Name____ Biol 211 - Group Number________

Active Learning Exercise 5. Cellular Respiration

Reference: Chapter 9 (*Biology* by Campbell/Reece, 8th ed.)

1. Give the overall balanced ***chemical equation for aerobic cellular respiration*** and *explain in your own words why almost all organisms do this*.

2. **Fill in the blanks.** (You may want to complete this after completing the other page of this ALE.)

   (1a) Autotrophic / Heterotrophic (circle one) organisms can synthesize and stockpile energy-rich organic compounds such as carbohydrates, lipids, and other molecules from inorganic raw materials and(1b)______________________ as an energy source. However, *both* autotrophs and heterotrophs must break down organic compounds to obtain a form of energy that can be used by their cells. For example, carbohydrate, (2)_________________, is partially dismantled by the glycolysis, during which some of its stored energy is used to produce other high-energy compounds. The high-energy compounds formed during glycolysis are (3)_________ and (4)__________. The reactions of glycolysis take place in the (5a)___________ of the cell. Glycolysis results in a *net* production of (5b)_____ molecules of the nucleotide, (5c)_______. At the end of glycolysis, the starting molecule has been converted into two molecules of (6)__________________, each of which contains three carbon atoms. If (7)_______________ is not present in sufficient amounts, the end product of glycolysis enters (8) *Aerobic* / *Anaerobic* (circle one) pathways, in which it is converted into (9)______________ in animal cells, or into (10)________________ and (11)__________ _____________ (two words) in yeast and some bacteria . If sufficient oxygen is present, the end product of glycolysis enters (12)_____________ pathways, the (13)_________ cycle and the (14)_____________ __________________ (three words), during which a total of (15)________ molecules of the high-energy compound(16)_________ are generated by the aerobic pathways. In the Kreb's cycle the food molecule fragments are further broken down into the carbon containing compound(17)__________ __________ . During these reactions hydrogen atoms with their negatively charged (18) ___________ are stripped from the fragments and are transferred to the energy carries (19)________ and (20)_________. The electrons are then sent down a series of transport (21)__________ , and the energy that they give off is used to form (22)__________. Electrons leaving the chain combine with hydrogen ions and (23)___________ molecules to form water. These reactions occur only in the (24)_________________ of a cell or on the inner membrane of aerobic bacteria.

3. What is achieved by two molecules of ATP being consumed during the energy-investment phase of glycolysis where ATP reacts first with glucose and then with fructose-6-phosphate?

4. a.) What happens to the ATP produced during aerobic or anaerobic respiration? (i.e. For what processes is ATP used for in cells?)

   b.) Why is the concentration of ATP in cells very low, even in the most active cells, such as the muscle cells in the legs of an athlete?

5. What roles do the co-enzymes NAD^+ and FAD serve in a cellular respiration?

6. a.) Write the "abbreviated formulas" for the reduced forms of NAD^+ and FAD.

   b.) Where do the electrons come from that reduce NAD^+ and FAD during cellular respiration?

7. What happens to the NADH produced during glycolysis under ***anaerobic*** conditions in....
   a.) animal cells?

   b.) yeast cells?

8. a.) Into what process are the ***reduced*** forms of NAD^+ and FAD fed under ***aerobic*** conditions?

   b.) How many molecules of ATP are produced per molecule of NADH and $FADH_2$?

   i.) NADH generates _______ ATP ii.) $FADH_2$ generates _______ ATP

   c.) Why is there a difference in the number of ATP produced?

9. Per molecule of glucose, how many ***net*** molecules of ATP are generated ***directly*** (i.e. Substrate level phosphorylation) during…

   a.) glycolysis? ________ b.) the Citric Acid Cycle? ________

10. ***Aerobic respiration*** stops when molecular oxygen becomes scarce. Why can't the citric acid cycle and electron transport continue under anaerobic conditions? What role does oxygen play in aerobic respiration?

11. How many ATP molecules can be made from the breakdown of one glucose molecule the following cellular processes:
    a.) aerobic respiration (i.e. the complete breakdown of one glucose molecule by glycolysis, citric acid cycle, and electron transport to CO_2 and H_2O)? __________
    b.) by anaerobic respiration (i.e. Glycolysis)? __________
    c.) Explain the difference in the number of ATP produced.

12. Record in the spaces below the substances or structures labeled with the letters a - f in the diagram of a portion of a mitochondrion.

a. ________________________________

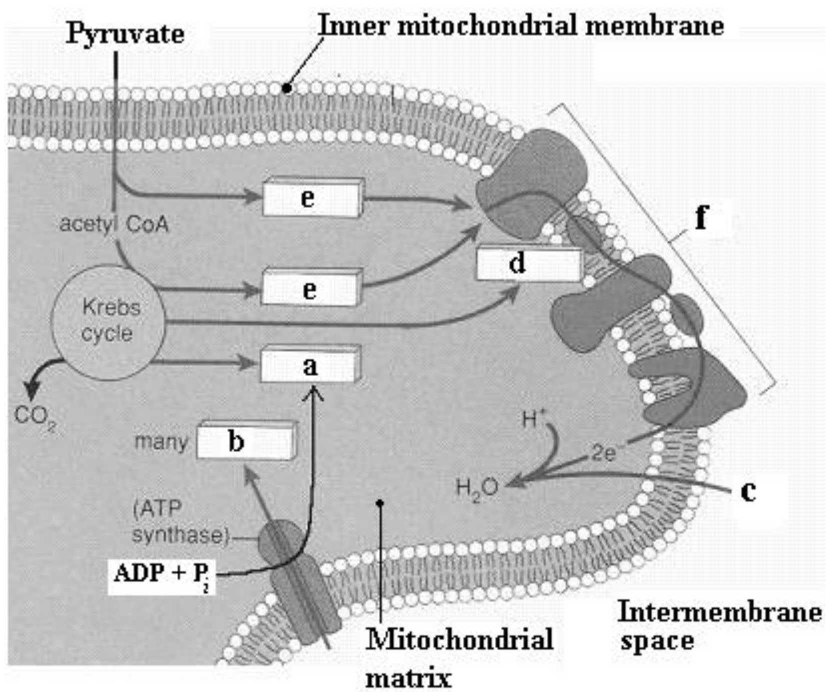
b. ________________________________

c. ________________________________

d. ________________________________

e. ________________________________

f. ________________________________



#'s 13 - 16: True-False Questions. *If false, rewrite the statement to make it true*.

13. ______ Glucose is the only carbon -containing molecule that can be fed into the glycolytic pathway.

14. ______ Fats are efficient long-term energy storage molecules that gram for gram contain twice the energy as carbohydrates.

15. ______ Glycolysis is an anaerobic process, therefore it can only occur in the absence of oxygen.

16. ______ Carbon dioxide and water, the products of aerobic respiration, generally get into the blood and are carried to the gills or lungs, kidneys, and skin, where they are expelled from the animal's body.

17. Record in the spaces below the processes or substances labeled with letters in the diagram of intermediary metabolism. *Hint*: With the exception of c and e, all letters represent substances.

a.______________________________

b.______________________________

c.______________________________

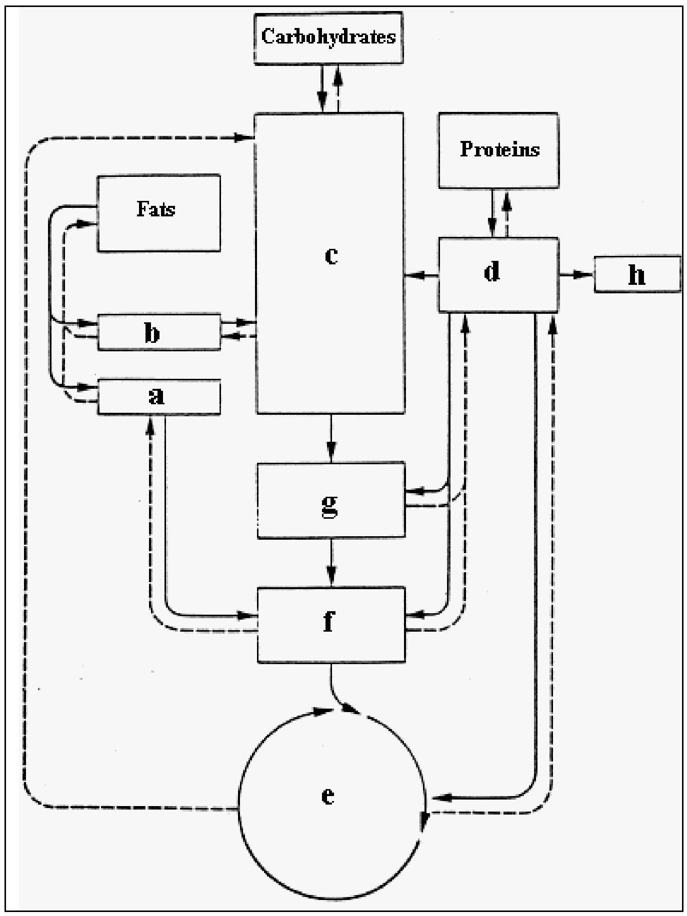
d.______________________________

e.______________________________

f.______________________________

g.______________________________

h.______________________________



18. Explain the ***chemiosmotic theory***. i.e. Explain how the exergonic "slide" of electrons down the electron transport chain is coupled to the endergonic production of ATP by chemiosmosis. *Use a labeled diagram to support your response*.

19. ***Cyanide*** can combine with and deactivate ***cytochrome a*** and ***cytochrome*** a_3, the last two carrier proteins of the electron transport chain. In our bodies, however, cyanide tends to react first with the iron in hemoglobin to make it impossible for oxygen to bind to hemoglobin. Either way, cyanide poisoning has the same effect—it inhibits the synthesis of ATP. *Explain why this is so*.

20. In the 1940's , some physicians prescribed low doses of ***dinitrophenol***, ***DNP***, to help patients lose weight. This unsafe method was abandoned after a few patients died. Recall that DNP uncouples the chemiosmotic machinery. *Explain how DNP causes weight loss and in some cases death*.

21. Cells do not waste resources—Carbohydrates and fats are not oxidized to produce ATP unless there is a need to. Explain how ATP production is controlled by the cell and what role the ***allosteric*** enzyme, ***phosphofructokinase*** (***PFK***), plays.

#'s 22 - 38: Multiple Guess: Circle the letter of the *best* response for each of the following. Be able to explain the reasoning behind your selections.

22. ***Glycolysis*** would quickly halt if the process ran out of _____, which serves as the hydrogen and electron acceptor.
    a.) $NADP^+$ b.) ADP c.) NAD^+ d.) H_20 e.) an approved line of credit

23. The ***ultimate electron acceptor*** in aerobic respiration is ______________.
    a.) NADH b.) CO_2 c.) O_2 d.) ATP e.) Kenji Jojima

24. When glucose is ***used*** as an energy source, the largest amount of ATP is **used** by the ________________ portion of the entire respiratory process.
    a.) glycolytic b.) acetyl-CoA formation c.) Krebs cycle d.) E.T.C. e.) aerobic

25. The process by which only about 10% of the energy stored in a sugar molecule is released as it is converted into two small organic-acid molecules is _____________.
    a.) electron transport b.) glycolysis c.) Krebs cycle d.) Redox reactions e.) Mariner pitchers

26. During which of the following phases of ***aerobic*** respiration is ATP produced directly at the substrate level?
    a. glycolysis b. ethyl-alcohol production c. the Kreb's cycle d. E.T.C.

27. ***Pyruvic acid*** can be regarded as the end product of _________________.
    a.) glycolysis b.) acetyl-CoA formation c.) fermentation d.) the Krebs cycle e.) life

28. Which of the following contains the *most* chemical energy? One molecule of....
    a.) ATP b.) glucose c.) starch d.) fat (triglyceride) e.) NADH + H^+

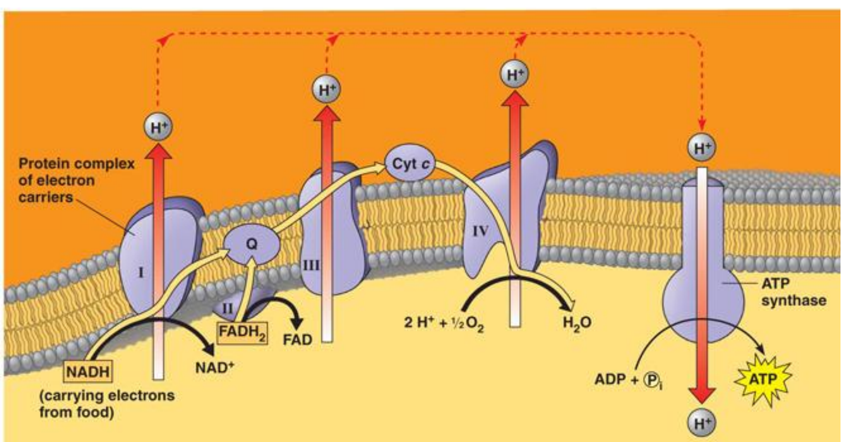
29. The rate of ***glycolysis*** is (Select all correct responses *if* more than one is correct)
    a.) stimulated by ATP.
    b.) stimulated by AMP.
    c.) stimulated by O_2.
    d.) stimulated by citric acid (citrate)
    e.) inhibited by ATP.
    f.) inhibited by AMP.
    g.) inhibited by O_2.
    h.) inhibited by citric acid (citrate)

30. To sustain high rates of ***glycolysis*** under <u>*anaerobic*</u> conditions, cells require
    a.) functioning mitochondria.
    b.) oxygen.
    c.) oxidative phosphorylation of ATP.
    d.) NAD^+.
    e.) All of the above are correct

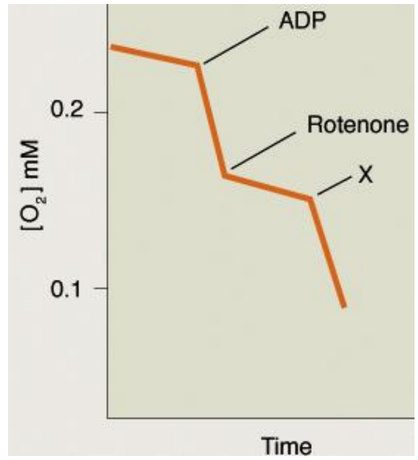
31. *Petite* mutants of yeast have defective mitochondria incapable of oxidative phosphorylation. What carbon sources can these mutants use to grow?
    a.) glucose b.) fatty acids c.) pyruvate d.) all of the above. e.) none of the above

32. Newborn mammals have a specialized organ called brown fat, where cells burn fat to CO_2 without capturing the energy to reduce electron carriers or make ATP. This energy may be used, instead, to
    a.) synthesize glucose from CO_2.
    b.) directly power muscle contraction.
    c.) provide energy for endergonic biosynthetic reactions.
    d.) generate heat.

33. Some drugs known as uncouplers facilitate diffusion of protons across the mitochondrial inner membrane. When such a drug is added, what will happen to ATP synthesis and oxygen consumption?
    a.) Both ATP synthesis and oxygen consumption will decrease.
    b.) ATP synthesis will decrease; oxygen consumption will increase.
    c.) ATP synthesis will increase; oxygen consumption will decrease.
    d.) Both ATP synthesis and oxygen consumption will increase.
    e.) ATP synthesis will decrease; oxygen consumption will stay the same.



34. ***Rotenone***, an insecticide approved for use by organic gardening, ***inhibits complex I*** (NADH dehydrogenase), the first complex of carrier proteins in the electron transport chain. When complex I is completely inhibited, cells will…
    a.) neither consume oxygen nor make ATP.
    b.) not consume oxygen and will make ATP through glycolysis and fermentation.
    c.) not consume oxygen and will make ATP only through substrate-level phosphorylation.
    d.) consume less oxygen but still make some ATP through both glycolysis and respiration

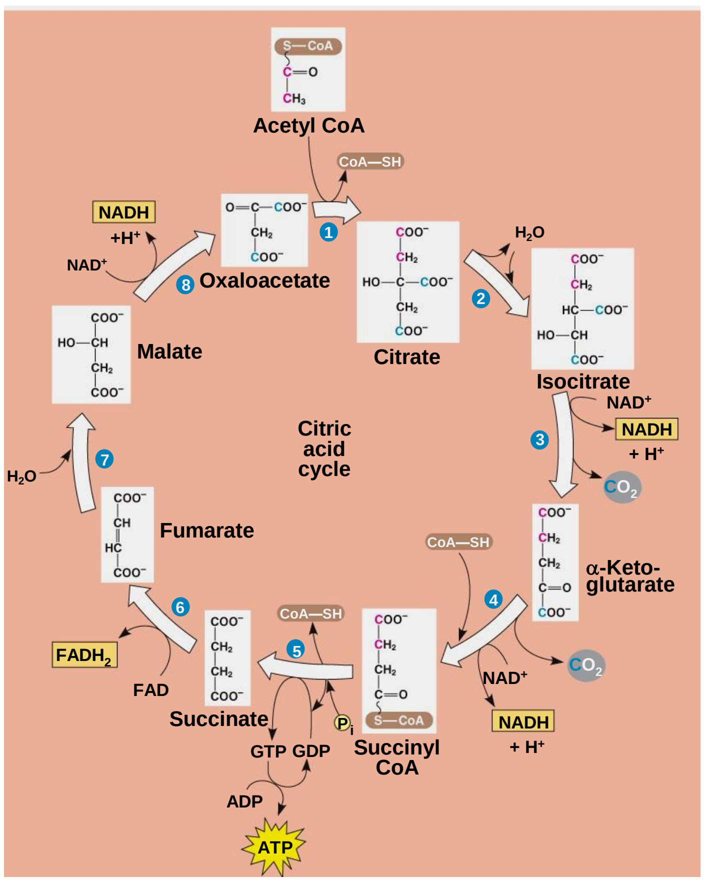


35. This graph shows the oxygen concentration in a sealed chamber containing isolated mitochondria plus citrate. The addition of ADP…
    - a.) stimulates respiration by acting as a substrate for the ATP synthase
    - b.) stimulates respiration by speeding up glycolysis.
    - c.) inhibits respiration by depleting oxygen.

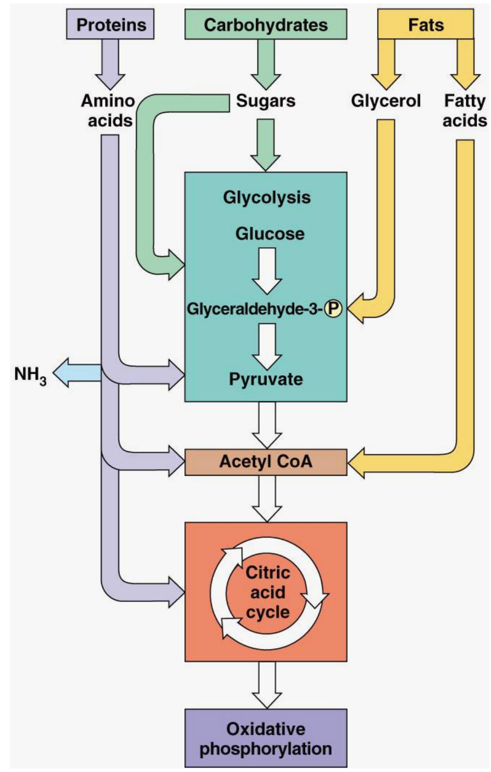
36. Rotenone inhibits complex I of the electron transport chain and thereby inhibits respiration. Which compound below could be compound "X" in the graph that restored respiration in the presence of rotenone? ***Hint***: Examine the citric acid cycle, below, and the diagram of the electron transport chain on page 7.

    a.) NADH   b.) Isocitrate   c.) Succinate

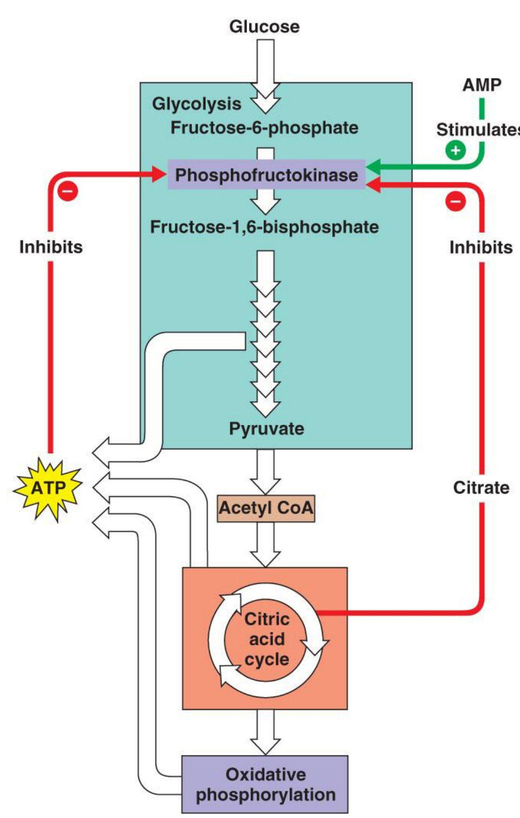
    d.) Malate   e.) Pyruvate



37. During intense exercise, as muscles go into anaerobiosis, the body will increase its consumption of…
    - a.) fats.
    - b.) proteins.
    - c.) carbohydrates.
    - d.) all of the above



38. How will a respiratory ***uncoupler*** affect the rates of ***glycolysis*** and the ***citric acid cycle***?
    a.) Both will increase.
    b.) Both will decrease.
    c.) Only glycolysis will increase because of fermentation.
    d.) Only the citric acid cycle will increase.

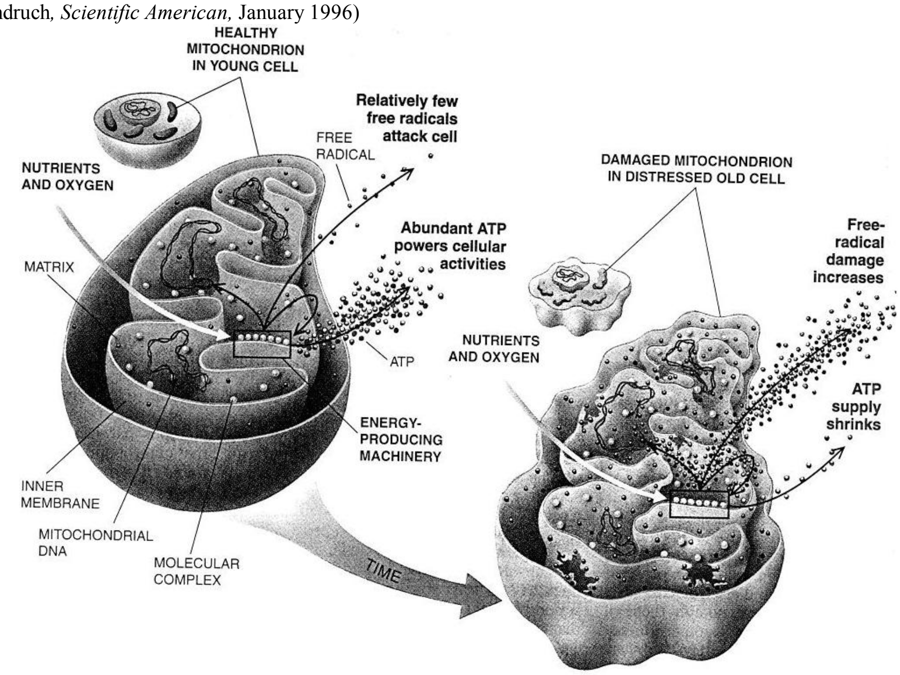


39. The following question is based on the information below and on the next page from *Caloric Restriction and Aging* by Richard Weindruch, *Scientific American,* January 1996: Explain why vitamins C and E, both of which inactivate free radicals both in vitro (in the test tube) and in vivo (in cells) are hypothesized to have anti-aging properties. *Record your response in the space below*.

    Note: Vitamin C is water-soluble and will therefore dissolve in the body's fluids, including the cytoplasm of cells and the aqueous environment of the mitochondrial matrix. Vitamin E is fat-soluble and therefore accumulates in the fatty tissues of the body and within the lipid bilayer of the plasma membrane of cells and cell organelles such as mitochondria.

A Theory of Aging

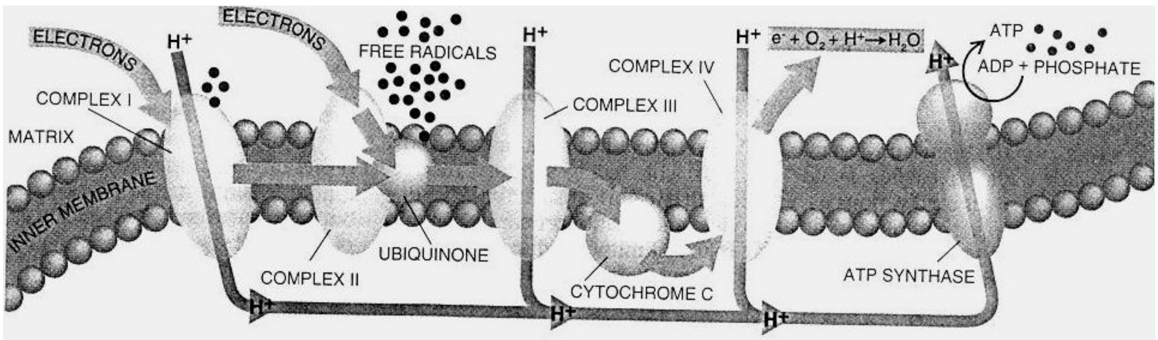
(from *Caloric Restriction and Aging* by Richard Weindruch, *Scientific American,* January 1996)



A leading explanation for why we age places much of the blame on destructive free radicals generated in mitochondria, the cell's energy factories. The radicals form when the energy-producing machinery in mitochondria uses oxygen and nutrients to synthesize ATP (adenosine triphosphate)—the molecule that powers most other activities in cells. Those radicals attack, and may permanently injure, the machinery itself and the mitochondrial DNA that is needed to construct parts of it. They can also harm other components of mitochondria and cells. The theory suggests that over time the accumulated damage to mitochondria precipitates a decline in ATP production. It also engenders increased production of free radicals, thereby accelerating the destruction of cellular components. As cells become starved for energy and damaged, they function less efficiently. Then the tissues they compose and the entire body begin to fail. Many investigators suspect caloric restriction slows aging primarily by lowering free-radical production in mitochondria.

The Making of Energy and Free Radicals

The energy-producing machinery in mitochondria consists mainly of the electron-transport chain: a series of four large and two smaller molecular complexes. Complexes I and II take up electrons from food and relay them to ubiquinone, the site of greatest free-radical generation. Ubiquinone sends the electrons down the rest of the chain to complex IV, where they interact with oxygen and hydrogen to form water. The electron flow induces protons (H^+) to stream to yet another complex—ATP synthase—which draws on energy supplied by the protons to manufacture ATP. Free radicals form when electrons escape from the transport chain and combine with oxygen in their vicinity.



Time is a great teacher, but unfortunately it kills all its pupils
Louis Hector Berlioz