

## Chapter 7 Reading Guide

1. Which 3 nutrient classes include nutrients that cells can use for energy?
2. Within those 3 nutrient classes what specific chemicals are actually split by cells to release energy?
3. When liver cells build glycogen, is this a catabolic or anabolic process? What about when glucose is split to release energy?
4. Describe the general structure of a mitochondrion.
5. Compare and contrast glycolysis and cellular respiration.
6. Can fatty acids be used in glycolysis? Does glucose enter cellular respiration directly, as glucose?
7. Why do cells produce more CO<sub>2</sub> when they are very active vs. when they are less active?
8. What chemical is split by cells to do WORK directly?
9. Describe generally what a coenzyme is. How are the B-vitamins related?
10. List several functions of liver cells (see table 7-1; most of this should be review)
11. How many carbons does glucose have? Pyruvate? Acetyl? Lactic acid?
12. How many hydrogen atoms does glucose have?

For the following questions, be sure to use my supplemental lecture in addition to the text:

13. What is the point of the TCA cycle?
14. Where is the usable energy actually located in a hydrogen atom?
15. How many pyruvates is glucose split into during glycolysis?
16. Where are the pyruvates taken after glycolysis?
17. What happens to pyruvates if there is not enough O<sub>2</sub> to support cellular respiration? How is this helpful to other cells of the body?
18. When pyruvates will continue on in cellular respiration, what substance are they converted to within the mitochondria?

19. What coenzyme will stabilize this substance? From what vitamin is this coenzyme derived?
20. The substance from #10 will then enter which process of cellular respiration?
21. When the above substance (okay, let's just be open about it now, we're talking about acetyl) enters the first process of cellular respiration, coA will release it. When acetyl is released from coA, what other substance will it join up with?
22. During the TCA cycle, the remaining H atoms on each acetyl are carefully removed. Why must these atoms be so painstakingly removed; why can't the cell just pluck them all off at once?
23. Where (to what process, and where in the mitochondrion does it occur) will the H atoms go, once they are removed?
24. Name the substances that will pick up the H atoms and carry them to the next process. From what vitamins are each of these "shuttle vans" derived?
25. Once the H atoms get to the ETC, what will happen to them, right away?
26. What happens to their electrons?
27. What happens to their H<sup>+</sup> (protons)?
28. How is the production of ATP ACTUALLY powered; that is, what is the direct energy source that drives the enzyme that makes ATP?
29. Name the enzyme that makes ATP in the electron transport chain, and explain where it is located in relation to the other enzymes, and how it works (ie, how it is powered... this should be very similar to your answer for #19, just a slightly different way of approaching it).
30. What is the role of O<sub>2</sub> in cellular respiration?
31. Why is water a bi-product of cellular respiration?
32. Why are ALL of the processes of cellular respiration aerobic, even though O<sub>2</sub> is only actually used during the ETC?
33. Whenever C and O are lost from molecules during cellular respiration, what happens to them?

34. Provide an example of a real-life cell and situation in which lots of ATP would be needed quickly, but not enough O<sub>2</sub> would be available for cellular respiration to make enough ATP. What process would have to provide the bulk of the ATP in this situation? Why would lactic acid be produced in this situation?
35. When fatty acids are used for energy by a cell, how are they processed?
36. Can fatty acids be used to provide energy anaerobically? Why or why not? Explain this on the level of where they enter the energy pathways.
37. What substances will be produced when lots of fatty acids are being used for energy?
38. Why are these substances valuable sources of energy; that is, what is different about them compared with fatty acids?
39. Can you have too many of these substances in your blood? What is this condition called?
40. What needs to happen to amino acids before they can be used for energy? What happens to the amino groups?
41. List some possible fates of amino acids in terms of where they might enter ATP-production pathways.
42. Explain generally, and provide some examples, of which types of substances can be used to make glucose and which types of substances can be used to make fatty acids.
43. Why would liver cells want to make glucose?
44. When would acetyl be used to make fatty acids rather than be used to produce ATP?
45. Why is it more energetically efficient for the body to store excess dietary fats as fat than to store excess dietary glucose and amino acids as fat?
46. Can excess dietary fatty acids be stored as glycogen?
47. What B-vitamin is required for deamination and transamination reactions?

48. Which can provide more ATP: one glucose, or one oleic acid molecule (review fats to remind yourself how many carbons oleic acid has)
49. Why is ketosis an important adaptation for starvation (I'm thinking of two reasons)?
50. Why does gluconeogenesis increase during fasting/starvation?
51. Explain the physiological processes that occur during feasting, fasting for several hours, and fasting/starvation beyond several hours. Be sure to mention: i) storage of carbs, proteins and fats as fat, ii) storage of glycogen, iii) gluconeogenesis, iv) deamination and use of proteins/breakdown of body proteins to use for energy, vi) what nutrient/s brain cells are using for energy when, vii) what nutrient/s other body cells are using for energy when.
52. What is the chemical name of the alcohol that we drink?
53. Define "moderate" alcohol intake.
54. Name the enzyme in liver cells and the stomach that processes alcohol.
55. Explain some negative effects on the liver, the brain, and vitamin adequacies that can occur as a result of excess alcohol intake.
56. Are there any positive effects of moderate alcohol intake?

**Supplemental Lectures:** this pretty much sums up most of what you need to know from this chapter. I'd recommend that you read through this first, then read the chapter again. You WILL be responsible for the last section which I have not discussed here: pp. 232-238.

- I. **Some Reminders of Energy Basics:**
  - a. Energy in carbs, proteins and fats are stored in chemical bonds. We'll see more specifically how later on in the chapter! Anyway, the actual chemicals that cells split to

release energy are glucose, fatty acids, glycerol (remember, from triglycerides), and amino acids.

Now, recall that when amino acids are used for energy, they must first be deaminated. The remaining carbon chain ends up as glucose OR a derivative of glucose or fatty acids. Glycerol is actually a glucose derivative. So, when it comes to using chemicals for energy, cells really use glucose, fatty acids, or some derivative of them!

- b. Recall also that the energy stored in glucose and fatty acids is NOT used by cells directly to do work; instead, cells use the energy to make ATP.

Again, ATP is like a AA battery. When a cell needs to do a job, it will split ATP and use the energy released to do the job. When ATP is split, the remnants of the split are ADP and Pi (inorganic phosphate). See the picture provided in your book to help clarify this split.

Energy from glucose and fatty acids are simply used to re-attach ADP and Pi and make more ATP. It's like ATP is a rechargeable battery: the cell depletes the battery doing a job. To recharge the battery, it needs a larger energy source (like the electric socket you would use). That larger energy source is food.

Glucose has enough energy to "recharge" about 36-38 ATP batteries. Fatty acids, since there are so many of different lengths, vary. The longer the fatty acid, the more energy it stores!

- II. An introduction/overview of the processes used to extract energy from nutrients to "recharge" ATP-** Both processes include many steps. Virtually every step is driven by a specific enzyme.

- a. **Glycolysis-** ONLY glucose undergoes this process. The term literally means “splitting glucose.” And that’s exactly what happens, glucose gets split in two.

This is a 10-step process that occurs in the CYTOSOL- general fluid of the cell. So, that means that the enzymes that drive this process are floating around in the general fluid of the cell.

During glycolysis, glucose is split into two pieces. Those pieces are called pyruvate. This initial split releases enough energy to allow the cell to recharge 2 ATP.

Glycolysis does NOT require O<sub>2</sub>; it is anaerobic. And it’s a way for a cell to get ATP fast!

- b. **Cellular Respiration-**

The remnants of glycolysis (pyruvates) and all other energy-providing nutrients, go through this process.

This is a very complex series of reactions that occurs within MITOCHONDRIA. Mitochondria are isolated “rooms” in the cell where the enzymes that drive the reactions of cellular respiration are kept.

This is where the remainder of the energy from glucose will be extracted (remember, after glycolysis the 2 pyruvates are still storing about 34 ATPs worth of energy!). This is an extremely efficient process. However, it takes a little longer to kick in to full steam than does glycolysis, if a cell’s energy needs increase suddenly. However, once it gets going, it can pump out serious amounts of ATP!

This process is THE reason... not one of the reasons, THE reason... that you need to breath in O<sub>2</sub> approximately every 3-5 seconds every minute of your life. This process NEEDS O<sub>2</sub>. Cells of your body do it constantly, and they

therefore require a constant source of O<sub>2</sub>. Since cellular respiration requires O<sub>2</sub>, it is called an aerobic process.

**c. What happens to glucose after it's been split up and depleted of its energy?**

Well, remember that glucose is C<sub>6</sub>H<sub>12</sub>O<sub>6</sub>. When it is split up, its Cs and Os stick together to form CO<sub>2</sub> (carbon dioxide). Its Hs join up with the O<sub>2</sub> provided by your breathing to form H<sub>2</sub>O.

You then breathe out the CO<sub>2</sub> as waste, and the H<sub>2</sub>O becomes part of the water used by your body. This is why food can provide more water than is revealed by its absolute water content; this is metabolic water!

**III. Cellular Respiration, using glucose as the example-**

In part I, you learned a little bit about glycolysis, in which a molecule of glucose was split into 2 pyruvates. Now, you will see what happens to those 2 pyruvates.

**\*Please follow along with figures 7-9, 7-18, and 7-19 from your text.**

**a. An overview before we get to the details:**

- i. The pyruvates are taken into a mitochondrion, where each will be converted to a compound called acetyl
- ii. The rest of cellular respiration involves 2 complicated processes; each requires many steps and many enzymes. The two processes are called:
  1. The TCA cycle- in this process, H atoms are carefully removed from each acetyl. The H atoms carry energy-rich electrons. They will then be transported to:

2. The Electron Transport Chain- in this process, the H atoms will give up their energy-rich electrons. Energy will be sapped from the electrons and used to make ATP. The ETC occurs along the inner membrane of mitochondria.

**b. Some reminders before the details:**

- i.** Keep in mind that cells always keep a stockpile of ADP (adenosine Diphosphate) and Pi (inorganic phosphate) around. To “make” ATP, the cell uses energy to attach the Pi to the ADP. Remember, this is like “recharging” a battery.
- ii.** Remember that food molecules are made of atoms: carbon, oxygen, hydrogen, etc. Atoms are composed of subatomic particles such as protons, neutrons and electrons. The energy in food, at least the portion that cells are able to extract, is actually in the electrons. Electrons have a lot of energy, they zip around constantly!
- iii.** The electrons that cells are able to get to in food molecules are electrons associated with H atoms. An H atom consists simply of one proton and one electron, and the proton (H<sup>+</sup>) is perfectly stable in water. So, an H atom can easily give up its high-energy electron for the cell to use.
- iv.** The electrons in food are HIGH energy: think about it this way: a plant makes glucose using energy from the sun. Energy from the sun causes electrons to speed up. So the electrons in food molecules are zipping around extra fast. Now, when you ingest food, your cells are able to extract some of that energy, we’ll say by causing the electrons to slow down. When electrons (or anything) lose energy, that energy has to go somewhere. The Electron Transport

Chain is a mechanism that is able to capture the energy given off by electrons as they slow down.

c. **More details:**

i. The intermediate step: Pyruvates are converted to acetyl

1. First, pyruvates will be transported into a mitochondrion.
2. Next, they will each have a C, 2 Os, and a H atom chopped off. The C and 2 Os will join up to form CO<sub>2</sub>. The CO<sub>2</sub> will diffuse out of the cell and into the blood. When the CO<sub>2</sub> gets to the lungs, you will breathe it out.
3. After the C, 2Os, and H are chopped off, what's left is an unstable compound called acetyl. Acetyl has 2 C and 3 H and some Os. It will be stabilized when a coenzyme called coenzyme A attaches to it.
4. The H atom that was given off will be taken to the ETC.

ii. The TCA cycle: in this process, the H atoms that still remain on each acetyl will be carefully removed. This is a multiple step process. The cell can't just rip off the H's because if it did, what would be left would be highly unstable and would run rampant in the cell, causing all sorts of harmful reactions. So, this must be done very carefully.

What happens is that coA takes acetyl to the first enzyme of the TCA cycle in the mitochondrion. The coA lets go of acetyl, which then immediately attaches to a molecule called **oxaloacetate**. Again, this is a stabilizing mechanism. Oxaloacetate is simply

a carrier to keep acetyl stable. When acetyl attaches to oxaloacetate, a new compound is formed: **citrate**.

Anyway, then a series of enzymes carefully rearranges the chemical bonds of citrate in a step-by-step manner. **The point is to release H atoms in a safe way.**

Each time a H atom is released, it will be immediately picked up by a “molecular shuttle van,” a molecule that will shuttle the H to the ETC. The shuttle vans will drop off H at the ETC, and return to the TCA to pick up more Hs. The molecular shuttle vans used to transport H from the TCA to the ETC are NAD<sup>+</sup> and FAD! Sound familiar?

Remember that acetyl also had some Cs and Os. They are useless to the cell; and, in a couple of steps, the Cs and Os that acetyl contributed to citrate are chopped off and released as waste: CO<sub>2</sub>.

- iii. The ETC: in this process, the energy of the electrons from H atoms is collected and used to make ATPs.

How is this done? I know you’re just dying to find out.

Well, embedded into the inner mitochondrial membrane is a series of enzymes. Some of these enzymes have tunnels that can transport H<sup>+</sup> (remember, H<sup>+</sup> means a H that lost its electron).

What happens is, when H atoms are dropped off, they immediately pop off their electrons.

The electrons are “caught” by the first enzyme in the series. That enzyme tosses it to the next, which tosses it to the next, and so on.

With each toss, the electron loses energy (again, kind of like it slows down). The energy lost is used to take the  $H^+$  and drive it across the inner membrane, through the tunnels. Look at fig. 7-19 in your book. You will see that lots of  $H^+$  start to build up on one side of that membrane. That’s a lot of pressure! The mitochondrion is “collecting” the energy from electrons by piling all those  $H^+$  s up.

Okay, now for the nitty gritty. We know the ETC has been collecting energy from electrons. Now, how does it use all that stored energy to make ATP? Well, it turns out that at the end of the line of enzymes, there is another enzyme called ATP synthase. As the name implies, ATP synthase can make ATP if it has enough energy. And it will: it has a tunnel that lets  $H^+$  flow through it. When those built up  $H^+$  get to ATP synthase, they rush through like water through a dam. This actually causes ATP synthase to start spinning. Once ATP synthase gets to spinning, it will grab ADPs and P<sub>i</sub> and pop them together.

Voila! The cell has ATP!

Okay, now for the role of  $O_2$ : remember all those electrons that have been sapped of their energy? Well, they may be slow but they still exist and must be rid.  $O_2$  is waiting there at the end of the line of electron-tossing enzymes. Oxygen LOVES electrons, so it will grab onto them. Since electrons have a negative charge, this will give oxygen a negative charge. Then,

H<sup>+</sup> comes flooding through the ATP synthase tunnel, meets this lovely negative oxygen, and it's love! The positive of H<sup>+</sup> and negative of oxygen attract and they get together to make water: H<sub>2</sub>O.

d. Misc:

- i. You know the B-vitamins that contribute to coA, NAD, and FAD. Remind yourself, this will be testable.
- ii. Oxaloacetate is made from carbohydrates
- iii. Remember, the overall process of cellular respiration yields about 34-36 ATP PER glucose (that's for every two pyruvates). Add that to the 2 from glycolysis, and the cell gets a total of about 36-38 ATP for each glucose.
- iv. All of the processes within the mitochondria are dependent on the presence of adequate O<sub>2</sub>. If there is a lack of O<sub>2</sub>, the electron-tossing enzymes cannot give up their electrons, and the WHOLE system gets backed up, all the way back to pyruvate. In fact, if there's not enough O<sub>2</sub>, pyruvates will not be converted to acetyl. Will consider what happens then later.

#### **IV. Some Other Aspects of Cellular Respiration:**

##### **a. How fatty acids are used for ATP-**

Remind yourself of the structure of fatty acids. They are long chains of C, H, and one O. With the help of water, fatty acids are chopped up at every 2<sup>nd</sup> C. The pieces left over are acetyl. coA stabilizes these acetyls, and they go right to the TCA cycle.

\*So, can fatty acids be used to make ATP in the absence of O<sub>2</sub>? Why or why not?

When LOTS of fatty acids are being used for energy, like if you are diabetic, on a low-carb diet, or exercising for extended periods, sometimes excess

acetyls get made. There will be a backup, basically not enough TCA enzymes and oxaloacetates are available to accept the acetyls. So, cells have a way of sharing their excess energy with other cells: the acetyls are converted to other 2-C substances called ketone bodies.

Ketone bodies can leave the cell and enter the blood (acetyls cannot). Other cells of the body can take in the ketone bodies, convert them to acetyls, and use them for energy. In fact, **even neurons can use ketone bodies for energy.**

If you are using all your ketone bodies, or excreting them through breath or urine, you may be in a state of ketosis, but not dangerous ketoacidosis. If enough ketone bodies build up in your blood, they can change the pH dangerously; this ketoacidosis can be life threatening.

#### **b. How amino acids are used for ATP**

When amino acids are used to make ATP, they must first be deaminated. The C-chain that is left over is something related to either glucose (for example, it could be pyruvate) or to fatty acids (for example, it could be acetyl).

Each amino acid has a different fate, based on its structure.

The amino group becomes ammonia; liver cells will immediately convert ammonia to the less toxic urea, which will be excreted.

#### **c. Making glucose and fatty acids**

Only compounds with 3 or more carbons can be used to make glucose. That means, any substance that can be converted to pyruvate, glycerin or lactic

acid (see below) can be used to make glucose. The primary source of these compounds during a fast is amino acids (a little bit of glycerol comes from triglycerides).

During a fast, neurons will eat both ketone bodies and glucose; but the glucose will be made from amino acids. So, when you are fasting or on a low carb diet, your body proteins (mostly muscles at first) will be digested to provide amino acids to make glucose.

Acetyl and ketone bodies cannot be used to make glucose.

However, acetyl CAN be used to make fatty acids:

So, anything that can be reduced to acetyls (glucose, amino acids) can be used to make fat for storage.

On the other hand, fat cannot be converted to glucose, since it is only chopped up into acetyls.

#### **d. What happens if there isn't enough O<sub>2</sub> to support ATP needs**

Let's say you've decided to lift a couch over your head. Here you've got muscle cells in your arms, legs and back that were resting, using very little ATP, and all of a sudden you're going to ask them to do this work that requires massive amounts of ATP.

Well, these cells are having a normal blood supply to them (so adequate, but not lots of O<sub>2</sub> are getting to them), and their mitochondrial enzymes are not really warmed up at this point.

Remember that glycolysis yields ATP much faster than cellular respiration.

When you lift the couch, there's no way that cellular respiration will be able to supply that much ATP that quickly. It will take a while for blood flow to increase enough to provide enough O<sub>2</sub> and for the enzymes to get warmed up.

So, TONS of glucose gets split as glycolysis powers your lifting. That means, TONS of pyruvate gets produced. That means, there's not enough oxygen yet to allow all those pyruvates to enter mitochondria and be converted to acetyl!

So, the excess pyruvates will be converted to another 3-C compound, lactic acid (lactate). Lactic acid, unlike pyruvate, can leave the cell.

In this way, cells can share all that excess energy with other cells. It's really the liver that uses lactic acid. Its cells can use lactic acid to make and use pyruvate for energy, or it can attach 2 lactic acids together and make glucose, which can then enter the blood for other cells to use.