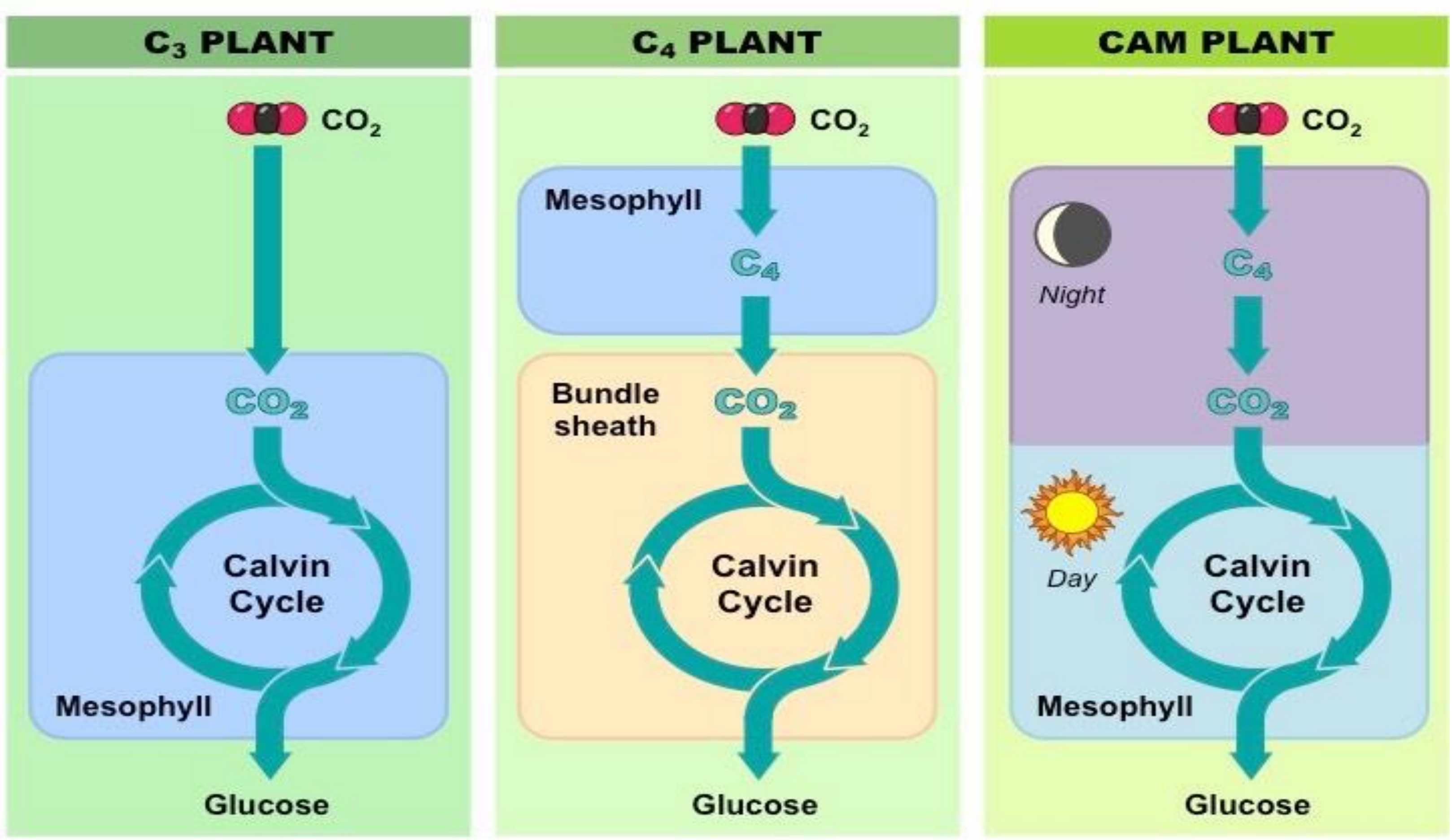
During night

- Stomata opened at night allow CO_2 react with PEP in mesophyll cells to form oxaloacetate.
- Oxaloacetate converted into 4-carbon malate
- Malate is synthesized in plenty and stored in the vacuole

During day time

- Light dependent reaction generate ATP and NADPH so that Calvin cycle continue
- Malate released from vacuole and yield free CO_2 and 3 carbon pyruvate
- pyruvate phosphorylated to regenerate phosphoenol pyruvate
- CO_2 released from malate is used for the reaction of Calvin cycle

Compare C3, C4 and CAM Photosynthesis



A comparison of C3 and C4 photosynthesis

Feature	C3	C4
❖ Bundle sheath cells	Lack chloroplasts	Have chloroplasts with no thylakoids
❖ Enzyme used to fix CO_2	Rubisco	Pepc (PEP carboxylase)
❖ Optimum temperature	15–25^{0}C	30–40^{0}C
❖ Optimum CO_2 Concentration	700 ppm	400 ppm
❖ Fixation of CO_2	Mesophyll cells	Mesophyll cells
❖ Calvin cycle	Mesophyll cells	Bundle sheath cells

Factors affect the rate of photosynthesis

- Rate of photosynthesis affected by **two factors**, these are

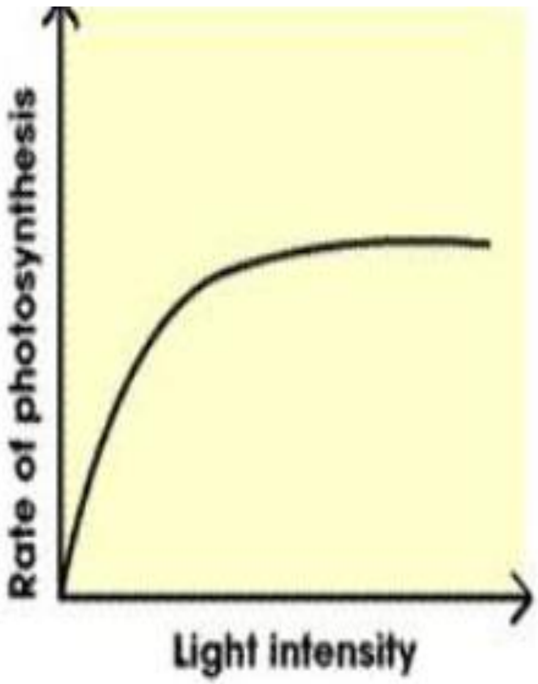
Environmental factor	Internal factor
✓ light intensity ✓ temperature, ✓ CO_2concentration ✓ water	✓ Leaf age ✓ Chlorophyll content ✓ Leaf anatomy

Rate of photosynthesis is different on different days.

- **On a cold, bright day in an Arctic country.**
  - Have **high light intensity** but **low temperature**
  - Low **temperature affect enzymatic activity** and limit the rate of photosynthesis. So **temperature is a limiting factor** is cold, bright day.
- **On a warm, cloudy day in summer.**
  - Low **light intensity but, high temperature**
  - **Low light intensity** affect the number of electron exited in l**ight dependent reaction** on antenna complex. Light intensity is likely to limit the rate.
- **On a warm, sunny day in summer.**
  - High temperature and light intensity
  - **Carbon dioxide concentration is a limiting factor**
- The rate of photosynthesis is limited by the factor that is present in a limiting quantity is called the **principle of limiting factors**.

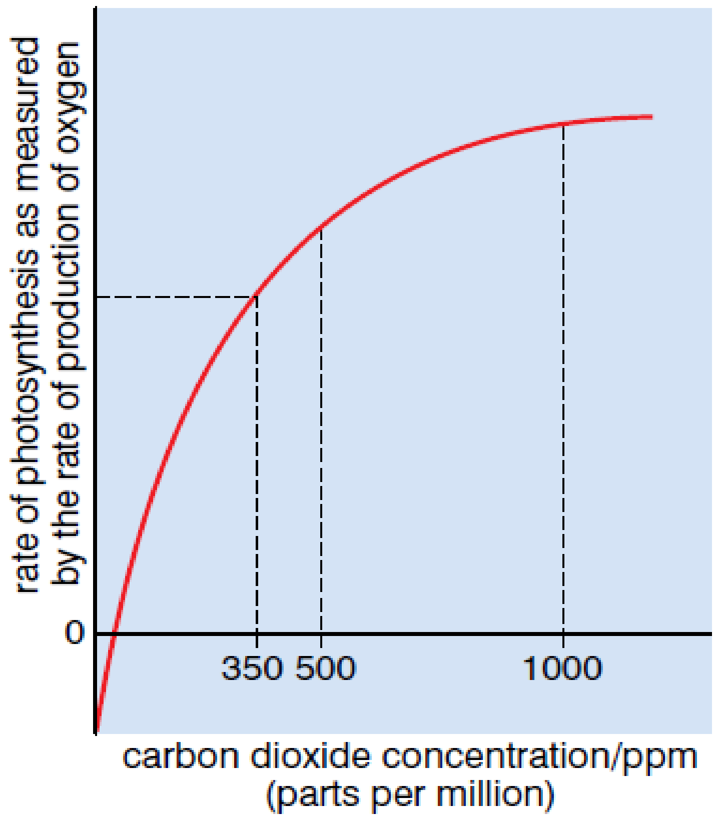
Effect of light intensity on rate of photosynthesis

- Higher light intensity causes more electrons in the chlorophyll molecules to become excited (gain energy)
  - As more and more **electrons are excited** more **ATP and NADPH** are generated used by light independent reaction .
- However, as **light intensity increases** the **rate of photosynthesis up to the levels off plateau.**
  - Plateau represents the maximum rate of photosynthesis **(light saturation)**
  - Very high light intensities limits rate of photosynthesis by other factor such as carbon dioxide and temperature.
- The effect of light intensity on the **rate of photosynthesis** measured by the **rate of production of oxygen**



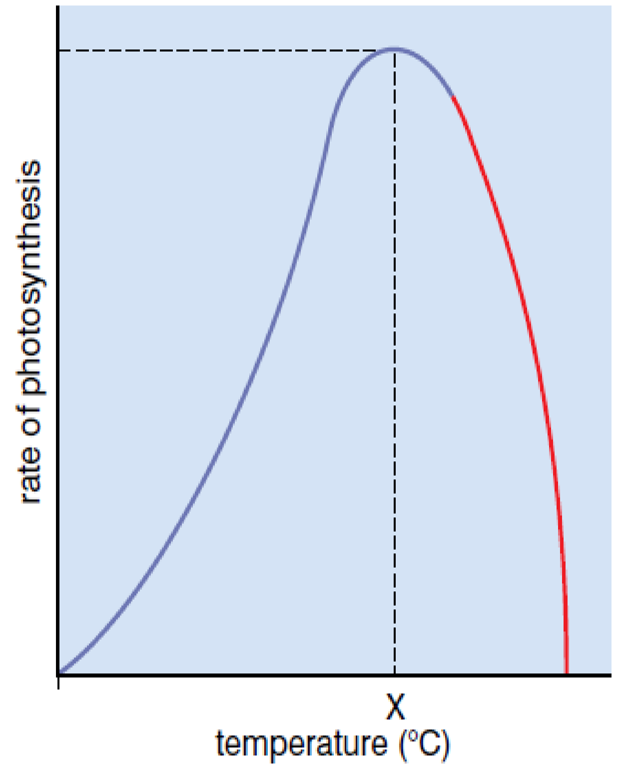
Effect of carbon dioxide on rate of photosynthesis

- **CO_2** concentrations limit the light-independent reactions by influencing the rate of the initial reaction with RuBP. .
- At very low carbon dioxide concentrations rate photosynthesis decrease
- An increase in carbon dioxide concentration increases rate of photosynthesis.
- However, **further increase in CO_2** concentrations the rate of photosynthesis stays constant due to **the saturation of Rubisco**



Effect of temperature on rate of photosynthesis

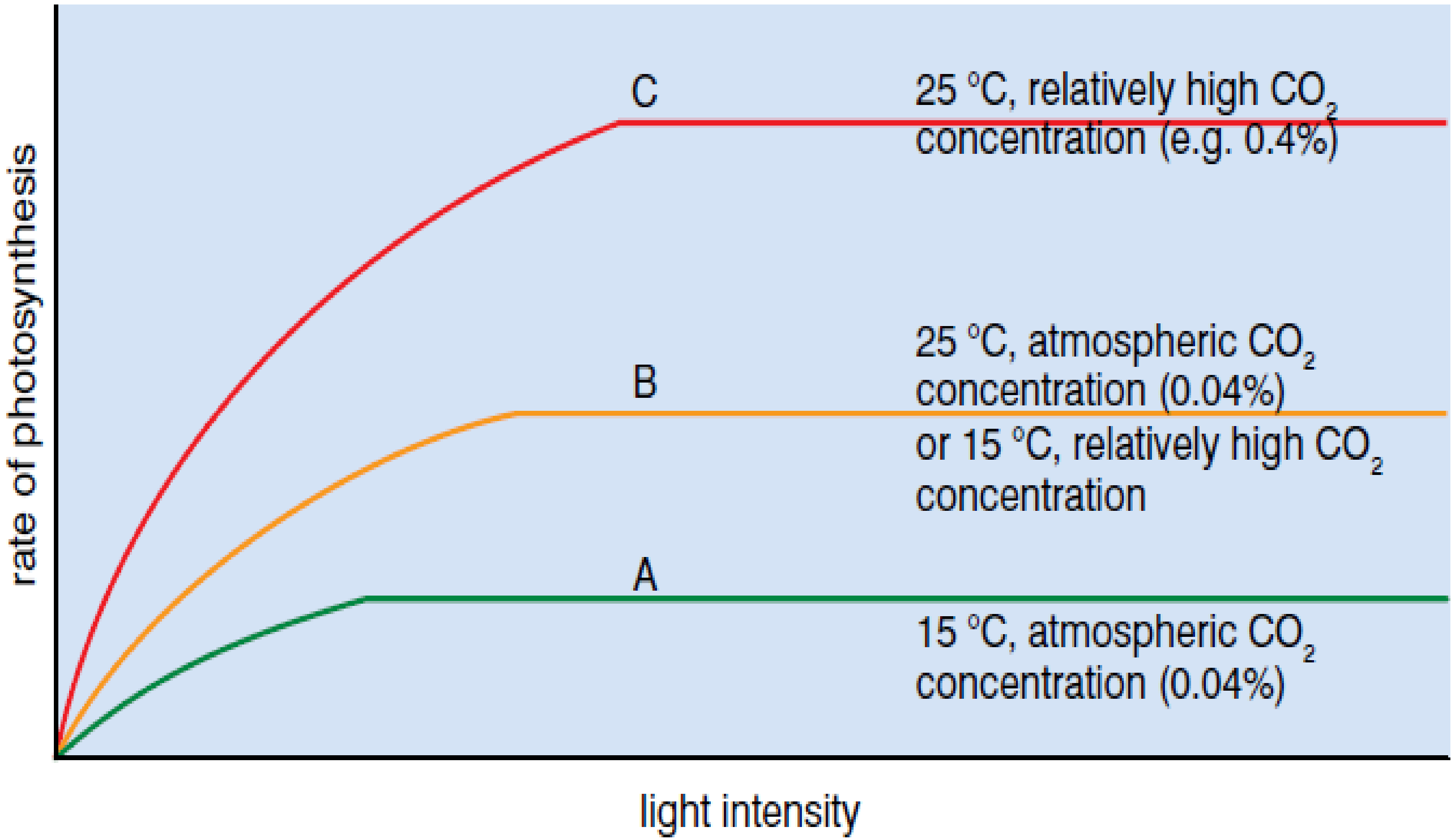
- At **low temperature** the **rate of photosynthesis decreases** because enzymes do not work efficiently.
- At **optimum temperature rate of photosynthesis increase** since enzymes work efficiently.
- **Above optimum temperature the rate of photosynthesis decreases** rapidly as the enzyme denatures



Interaction of several factor on rate of photosynthesis

- Light intensity, carbon dioxide concentration interact to influence the rate of photosynthesis.
- **Increasing the light intensity, results in**
  - **Increase** the rate at which **ATP and reduced NADP (NADPH)** are produced in the light-dependent reactions
  - **Increase the rate at which the Calvin cycle** can take place.
  - **However,** the rate at which the **Calvin cycle can be limited by:**
    - **Low temperature** (limiting the rate at which enzymes work), **Low concentration of carbon dioxide**. Limits the rate at which NADPH and ATP can be used, this, in turn, limits the amount of NADP and ADP + Pi that can be reused by the light-dependent reactions.

Interaction of several….



Interaction of several….

A. **Low temperature and low carbon dioxide concentration**
   - Both CO2 and temperature limit the rate of photosynthesis

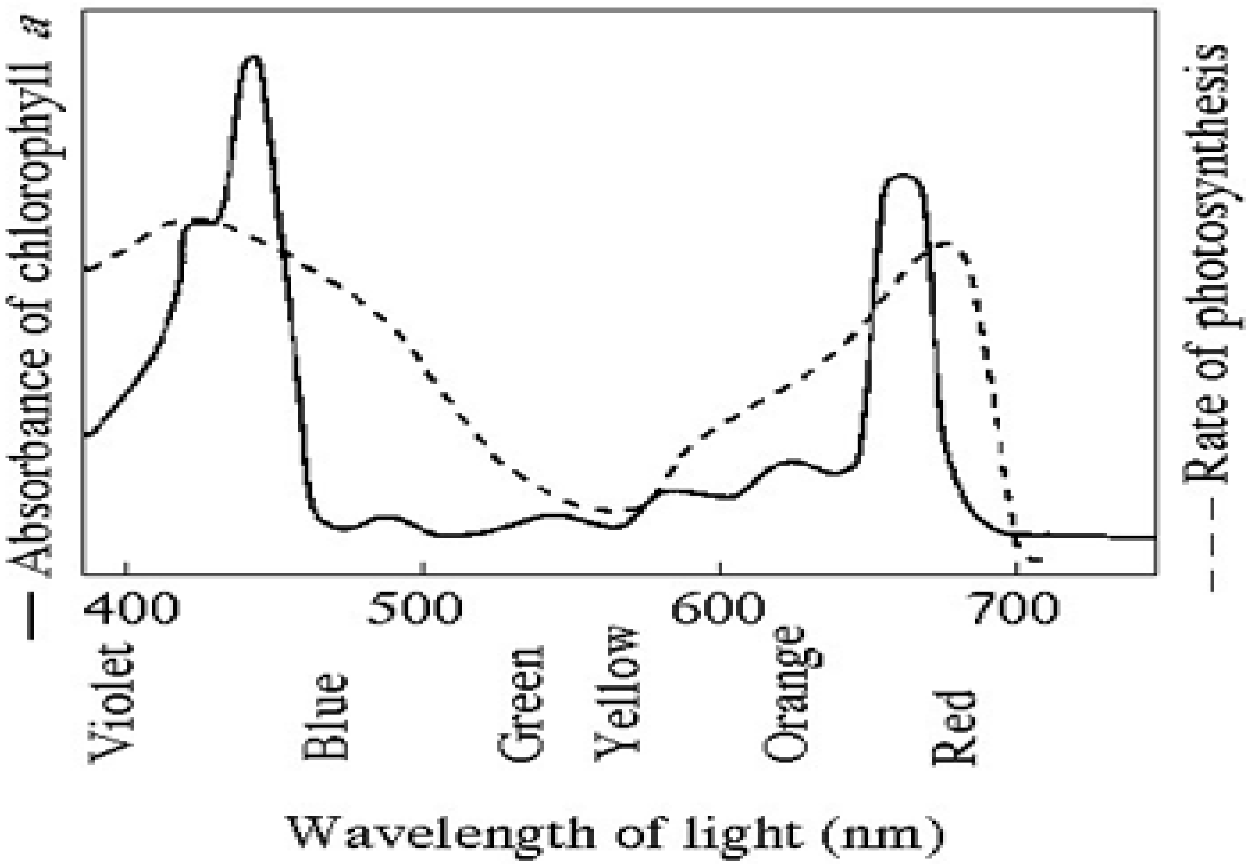
B. **High temperature and low CO_2 concentration or Low temperature and high CO_2 concentration**
   - Temperature or carbon dioxide concentration limit rate of photosynthesis
   - increasing the temperature increases the rate to level C

C. **High temperature and high CO_2 concentration**
   - Photosynthesis limited by other factor such as enzymes

Other factor affect the rate of photosynthesis

- **The wave length of light**
  - Photosynthesis occurs only in the **visible part of the light** spectrum i.e., **between 400 and 700 nm.**
  - Photosynthesis faster in **red and blue wave length**
  - The **maximum rate of photosynthesis** occurs at **red light** followed by blue light.
  - The **green light has minimum** effect and photosynthesis
- **The amount of chlorophyll**
  - Low chlorophyll concentration decrease rate of photosynthesis
- **Water**
  - Water is the raw material of photosynthesis
  - Lack of water affect the rate of photosynthesis
  - Plants become wilt and dry in low water concentration

Rate of photosynthesis on different wave length



- The **maximum rate of photosynthesis** occurs at **red light** followed by **blue light.**
- The **green light has minimum** effect on rate of photosynthesis