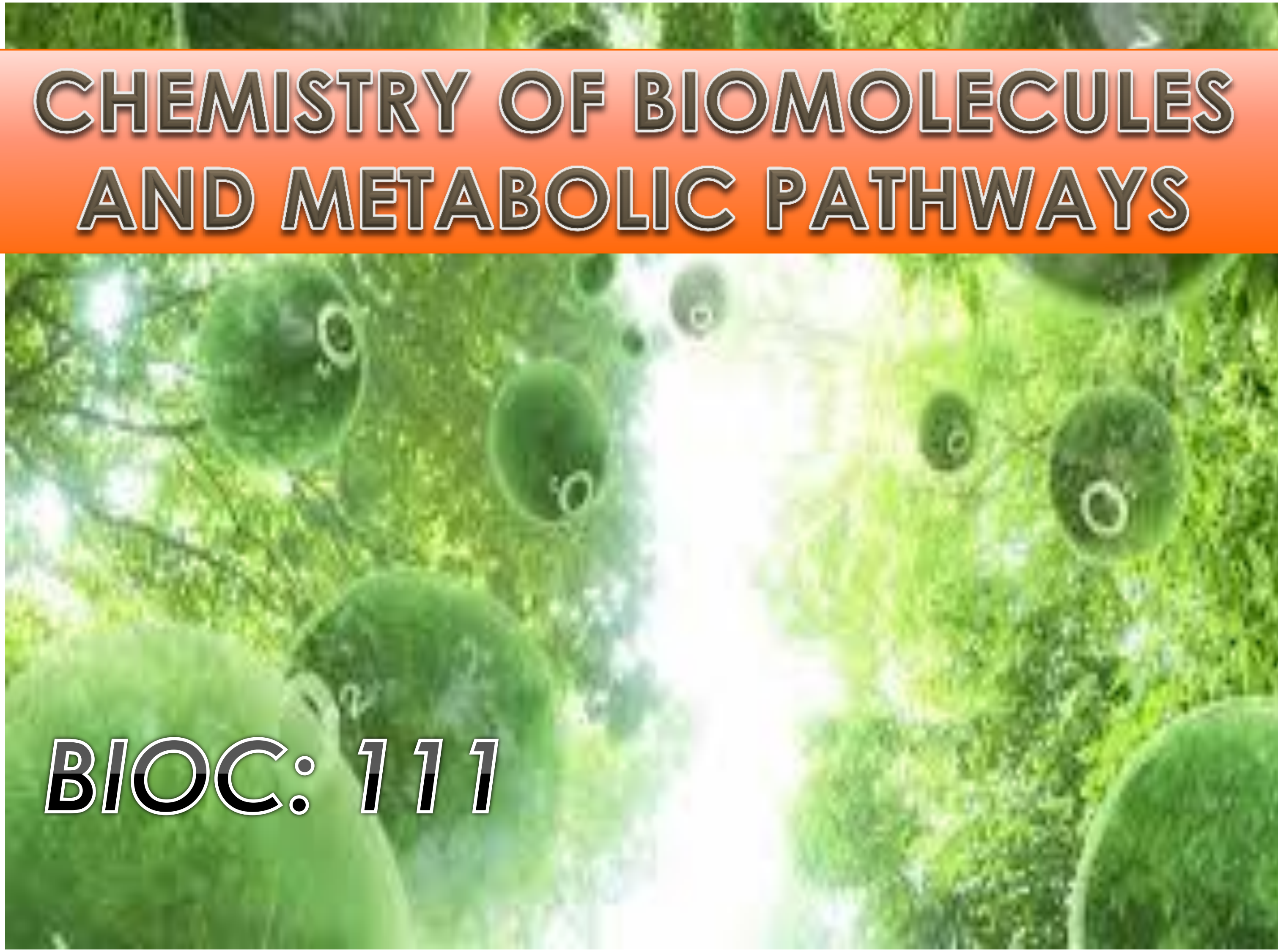
CHEMISTRY OF BIOMOLECULES AND METABOLIC PATHWAYS



BIOC: 111

PRESENTATION BY

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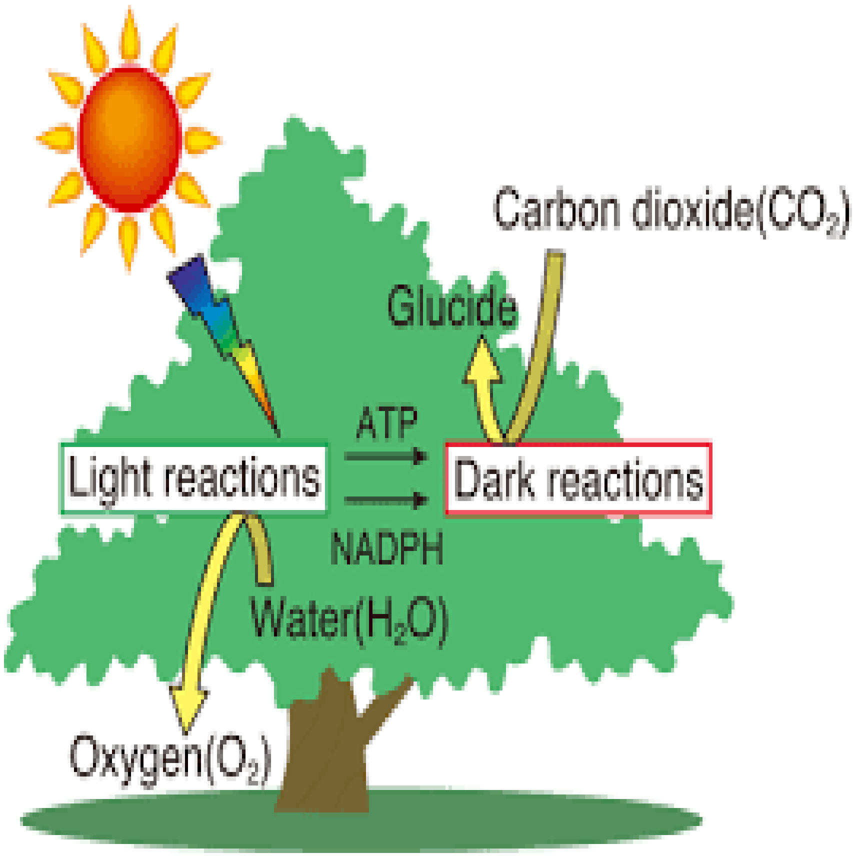
QUESTION;

"Explain the mechanisms by which C4 plants are able to undertake photosynthesis without photorespiration."

OBJECTIVES

- Understand what C4 plants are.
- Understand the differences between C3 and C4 plants.
- Understand photo-respiration.
- Understand the difference between the C3 and C4 pathways.
- Understand the mechanisms of the C4 pathway.

What are C4 plants?



"Photosynthetic plants that cycle CO_2 into a four-carbon (C4) sugar compound which enters the Calvin cycle" (Munks, 2016).

- These plants are highly efficient in hot, dry climates and they make a lot of energy (that is carbohydrates).

C4 plants have ***high photosynthetic yield*** because they are well adapted to reduce or completely eliminate ***photorespiration***.

Characteristics of C4 PLANTS

1. Their leaves have Krans Anatomy.
2. Chloroplasts have peripheral reticulum.
3. Chloroplasts are types of dimorphic.
4. Bundle sheath cells usually possess prominent chloroplasts.

Continuation…

5. They have two types of Chloroplasts;
   - Granal – Found in mesophyll cells
   - Agranal – Found in Bundle Sheath cells.

   They lack photosystem II

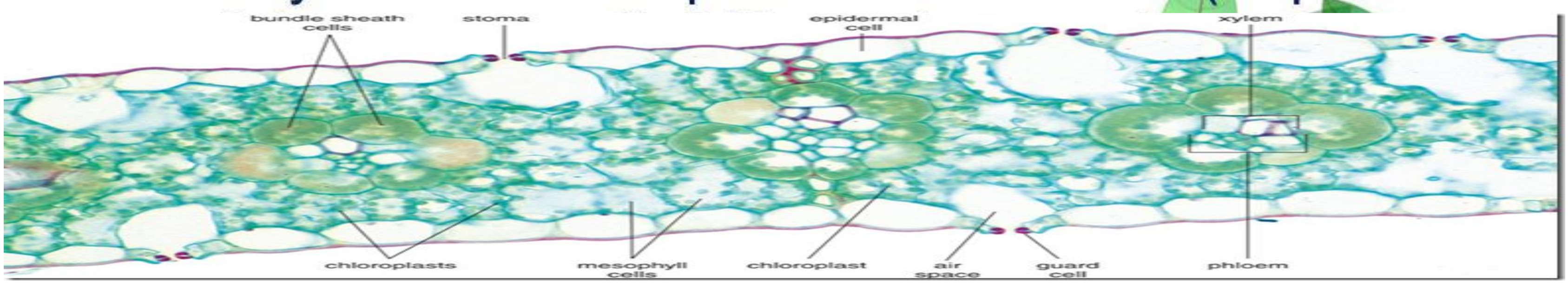
6. Mesophyll cells perform only initial fixation of CO_2.

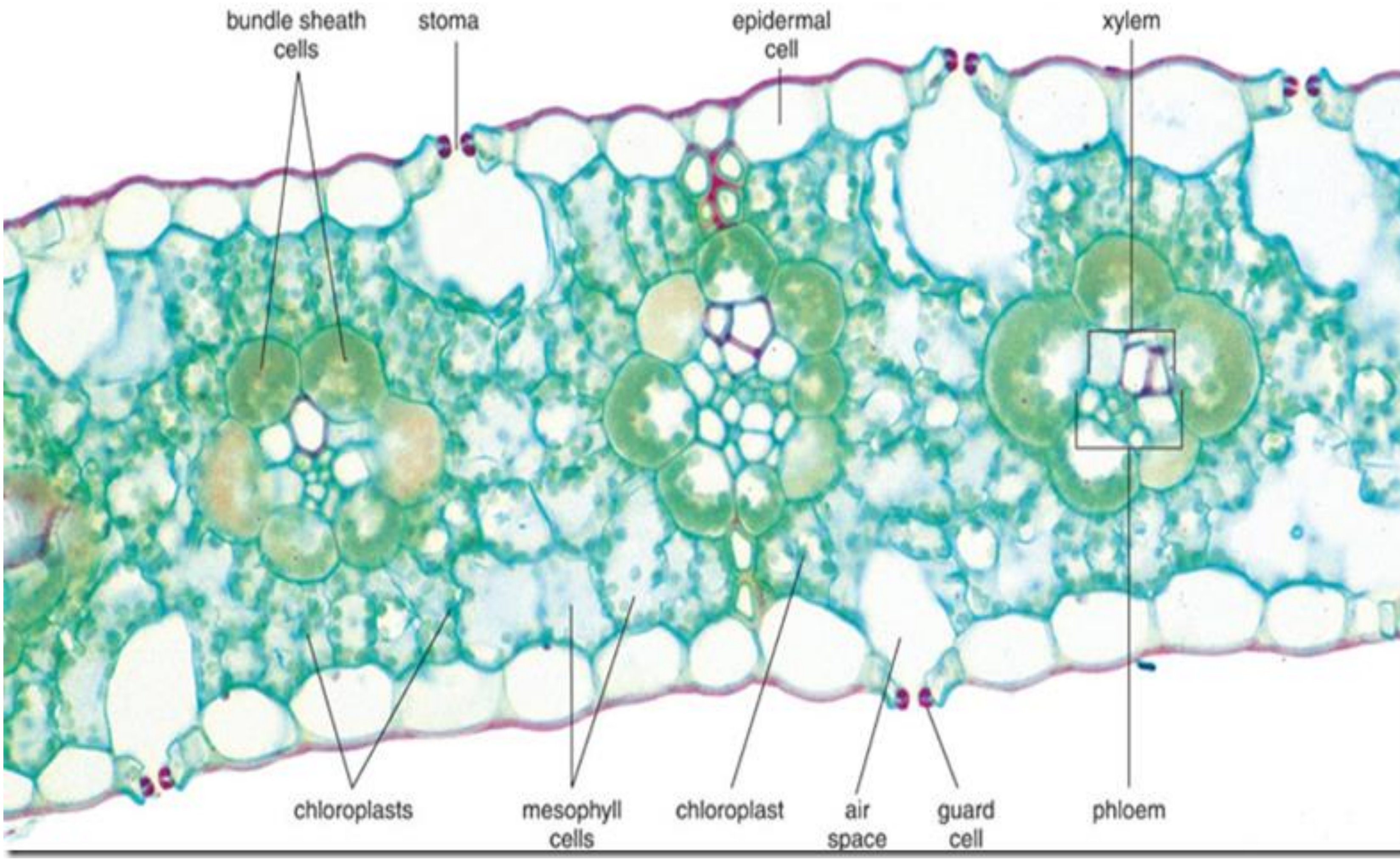
7. They perform photosynthesis even when stomata are closed.

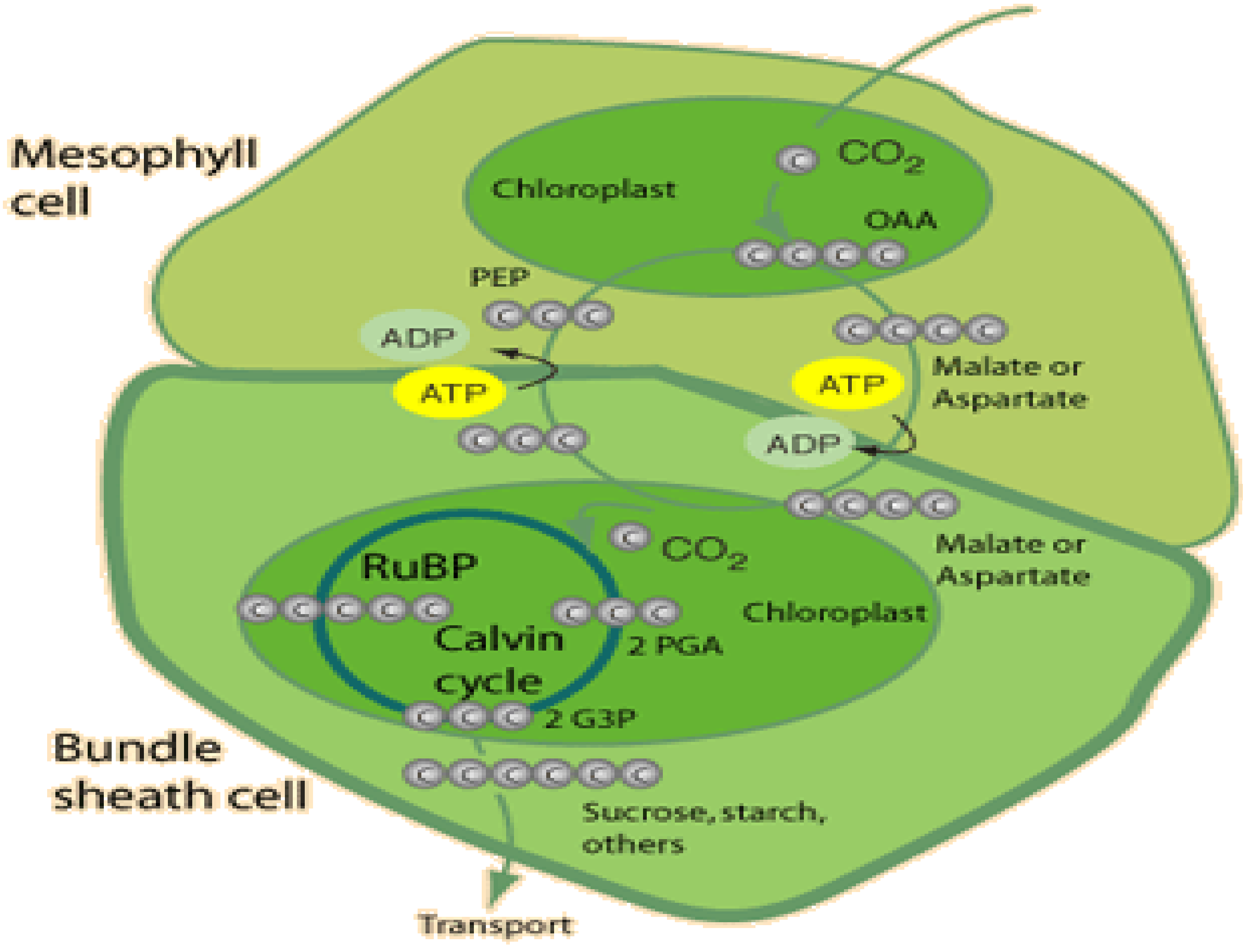
8. C_4 plants are more efficient in photosynthesis than C_3 plants.

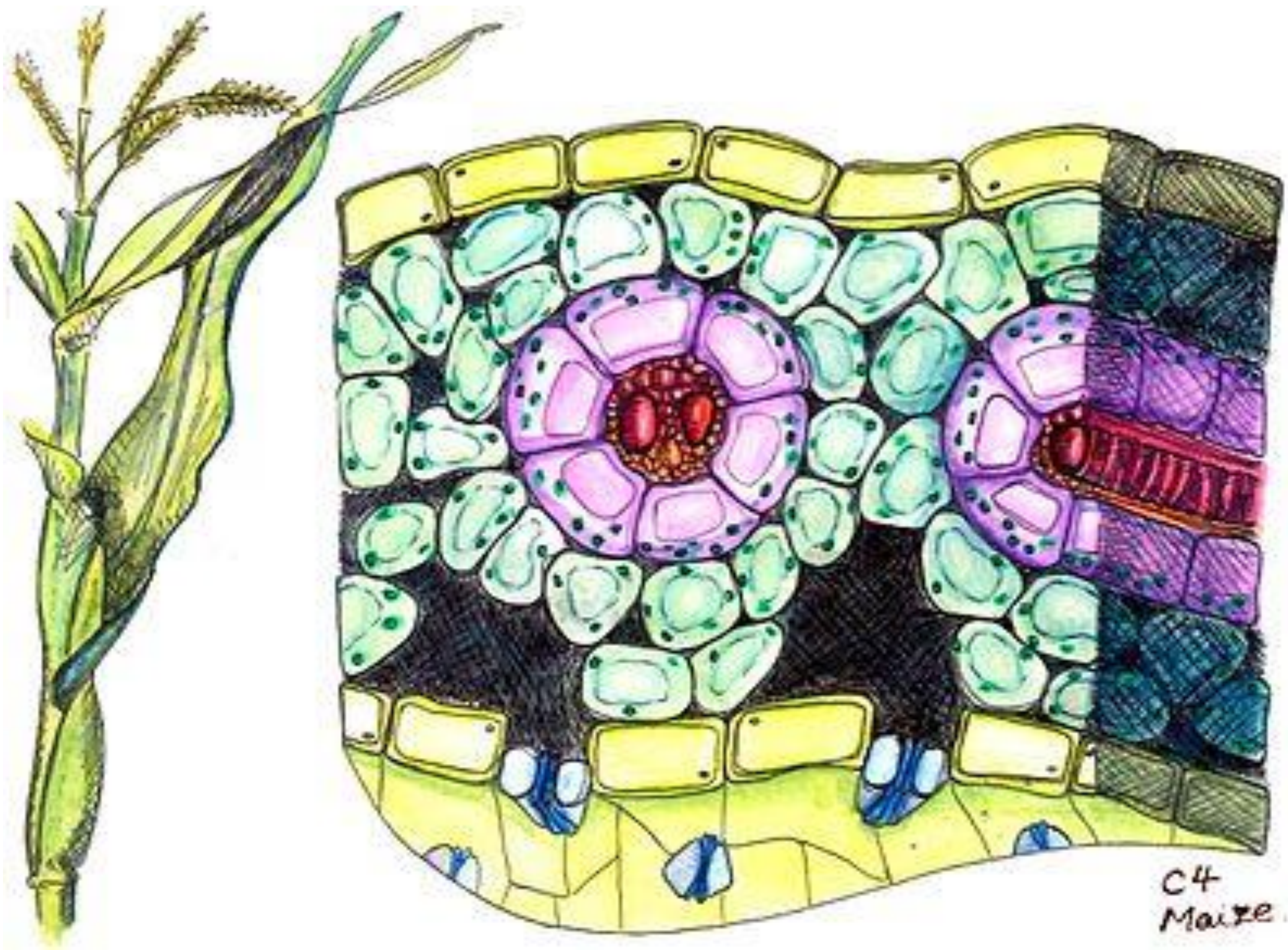
C4 Plants

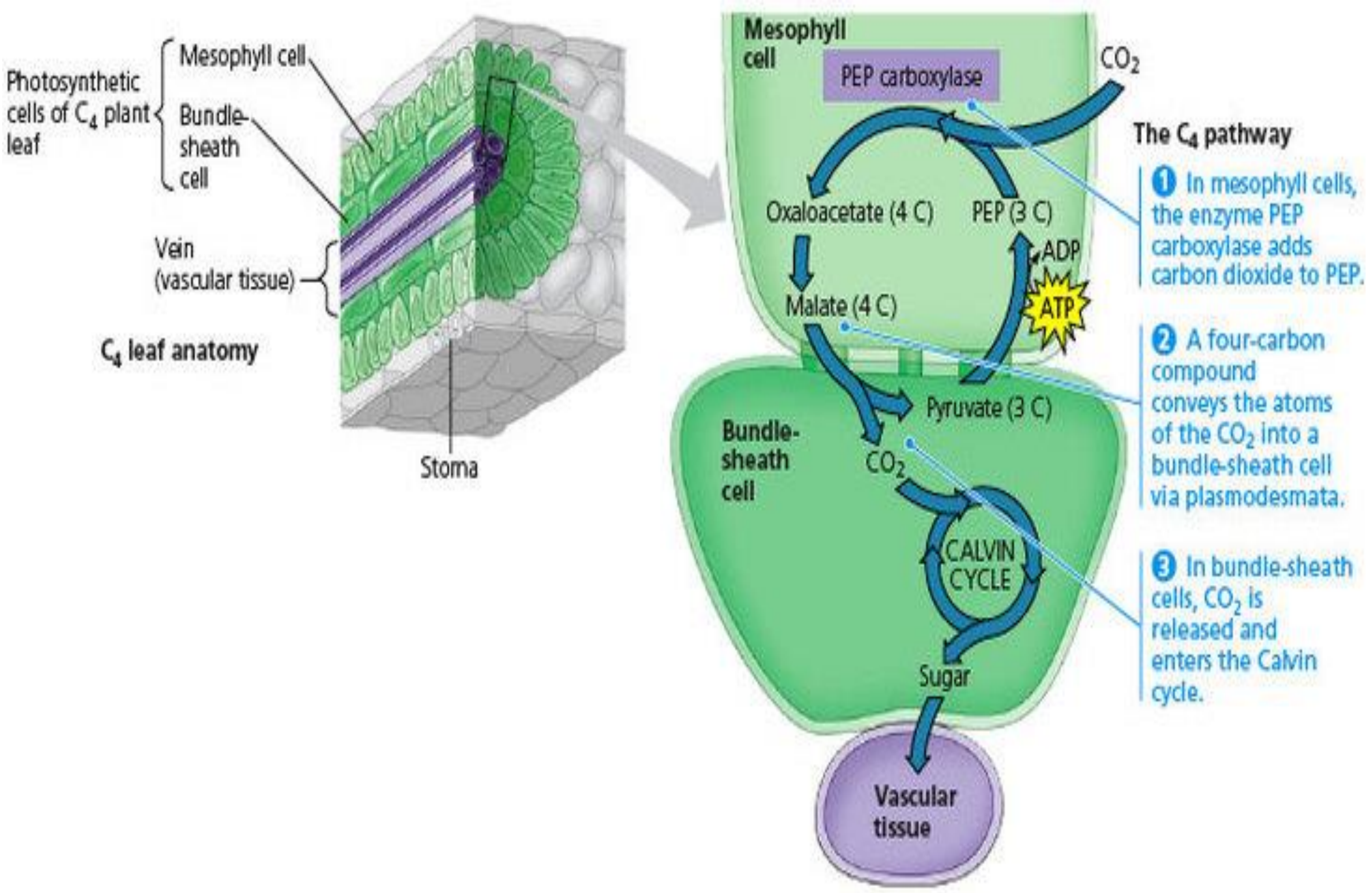
- Called C4 because the CO_2 is first incorporated into a 4-carbon compound.
- Stomata are open during the day.
- Uses PEP Carboxylase for the enzyme involved in the uptake of CO_2. This enzyme allows CO_2 to be taken into the plant very quickly, and then it "delivers" the CO_2 directly to RUBISCO for photsynthesis.
- Photosynthesis takes place in inner cells (requires




bundle sheath cells
stoma
epidermal cell
xylem
chloroplasts
mesophyll cells
chloroplast
air space
guard cell
phloem


Mesophyll cell
Chloroplast
CO2
OAA
PEP
ADP
ATP
Malate or Aspartate
ATP
ADP
Malate or Aspartate
CO2
RuBP
Calvin cycle
Chloroplast
2 PGA
2 G3P
Bundle sheath cell
Sucrose, starch, others
Transport


C4
Maize.



Photosynthetic cells of C_4 plant leaf
Mesophyll cell
Bundle-sheath cell
Vein (vascular tissue)
C_4 leaf anatomy
Stoma
Mesophyll cell
PEP carboxylase
CO_2
Oxaloacetate (4 C)
PEP (3 C)
ADP
Malate (4 C)
ATP
Pyruvate (3 C)
Bundle-sheath cell
CO_2
CALVIN CYCLE
Sugar
Vascular tissue
The C_4 pathway
1 In mesophyll cells, the enzyme PEP carboxylase adds carbon dioxide to PEP.
2 A four-carbon compound conveys the atoms of the CO_2 into a bundle-sheath cell via plasmodesmata.
3 In bundle-sheath cells, CO_2 is released and enters the Calvin cycle.

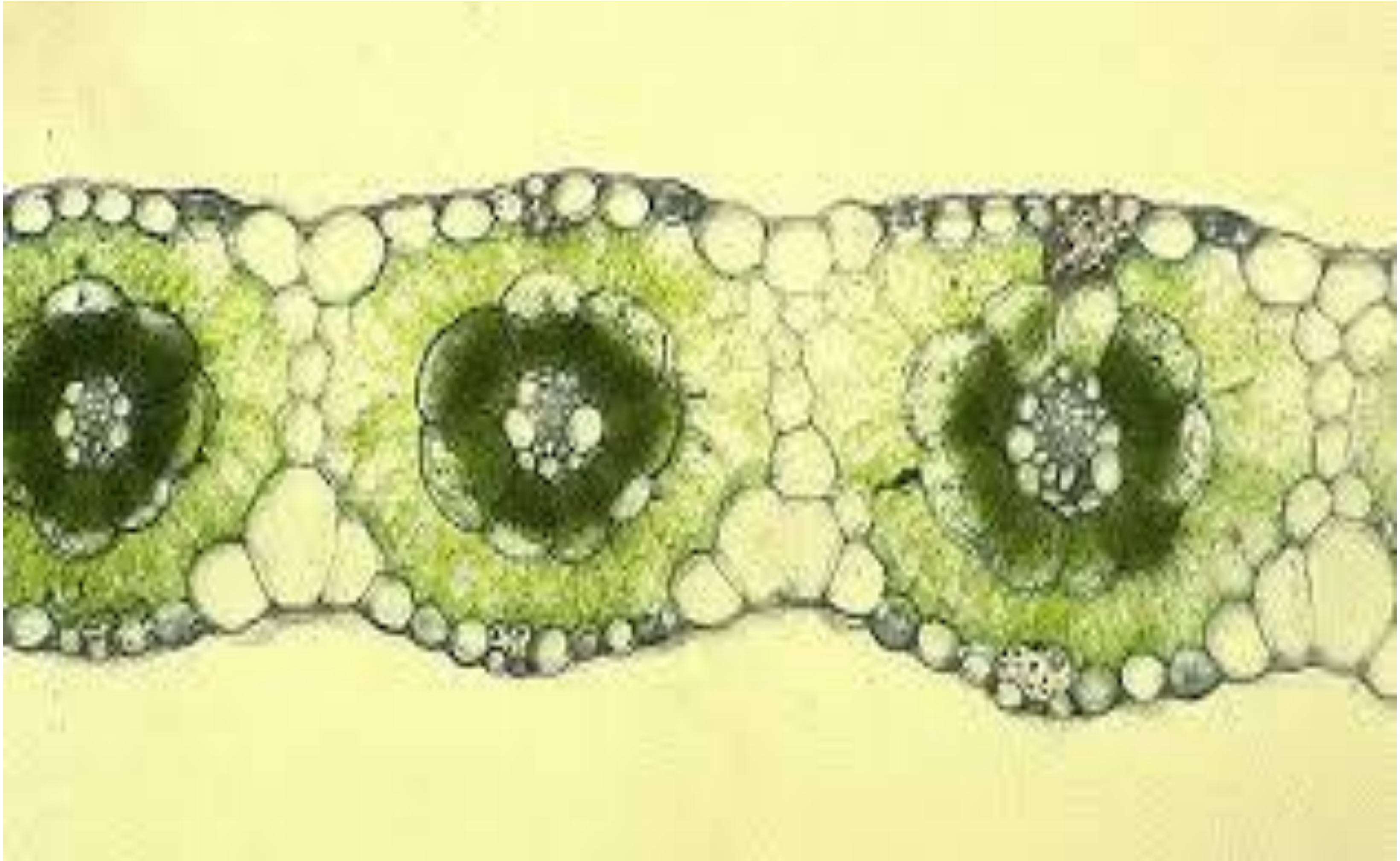
COMMMON EXAMPLES OF C4 PLANTS

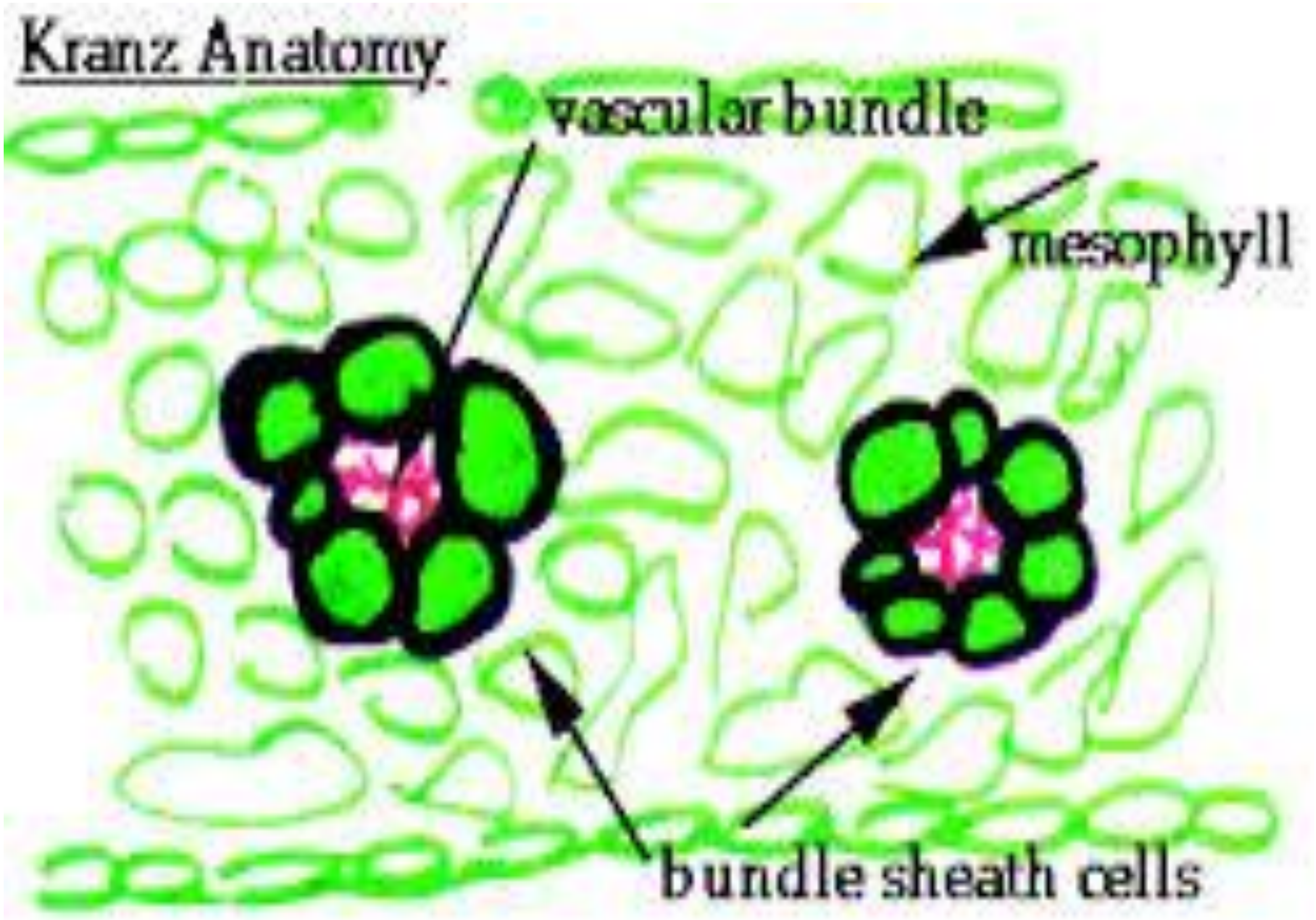
- Maize (Corn)
- Sorghum
- Millet
- Sugar Cane
- Crab Grass

KRANS ANATOMY

This is the special structure of leaves in C_4 PLANTS (e.g. maize) where the tissue equivalent to the spongy mesophyll cells is clustered in a ring around the leaf veins, outside the bundle-sheath cells.

(The term 'Kranz' means wreath or ring in German). The bundle-sheath cells contain large CHLOROPLASTS whereas the spongy mesophyll cells have few if any chloroplasts, unlike their counterparts in C_3 plants.




Kranz Anatomy
vascular bundle
mesophyll
bundle sheath cells

C3 PLANTS

"Photosynthetic plants that utilize C3 carbon fixation pathways as the sole mechanism to convert CO_2 into an organic compound (3 – phosphoglycerate)" (Biology Online, 2016).

- These are also called temperate or cool season plants.
- They are the most abundant types of plants.
- They carry out photosynthesis using the C_3 pathway. The C_3 pathway is the most common.

Characteristics of C_3 PLANTS

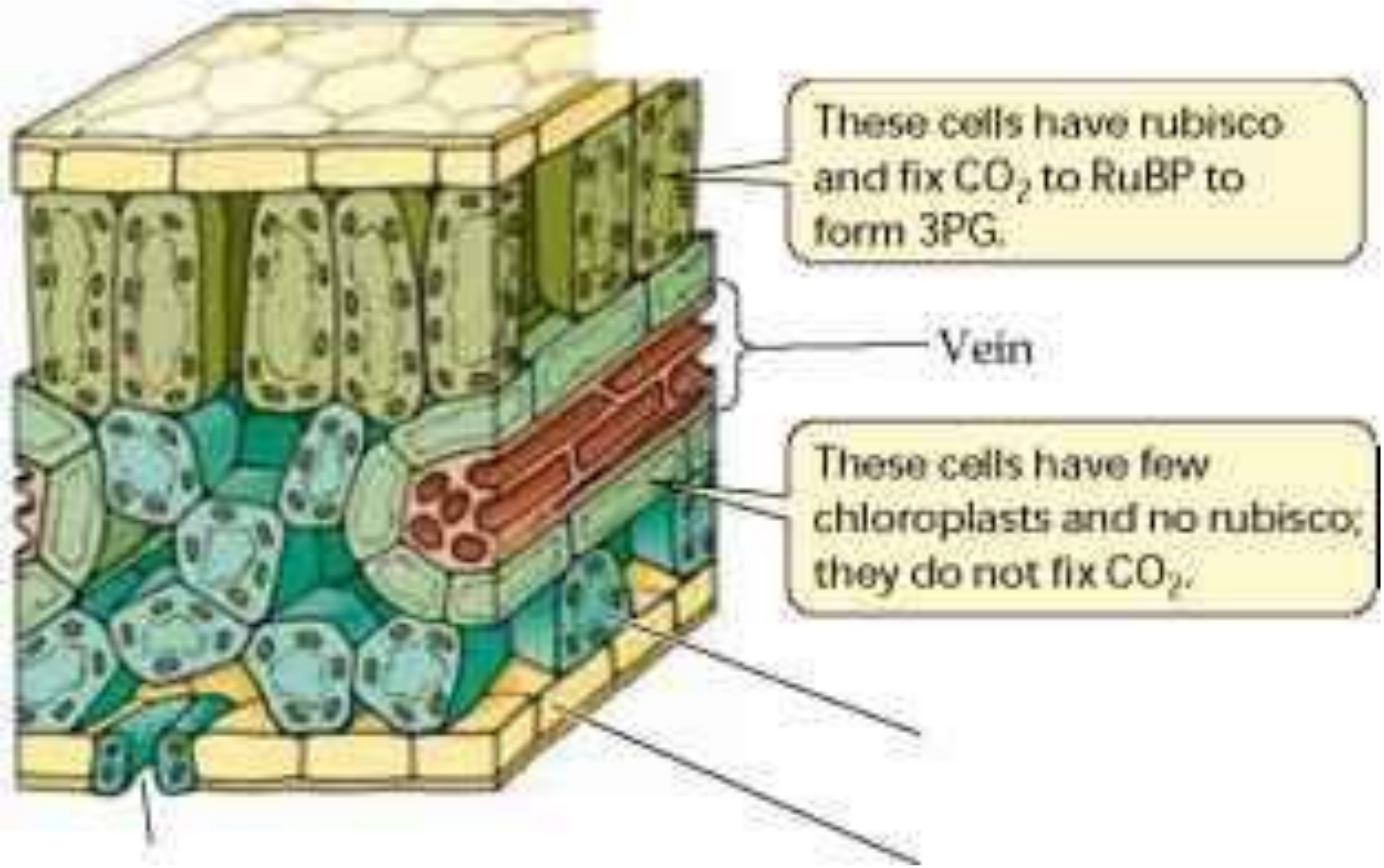
1. The leaves do not possess Krans Anatomy.
2. Chloroplasts do not have peripheral reticulum.
3. Chloroplasts are one type (monomorphic).
4. Bundle sheath cells do not usually contain chloroplasts.

Continuation…

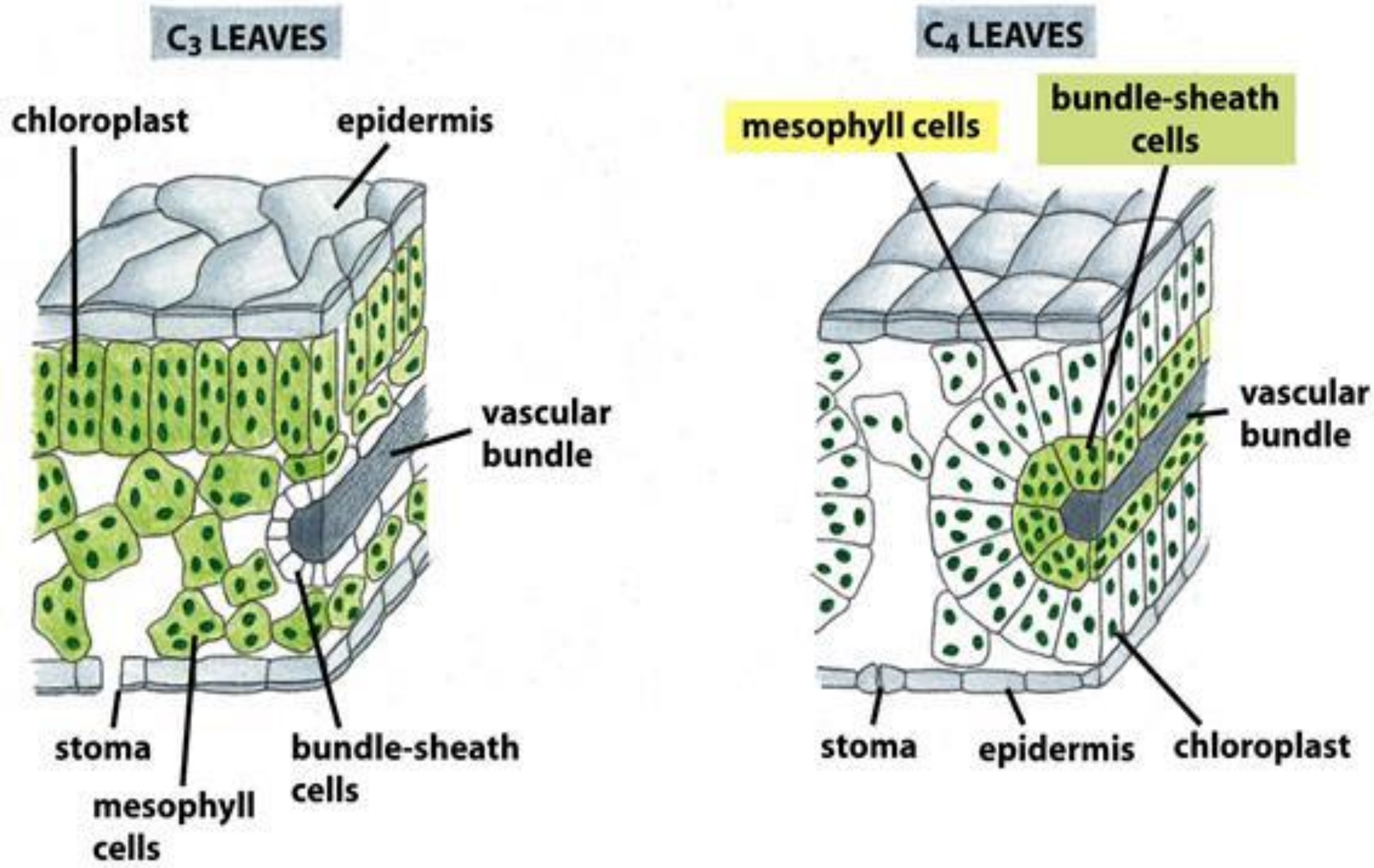
5. In the higher plants, operating C3 cycle, the chloroplasts are all granal and have both photosystems I and II.
6. Mesophyll cells perform complete photosynthesis.
7. They perform photosynthesis only when stomata are open.
8. C3 plants are less efficient in photosynthesis.

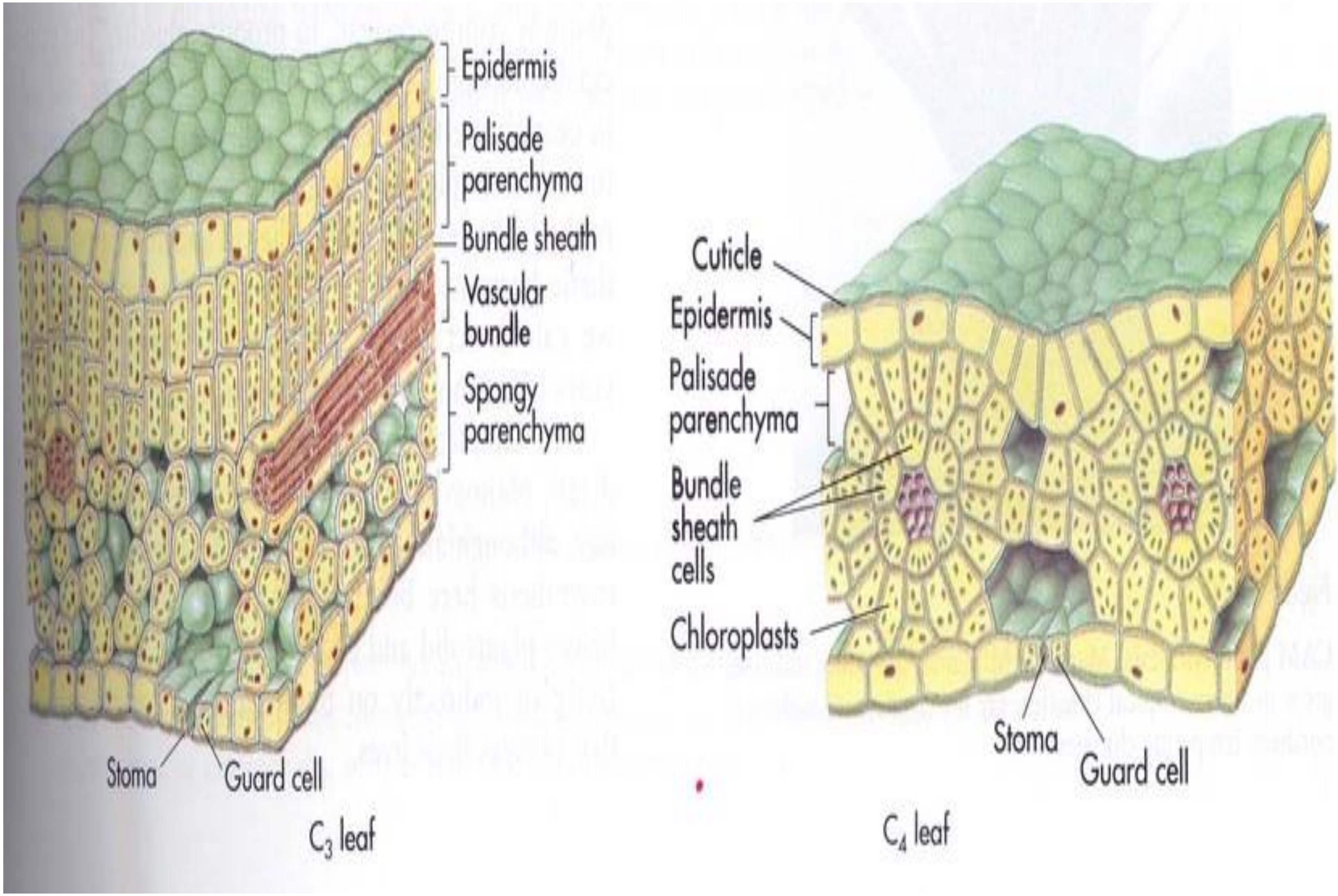
Examples of C3 plants

- Beans
- Rice
- Wheat
- Potatoes



These cells have rubisco and fix CO_2 to RuBP to form 3PG.
Vein
These cells have few chloroplasts and no rubisco; they do not fix CO_2.


C3 LEAVES
chloroplast
epidermis
vascular bundle
stoma
mesophyll cells
bundle-sheath cells
C4 LEAVES
mesophyll cells
bundle-sheath cells
vascular bundle
stoma
epidermis
chloroplast


Epidermis
Palisade parenchyma
Bundle sheath
Vascular bundle
Spongy parenchyma
Stoma
Guard cell
C3 leaf
Cuticle
Epidermis
Palisade parenchyma
Bundle sheath cells
Chloroplasts
Stoma
Guard cell
C4 leaf

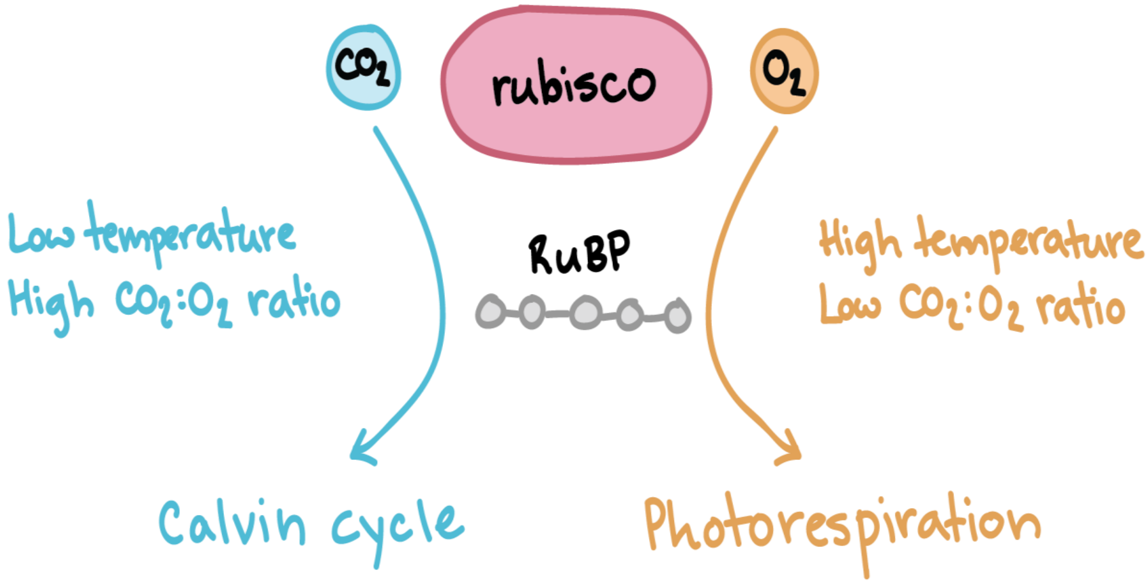
PHOTOREPSPIRATION

What is "Photorespiration?"

"Photorespiration is a process of *metabolic pathway* that consumes oxygen, releases carbon dioxide, generates no ATP, and *decreases photosynthetic output*;…" (Yahoo Answers, 2016).

This process generally takes place on hot, dry, bright days when stomata close and the oxygen concentration in the leaf exceeds that of carbon dioxide.

THE MECHANISM

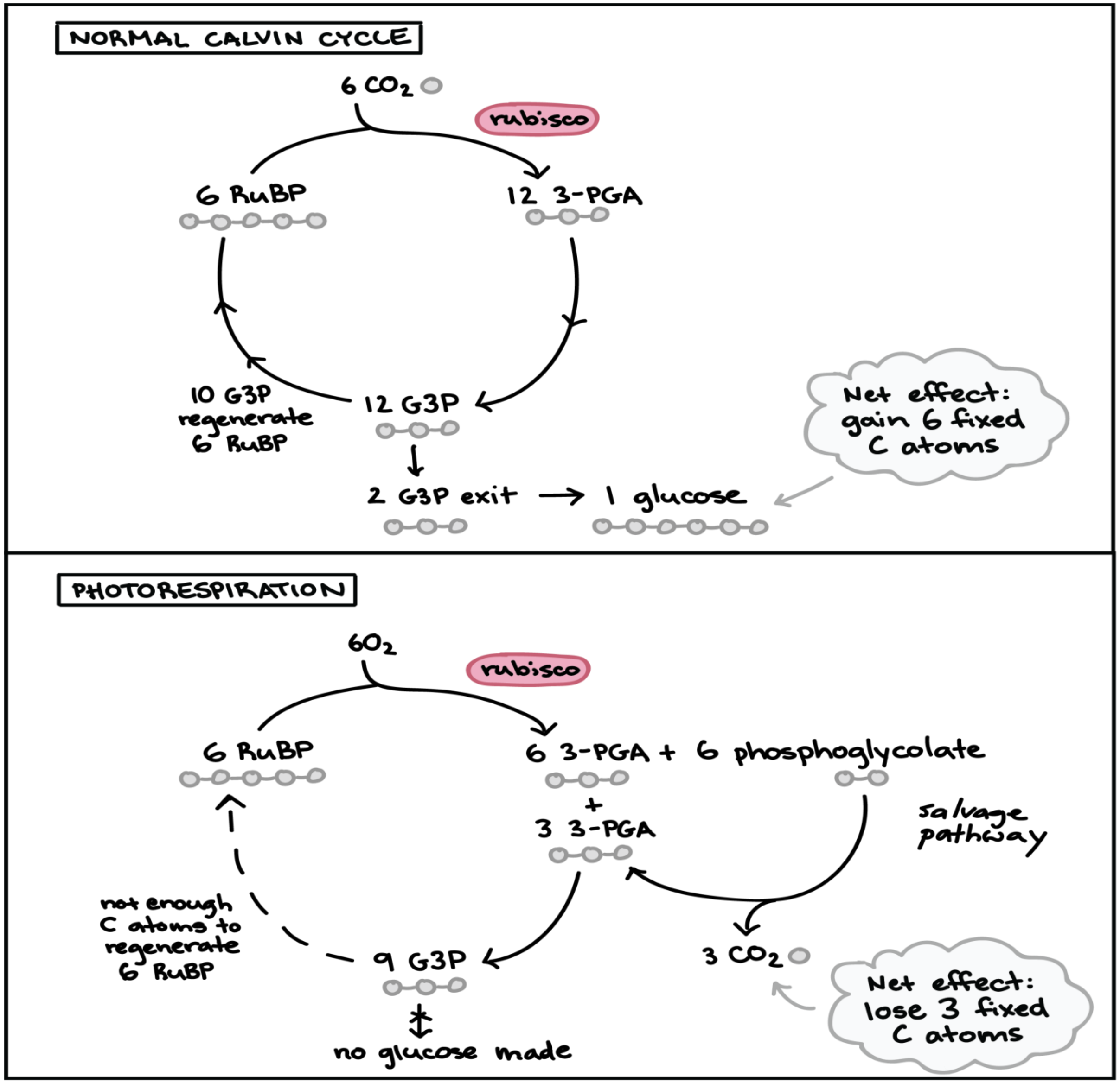


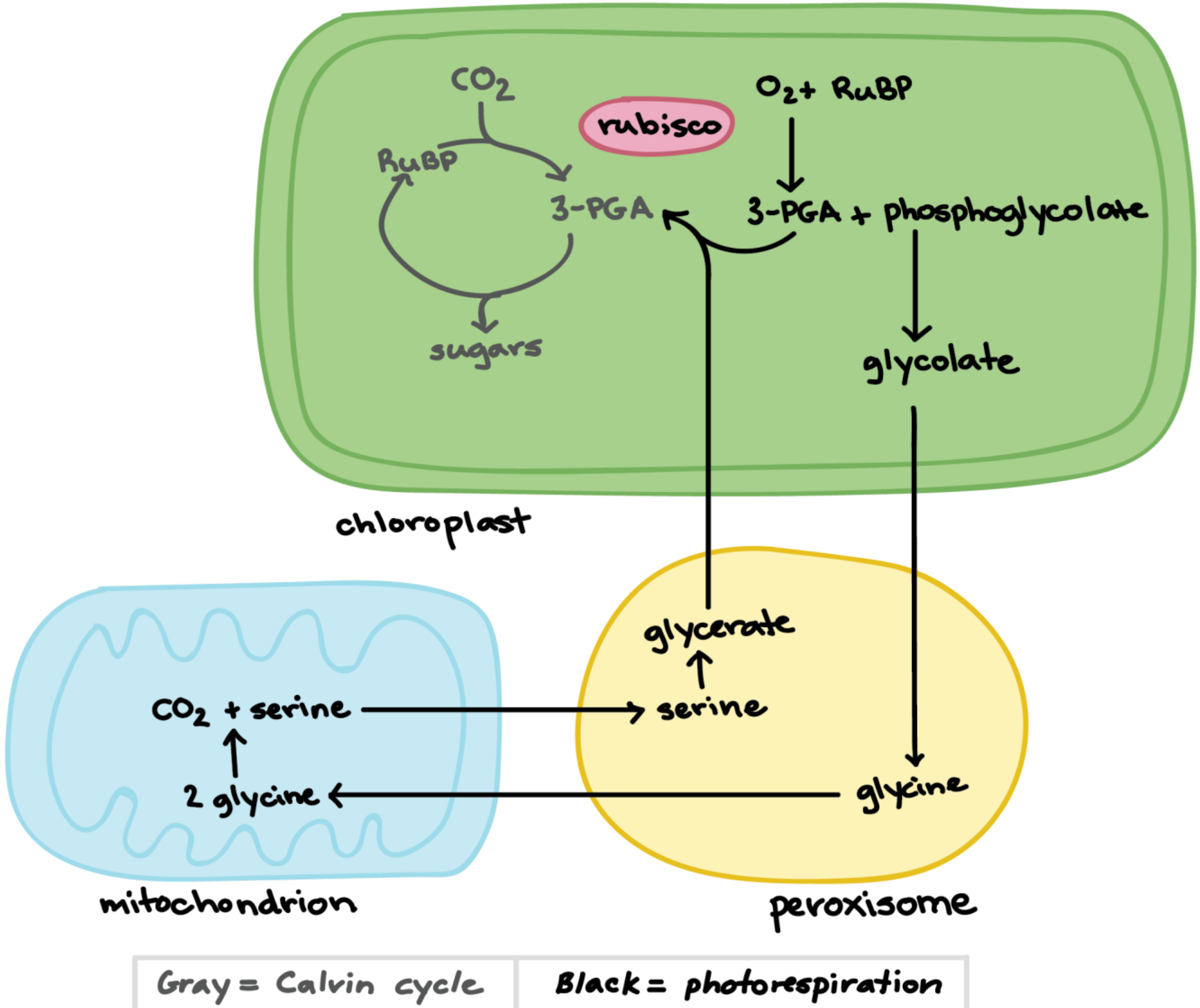
- As its name suggests, **RUBISCO** catalyzes two different reactions:
  - adding CO_2 to ribulose bisphosphate — the **carboxylase** activity.
  - adding O_2 to ribulose bisphosphate — the **oxygenase** activity.

The RUBISCO (Ribulose Biohosphate Carboxylase Oxidase) plays a role of attaching CO_2 to Ribulose-1, 5-biophosphate (RuBP). However, under particular conditions this enzyme attaches O_2 instead of CO_2.

- What determines what attaches to RUBISCO includes;
  - ✓Concentration
  - ✓Temperature

Instead of producing about 3-GPA (a building block of carbohydrates during photosynthesis), photorespiration produces 3-GPA as well as PG (a 2-carbon compound).


NORMAL CALVIN CYCLE
6 CO_2
rubisco
6 RuBP
12 3-PGA
10 G3P regenerate 6 RuBP
12 G3P
2 G3P exit
1 glucose
Net effect: gain 6 fixed C atoms
PHOTORESPIRATION
6O_2
rubisco
6 RuBP
6 3-PGA + 6 phosphoglycolate
+
3 3-PGA
salvage pathway
not enough C atoms to regenerate 6 RuBP
9 G3P
3 CO_2
no glucose made
Net effect: lose 3 fixed C atoms



CO_2
RuBP
rubisco
O_2 + RuBP
3-PGA
3-PGA + phosphoglycolate
sugars
glycolate
chloroplast
glycerate
CO_2 + serine
serine
2 glycine
glycine
mitochondrion
peroxisome
Gray = Calvin cycle
Black = photorespiration

Mechanism

- The uptake of O_2 by RUBISCO forms:
  - the 3-carbon molecule 3-phosphoglyceric acid — just as in the Calvin cycle
  - the 2-carbon molecule glycolate (Phosphoglycolate).
- The phosphoglycolate enters peroxisomes where it uses O_2 to form intermediates that enter mitochondria where they are broken down to CO_2.

- So this process **uses** O_2 and **liberates** CO_2 as cellular respiration does which is why it is called **photorespiration.**

- Photorespiration is a disadvantage to plants in that it reduces the amount of CO_2 in the plant. As the result of this reduction, the yield during photosynthesis is reduced.

- This metabolic process usually occurs in C_3 plants.

Benefits of Photorespiration

- Apart from the disadvantages, scientists have also found out that photorespiration is in some way beneficial to plants. These ways include;
  - Helps maintain redox balance in plants.
  - Supports plant immune defenses.
  - It has protective effects – it prevents light induced damage to molecules involved in photosynthesis.

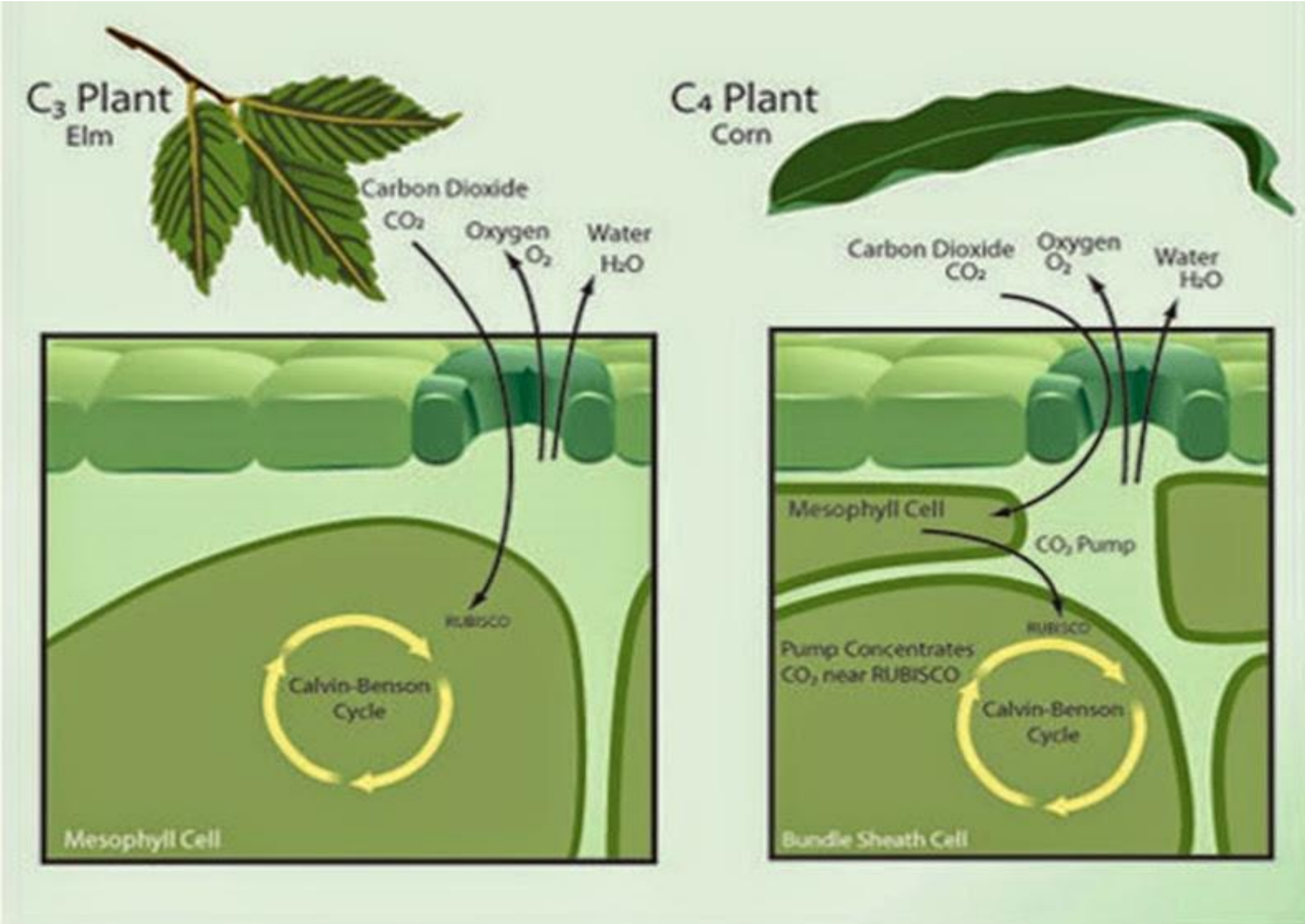
THE C_3 AND C_4 PATHWAYS

THE C3 AND C4 PATHWAYS

C3 Pathway: A metabolic process used by C3 plants to fix CO to RuBP during the dark stage of photosynthesis.

C4 Pathway: A metabolic process used by C4 plants to change/ convert atmospheric CO_2 into a chemical compound containing four carbons.

- Below is a diagram showing differences between the C4 and C3 pathways.


C3 Plant
Elm
Carbon Dioxide
CO2
Oxygen
O2
Water
H2O
RUBISCO
Calvin-Benson Cycle
Mesophyll Cell
C4 Plant
Corn
Carbon Dioxide
CO2
Oxygen
O2
Water
H2O
Mesophyll Cell
CO2 Pump
RUBISCO
Pump Concentrates CO2 near RUBISCO
Calvin-Benson Cycle
Bundle Sheath Cell

C4 PATHWAY (Hack-Slack)

Definition: A metabolic process used by C4 plants to change/ convert atmospheric CO_2 into a chemical compound containing four carbons.

MECHANISM OF C4 PATHWAY

- After entering through stomata, CO_2 diffuses into a **mesophyll cell**.
- Being close to the leaf surface, these cells are exposed to high levels of O_2, ***but have no RUBISCO*** so cannot start photorespiration (nor the dark reactions of the Calvin cycle).

Continuation…

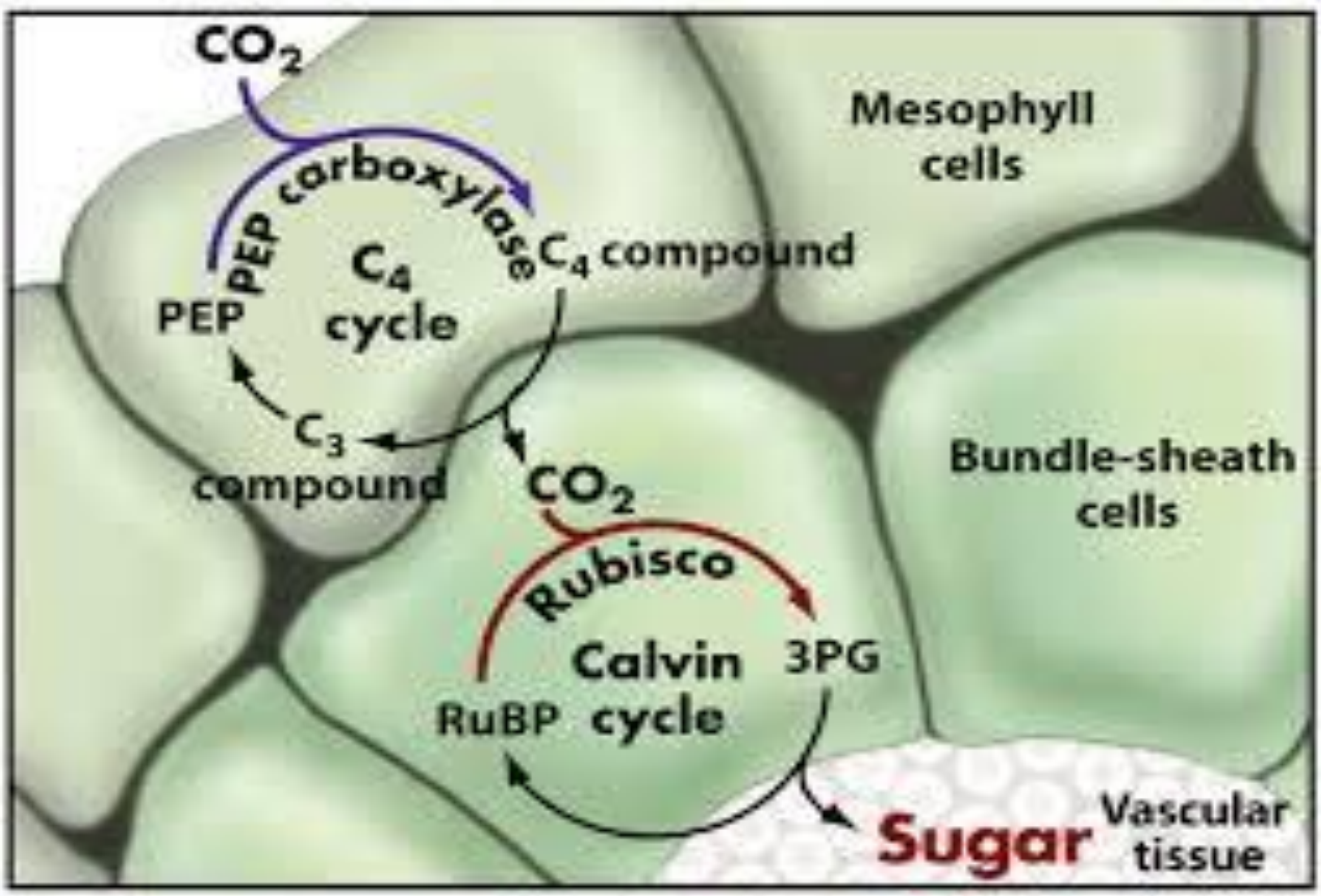
- Instead the CO_2 is inserted into a 3-carbon compound called phosphoenolpyruvic acid (PEP) forming the 4-carbon compound oxaloacetic acid.

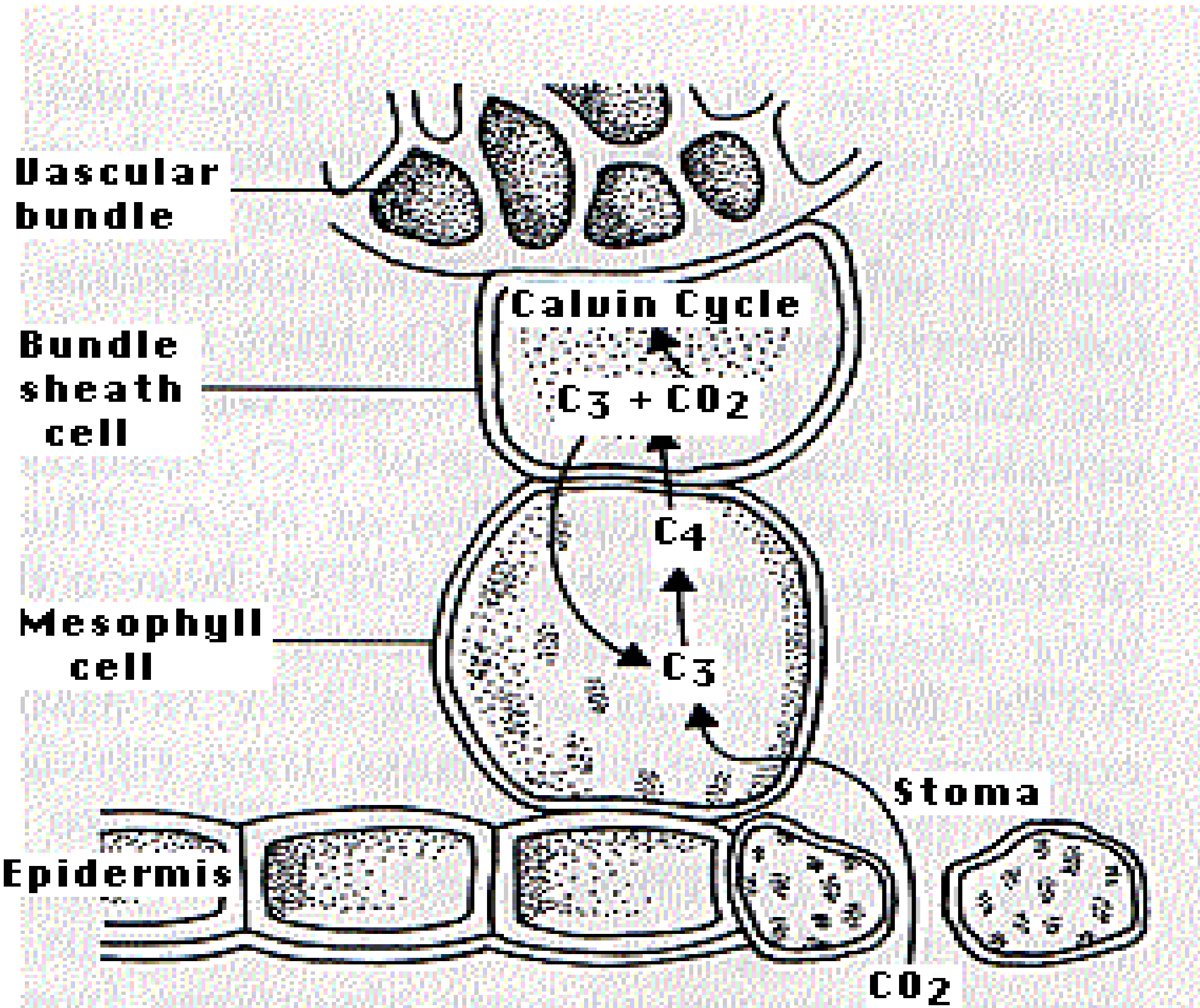
- Oxaloacetic acid is converted into ***malic acid (malate)*** or ***aspartic acid* (aspartate)** (both have 4 carbons).

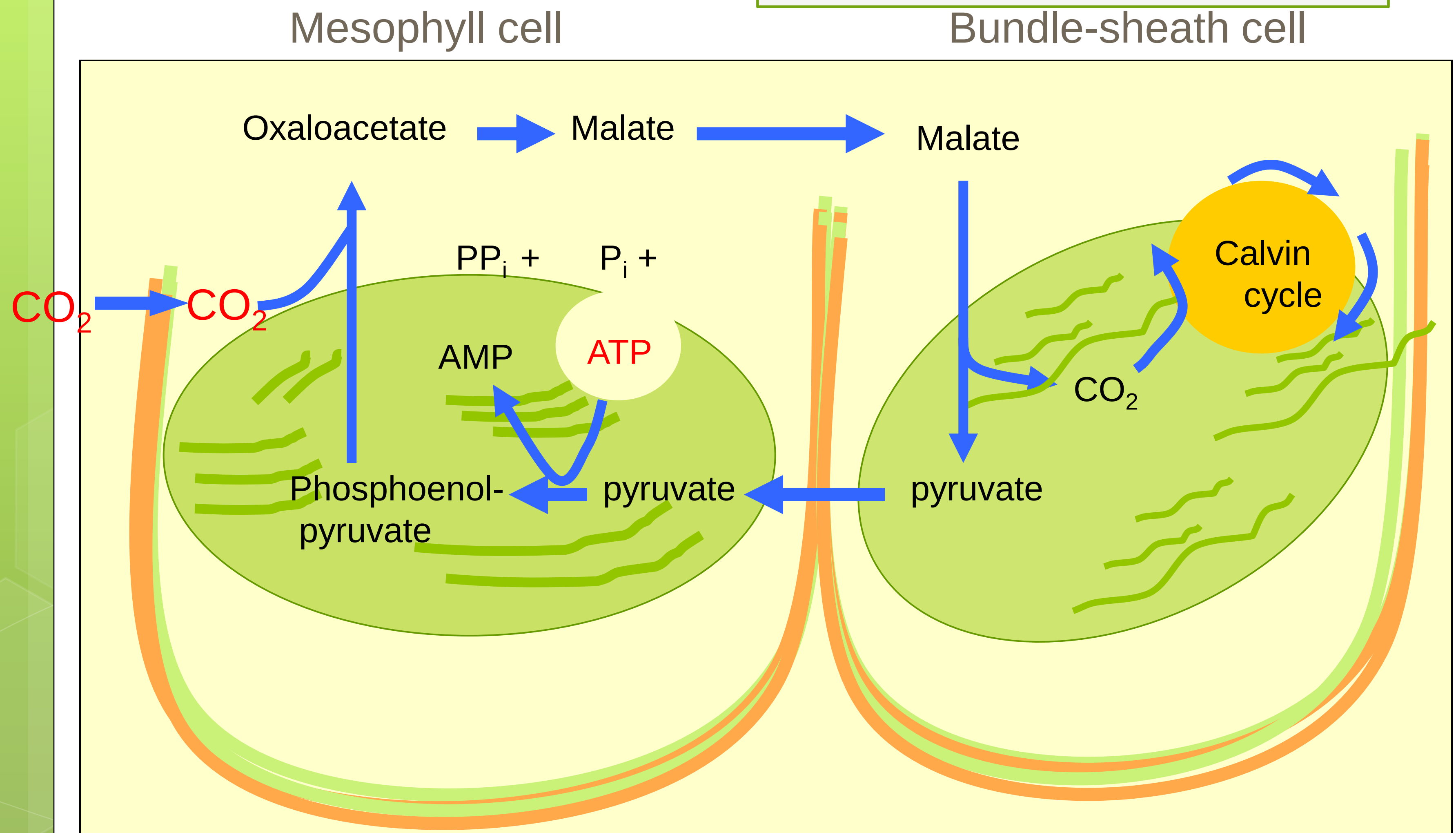
- This is transported (by plasmodesmata) into a **bundle sheath cell**. Bundle sheath cells are deep in the leaf so atmospheric oxygen cannot diffuse easily to them;
  - often have thylakoids with reduced photosystem II complexes (the one that produces O_2).
  - Both of these features keep oxygen levels low.

- Here the 4-carbon compound is broken down into;
  - **Carbon dioxide:** which enters the Calvin cycle to form sugars and starch.
  - **Pyruvic acid** (3 carbons): which is transported back to a mesophyll cell where it is converted back into **PEP**.

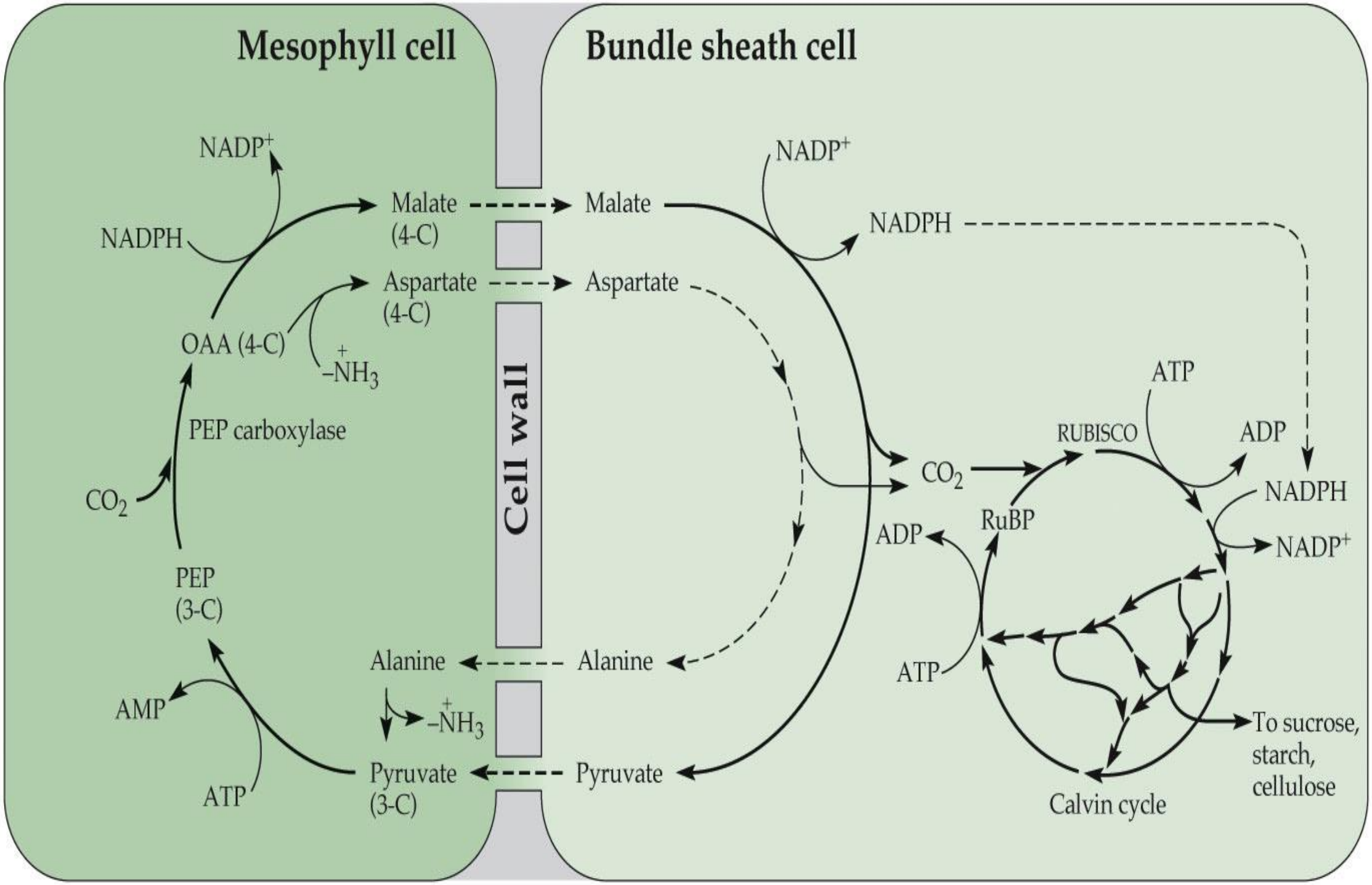
- The C4 pathway is adaption by some plants to present photorespiration.
- These C4 plants are well adapted to (and likely to be found in) habitats with
  - high daytime temperatures
  - intense sunlight


CO2
PEP corboxylase
C4 compound
C4 cycle
PEP
C3 compound
CO2
Rubisco
Calvin cycle
3PG
RuBP
Sugar
Mesophyll cells
Bundle-sheath cells
Vascular tissue


Vascular bundle
Bundle sheath cell
Mesophyll cell
Epidermis
Calvin Cycle
$C_3 + CO_2$
C_4
C_3
Stoma
CO_2



ATP energy is required to concentrate CO_2
in bundle-sheath cells


Mesophyll cell
Bundle sheath cell
NADP+
Malate
(4-C)
NADPH
Aspartate
(4-C)
OAA (4-C)
–NH3
PEP carboxylase
CO2
PEP
(3-C)
AMP
ATP
Pyruvate
(3-C)
Alanine
Cell wall
Malate
NADP+
NADPH
Aspartate
ATP
RUBISCO
ADP
CO2
NADPH
RuBP
ADP
NADP+
ATP
Alanine
Pyruvate
To sucrose,
starch,
cellulose
Calvin cycle

ADVANTAGES AND DISADVANTES

Advantages of C_4 photosynthesis

- don't lose energy and carbon to photorespiration
- higher light saturation (O_2 doesn't interfere) (draw graph)
- can more effectively get CO_2 from intercellular spaces
  - means can still do PS when stomates partly closed
- great for hot, bright, dry areas

Disadvantages

- extra step (first carboxylation) takes 2 extra ATP
  - if low light, energy is in short supply – C_4 no good
- light below 12 degrees IN THE LIGHT may damage chloroplasts
  - C4 lawn grass
  - some kinds of C4 plants don't have this problem

References;

- Biology Online. (2016). Photorespiration. Retrieved from: http://www.biology-online.org/dictionary/Photorespiration. 24/11/2016. 10:08am.

- Hyper physics. (2016). Systems of photosynthesis. Retrieved from: http://hyperphysics.phy-astr.gsu.edu/hbase/Biology/phoc.html#c5. 24/11/2016. 10:08am.

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