Independent Study Guide – Metabolism

I. Principles of metabolism (section 6.1)

a. Cells must: (figure 6.1)
   i. Synthesize new components (anabolism/biosynthesis)
   ii. Harvest energy and convert it to a usable form (catabolism)

b. Harvesting energy
   i. Exergonic
   ii. Endergonic

c. Components of metabolic pathways (figure 6.4)
   i. Pathways - linear, branched, cyclical
      1. Starting compound
      2. Intermediate
      3. End product
   ii. The role of enzymes (figure 6.5)
      1. Substrate → Product
      2. Activation energy
   iii. The role of ATP (figure 2.10 and 6.6)
      1. Substrate level phosphorylation - chemical energy is harvested
      2. Oxidative phosphorylation – harvests the energy of proton motive force
      3. Photophosphorylation – radiant energy is used to create the proton motive force (involves an electron transport chain)
   iv. The role of the chemical energy source - oxidation of the chemical energy source releases energy
      1. Oxidation/reduction reactions (redox reactions) (figure 6.7)
         a. LEO – lose electrons oxidized
         b. GER – gain electrons reduced
         c. In redox reactions, protons often follow electrons (i.e. a hydrogen atom is extracted/added)
   v. The role of electron carriers ("reducing power") - As glucose is oxidized to CO₂ (glucose + 6 O₂ → 6 CO₂ + 12 H₂O), 12 pairs of electrons are removed from glucose (snatched by electron carriers)
      1. Passed to the electron transport chain (used to create PMF); ultimately passed to a terminal electron acceptor (see figure 3.26)
      2. Used in biosynthesis (to reduce compounds)
      3. Electron carriers (see table 6.1)
         a. NAD⁺
         b. FAD
         c. NADP⁺
   d. Precursor metabolites – intermediates of catabolism also used in biosynthesis (table 6.2; know concept but DO NOT MEMORIZE)
II. Overview of Metabolism

\[
\text{Glucose} + \text{O}_2 \rightarrow \text{Carbon dioxide} + \text{H}_2\text{O}
\]

\[
\text{(C}_6\text{H}_{12}\text{O}_6) \rightarrow (\text{CO}_2)
\]

\[
\text{Energy} \rightarrow \text{ATP (substrate level phosphorylation)}
\]

\[
\text{NADH/FADH}_2 \rightarrow \text{electron transport chain} \rightarrow \text{proton motive force} \rightarrow \text{ATP (oxidative phosphorylation)}
\]

Glycolysis
Pentose phosphate pathway
Transition step
TCA cycle
Respiration
Fermentation
III. Central Metabolic Pathways (section 6.3)
   a. Glycolysis (fig. 6.14); glucose to 2 pyruvate
      i. 2 ATP (net gain) 2 spent, 4 made
      ii. 2 NADH
      iii. six different precursor metabolites
   b. Pentose phosphate pathway (not illustrated); glucose to intermediate of glycolysis
      i. NADPH (amount varies)
      ii. two different precursor metabolites
   c. Transition step (fig. 6.15); pyruvate (3 C) to acetyl CoA (2 C) + CO₂ (twice per glucose)
      i. NADH
      ii. precursor metabolite
   d. TCA cycle (aka Kreb’s cycle or citric acid cycle) (fig. 6.15); acetyl CoA (2 C) to 2 CO₂ (twice per glucose)
      i. 3 NADH
      ii. FADH₂
      iii. ATP
      iv. two different precursor metabolite
IV. Respiration (section 6.4); central metabolic pathways oxidize glucose, but where do the electrons go?
   a. Electron transport chain of mitochondria (part of figure 3.53)
   b. Electron transport chain of \textit{E. coli}
      i. Aerobic respiration
      ii. Anaerobic respiration
         1. \( \text{NO}_3 \) is the terminal electron acceptor
         2. Quinone used provides humans with vitamin K
   c. Overall maximum energy yield of glucose metabolism using aerobic respiration (ignoring the pentose phosphate pathway)
      i. 4 ATP by substrate phosphorylation
      ii. 10 NADH to 30 ATP by oxidative phosphorylation
      iii. 2 FADH\(_2\) to 4 ATP by oxidative phosphorylation
V. **Fermentation (section 6.5)**
   a. Used when respiration is not an option – lack of TEA, or no electron transport chain
   b. Oxidation of glucose stops at pyruvate
   c. Passes electrons from NADH to pyruvate or a derivative
   d. The logic:
      i. Oxidizes NADH, generating NAD for use in further rounds of glucose breakdown
      ii. Stops short of the transition step and the TCA cycle, which together generate 5X more NADH
   e. End products of fermentation (Fig. 6.21)

VI. **Energy source versus terminal acceptor**
VII. **Catabolism of Organic Compounds Other than Glucose (section 6.6)** Compounds enter the central metabolic pathways as precursor metabolites (figure 6.22)
   a. Polysaccharides and disaccharides
   b. Proteins
   c. Lipids

VIII. **Enzymes (section 6.2)**
   a. General information (figure 6.9)
      i. A specific, unique enzyme catalyzes each biochemical reaction
      ii. Enzyme activity can be controlled by a cell
      iii. Enzymes can be exploited medically, industrially
      iv. Enzyme names usually reflect the function and end in –ase
   b. Cofactors act in conjunction with certain enzymes (figure 6.10)
   c. Coenzymes are organic cofactors (table 6.4)
   d. Allosteric regulation (figure 6.12)
   e. Enzyme inhibition (table 6.5)
      i. Competitive inhibition; sulfa drugs as an example (figure 6.13)
      ii. Non-competitive inhibition
         1. Regulation (allosteric)
         2. Enzyme poisons
   f. Environmental factors influence enzyme activity

IX. **Study Questions**
1. What is the difference between catabolism and anabolism?
2. Would a reaction that releases energy be exergonic, or endergonic?
3. How is substrate-level phosphorylation different from oxidative phosphorylation?
4. How is a reduction different from an oxidation?
5. Is removal of a hydrogen atom generally an oxidation or a reduction?
6. Why can a hydrogen carrier also be called an electron carrier?
7. What is the fate of the electrons carried by NADH and FADH$_2$?
8. What is the fate of the electrons carried by NADPH?
9. What is "reducing power"?
10. What is a precursor metabolite?
11. What are the three central metabolic pathways?
12. What is the end product of glycolysis?
13. What is the significance of pyruvate in metabolism?
14. What is the transition step?
15. What is the end product of the TCA cycle?
16. The transition step and the TCA cycle repeat "twice per glucose molecule"; why is this so?
17. Which two central metabolic pathways can initiate the breakdown of glucose?
18. Which central metabolic pathway is generally used exclusively for biosynthesis?
19. Which central metabolic pathway generates the most different precursor metabolites?
20. Which central metabolic pathway generates the most reducing power?
21. Which central metabolic pathway generates the most ATP?
22. Which central metabolic pathway includes steps that use ATP?
23. How would a bacterium use protein as an energy source?
24. What is an enzyme?
25. What would you expect to be the function of a protease?
26. What are allosteric enzymes and why are they important?
27. What is the mechanism of action of sulfa drugs?
28. Where do the electrons carried by NADH enter the electron transport chain relative to those carried by FADH₂?
29. What is proton motive force used for in mitochondria?
30. What is proton motive force used for in bacteria?
31. Generally speaking, how is the electron transport chain of *E. coli* different from that of mitochondria?
32. What is the significance of the quinone used in anaerobic respiration to human health?
33. In the breakdown of glucose, which generates the most ATP - substrate-level phosphorylation or oxidative phosphorylation?
34. How is fermentation different from respiration?
35. How is aerobic respiration different from anaerobic respiration?
36. Give two examples of why the end products of fermentation are important.
37. When glucose serves as the energy source, which terminal electron acceptor - NO₃ or O₂ - results in the release of the most energy?