

# Cell Energetics Review

**KEY**

## AP Biology

### I. Glycolysis

Reaction Location	Reactants	Yields:
Cytosol	Glucose	ATP 2 (-2+4)
	<b>Products</b>	NADH•H <sup>+</sup> 2
	2 Pyruvate	FADH <sub>2</sub> 0

### II. Mitochondrial Transport

Reaction Location	Reactants	Yields:
Membrane of Mitochondria	Pyruvate	ATP 0
	<b>Products</b>	NADH•H <sup>+</sup> 1
	Acetyl-CoA + CO <sub>2</sub>	FADH <sub>2</sub> 0

### III. Krebs Cycle

Reaction Location	Reactants	Yields:
Matrix of Mitochondria	Acetyl-CoA	ATP 1
	<b>Products</b>	NADH•H <sup>+</sup> 3
	2CO <sub>2</sub>	FADH <sub>2</sub> 0

### IV. Electron Transport Chain

Reaction Location	Reactants	Yields of ATP per:
Cristae of mitochondria	O <sub>2</sub>	
	<b>Products</b>	NADH•H <sup>+</sup> 3 ATP
	H <sub>2</sub> O	FADH <sub>2</sub> 2 ATP

V. How many ATP would be generated by the following molecules entering at the earliest part of the cell respiration pathways and reacted completely:

- 12 NADH•H<sup>+</sup> ( $\bullet 3 \text{ ATP/NADH}\bullet\text{H}^+$ ) = 36 ATP
- 3 Pyruvate (through mitochondrial transport, Krebs, then ETC) = 45 ATP
- 4 Acetyl-CoA (through Krebs then ETC) = 48 ATP
- 3 Glucose (though entire reaction) = 108 or 114 ATP

VI. Describe what happens during fermentation. Why does fermentation occur? What product is produced by mammals?

*Fermentation occurs when there is not enough oxygen present to serve as the terminal electron receptor to permit the ETC to run continuously. Since the  $\text{NADH}\cdot\text{H}^+$  molecules have no place to dump their electrons, they build up until all of the cell's  $\text{NAD}^+$  molecules are reduced. Without any  $\text{NAD}^+$  to react with glucose, even the limited amount of ATP available in glycolysis is unattainable. As a result, cells ferment, or react  $\text{NADH}\cdot\text{H}^+$  with pyruvate, to regenerate  $\text{NAD}^+$  so that glycolysis can occur. Mammals ferment pyruvate to lactate or lactic acid. [Another common fermentation product in other life forms is ethanol.]*

VII. Describe the light reactions of photosynthesis. Provide the reactants, the products, and a brief description of the pathway.

*The light reactions of photosynthesis produce large quantities of ATP and  $\text{NADPH}\cdot\text{H}^+$ . It requires water, and produces  $\text{O}_2$  as a waste product. Chlorophyll molecules bound to photosystem II enzymes (PSII) hold magnesium metal atoms in a manner such that photons strike the metal and excite its valence electrons. The construction of PSII is such that these two excited electrons can actually ionize off the magnesium and then pass to a proton pump (similar to those in the electron transport chain of mitochondria). The pump moves two protons per electron pair into the thylakoid space, where they will build up such that their concentration gradient will drive into the stroma through an ATP synthase complex. Meanwhile the electrons continue their travel along the thylakoid membrane. Next, they will reduce an "empty" magnesium in photosystem I, where they will be re-excited by an incoming photon. These reenergized electrons reach the end of the electron transport chain, where they are accepted by  $\text{NADPH}^+$  (reducing it to  $\text{NADPH}\cdot\text{H}^+$ ), for use in biosynthetic pathways or the mitochondria to produce ATP, as conditions warrant. Meanwhile, PSII has reacted with water, taking  $2e^-$  to restore the magnesium metal in chlorophyll to its neutral state so the reaction can repeat. With the loss of its electrons, water decomposes into two protons and eventually oxygen gas.*

VIII. What is cyclic photosynthesis? When is it used?

*Cyclic photosynthesis involves the lesser photosystem, PSI. As electrons fall down the electron transport chain, they will eventually reach PSI. Here, the energy from photons re-excite the electrons to an level where they can be passed back to the beginning proton pump. This can continue as long as there is light, reusing the same pair of electrons to pump protons. This yields huge amounts of ATP, without the need for water to regenerate the magnesium metal at the start of another round. The downside of this reaction is that no  $\text{NADPH}\cdot\text{H}^+$  molecules are generated, meaning no biosynthesis or future mitochondrial energy production can occur.*

- IX. What is the Calvin Cycle? Describe the reactants, the products, and include a discussion of the energy cost relative to glucose consumption.

*The Calvin cycle is a complex chemical pathway that uses the tremendous amount of ATP and reducing power (in the form of  $\text{NADPH}\cdot\text{H}^+$ ) made in the light reactions to take inorganic carbon (in the form of  $\text{CO}_2$  from the atmosphere) and fix it into usable biological molecules. The enzyme Rubisco (Ribulose-bis-phosphate carboxylase) adds carbon dioxide to the carbohydrate ribulose-bis-phosphate. After many complicated, energy expensive steps, you generate a molecule of glyceraldehyde-3-phosphate (G3P), or, in essence, half a glucose molecule. It takes roughly 54 ATP equivalents to synthesis one glucose, relative to the energy yield of bacterially perfect respiration of 38 ATP.*

- X. What role do leaf stomata play in cellular energetics?

*Stomata are small, regulatable openings in the surface of leaves. Their primary role appears to be conservation of water. When evaporation of water from plant tissues is too high, they close and greatly reduce water loss. Unfortunately, this leads to a reduction of the diffusion of  $\text{CO}_2$  into the leaves, and the waste  $\text{O}_2$  out.*

*High levels of  $\text{O}_2$  can react with rubisco and convert ribulose-bis-phosphate into a molecule useless to the cell that must be recycled at the expense of energy. Thus, the cell not only fails to make a G3P, it also loses part of the Calvin cycle and must remake it and expend energy to disassemble the wasted ribulose-bis-phosphate. This unwanted consumption of oxygen by the photosystem is called photorespiration.*

- XI. CAM and  $\text{C}_4$  plants are evolutionary adaptations for what?

*These are adaptations for water conservation and reduction of photorespiration. Plants in warm climates must close their stomata during the day to reduce water loss. When they do,  $\text{O}_2$  builds up and  $\text{CO}_2$  levels drop. These plants have found two different ways to maintain artificially high levels of  $\text{CO}_2$  in their leaves without relying on diffusion from the atmosphere. The high levels of  $\text{CO}_2$  not only permit the Calvin cycle to proceed by providing a vital reactant, but the  $\text{CO}_2$  is in such excess that it is also able to out compete the  $\text{O}_2$  for occupancy of the rubisco thus reducing photorespiration.*

*$\text{C}_4$  plants have another enzyme that can fix  $\text{CO}_2$  besides rubisco. This enzyme does not react with oxygen, and thus works well even when oxygen levels are high after the stomata close. This enzyme, which varies depending on the type of plant, combines  $\text{CO}_2$  with a three-carbon compound (usually from glycolysis or the Krebs cycle) making a four-carbon compound (or  $\text{C}_4$ ).  $\text{C}_4$  plants are structurally isolated: the carbon fixation occurs in mesophyll cells close to the leaf surface. The fixed carbon they make is then transported into the interior of the leaf, where the fixed  $\text{CO}_2$  is then released to react with Rubisco in the Calvin cycle. The restored three-carbon compound returns to the outer-parts of leaf to pick up more  $\text{CO}_2$ .*

*In CAM plants,  $\text{CO}_2$  is fixed into organic molecules at night (when the stomata can open with little water loss) and then stockpiled until sunrise. As the temperature rises during the day, the stomata close.  $\text{CO}_2$  is released from the stores in the cell and reacted in the Calvin cycle. Thus, CAM plants are temporally isolated, taking in  $\text{CO}_2$  at a different time then the Calvin cycle occurs.*