Cambridge Assessment International Education

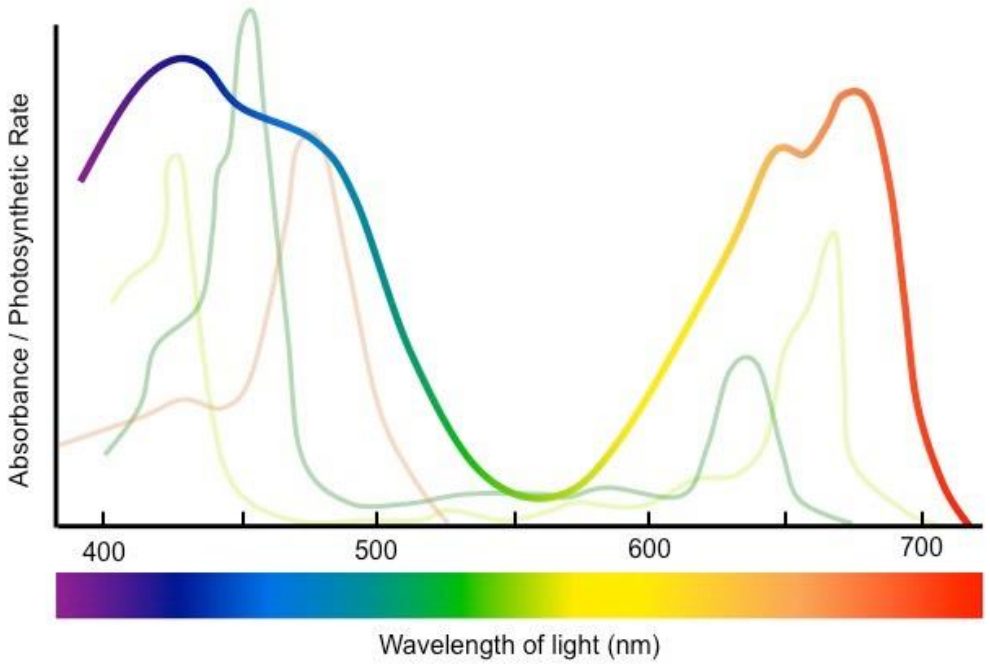
Chapter 13 A2 Level

Photosynthesis

Chapter Outline

Part 1

- Chloroplast pigments
- **Light absorption and action spectra** of chloroplast pigments
- P5: Chromatography and calculating R_f values

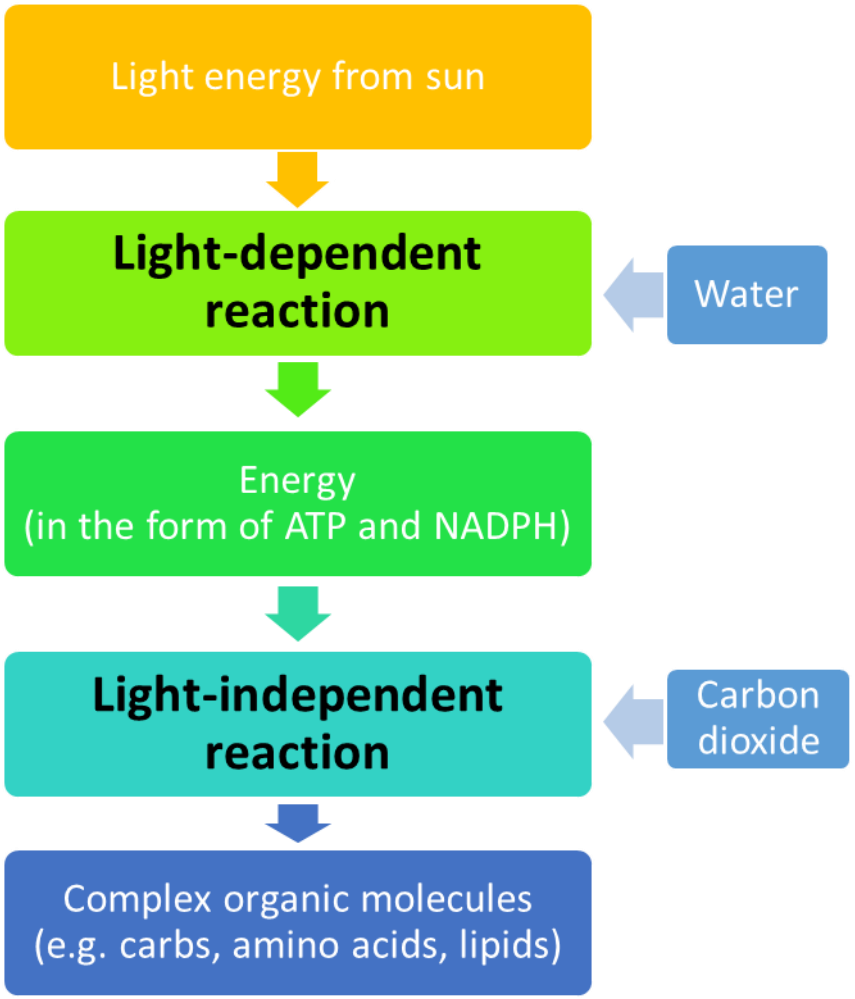


Chapter Outline

Part 2

- **Light dependent stage**
  - **Cyclic** and **non-cyclic** photophosphorylation
- P5: The Hill reaction
- **Light independent stage (Calvin cycle)**

- How structure relates to function in chloroplast

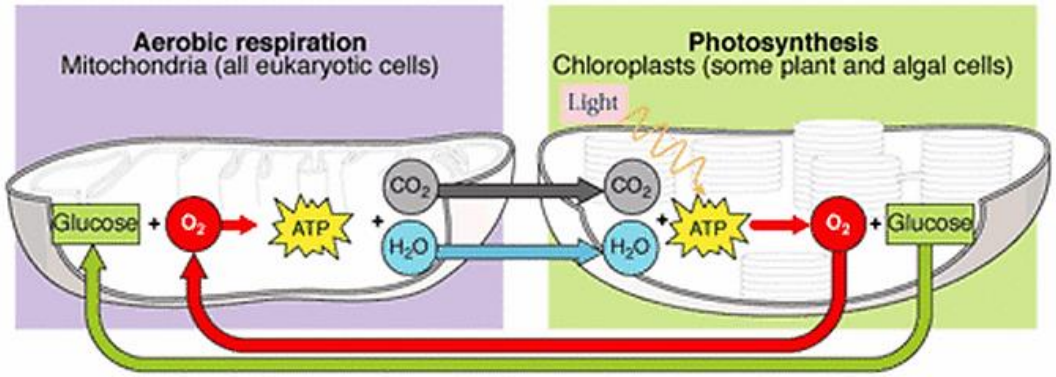


Chapter Outline

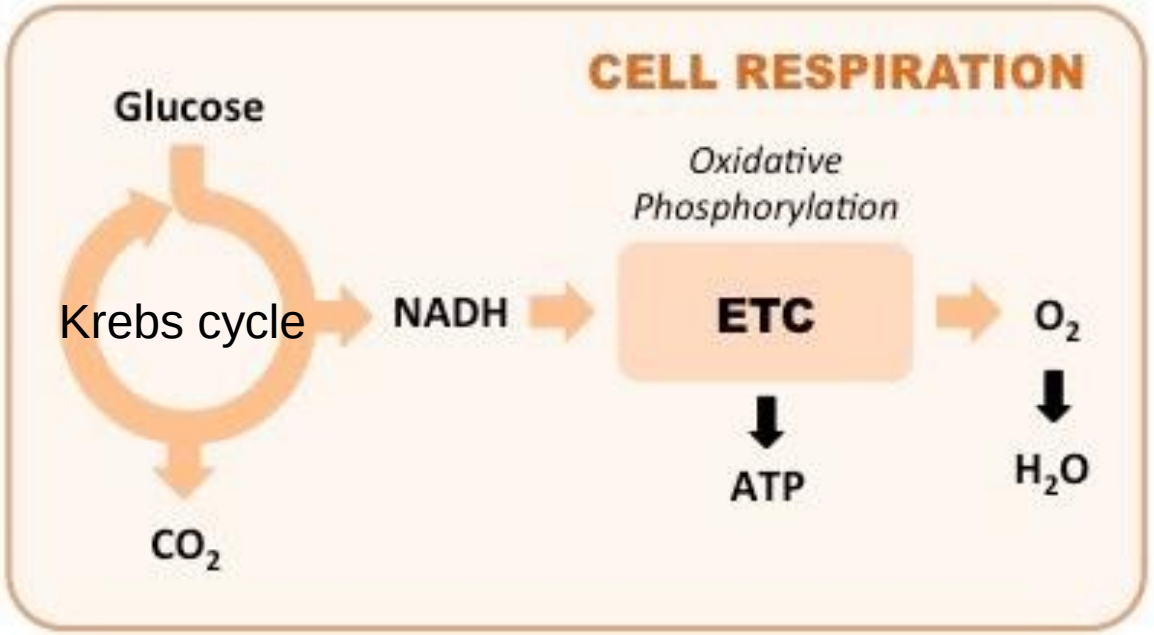
Part 3

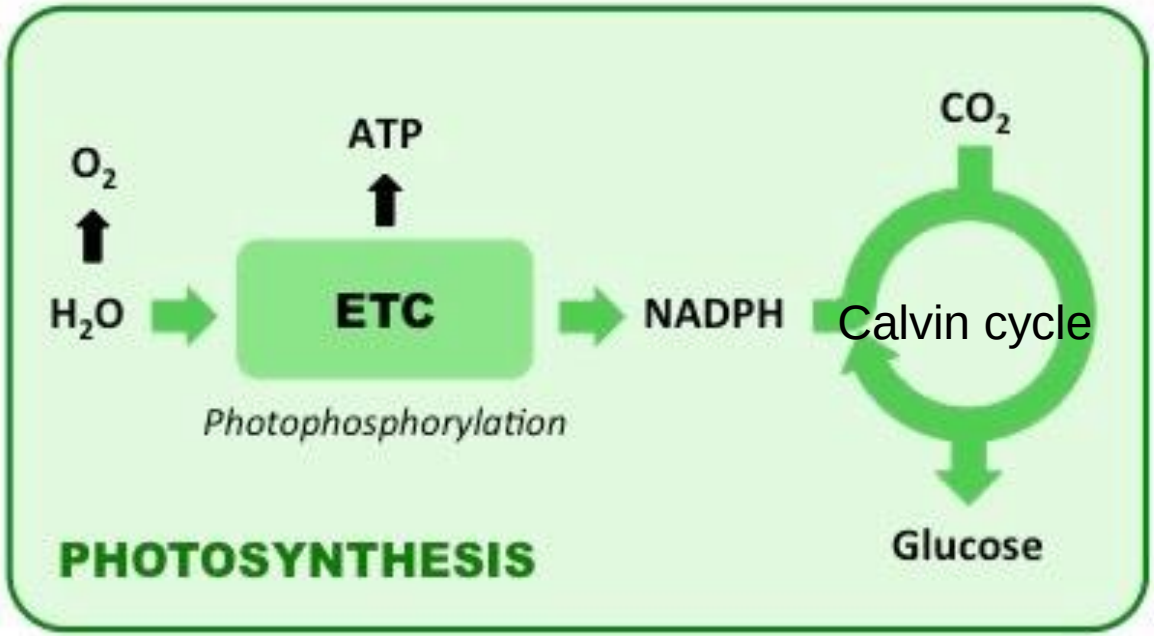
- P5: Investigating the rate of photosynthesis using an aquatic plant
- Limiting factors affecting rate of photosynthesis
  - Light intensity
  - Carbon dioxide concentration
  - Temperature

Introduction to Photosynthesis



	Aerobic Respiration	Photosynthesis
Reactants	Glucose, oxygen	Carbon dioxide, water
Products	Carbon dioxide, water	Glucose, oxygen
Energy Stored/Released?	Releases energy in glucose	Stores energy as glucose
Location	Cytoplasm + mitochondria	Chloroplast
Occurs in photoautotrophic producers?	Yes	Yes
Occurs in consumers?	Yes	No


CELL RESPIRATION
Glucose
Krebs cycle
NADH
Oxidative Phosphorylation
ETC
ATP
O_2
H_2O
CO_2


O_2
H_2O
ATP
ETC
Photophosphorylation
NADPH
CO_2
Calvin cycle
Glucose
PHOTOSYNTHESIS

Outline of Photosynthesis

$6CO_2 + 6H_20 \rightarrow C_6H_{12}O_6 + 6O_2$

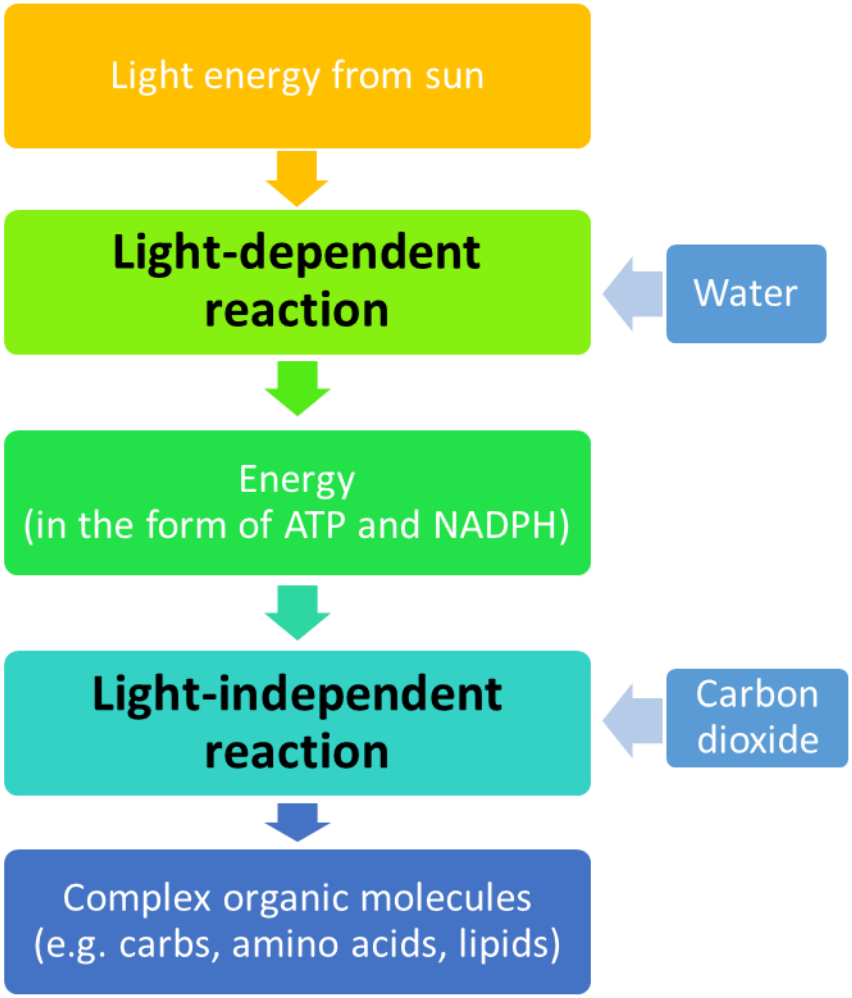
Two reactions involved:

1. Light-dependent reaction

- Trapping of light energy by photosynthetic pigments in chloroplast
- **Energy produced as ATP and NADPH** (reduced NADP)
- Energy transferred to light-indep. reaction

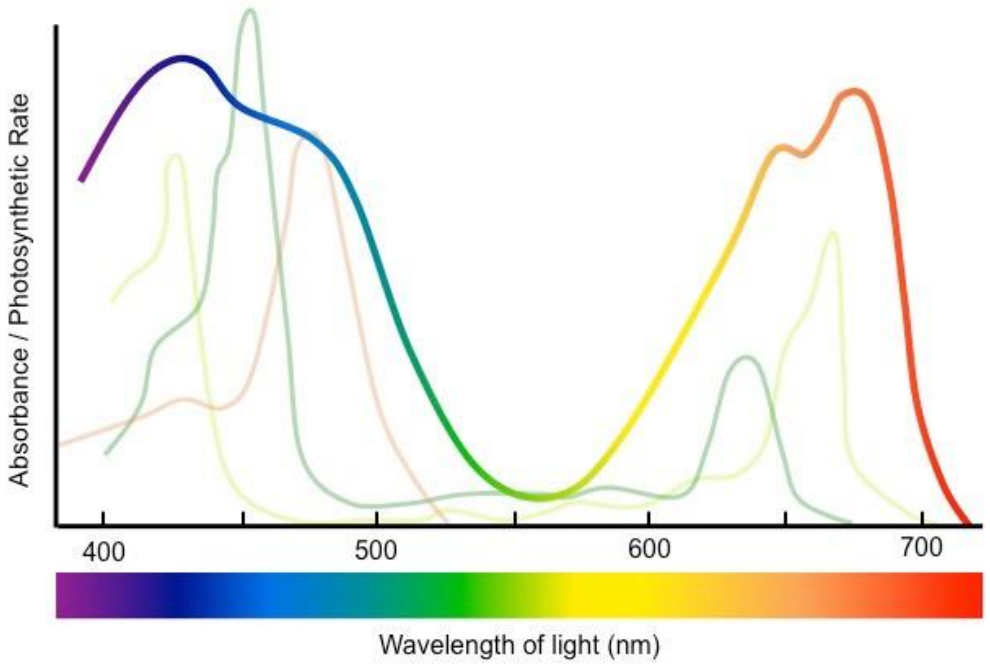
2. Light-independent reaction

- aka the **Calvin cycle**
- Energy from light-dep. reaction used for….
- **Fixation of carbon dioxide** / carbon fixation to **produce of complex organic molecules**



Part 1

- Chloroplast pigments
- **Light absorption and action spectra** of chloroplast pigments
- P5: Chromatography and calculating R_f values



Photosynthetic Pigments

- **Trap light energy**
- Found on **thylakoid membranes** of chloroplasts
- Pigments are arranged in light-harvesting clusters = **photosystems**

- Diff pigments absorb diff wavelengths of light

Two groups of photosynthetic pigments:

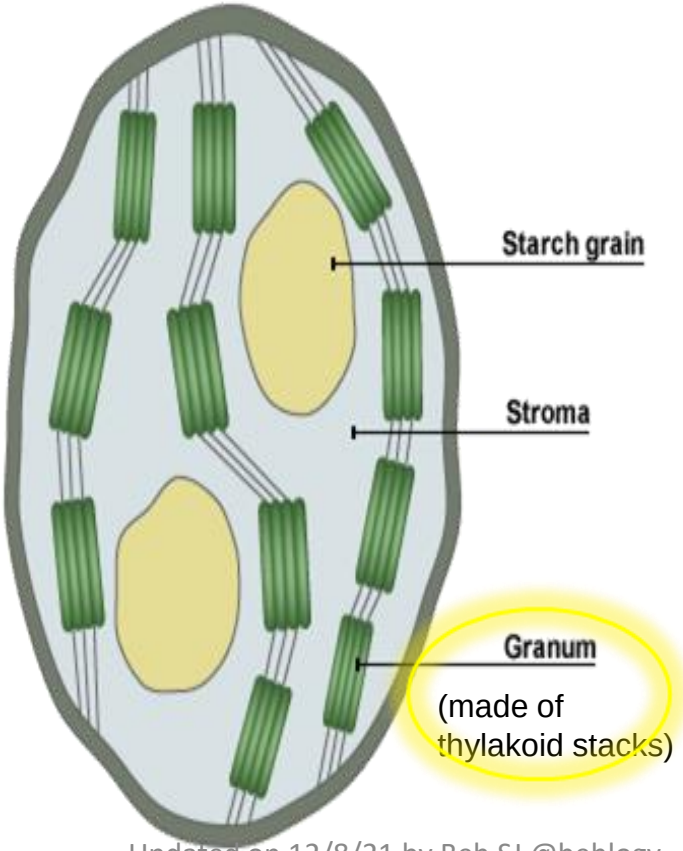
1. Chlorophylls

- E.g. chlorophyll *a*, chlorophyll *b*

2. Carotenoids

- E.g. β-carotene, xanthophyll

- **Chlorophyll *a* is a primary pigment**
- The rest are **accessory pigments**



Photosynthetic Pigments

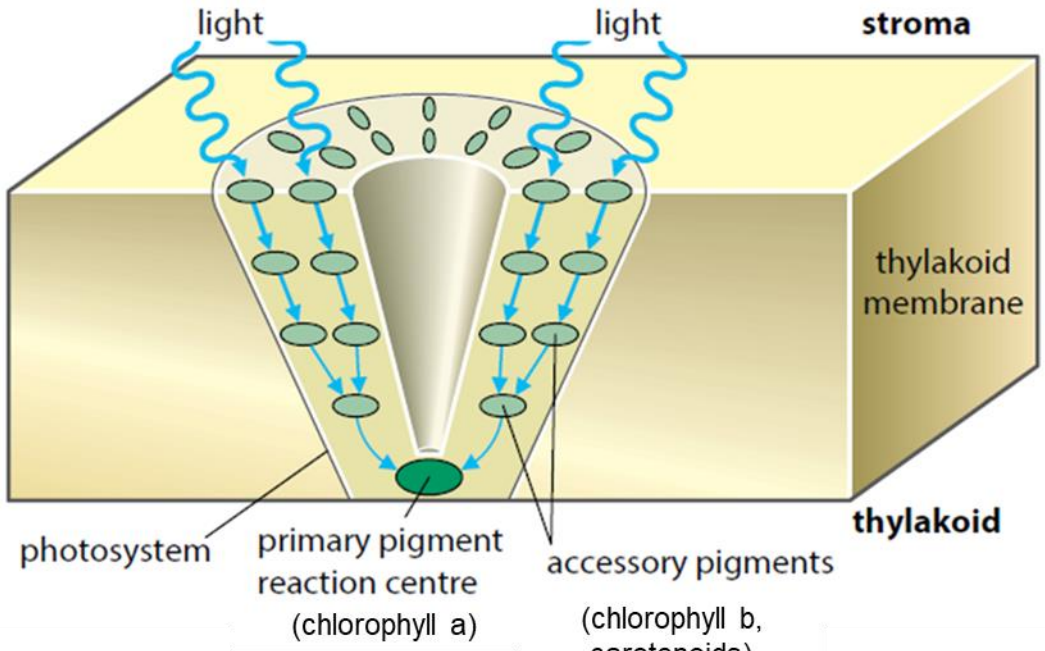
- Pigments are arranged in light-harvesting clusters = **photosystems** / antenna complex
- Primary pigments absorb light and act as **reaction centres** in the light-dependent reactions of photosynthesis
- Accessory pigments surround a primary pigment

→ **Accessory pigments may absorb diff wavelengths of light**

→ **Light energy are then passed to primary pigments**

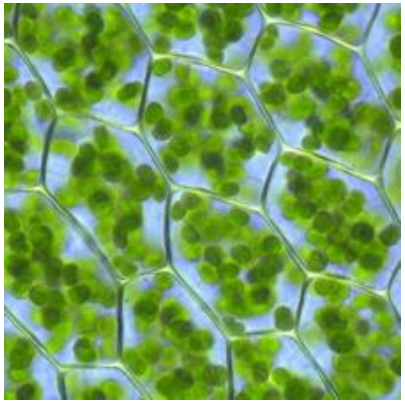
Two types of photosystems:

- Photosystem II (PSII)
- Photosystem I (PSI)



Photosynthetic Pigments

Group	Pigment	Colour
Chlorophylls	chlorophyll *a*	yellow-green
	chlorophyll *b*	blue-green
Carotenoids	β-carotene	orange
	xanthophyll	yellow

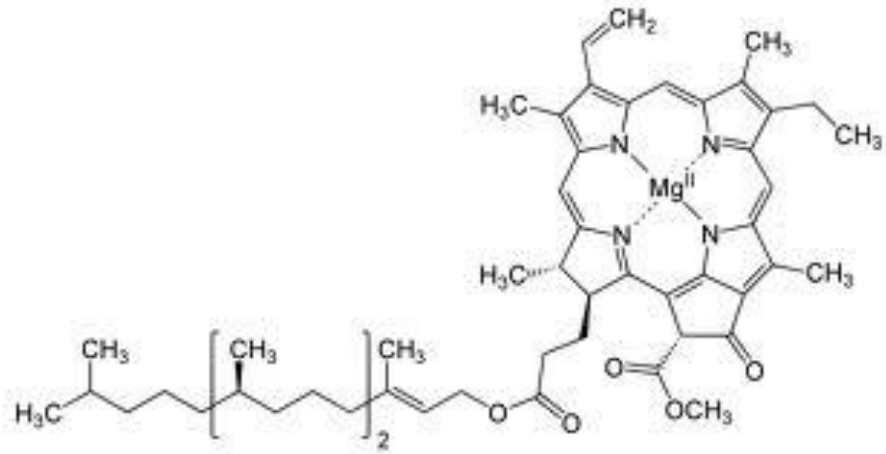


1. Chlorophylls

- Absorb mainly red & blue-violet lights
- Reflects green light

2. Carotenoids

- Absorb mainly blue-violet lights
- Reflects red light



Structure of chlorophyll *a*
(has head and tail, no need to memorise structure)

Photosynthetic Pigments

Light Absorption Spectrum

- Graph of **light absorbance by pigments** at diff wavelengths of lights

Group	Pigment	Colour
Chlorophylls	chlorophyll *a*	yellow-green
	chlorophyll *b*	blue-green
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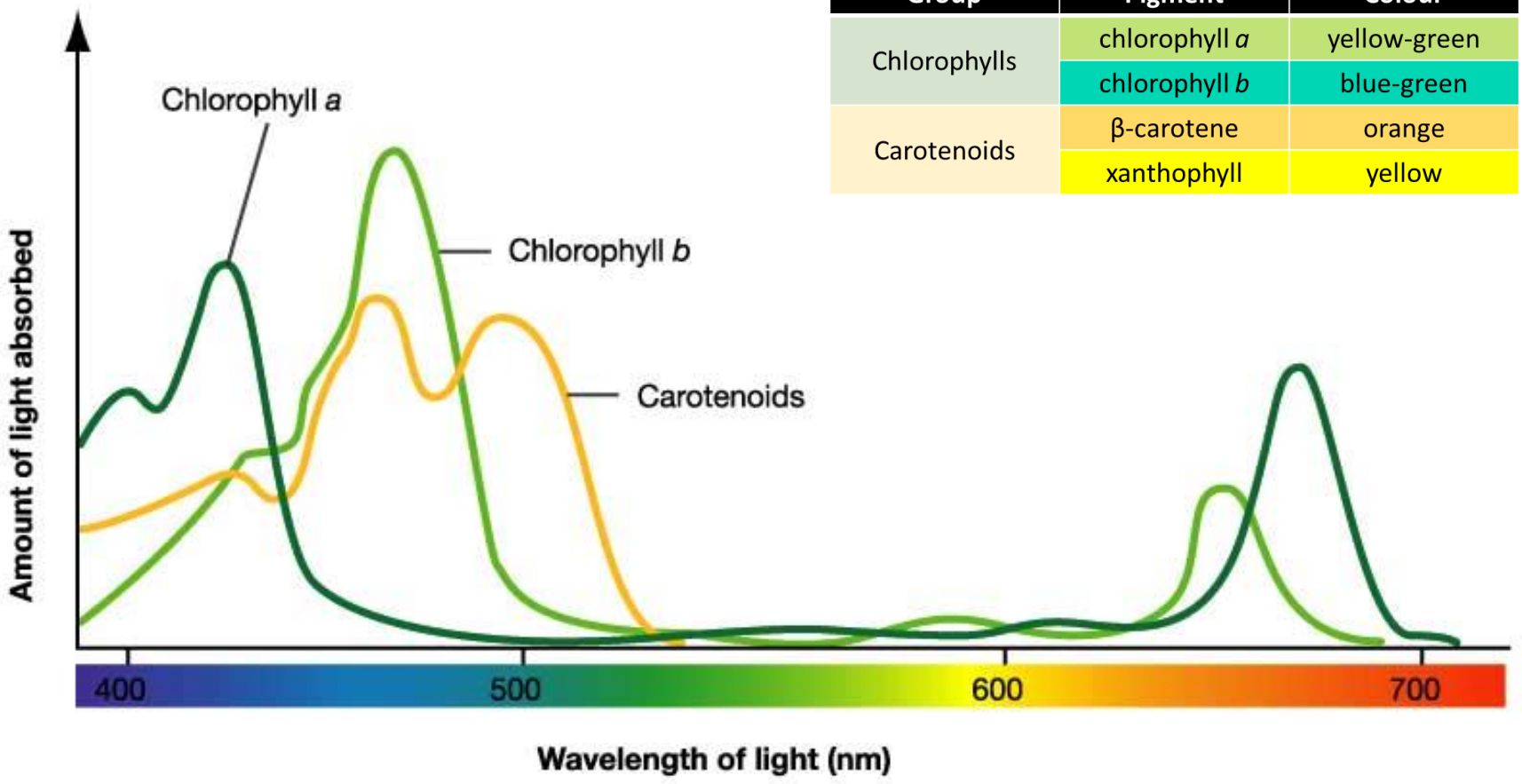
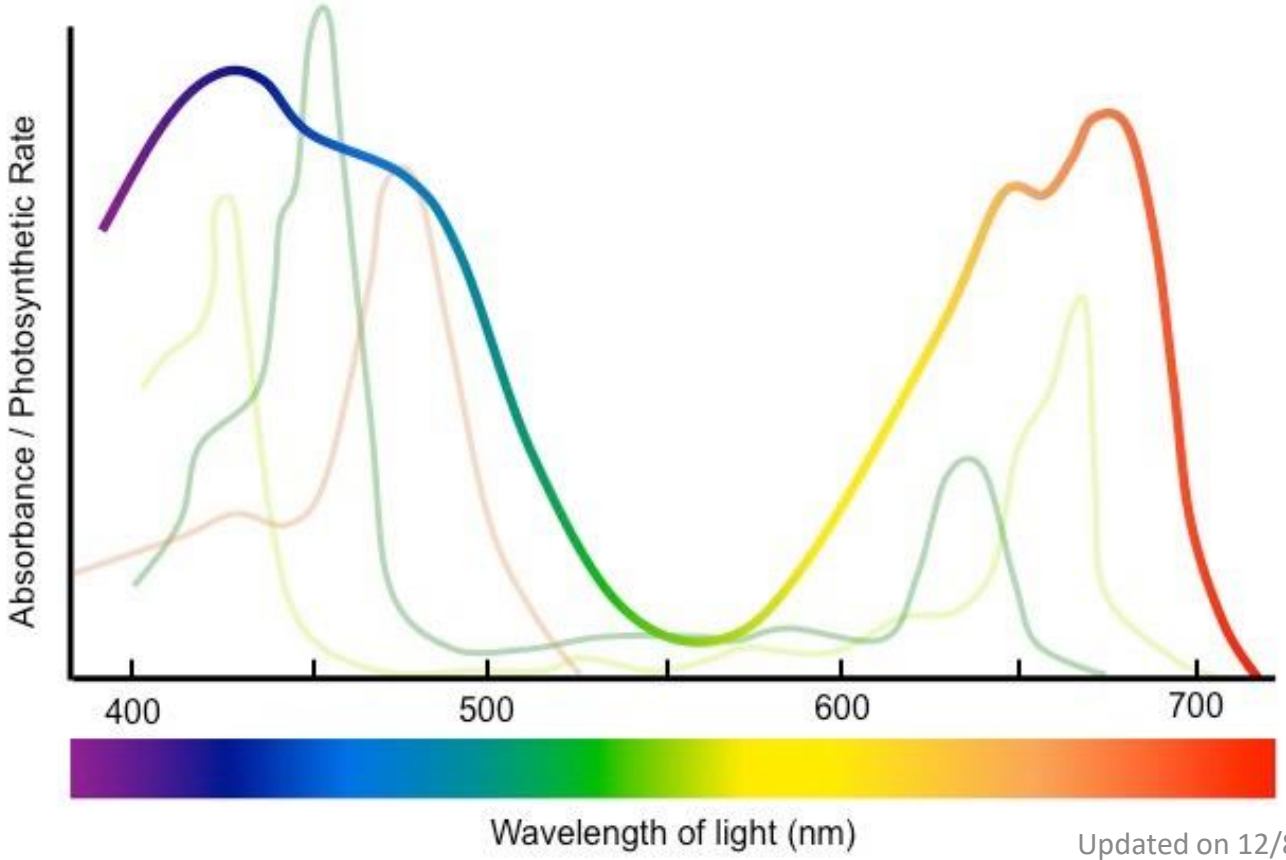


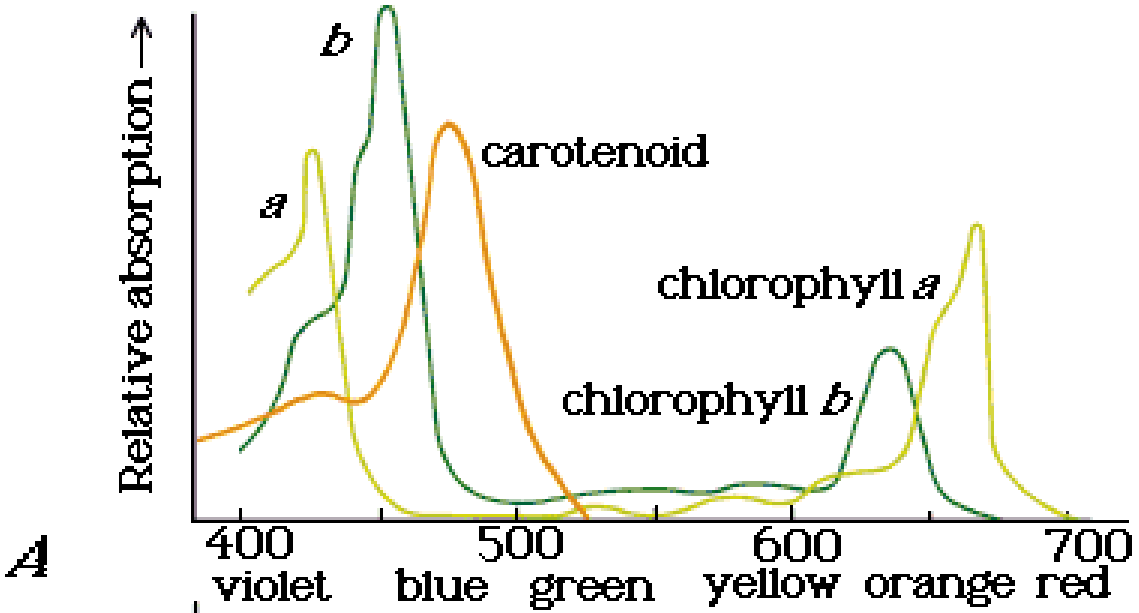
Photosynthetic Pigments

Photosynthetic Action Spectrum

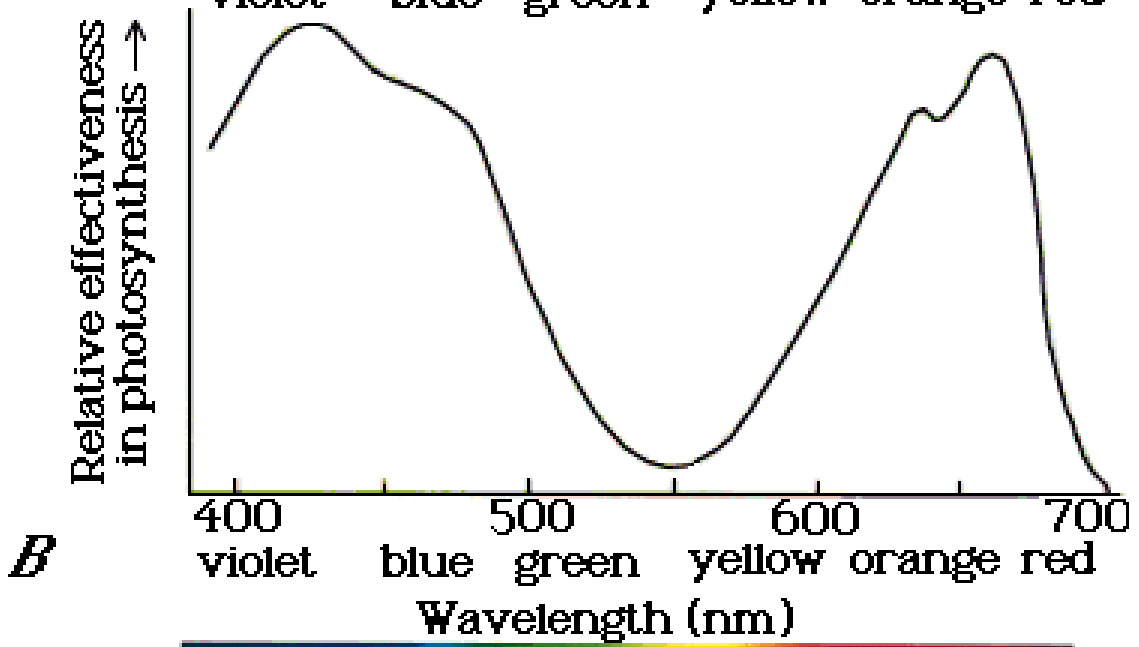
- Graph of **rate of photosynthesis** at diff wavelengths of light
- Related to absorption spectrum (but different)
- Also dependent of wavelength of light (shorter wavelength, more energy!)



Light absorption spectrum



Photosynthetic action spectrum



They are differentttt!

P5

Photosynthetic Pigments
Chromatography

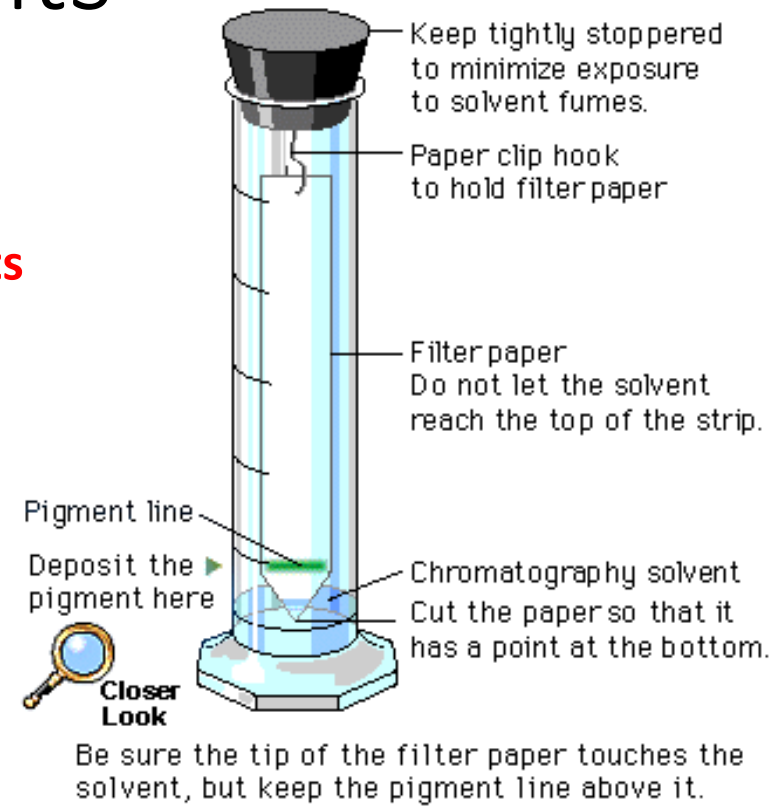
- Used to **separate and identify different pigments**

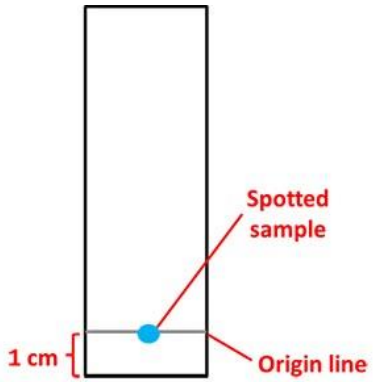
1) Grind/blend leaves

- Form suspension of plant extract with mixture of diff pigments

2) Place extract on a marked line of the **chromatography paper** using a small dropper. Dry and repeat.

3) Place paper into **solvent** so that solvent is just below the extract

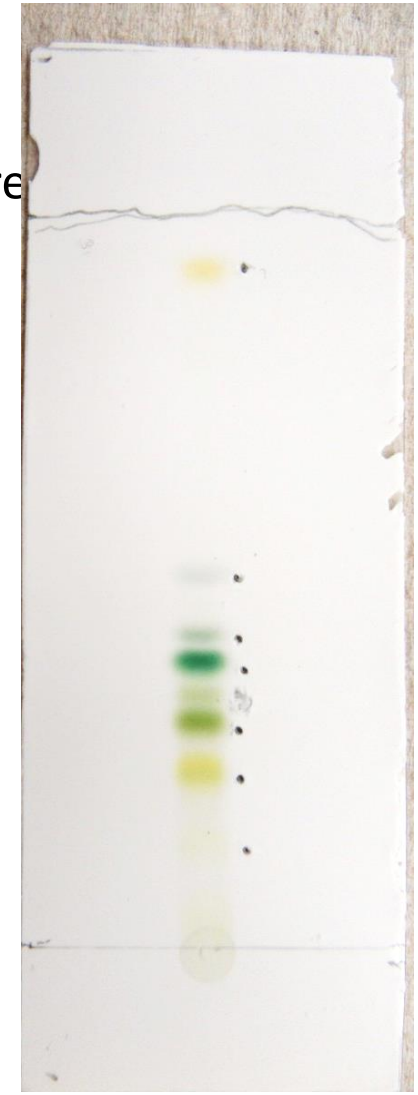




Photosynthetic Pigments
Chromatography

4) **Allow solvent to run** (rise up paper) for a fixed distance before it reaches end of paper

- Solvent carry diff pigments at diff speed, so diff distance from loading line
- Depends on pigment's mass
- Pigments separated → Chromatogram



Photosynthetic Pigments

Chromatography

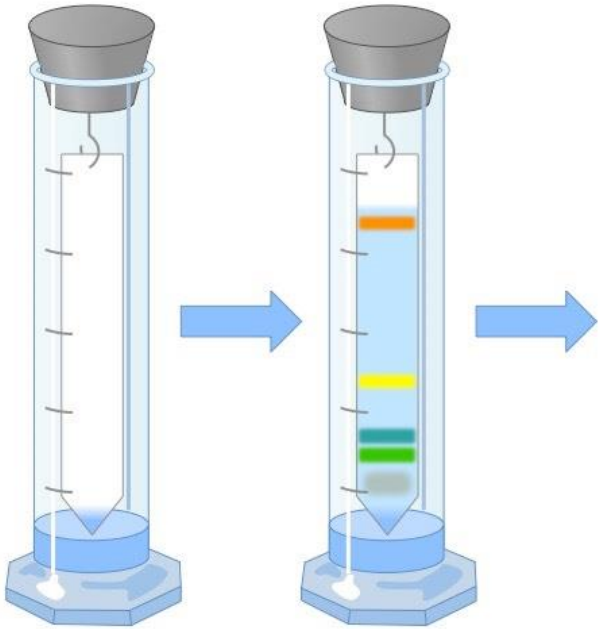
P5

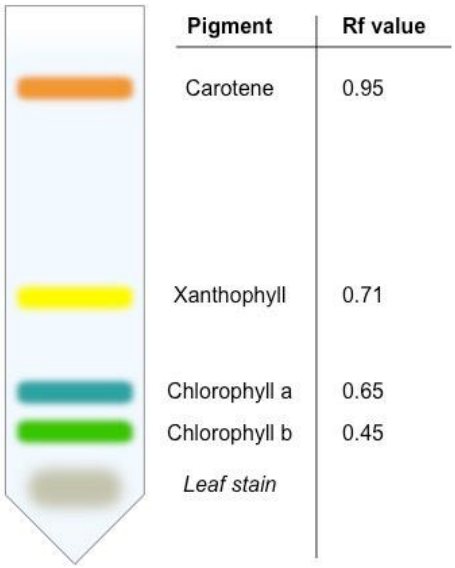
5) Measure distance travelled by solvent and pigment

6) **Calculate Rf value**

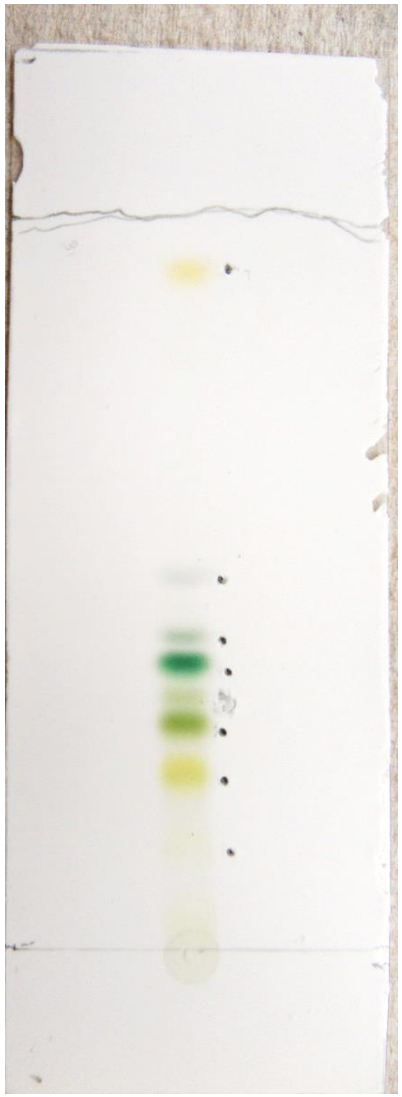
Rf = distance travelled by pigment
distance travelled by solvent

7) Compare Rf values against published values to identify pigments





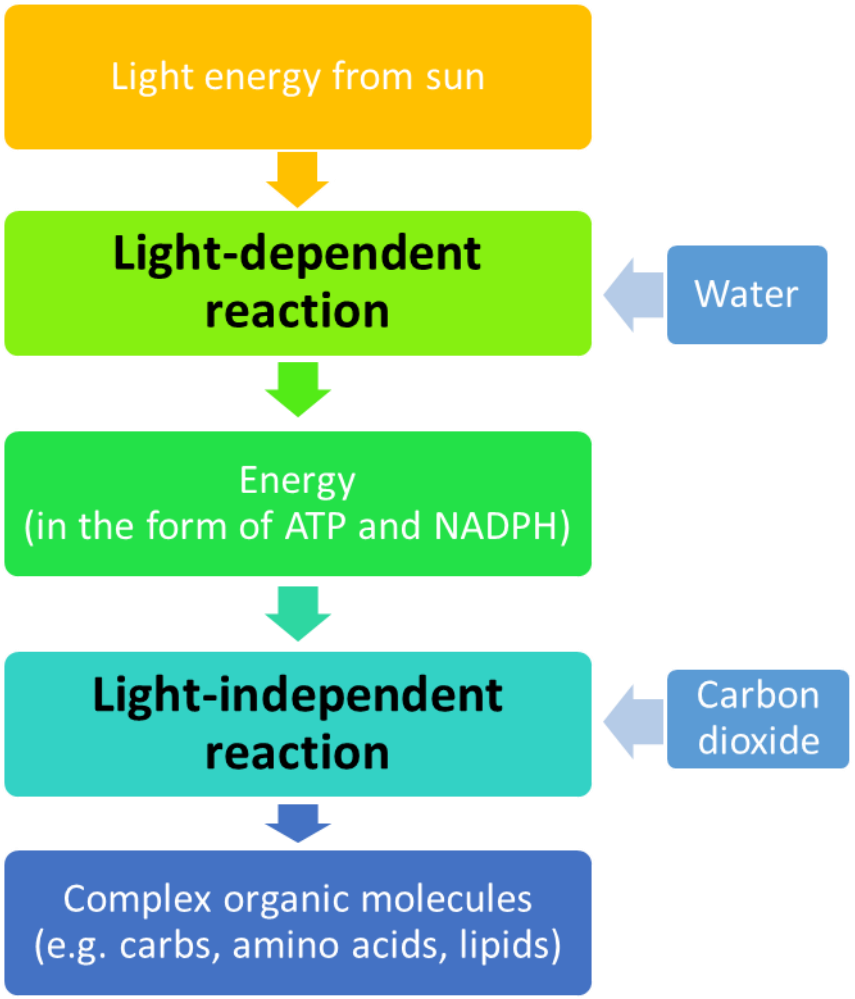
Pigment	Rf value
Carotene	0.95
Xanthophyll	0.71
Chlorophyll a	0.65
Chlorophyll b	0.45
Leaf stain	



Part 2

- **Light dependent stage**
  - **Cyclic** and **non-cyclic** photophosphorylation
- P5: The Hill reaction
- **Light independent stage (Calvin cycle)**

- How structure relates to function in chloroplast



Outline of Photosynthesis

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- aka the **Calvin cycle**
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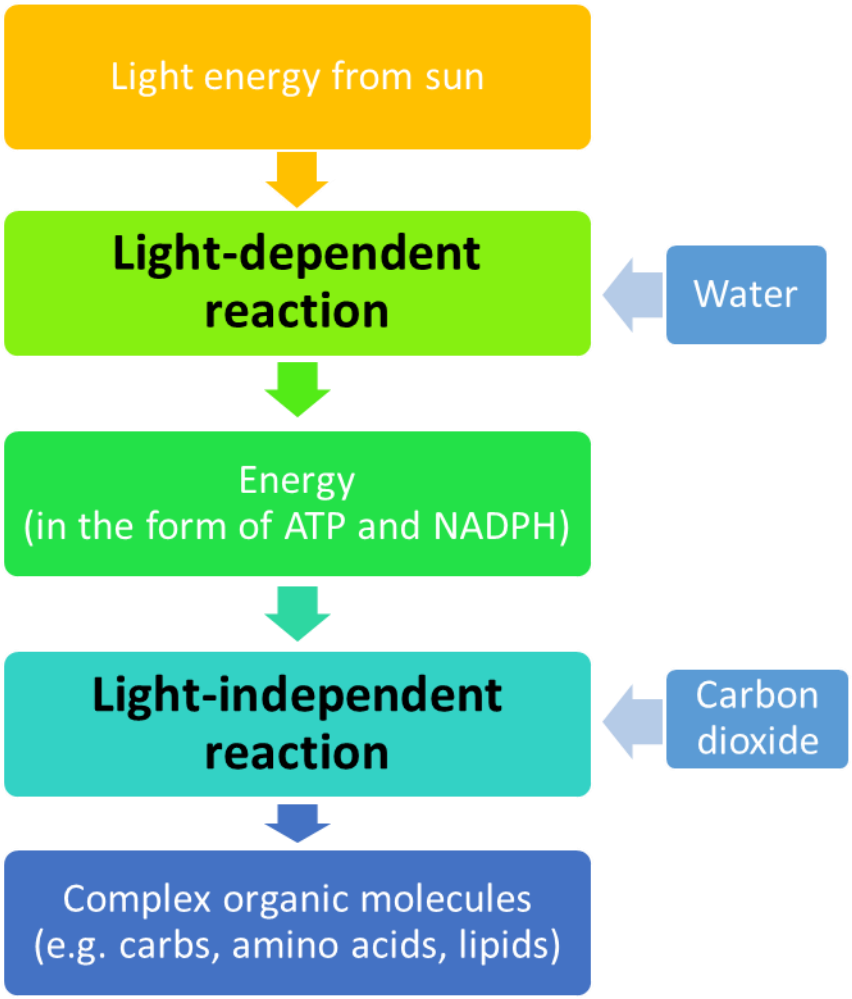
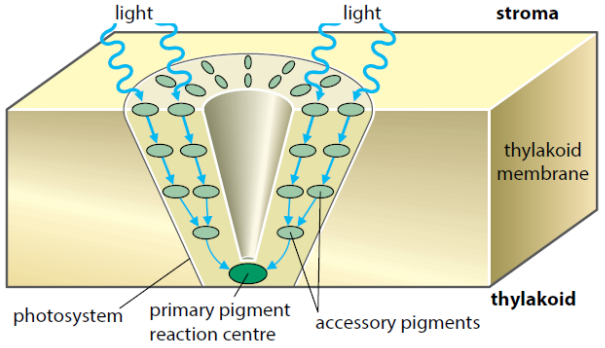


Light-Dependent Reaction

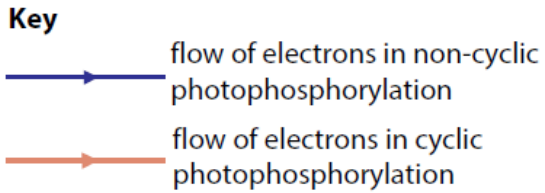
- Occurs in the **thylakoids**
- Trap **light energy**
- Use light energy to excite electrons in chlorophyll **(photoactivation)** and split water **(photolysis)**
- For the synthesis of **ATP and NADPH**

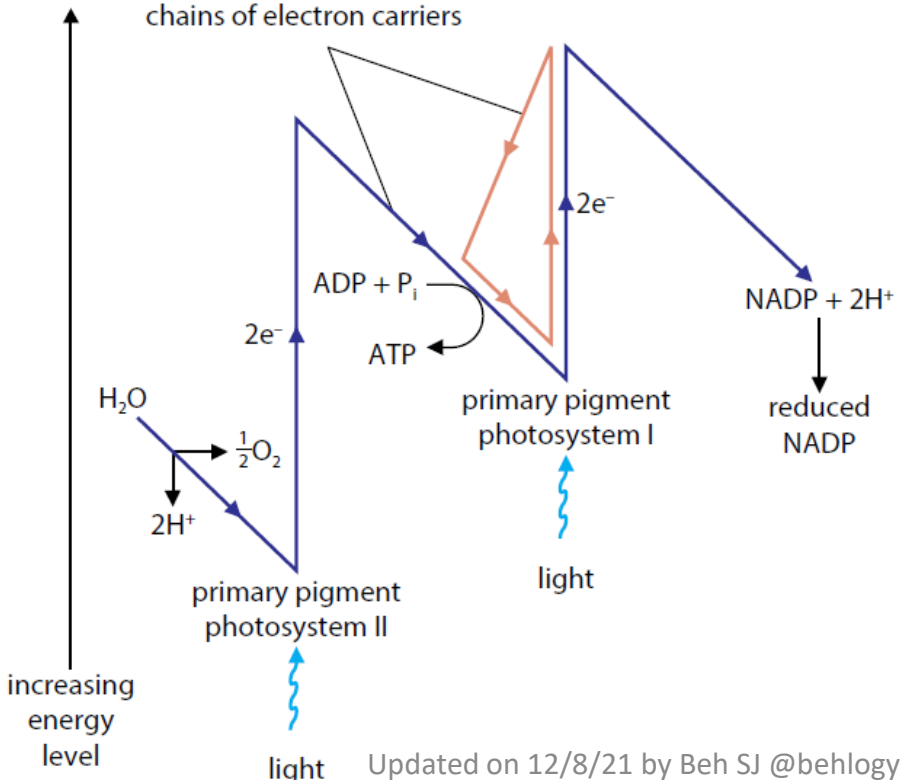
→ Which is used in light-independent reactions



Two pathways:

1. **Non-cyclic photophosphorylation**
2. **Cyclic photophosphorylation**

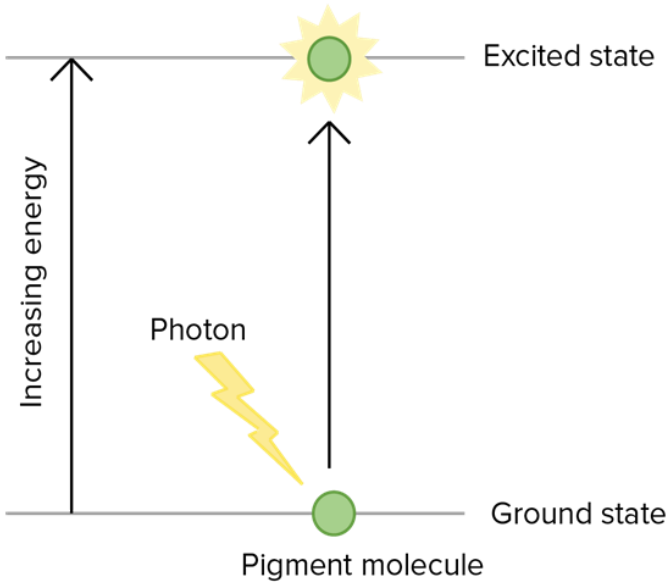


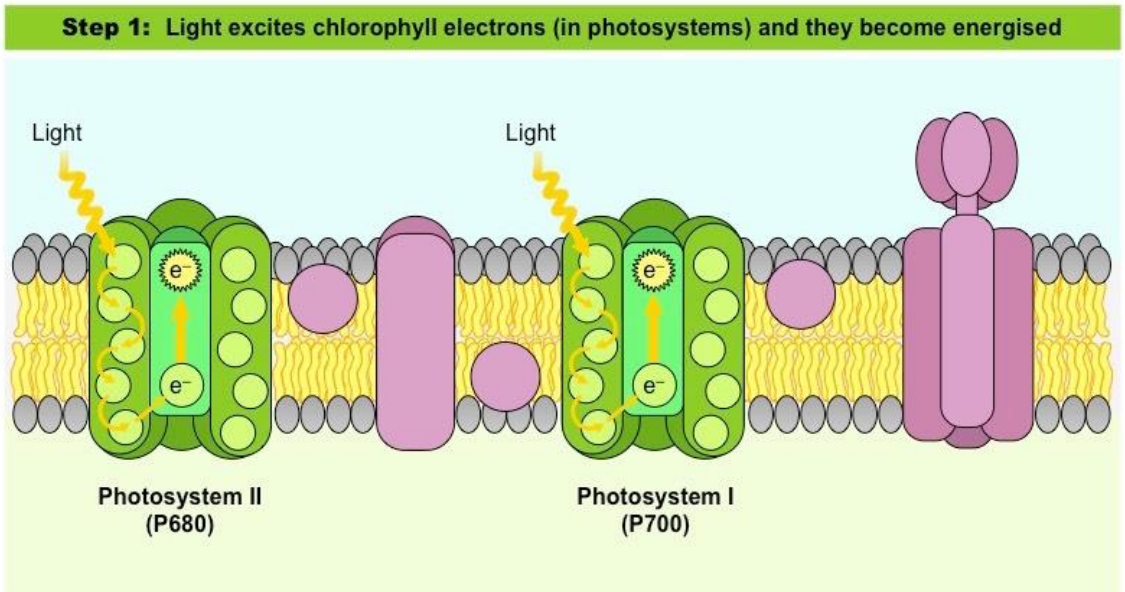


Light-Dependent Reaction
Non-Cyclic Photophosphorylation

Step 1: Photoactivation

- **Light energy absorbed** by **both photosystems (PSII and PSI)**
- Passed to primary pigment at **reaction centre**
- **Electrons excited** to a **higher energy level**
- **Electron emitted** from reaction centres
- Electrons **captured by electron acceptors**





Light-Dependent Reaction
Non-Cyclic Photophosphorylation

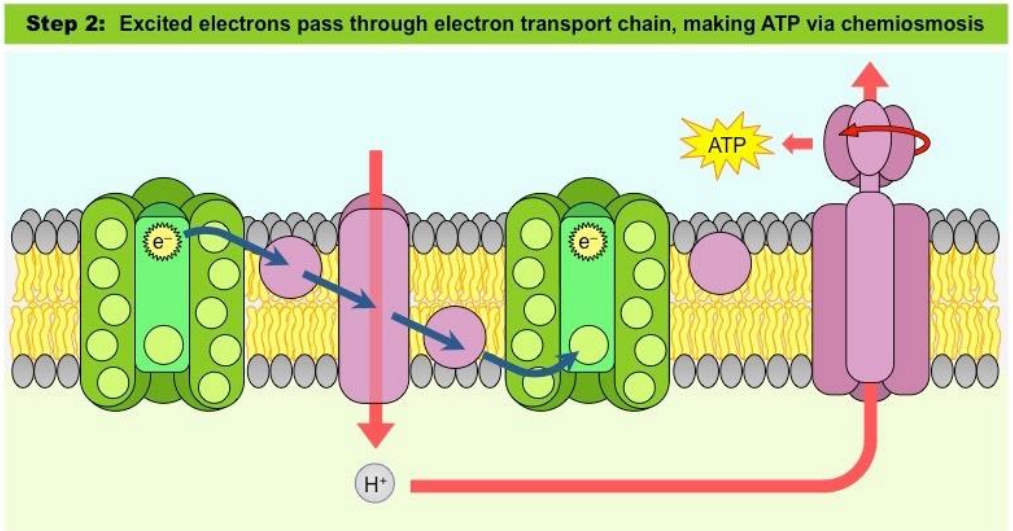
Step 2: Electron Transport Chain and ATP synthesis

- Electrons passed along the electrons carriers of the **ETC**
- Electrons releases energy to produce ATP using **chemiosmosis**

- Energy used to **pump H+ across membrane into the thylakoid lumen**
- **Proton gradient formed** across the thylakoid membrane
- H+ move down the gradient **into stroma**
- Via **ATP synthase**

→To synthesize ATP (from ADP & Pi)

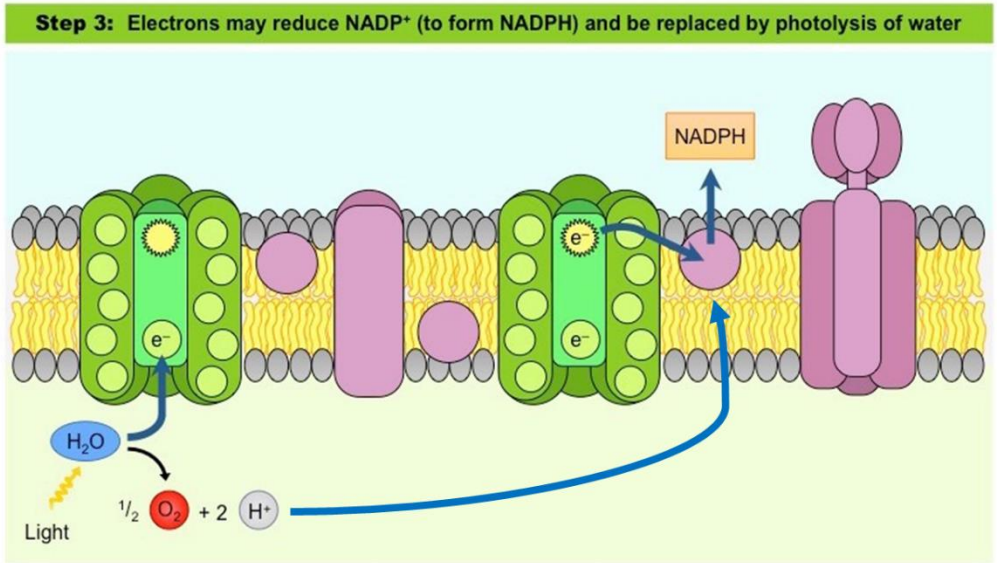
- ATP made is passed to light-independent reaction
- Electrons passed to **PS I**



Light-Dependent Reaction
Non-Cyclic Photophosphorylation

Step 3: Photolysis and Reduction of NADP

- Occurs at **PS II** only
- Requires enzyme



- Splitting of water to H^+ and OH^-
- Electrons are removed from OH^-

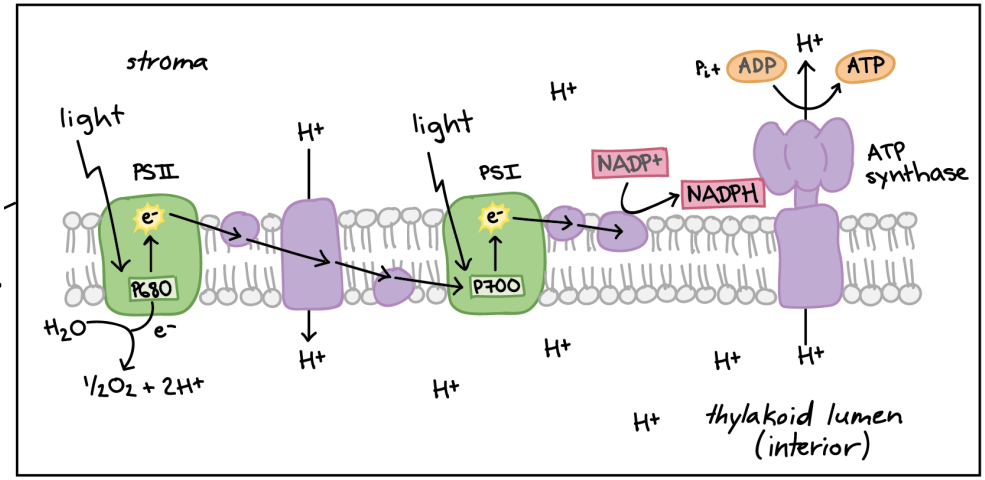
$H_2O \rightarrow 2H^+ + ½O_2 + 2e^-$

- Electrons – replace electrons lost from PS II
- Oxygen – waste gas, released
- H^+ ion – combine with de-energized electrons from PS I to reduce NADP

$NADP + 2H^+ + 2e^- \rightarrow NADPH$

Light-Dependent Reaction
Non-Cyclic Photophosphorylation

How are lost electrons replaced?



Electrons lost from:

1) PS II

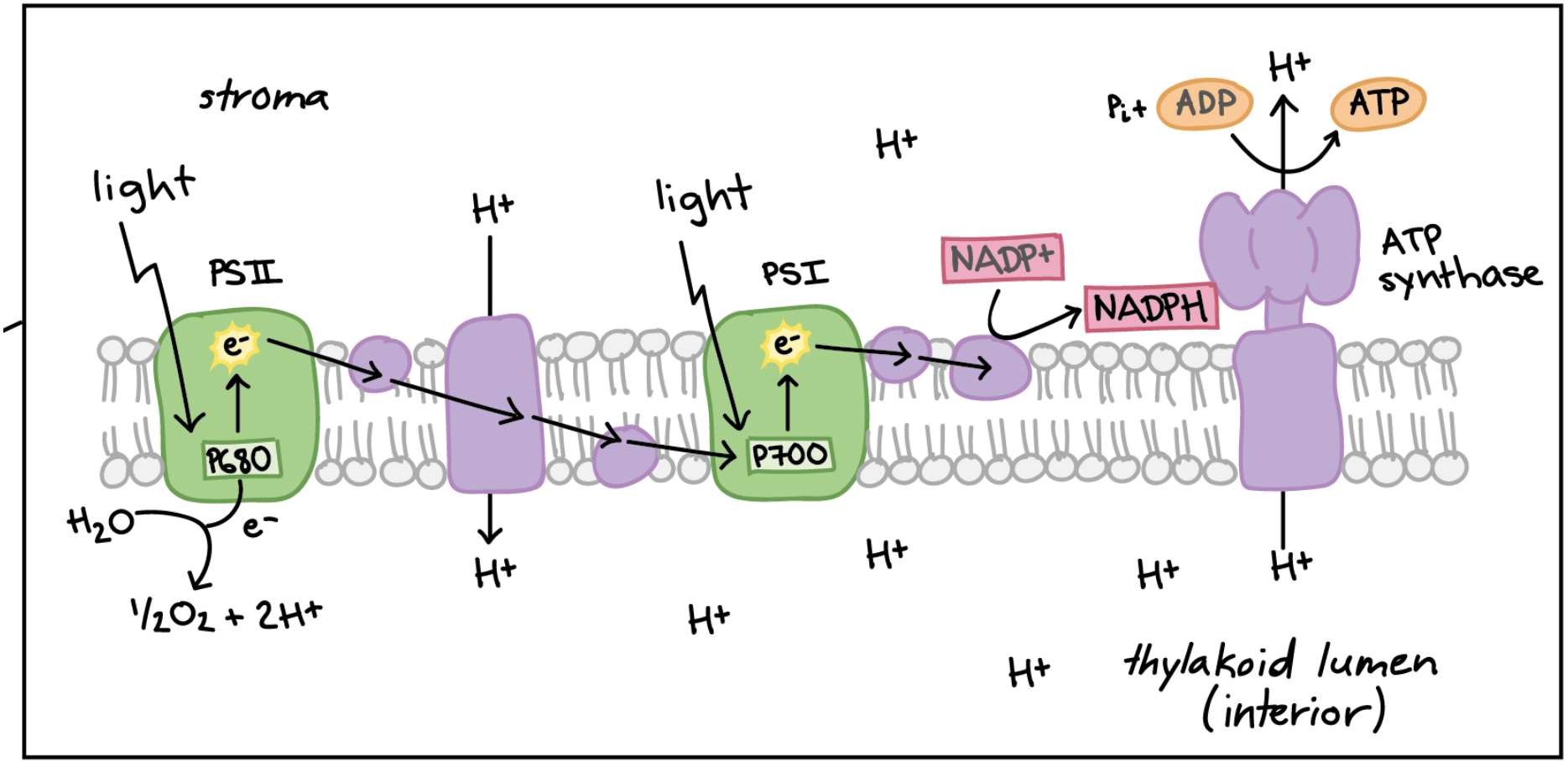
→ electrons from photolysis of water

$H_2O \rightarrow 2H^+ + ½O_2 + 2e^-$

2) PS I

→ electrons from PS II, after passing through the ETC

- Electron donor = **H_2O**
- Final electron acceptor = **NADP**
- NADP reduced to NADPH


stroma
light
PSII
P680
e⁻
H₂O
e⁻
½O₂ + 2H+
H+
H+
light
PSI
P700
e⁻
H+
H+
H+
NADP+
NADPH
H+
Pi+
ADP
ATP
ATP synthase
H+
H+
thylakoid lumen (interior)

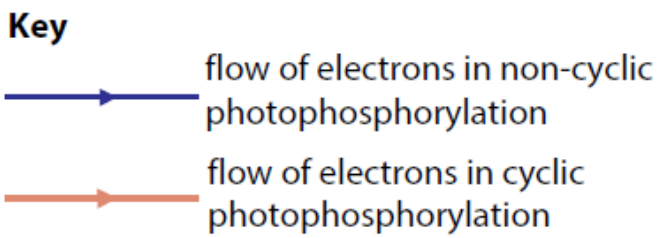
Light-Dependent Reaction

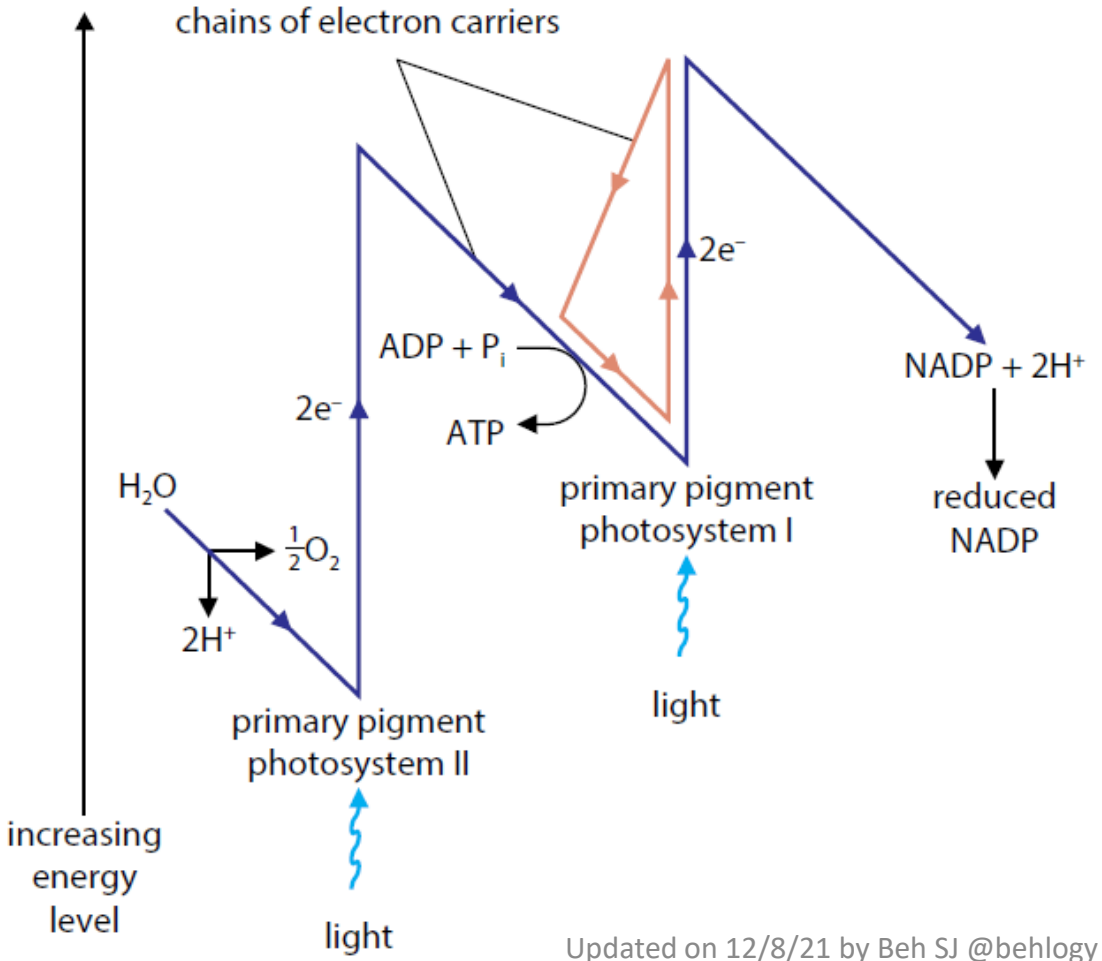
Non-Cyclic Photophosphorylation

- Involves **both photosystems**
- Electrons flow from PS II → PS I
- **'Z scheme'**
- Carried along electron carriers

→ ATP is synthesized

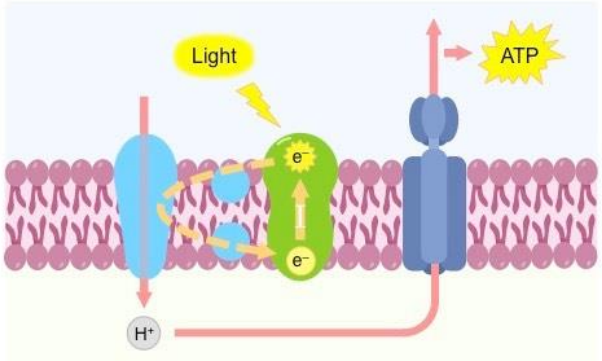
- Involves the photolysis of water
- Final electron acceptor = **NADP**



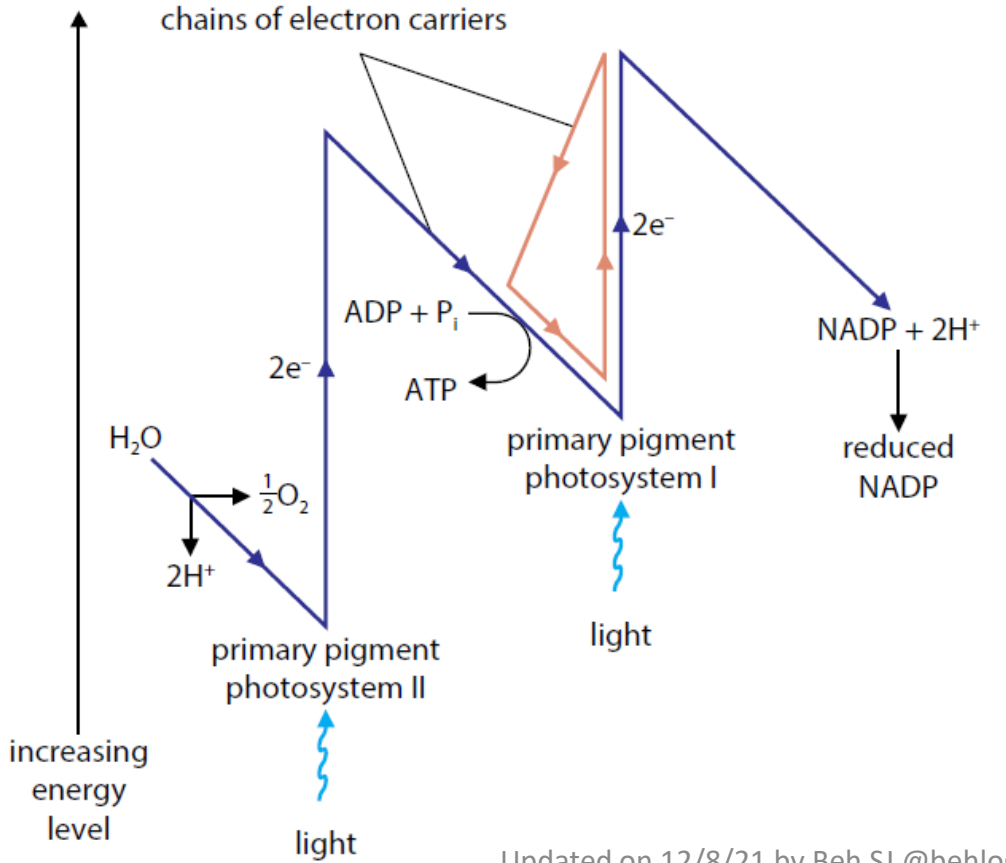


Light-Dependent Reaction

Cyclic Photophosphorylation



- Involves **only PS I**
- Reaction centre of PS I **photoactivated**
- Electrons excited and emitted from chlorophyll
- Captured by an electron acceptor
- Passed along **ETC**
- Energy released by electrons → ATP synthesis by chemiosmosis
- **Electrons returned to original photosystem, PS I**



- No photolysis of water involved
- No reduced NADP formed

- Final electron acceptor = **PS I**

The Hill Reaction

P5

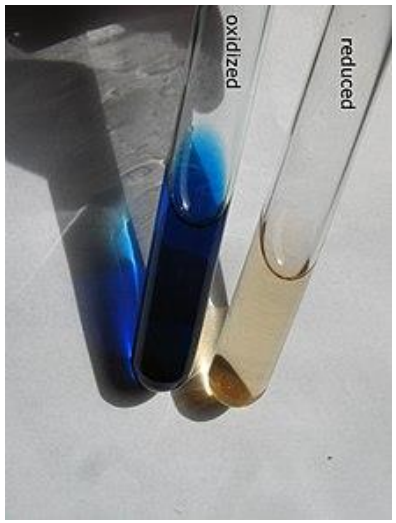
Used to determine the effect of light intensity/ wavelength of light on chloroplast activity

- Robert Hill, 1939
- Based on photolysis of water and reduction of NADP (ref. Step 3) in chloroplasts

In chloroplasts:

$H_2O \rightarrow 2H^+ + ½O_2 + 2e^-$

$NADP + 2H^+ + 2e^- \rightarrow NADPH$



In the Hill Reaction:

1)Chloroplasts are isolated

2)Presence of light and water

3) **Redox agents** (e.g. DCPIP)

- **DCPIP** = dichlorophenolindophenol
- **Substitute for NADP**
- Acts as electron acceptor / oxidising agent

When DCPIP reduced:

blue → colourless

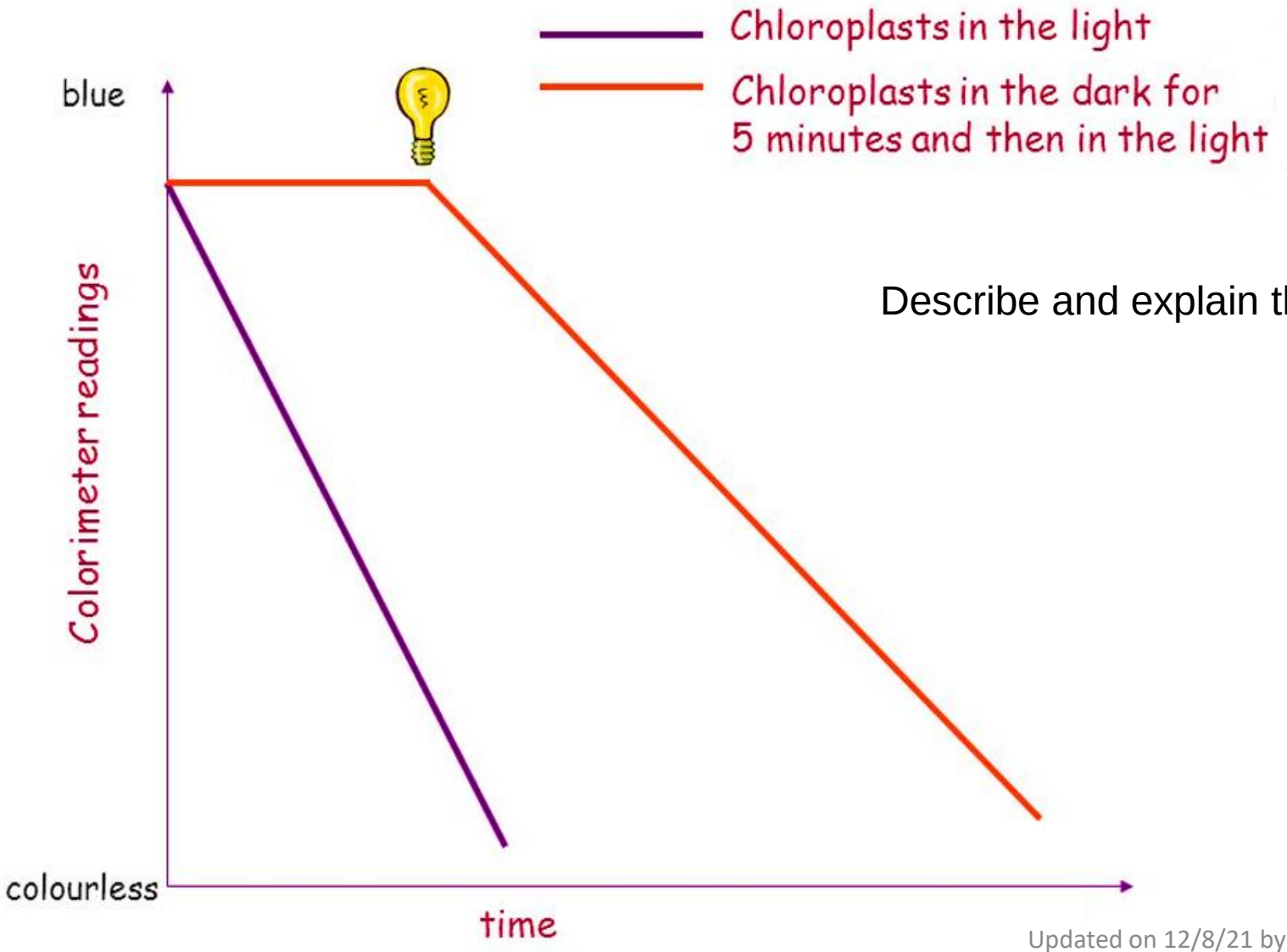
O_2 is produced

- **Rate of loss of blue colour = measure of chloroplast activity**
- Can investigate effect of light intensity / wavelength of light on chloroplast activity

The Hill Reaction

P5

Used to determine the effect of light intensity/ wavelength of light on chloroplast activity



Describe and explain this graph.

Outline of Photosynthesis

$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$

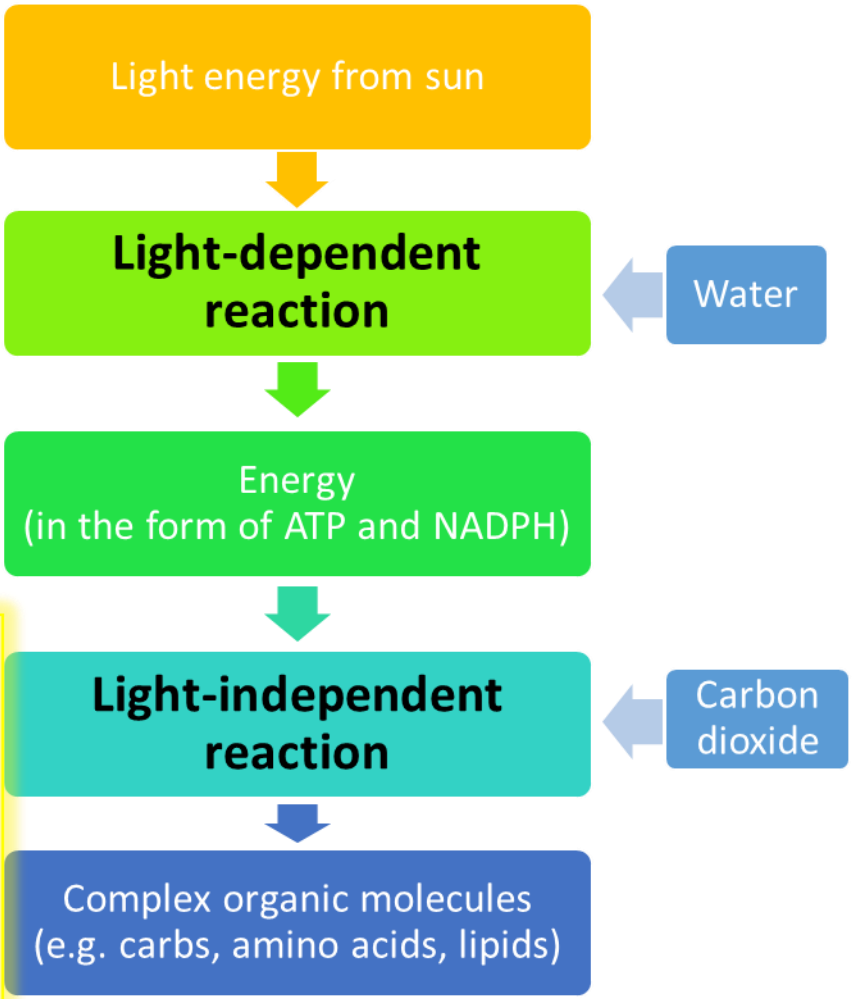
Two reactions involved:

1. Light-dependent reaction

- Trapping of light energy by photosynthetic pigments in chloroplast
- **Energy produced as ATP and NADPH** (reduced NADP)
- Energy transferred to light-indep. reaction

2. Light-independent reaction

- aka the **Calvin cycle**
- Energy from light-dep. reaction used for….
- **Fixation of carbon dioxide** / carbon fixation to **produce of complex organic molecules**

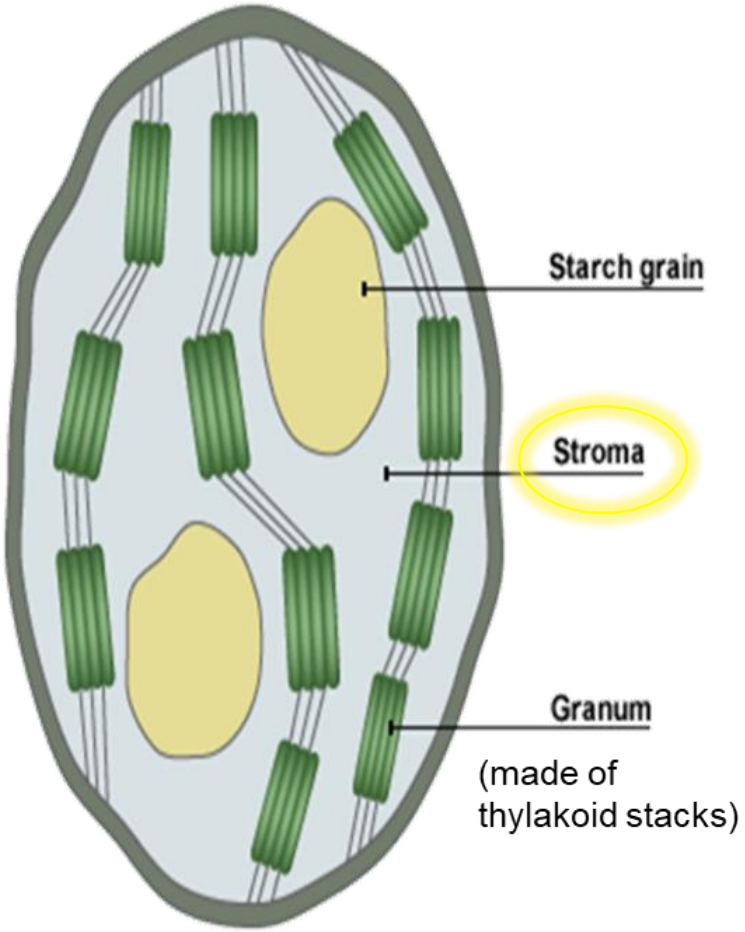


Light-Independent Reaction
(aka the Calvin Cycle)

- Occurs in the **stroma** of chloroplasts
- Does NOT require light

Steps:

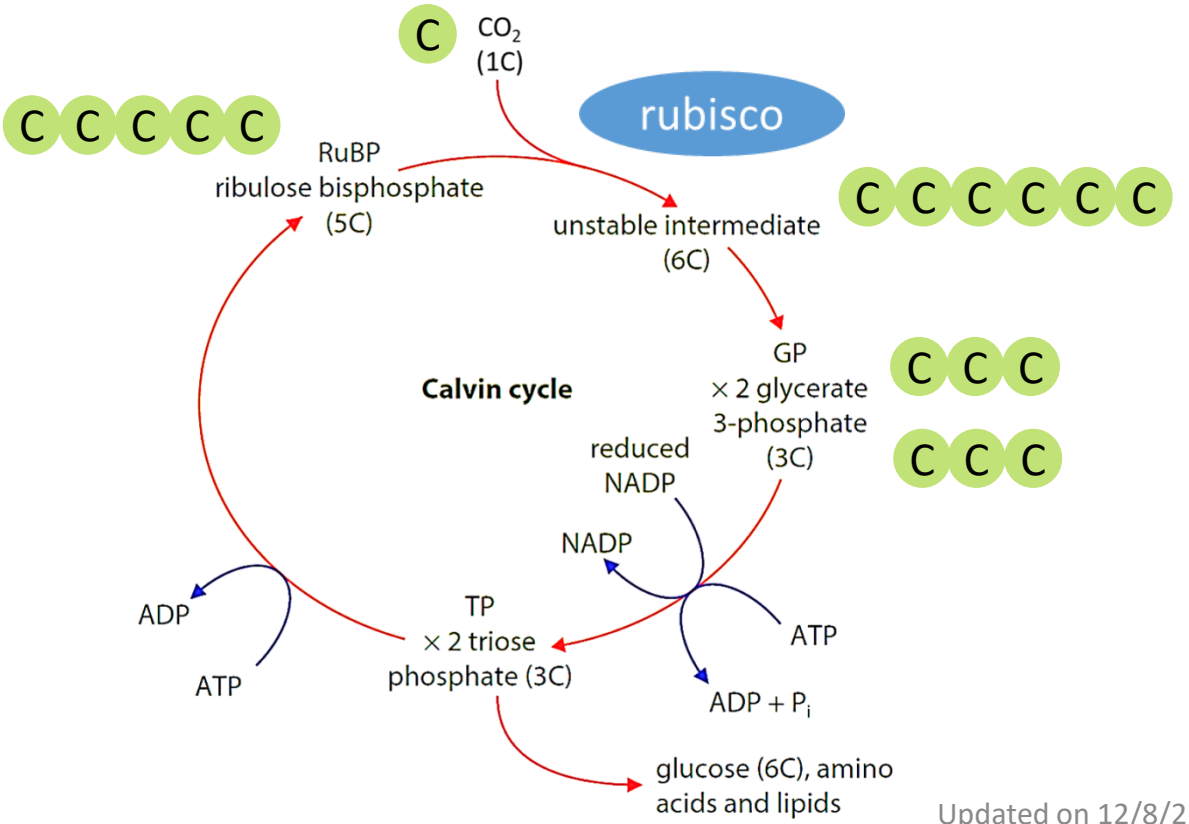
1) Fixation of carbon dioxide
2) Reduction
3) Regeneration



Light-Independent Reaction
(aka the Calvin Cycle)

Step 1: Fixation of Carbon Dioxide

- **Carbon dioxide (1C)** is combined with **ribulose bisphosphate (RuBP) (5C)**
- To produce **2 x glycerate-3-phosphate (GP or PGA) (3C)**
- Catalysed by enzyme, **ribulose bisphosphate carboxylase (rubisco)**



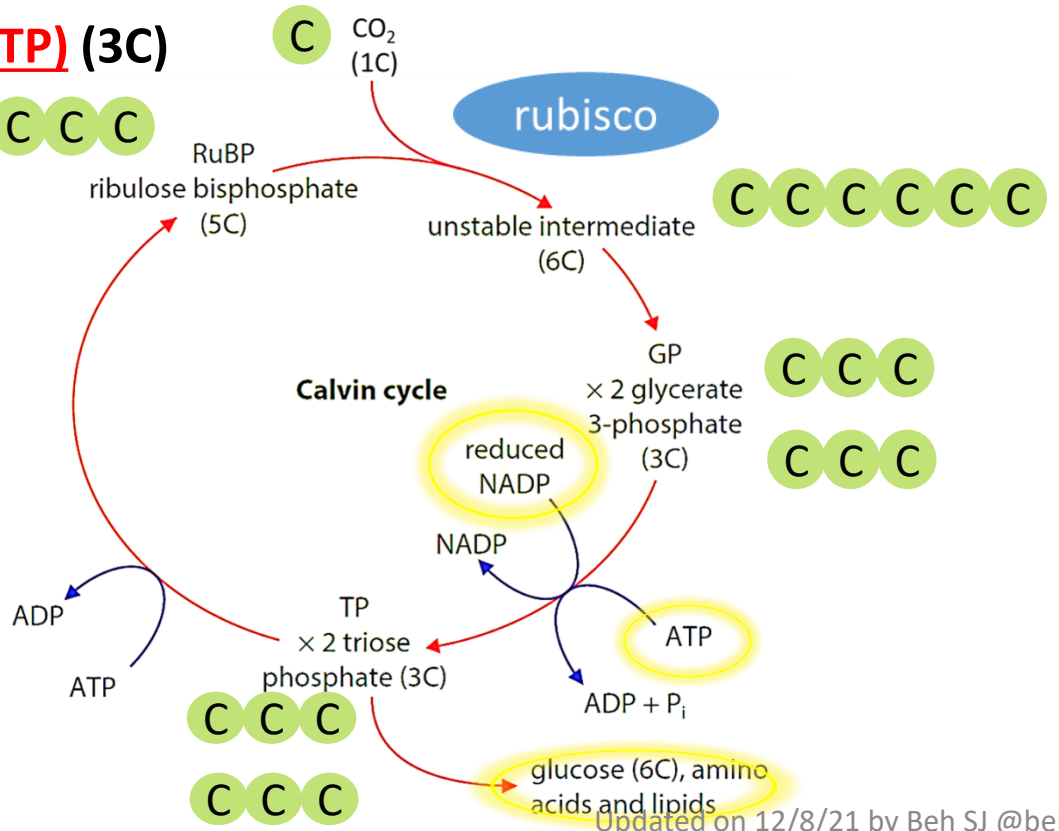
Light-Independent Reaction
(aka the Calvin Cycle)

Step 2: Reduction

- The **reduction of 2 x GP (3C)**
- **Uses ATP and reduced NADP**
- Some NADP regenerated
- Produces **2 x triose phosphate (TP) (3C)**

- 1/6 molecules of **TP is converted to other molecules** (e.g. carbs, amino acids, lipids) for uses in the plant cell

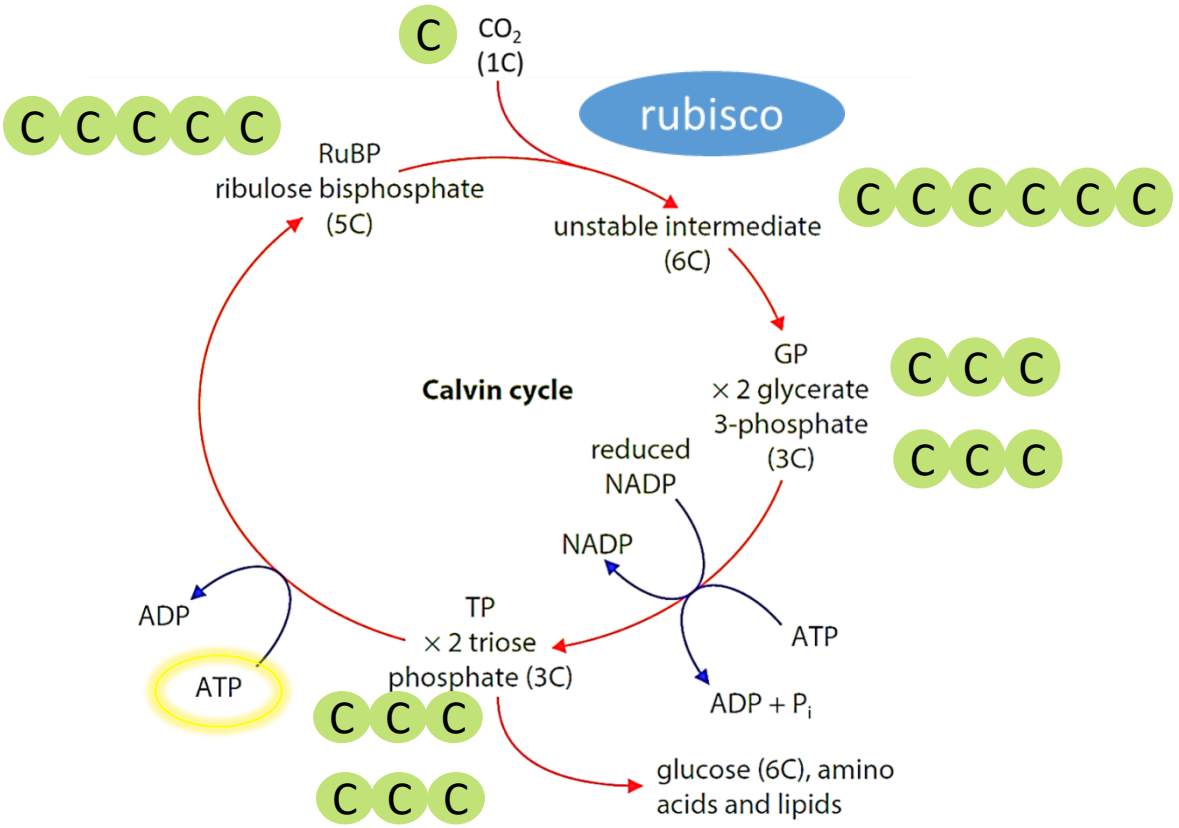
Can you think of some specific molecules and their uses in plant cells?

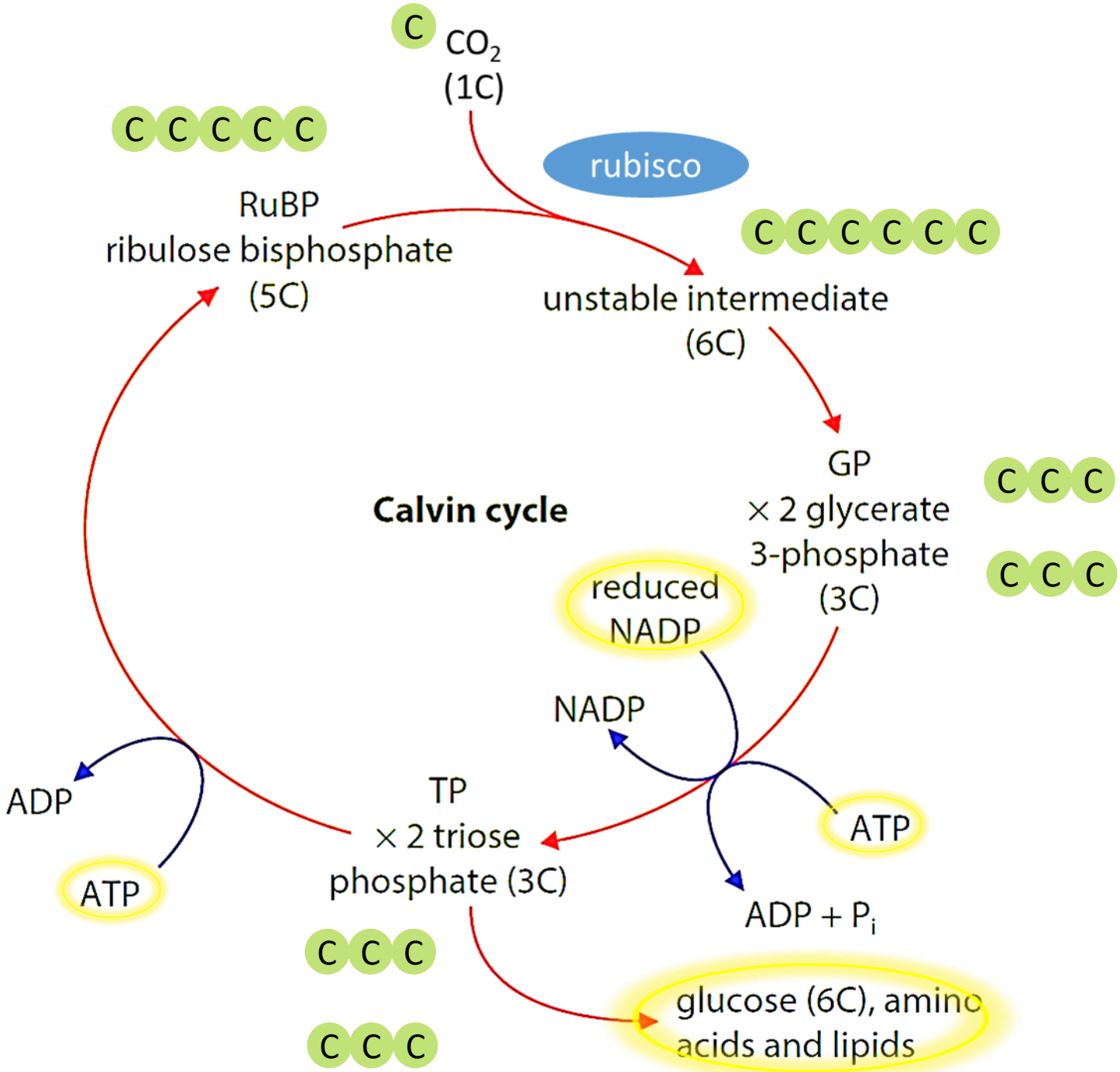


Light-Independent Reaction
(aka the Calvin Cycle)

Step 3: Regeneration of RuBP

- 5/6 molecules of **TP** is used to regenerate **RuBP**
- Uses ATP

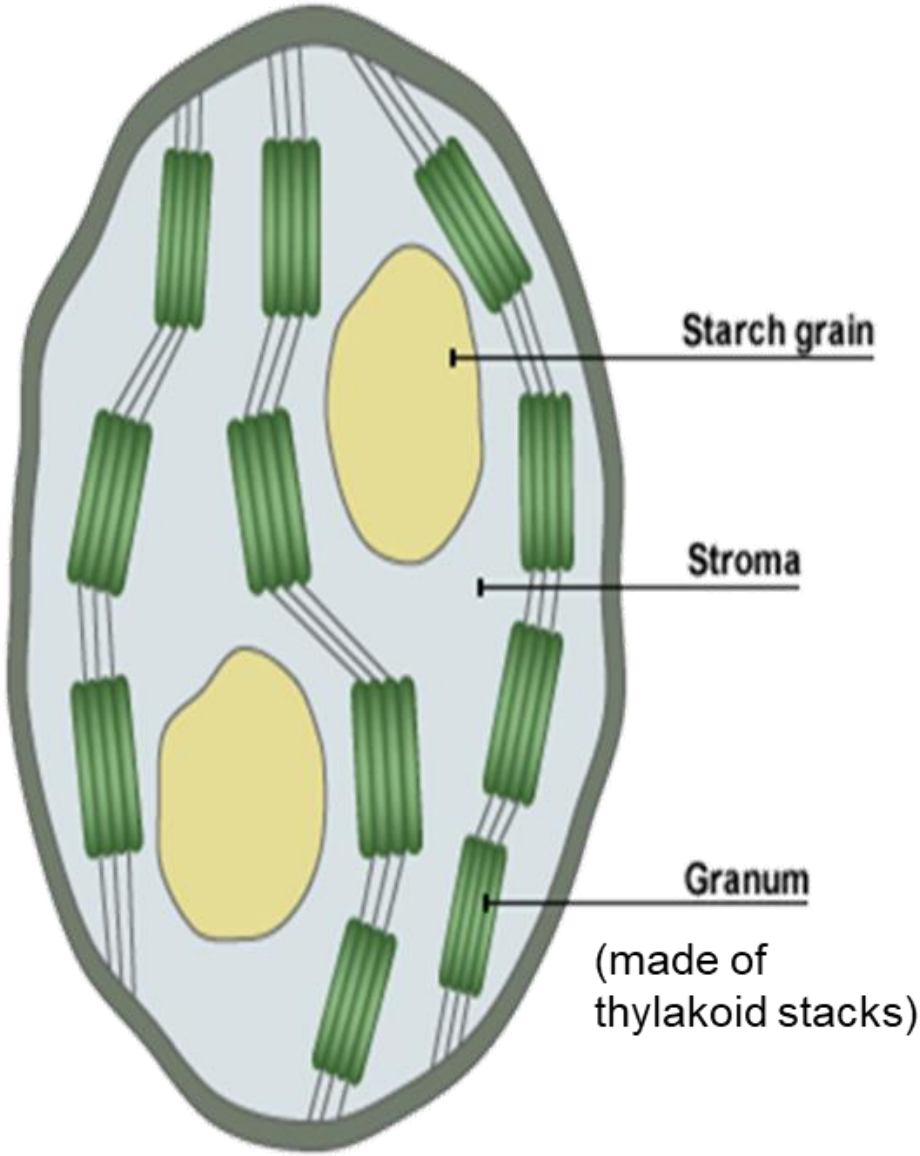



C
CO_2
(1C)
C C C C C
rubisco
RuBP
ribulose bisphosphate
(5C)
C C C C C C
unstable intermediate
(6C)
GP
× 2 glycerate
3-phosphate
(3C)
C C C
C C C
Calvin cycle
reduced
NADP
NADP
ADP
ATP
TP
× 2 triose
phosphate (3C)
ATP
ADP + P_i
C C C
C C C
glucose (6C), amino
acids and lipids

How structure relates to function in chloroplast

- Main photosynthetic organelle
- Can be seen with a light microscope
- 3-10 µm in diameter
- Appear as **biconvex discs**

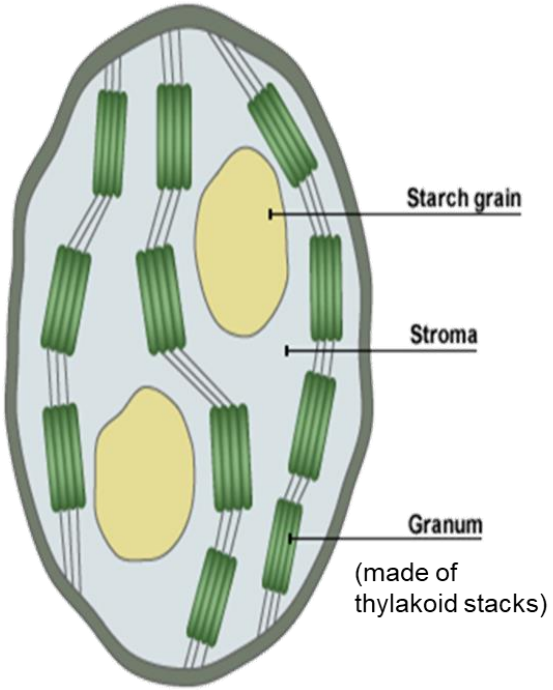
- **Has 2 phospholipid membranes**
- **Stroma** inside
- **Thylakoids** = fluid-filled sacs
- Stacks of thylakoids = **grana** (singular: granum)
- Has intergranal lamellae

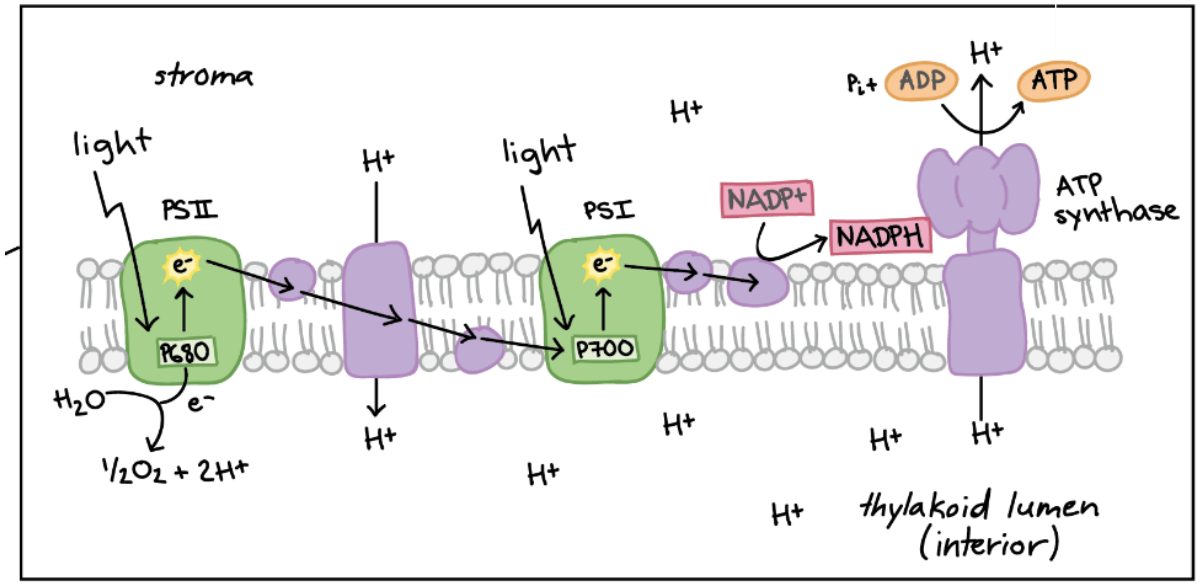


How structure relates to function in chloroplast

1. Grana

- Membrane has **large surface area**
- **Holds pigments, enzymes, electron carriers** needed for **light-dep. reactions**
- **Holds ATP synthase** needed for **ATP synthesis by chemiosmosis**

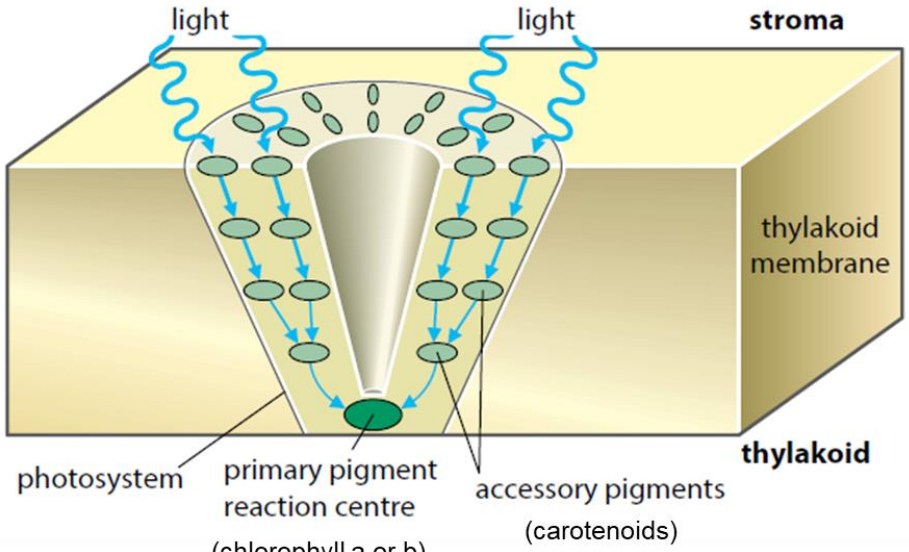




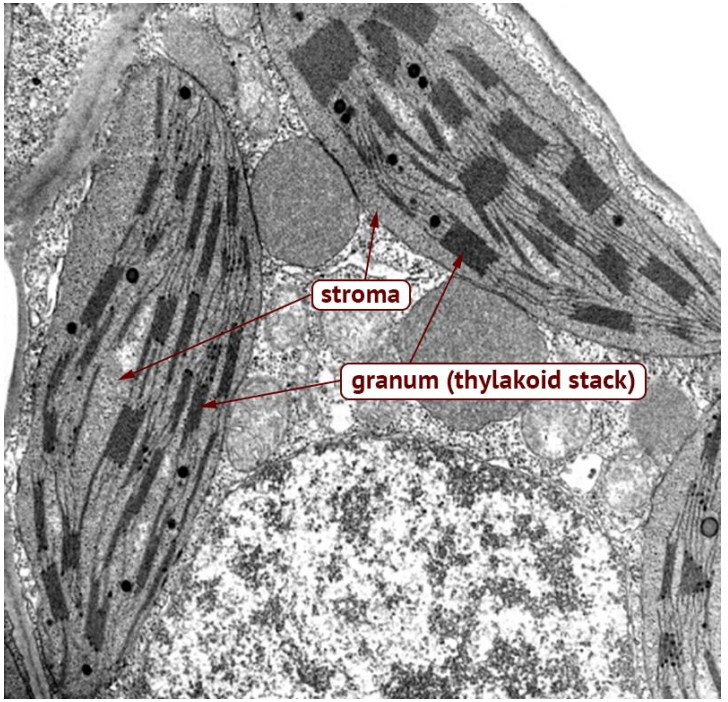
How structure relates to function in chloroplast

1. Grana

- **Large no. of pigment molecules** arranged to absorb light
- **Arranged in light-harvesting clusters (photosystems)**
- For **efficient light absorption**
- Diff pigments arranged in **funnel-like structures**
- Each pigments passes energy to next pigment
- Till it reaches the reaction centre



How structure relates to function in chloroplast



2. Stroma

•Site of **light-indep. reactions of the Calvin cycle**

•Contains **enzymes of the Calvin cycle, sugars and organic acids**

•Bathes grana membranes
so **receives products of light-dep. reactions**

• Has lipid droplets and starch grains

•Also has **70S ribosomes, loop of DNA**

Loop of DNA: codes for some chloroplast proteins

Ribosomes: produce chloroplast proteins (via translation)

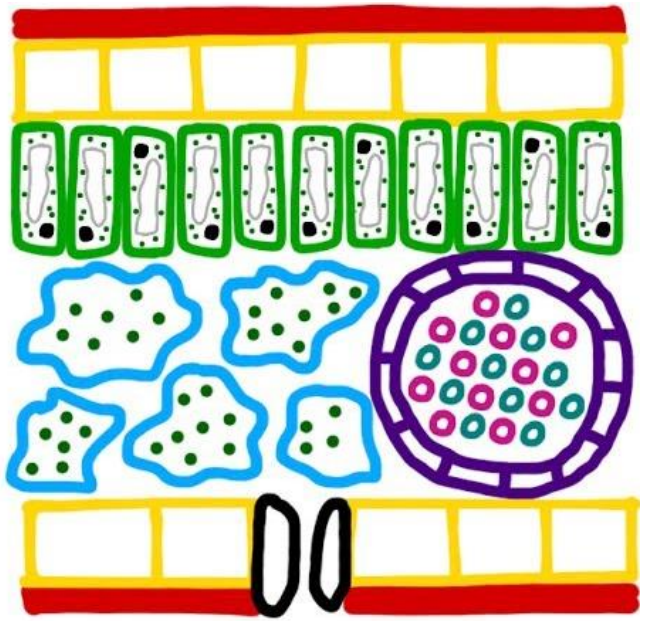
Part 3

- P5: Investigating the rate of photosynthesis using an aquatic plant
- Limiting factors affecting rate of photosynthesis
  - Light intensity
  - Carbon dioxide concentration
  - Temperature

How structure relates to function in a palisade mesophyll cell

1. Overall cell arrangement and shape

- Cells are **closely packed** to absorb maximum light
- **Large surface area** for diffusion of gases
- **Vertical to surface** of leaf to reduce number of cross walls



- **Cell walls thin** for maximum light penetration / diffusion of gases
- **Moist** cell surfaces for diffusion of gases
- **Cylindrical** so less air space between cells to maximise area near surface for light absorption
- **Near air spaces** to circulate gases / provide a reservoir of CO2

How structure relates to function in a palisade mesophyll cell

2. Chloroplasts

- **Large number of chloroplasts** to absorb maximum light

- **Large vacuole pushes chloroplasts to edge of cell**

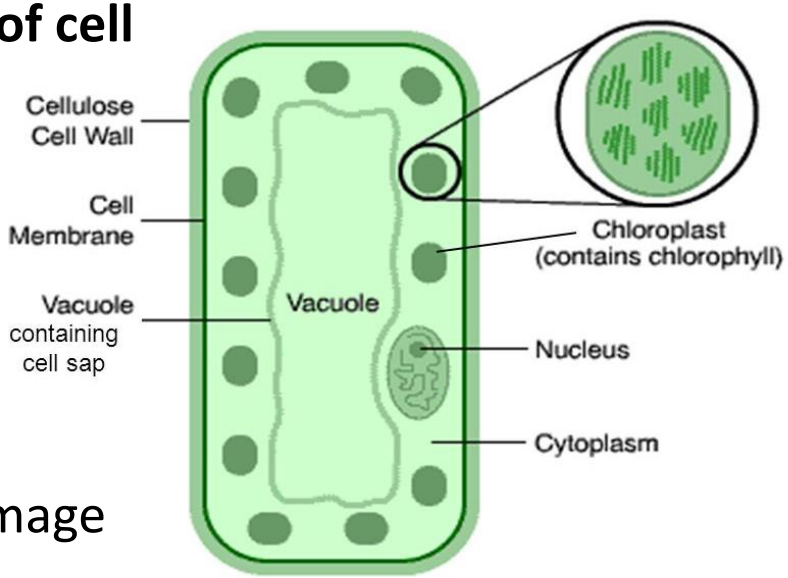
→ **Short diffusion path** for carbon dioxide

→Can absorb **maximum light**

- **Chloroplasts can move**

→ Towards light

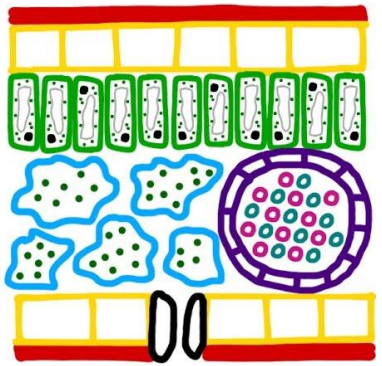
→ Away from high light intensity to avoid damage



How structure relates to function in a dicotyledonous leaf

- **Thin / flat** to give large surface area to volume ratio
- **Held at right angles to sun** to allow max. light absorption

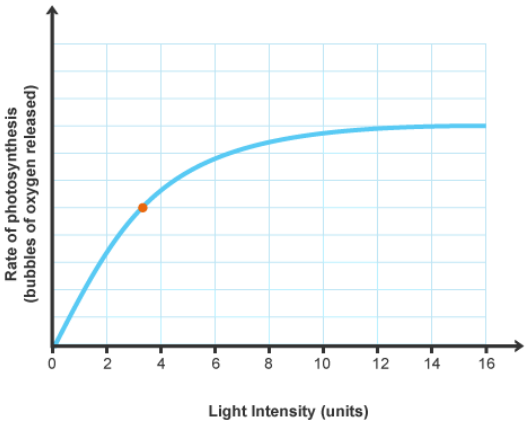
- Has **cuticle** on upper surface to prevent water loss via cuticular transpiration
- Has closely packed **palisade mesophyll** arranged vertical to the surface of leaf
- Has **spongy mesophyll** that provides large surface area for CO2 uptake / gaseous exchange
- Mesophyll cells have **moist surfaces** for diffusion of gases
- Has **stomata / guard cells** for entry of CO2



- Has **xylem** to supply water / mineral ions and act as support
- Has **phloem** for translocation of products of photosynthesis

Limiting Factors Affecting Rate of Photosynthesis

Limiting factors = **one of the several factors** that restrict a process's rate. **Rate is limited by the factor nearest its minimum value.**

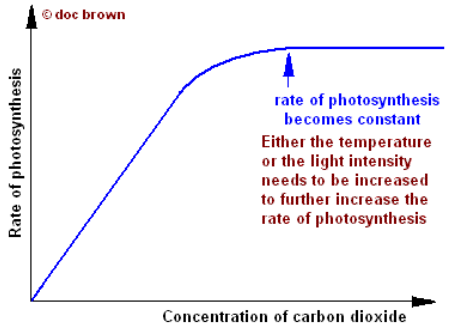


1. Light intensity

- Rate of photosynthesis increases with light intensity
- But levels off due to limiting factors: temp and [CO_2]

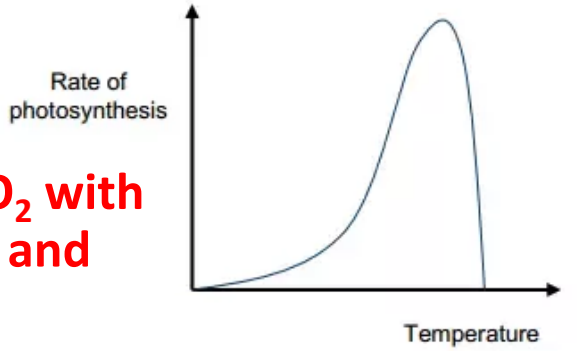
2. Carbon dioxide concentration

- Rate of photosynthesis increases with [CO_2]
- But levels off due to limiting factors: temp and light intensit



3. Temperature

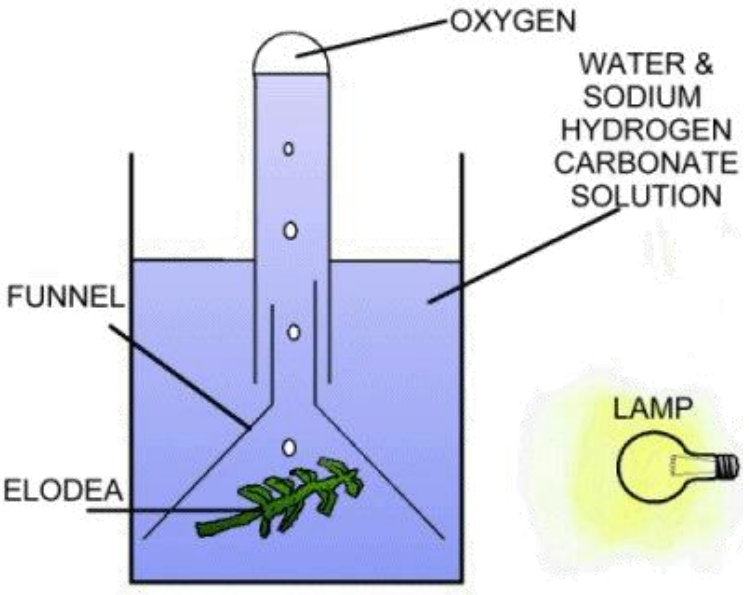
- Rate of photosynthesis increases with temperature
- But decreases after the optimum temp because:
- **Rubisco has higher tendency to catalyze reaction of O_2 with RuBP, instead of CO_2 (photorespiration) at high temp and high light intensity**
- Enzymes also start to denature



How to measure the rate of photosynthesis? Investigating the rate of photosynthesis using an aquatic plant

P5

- Use aquatic plants such as *Elodea* and *Cabomba*
- Use gas syringe/microburette/photosynthometer

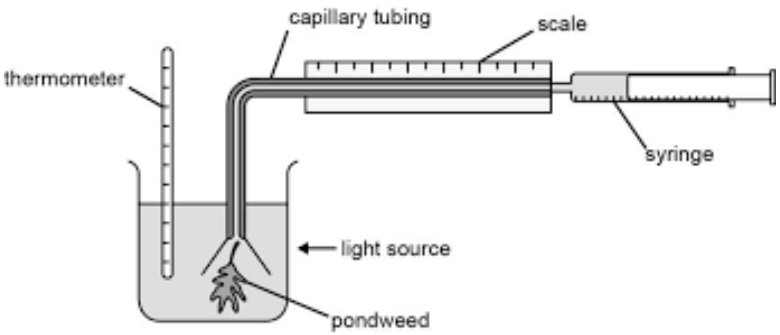


1. Cut shoot of aquatic plant

- Must cut stem cleanly, **under water**
- Plant must be well illuminated b4 use

2. Place shoot in tube of **hydrogen carbonate solution** (to provide CO_2) and water bath to maintain temp

- Water needs to be aerated beforehand by bubbling air through it, to prevent other gases from dissolving in water

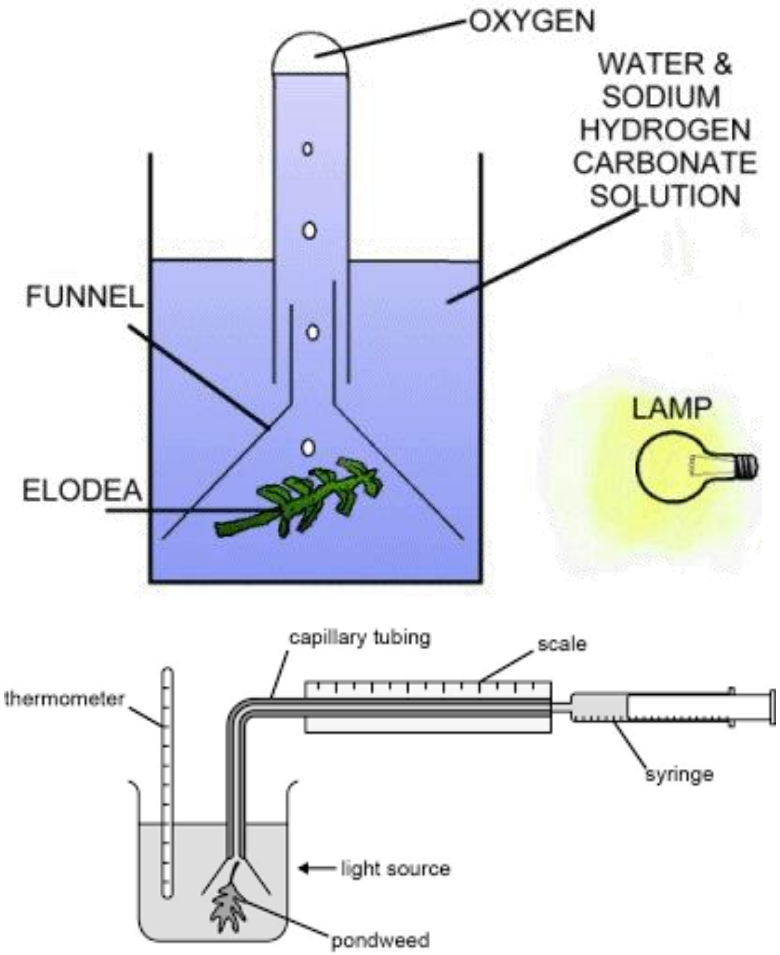


How to measure the rate of photosynthesis? Investigating the rate of photosynthesis using an aquatic plant

P5

3. Place in different conditions to investigate its effect on the rate of photosynthesis

- **Light intensity** – Place light source at min 5 different distances from plant
- **Wavelength of light** – Use min 5 different colour filters
- **Concentration of carbon dioxide** – Add min 5 diff concentrations of hydrogen carbonate solution to water surrounding plant
- **Temperature** – use water baths of min 5 diff temperatures



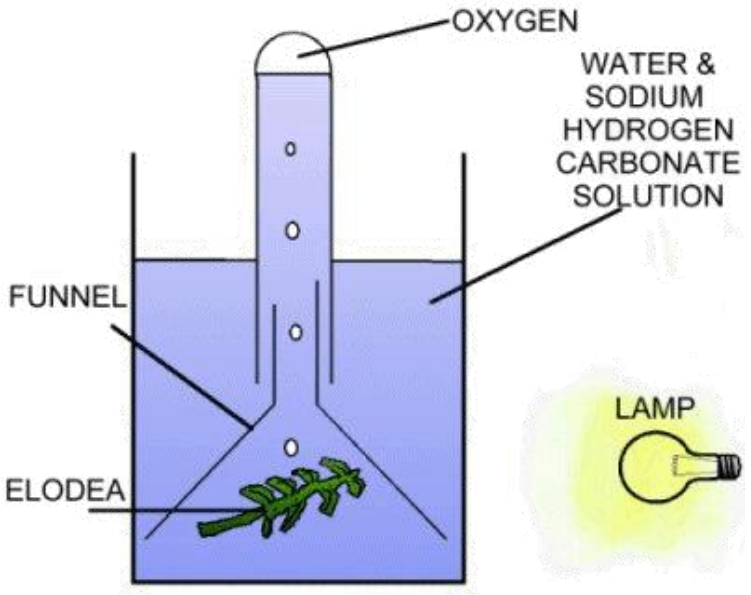
How to measure the rate of photosynthesis? Investigating the rate of photosynthesis using an aquatic plant

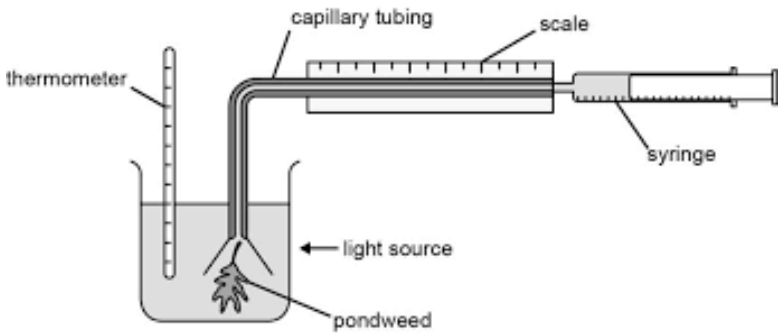
P5

4. Allow acclimatization

5. Count **no. of bubbles of oxygen gas produced** per unit time
   OR collect oxygen gas and measure length/ **volume produced** per unit time

6. Repeat at least 3 times + mean





Videos

Photosynthesis Light reaction, Calvin cycle, Electron Transport 3D Animation

https://www.youtube.com/watch?v=KfvYQgT2M-k

Photosynthesis: Comparing C3, C4 and CAM
(CAM plants are not in syllabus)

https://www.youtube.com/watch?v=13h5oC4jIsk

TED-Ed: Nature's smallest factory: The Calvin cycle - Cathy Symington

https://www.youtube.com/watch?v=0UzMaoaXKaM