1. Compare the energy yields (in terms of ATP per glucose) from glycolysis and the combination of pyruvate oxidation and the citric acid cycle.

\[ \text{Glycolysis} = 4 \text{ ATP} \]

2. High levels of ammonia (NH₃) are toxic to mammals. One reason is that ammonia bonds with alpha-ketoglutarate, forming the amino acid glutamate. This removes alpha-ketoglutarate from the citric acid cycle. Explain the consequence of this for the cell.

\[ \text{No } \alpha \text{-keto glutarate } \rightarrow \text{no cycle; no } NADH, FADH_2 \]

less ATP produced

3. Why is replenishing NAD⁺ crucial to cellular metabolism?

\[ \text{bc NAD}^+ \text{ needs to accept } e^-/H^+ \text{ to form NADH which makes ATP in ETC} \]

4. Compare the sources and total energy yield in terms of ATP per glucose in human cells in the presence versus the absence of oxygen.

\[ \text{36-38 ATP} \quad \text{4 ATP} \]

5. Conditions can become anaerobic in a heart muscle cell during a heart attack, because of the inadequate supply of blood. If oxygen is restored, what will happen to the lactate produced by the heart muscle?

\[ \text{lactate } \rightarrow \text{glucose} \]

6. The following reaction occurs in the citric acid cycle:
   a. Is this reaction an oxidation or reduction?
   b. Is the reaction exergonic or endergonic?
   c. This reaction requires a coenzyme. What kind of coenzyme?
   d. What happens to fumarate after the reaction is completed?
   e. What happens to the coenzyme after the reaction is completed?

\[ \text{COOH} \rightarrow \text{COOH} \]

\[ \text{FAD} \quad \text{malate dehydrogenase} \]

\[ \text{Succinate } \rightarrow \text{Fumarate } + \text{Hydration} \]

\[ \text{goes to ETC} \]
Cellular Respiration

begins with

Glucose

which is broken down during
produces a net gain of

Glycolysis

which occurs in the
Cytoplasm

which produces

Pyruvate

can be used in
anaerobic processes
such as
fermentation

which produces
lactic acid

Krebs

which occurs in the
Mitochondria

has a net yield of
1 FADH
4 NADH
1 ATP

which occurs in the
used in the

ETC

make
3 ATP
### Cellular Respiration Summary Chart

<table>
<thead>
<tr>
<th>Starting Molecule</th>
<th>End Product</th>
<th>Location</th>
<th>Substrate Level Phosphorylation</th>
<th>Energy shuttled to oxidative phosphorylation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Glycolysis</strong></td>
<td>glucose</td>
<td>pyruvate</td>
<td>cytoplasm</td>
<td>2(NADH)</td>
</tr>
<tr>
<td><strong>Formation of Acetyl CoA</strong></td>
<td>pyruvate</td>
<td>Acetyl Co A</td>
<td>mito.</td>
<td>2(NADH)</td>
</tr>
<tr>
<td><strong>Krebs Cycle</strong></td>
<td>citric acid cycle (AcCoA)</td>
<td>oxaloacetate</td>
<td>matrix</td>
<td>2 ATP</td>
</tr>
<tr>
<td><strong>ETS and Chemiosmosis (proton pump)</strong></td>
<td>(NADH) (FADH₂)</td>
<td>H₂O</td>
<td>cristae</td>
<td>32-34 ATP</td>
</tr>
</tbody>
</table>
1. What are the reactants for the light reactions of photosynthesis?

\[ \text{H}_2\text{O} \quad \text{NADP}^+ \quad \text{ADP} \quad \text{P}_i \]

2. What are the products for the light reactions of photosynthesis?

\[ \text{O}_2 \quad \text{NADPH} \quad \text{ATP} \]

3. What happens when electromagnetic radiation at the following wavelengths arrive at a leaf: 180nm; 400nm; 550 nm; 600 nm; 680 nm; 700 nm; 900nm?

\[ \text{transmitted} \quad \text{absorbed} \quad \text{transmitted} \quad \text{absorbed} \]

by chlorophyll
by chlorophyll
by chlorophyll

4. Trace the flow of the electron in noncyclic electron transport in the chloroplast.

\[ \text{H}_2\text{O} \rightarrow \text{P}_{II} \rightarrow \text{i}^\circ \text{acc} \rightarrow \text{plastoquinone} \rightarrow \text{cytochrome} \rightarrow \text{plastocyanin} \rightarrow \text{P}_i \rightarrow \text{NADPH} \]

5. Trace the flow of the electron in cyclic electron transport in the chloroplast.

\[ \text{H}_2\text{O} \rightarrow \text{P}_{II} \rightarrow \text{i}^\circ \text{acc} \rightarrow \text{plastoquinone} \rightarrow \text{cytochrome} \rightarrow \text{plastocyanin} \rightarrow \text{P}_{II} \]

6. Write equations for the production of the following and indicate whether they are oxidations, reductions, or neither.

   a. Chlorophyll (Chl)  \[ \text{Chl} + \text{light} \rightarrow \text{Chl}^* \quad \text{oxidation} \]

   b. \[ \text{O}_2 \quad \text{H}_2\text{O} \rightarrow \text{H}_2\text{O}_2 + 2\text{H}^+ \quad \text{oxidation} \]

   c. ATP  \[ \text{ADP} + \text{P}_i \rightarrow \text{ATP} \quad \text{neither} \]

   d. \[ \text{NADPH} \quad \text{NADP}^+ + \text{H}^+ \rightarrow \text{NADPH} \quad \text{reduction} \]

7. What are the three processes of the Calvin Cycle?

   1. carbon fixation
   2. reduction (sugar production)
   3. regeneration of RuBP
Chloroplasts are the sites of photosynthesis. They are a type of plastid. They are large disk-shaped organelles (4-6 µm in diameter). A mesophyll leaf cell will contain between 50-100 chloroplasts. The chloroplasts are generally aligned so that their broad surface runs parallel to the cell wall to maximize the surface area available for light absorption. Chloroplasts have a complicated internal structure, characterised by a system of membrane structures called thylakoids arranged into stacks called grana. Plants use special pigments, called chlorophylls and carotenoids, to absorb light of specific wavelengths and thereby capture the light energy. Chlorophylls give leaves their green color.

**The Structure of a Chloroplast**

- **Stroma lamellae:** Interconnections between stacks of grana. They account for 20% of the thylakoid membrane.
- **Stroma:**
- **Grana:**
- **Thylakoids:**

**TEM image of a single chloroplast**

**Chloroplasts visible in plant cells**

Label the transmission electron microscope image of a chloroplast below:

- (a) Stroma
- (b) Stroma lamellae
- (c) Outer membrane
- (d) Grana
- (e) Thylakoid
- (f) Inner membrane

1. Describe where chlorophyll is found in a chloroplast: **in thylakoid**

2. Explain why chlorophyll is found there: **It is where the photosystems are located**

3. Explain how the internal structure of chloroplasts helps absorb the maximum amount of light:

   It provides a large surface area for binding chlorophyll and capturing light. Membranes are stacked to maximize light absorption.
Photosynthesis is of fundamental importance to living things because it transforms sunlight energy into chemical energy stored in molecules, releases free oxygen gas, and absorbs carbon dioxide (a waste product of cellular metabolism). Photosynthetic organisms use special pigments, called chlorophylls, to absorb light of specific wavelengths and thereby capture the light energy.

Visible light is a small fraction of the total electromagnetic radiation reaching Earth from the sun. Of the visible spectrum, only certain wavelengths (red and blue) are absorbed for photosynthesis. Other wavelengths, particularly green, are reflected or transmitted. Photosynthesis is summarized in the chemical equation and diagram (below).

\[
\begin{align*}
6\text{CO}_2 + 12\text{H}_2\text{O} & \quad \xrightarrow{\text{Chlorophyll}} \quad \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 + 6\text{H}_2\text{O} \\
\text{Photosynthesis equation}
\end{align*}
\]

**Chloroplast**

- Light enters the chloroplast.
- Water from cell sap is used as a raw material.
- Carbon dioxide from the air provides carbon and oxygen as raw materials.
- Oxygen gas (from the breakdown of water molecules) is given off as a waste product.
- Hydrogen (from the breakdown of water molecules) is used as a raw material.
- Oxygen (from the breakdown of water molecules) is given off as a waste product.

**Photosynthetic process:**
- **Light-dependent phase:** Process: Energy capture via photosystems I and II.
- **Light-independent phase:** Process: Carbon fixation via the Calvin cycle.

**Monosaccharides:** Glucose is the fuel for cellular respiration and supplies energy for metabolism. Glucose can be converted to fructose.

**Cellulose:** Glucose is used as a building block for creating cellulose, a component of plant cell walls.

**Starch:** Stored as a reserve supply of energy in starch granules, to be converted back into glucose when required.

**Disaccharides:** Monosaccharides join to form disaccharides, e.g., fructose and glucose form sucrose, found in sugar cane.

1. Describe the three things of fundamental biological importance provided by photosynthesis:
   (a) Light energy → Chemical energy available for food chains
   (b) Creates organic molecules used as building blocks for larger molecules
   (c) Releases O₂ for life

2. Determine the role of the following in photosynthesis:
   (a) The earlier molecule NADP: carries H⁺ to Calvin Cycle
   (b) ATP: Provides energy to construct glucose
   (c) Chlorophyll molecules: absorb light energy, split water to release O₂, H⁺ + e⁻
   (d) Light: Provides ultimate source of energy to drive light reactions
1. Describe the role of the carrier molecule NADP in photosynthesis:

   carry H+ to Calvin Cycle

2. Explain the role of chlorophyll molecules in photosynthesis:

   - trap light energy and produce high energy e-; also
     its photosystem splits water \( \rightarrow H^+ , e^- + O_2 \)

3. Summarize the events of the light dependent reactions and identify where they occur:
   - requires light energy
   - makes ATP + NADPH
   - electrons + hydrogen ions come from splitting of water

4. Describe how ATP is produced as a result of light striking chlorophyll molecules during the light dependent phase:

   light hits chloroplast + high energy e-s are released.

   ETS - energy is lost + ADP \( \rightarrow \) ATP

   by chemiosmosis.

5. (a) Explain what you understand by the term non-cyclic phosphorylation:

   generation of ATP using light energy during photosynthesis + NADPH

(b) Suggest why this process is also known as non-cyclic photophosphorylation:

   it indicates that the energy for phosphorylation is coming from light.

6. (a) Describe how cyclic photophosphorylation differs from non-cyclic photophosphorylation:

   involves P1 only
   - only ATP produced
   - no photolysis

   involves P1 + P2
   - ATP + NADPH produced
   - photolysis occurs

(b) Both cyclic and non-cyclic pathways operate to varying degrees during photosynthesis. Since the non-cyclic pathway produces both ATP and NADPH, explain the purpose of the cyclic pathway of electron flow:

   non-cyclic isn't efficient enough so cyclic pathway makes up the difference. (Calvin cycle needs more ATP than NADPH)

7. Explain how the independence of photosystem I gives a mechanism for evolution of the photosynthetic pathway:

   The complex pathway is made of a less complex pathway that can operate independently.
The light-independent reactions of photosynthesis (the Calvin cycle) take place in the stroma of the chloroplast, and do not require light to proceed. Here, hydrogen (H\(^+\)) is added to CO\(_2\) and a 5C intermediate to make carbohydrate. The H\(^+\) and ATP are supplied by the light-dependent reactions. The Calvin cycle uses more ATP than NADPH, but the cell uses cyclic phosphorylation (which does not produce NADPH) when it runs low on ATP to make up the difference.

The Calvin cycle is a series of reactions driven by ATP and NADPH. It generates hexose sugars and reduces the intermediate products to regenerate ribulose 1,5 bisphosphate (RuBP) needed for the first step of the cycle.

The catalyzing enzyme RuBisCo joins carbon dioxide (CO\(_2\)) with RuBP to form glycerate 3-phosphate (GP). ATP driven reactions then form 1,3 bisphosphoglycerate before NADPH driven reactions form triose phosphate (TP). Some of this then leaves the chloroplast and forms sugars while the rest continues through the cycle to eventually reform RuBP.

The Calvin cycle occurs in the stroma of the chloroplast. One CO\(_2\) molecule is fixed for every turn of the cycle. To build one hexose sugar molecule, six turns of the cycle are required. The hexose sugar is not made directly from the cycle but is assembled from its net products.

1. In the boxes on the diagram above, write the number of molecules formed at each step during the formation of one hexose sugar molecule. The first one has been done for you:

   ____________ + catalyzes the reaction that splits \( \text{CO}_2 \) and joins it with RuBP.

2. Explain the importance of RuBisCo in the Calvin cycle: ____________

3. Identify the actual end product on the Calvin cycle: ____________

4. Write the equation for the production of one hexose sugar molecule from carbon dioxide:

   \[
   6 \text{CO}_2 + 18 \text{ATP} + 12 \text{NADPH} + 12 \text{H}^+ \rightarrow 1\text{C}_{6}\text{H}_{12}\text{O}_6 + 18 \text{ADP} + 18 \text{Pi} + 12 \text{NADP}^+ + 6 \text{H}_2\text{O}
   \]

5. Explain why the Calvin cycle is likely to cease in the dark for most plants, even though it is independent of light:

   **Because the light dependent reactions stop, therefore no ATP + NADPH**