Study Guide for Exam 3 (Nov 23 2026), filled from Lectures 23-24

Unit 5 Metabolism

A. Overview of Metabolism (13.1-13.3 6/e)

Metabolism is the sum of the chemical and physical processes that occur in cells.
It includes both anabolic (biosynthetic) and catabolic (breakdown) reactions.
It involves the capture and use of energy.
Book coverage: Chapters 13, 14, 15.1-15.2 and parts of 16.

a. What does a cell need to get from metabolism? Energy and Precursor metabolites

Cells need to capture energy and convert it to useful forms used for biosynthesis (building) and cell activities.
Energy is captured as ATP or in electron carriers (NADH).
Cells need to acquire carbon and other elements (N, S, P and O) to build cell components.
Catabolism (breakdown) of glucose gives carbon skeletons: pentose-phosphates, PEP, pyruvate, acetyl-CoA, oxaloacetate, 2-ketoglutarate.
Carbon skeletons plus SO4 2- and NH3 make the monomers (building blocks): fatty acids (~8), sugars (~25), amino acids (~20), nucleotides (~8).
Monomers are polymerized into lipid, lipopolysaccharide, glycogen, peptidoglycan, protein, RNA and DNA.
These are assembled into structures: envelope, inclusions, flagella, pili, cytosol, ribosomes, nucleoid.
To capture energy, cells need a source of electrons from electron donors.
Electron donors are molecules that give up electrons and often hydrogen atoms to make the energy storage molecules NADH and NADPH.
Electrons can come from organic (sugars, fats) or inorganic sources (H2O, H2S, H2, Fe); this varies a lot.
Precursor metabolites: 13 metabolites needed by all cells to synthesize cell components (section 15.1).
The 13: glucose-6-P, fructose-6-P, pentose-5-P, sedoheptulose-7-P, erythrose-4-P, triose-P, 3-phosphoglycerate, PEP (phosphoenolpyruvate), acetyl-CoA, 2-oxoglutarate, succinyl-CoA, oxaloacetate, pyruvate.
Fueling products the cell gets from its nutrient: energy (ATP, PMF (proton motive force)), precursor metabolites, and reducing power (NAD(P)H).
Heterotrophy starts from an organic nutrient; autotrophy starts from CO2 plus an inorganic energy source, or CO2 plus light.
Path: fueling products, then biosynthesis (building blocks), then polymerization (macromolecules), then assembly (structures).

b. Names of Central Metabolic pathways and why all organism have these pathways

Three central pathways are done by all organisms.
1. Glycolysis or EMP (Embden-Meyerhof-Parnas) pathway.
2. Pentose phosphate pathway (PPP) or hexose monophosphate pathway (HMP).
3. Tricarboxylic acid (TCA) or citric acid or Krebs cycle.
Why: they are needed by all organisms to generate precursor metabolites for biosynthesis.
They are even done by autotrophs (CO2 users) to make precursor metabolites; CO2 fixation feeds into the central pathways.
Precursor metabolites made by each pathway: glycolysis (EMP) 6, pentose phosphate pathway (HMP) 2, TCA 4.
EMP makes glucose-6-P (for polysaccharides), fructose-6-P (murein), triose-P (lipids), and 3-phosphoglycerate, PEP and pyruvate (amino acids).
HMP makes ribose-5-P (nucleic acids) and erythrose-4-P (amino acids).
TCA makes 2-ketoglutarate, succinyl-CoA and oxaloacetate (amino acids); acetyl-CoA (fatty acids) is listed as made from pyruvate, and the TCA count of 4 includes it.
Precursor metabolites are used to synthesize cell components: amino acids, nucleotides, sugars, lipids, vitamins and cofactors.
Glucose-6-P makes sugar nucleotides; fructose-6-P makes amino sugars.
Pentose-5-P makes purine and pyrimidine nucleotides, histidine and tryptophan; sedoheptulose-7-P makes the heptose in LPS.
Erythrose-4-P (with PEP, through chorismate) makes the aromatic family (tyrosine, tryptophan, phenylalanine) and some vitamins and cofactors.
Dihydroxyacetone-phosphate (a triose-P) makes glycerol-3-phosphate, then phospholipids.
3-Phosphoglycerate makes the serine family (serine, glycine, cysteine).
Pyruvate makes the pyruvate family (alanine, valine, leucine, isoleucine); acetyl-CoA makes fatty acids, murein and leucine.
Oxaloacetate makes the aspartate family (asparagine, threonine, methionine, isoleucine, lysine); 2-oxoglutarate makes the glutamate family (glutamate, glutamine, arginine, proline); succinyl-CoA makes heme.
Assignment 19 Q4: the pathways that generate the precursor metabolites are glycolysis, the pentose phosphate pathway and the TCA cycle.

c. Know the meaning of the different terms related to carbon and energy acquisition (13.1) (chemo-, photo-, organo-, litho-, auto- and hetero- troph)

Organisms show different ways of getting energy, electrons and carbon, and are classified by the combination they use.
Energy source: light = phototrophy (photo-); chemicals = chemotrophy (chemo-).
Electron source: inorganic molecules = lithotrophy (litho-); organic molecules = organotrophy (organo-).
Carbon source: CO2 = autotrophy (auto-); organic molecules = heterotrophy (hetero-).
Names are built in that order: energy + electron donor + carbon source (for example photo + litho + autotroph).

Know how combined: Chemoheterotroph, Chemolithoautotroph, Chemolithoheterotroph, Photoautotroph, Photoheterotroph

There are eight possible acquisition schemes; all have been observed in nature (bacteria), but three are rarely observed.
Some organisms (bacteria) can do more than one scheme.
Relatively common: chemoorganoheterotrophy (animals, fungi, plants and many bacteria).
Relatively common: photolithoautotrophy (plants, algae, some bacteria such as cyanobacteria).
Relatively common: chemolithoautotrophy (several bacteria such as Nitrobacter; some archaea such as Methanobacteria).
In a few bacteria: photoorganoheterotrophy (Rhodobacter, Heliobacterium, some green non-sulfur bacteria) and photolithoheterotrophy (purple non-sulfur bacteria).
Rare, only naturally in a few: photoorganoautotrophy (some Haloarchaea), chemoorganoautotrophy (anaerobic methanotrophic archaea; also synthetic E. coli and Pichia yeast) and chemolithoheterotrophy (Oceanithermus profundus).
Chemoheterotroph (chemoorganoheterotroph): energy from chemicals, electrons from organic chemicals, carbon from organic molecules (animals, fungi, many bacteria).
In a chemoheterotroph, organic substrates come in by solute transport, go through feeder pathways to the central pathways, and make ATP, NADH and precursor metabolites; NADH drives H+ pumping out.
Photoautotroph (plants and algae are photolithoautotrophs): energy from light, electrons from inorganic chemicals, carbon from CO2.
In a photoautotroph, light drives photophosphorylation (makes ATP and NADPH), and CO2 fixation feeds the central pathways.
Assignment 19 Q1a: the electron source for plants and algae is water (H2O), split by light in photosynthesis (photolysis of H2O).
Chemolithoautotroph: energy from inorganic chemicals, electrons from inorganic chemicals (such as H2, Fe2+, H2S, NH4+), carbon from CO2.
In a chemolithoautotroph, inorganic ions come in and give electrons (reductant) to a membrane electron flow that ends at an oxidant; this pumps H+ and makes ATP and NADH, and CO2 fixation feeds the central pathways.
Chemolithoheterotroph: energy from chemicals, electrons from inorganic molecules, carbon from organic molecules (rare; Oceanithermus profundus).
Photoheterotroph: energy from light, carbon from organic molecules (photoorganoheterotroph: Rhodobacter, Heliobacterium; photolithoheterotroph: purple non-sulfur bacteria).
Rhodopseudomonas lives in sunlit, stagnant or slow waters, muddy sediments and organic-rich anaerobic (no O2) soils.
Assignment 19 Q2, Rhodopseudomonas, no O2 with light, inorganic electrons (H2, H2S, thiosulfate), CO2 carbon: photolithoautotroph.
No O2 with light, organic electrons (acetate, lactate, succinate), organic carbon: photoorganoheterotroph.
No O2 with light, inorganic electrons, organic carbon: photolithoheterotroph.
O2 present (terminal acceptor) in the dark, organic energy, electrons and carbon: chemoorganoheterotroph.

d. Other features of metabolism

Pathways used by microbes are the same as or similar to those used by other organisms.
Microbes also have some unique, novel metabolic pathways.
Metabolism is used to identify microorganisms.
It is used to produce many useful products (foods, chemicals).
It affects our health (gut microbiome and SCFAs (short chain fatty acids)).
It is used for bioremediation: using organisms (usually bacteria) to get rid of pollutants and toxins.
All different possible means of acquiring energy and carbon have been observed in bacteria, and some bacteria can use several.
Alternative pathways: variations of the common pathways are seen in bacteria.
Glycolysis has the ED (Entner-Doudoroff) alternative; the TCA, fermentation, anaerobic respiration and CO2 fixation all have variants.
Per glucose, EMP gives 2 ATP and 2 NADH; ED gives 1 ATP, 1 NADH and 1 NADPH; PPP gives 2 NADPH, CO2 and sugars for biosynthesis.
A variant of a central pathway is made when one or more enzymes use a different nucleotide or cofactor.
Examples: GDP/GTP or AMP/ADP instead of ADP/ATP, or NADP+/NADPH instead of NAD+/NADH (or the reverse).
In the overall pathway, the isocitrate step makes NADPH and the succinyl-CoA step makes ATP.
Most pathways can be run in both directions; run backwards they generate precursor metabolites (for example gluconeogenesis, making glucose).
Many metabolic reactions are oxidation-reduction (redox) reactions.
Redox reactions transfer 1-2 electrons (and maybe a proton) from one molecule to another.
It is a reciprocal relationship: one molecule is oxidized and one is reduced.
The reduced compound (reducing agent) gives electrons to the oxidized compound (oxidizing agent), for example NAD+ becoming NADH.
Oxidation: loss of electrons, gain of bonds to O, loss of bonds to H, gives off energy, moves toward CO2.
Reduction: gain of electrons, loss of bonds to O, gain of bonds to H, stores energy, moves toward CH4.
Assignment 19 Q5: pyruvate to L-lactate, the product is reduced (C=O becomes H-C-OH).

B. Energetics (13.1-13.2 6/e)

Scientists noticed microbes grew faster and/or to higher densities on certain food sources.
This goes back to the amount of energy that can be released by consuming the food.
It also costs energy to build biomolecules.
They eventually determined the energetics of reactions seen in organisms.

Gibbs Free energy – what it is? What a value means about a reaction?

Chemical reactions are reversible; the direction depends on energetics.
A reaction goes toward products if the products have lower energy than the reactants: A + B → C + D + energy released.
Gibbs free energy (G) is a measure of the energy in molecules.
The change in Gibbs free energy (ΔG) must be negative for a reaction to be favorable.
ΔG = ΔH - TΔS (change in enthalpy minus temperature times change in entropy).
ΔG°′ is the theoretical ΔG in standard conditions (298 K, 1 atm, 1 M).
ΔG = ΔG°′ + 2.303 RT log([C][D]/[A][B]); R = gas constant, T = temperature in Kelvin.
Energetics of parts of a reaction (half reactions, A → C and B → D) can be calculated and used to predict which direction a reaction will go.
An unfavorable reaction can be coupled to a favorable reaction.
Example: glucose + Pi → glucose-6-P is +13.8 kJ/mol; ATP → ADP + Pi is -30.5 kJ/mol; coupled, glucose + ATP → glucose-6-P + ADP is -16.7 kJ/mol (+13.8 - 30.5).
Hydrolysis values of energy rich molecules are reported in kJ/mol or kcal/mol.
Hydrolysis ΔG°′ (pH 7.0, 25°C), kJ/mol: glucose-6-P -14, fructose-1,6-bis-P -16, PPi (pyrophosphate) -19, ATP → ADP -31.
More hydrolysis ΔG°′, kJ/mol: ADP → AMP -33, ATP → AMP + PPi -46, 1,3-bis-P-glycerate -49, PEP -62.
Second table (kJ/mol, kcal/mol): PEP -61.9, -14.8; 1,3-bisphosphoglycerate -49.3, -11.8; phosphocreatine -43.0, -10.3; ADP → AMP -32.8, -7.8; ATP → ADP -30.5, -7.3.
Second table, more: ATP → AMP + PPi -45.6, -10.9; AMP → adenosine -14.2, -3.4; PPi -19.2, -4.0; glucose-1-P -20.9, -5.0; fructose-6-P -15.9, -3.8; glucose-6-P -13.8, -3.3; glycerol-1-P -9.2, -2.2; acetyl-CoA (a thioester) -31.4, -7.5.
Assignment 19 Q6: the most favorable reaction is C, PEP → pyruvate + Pi (-62 kJ/mol).
The ΔG yield determines the energy and biomass that can be derived from a food (energy) source.
Biomass rises as ΔG gets more negative: glucose + O2 is -2,883 kJ/mol and gives 70.54 g/mol biomass.
With O2: propionate -1,487 (32.54 g/mol), lactate -1,333 (32.83), ethanol -1,308 (26.32), acetate -847 (18.72), formate -234 (4.99).
With NO3- (nitrate) as oxidant: glucose -2,774 (60.00 g/mol), lactate -1,282 (20.20), ethanol -1,257 (24.00), acetate -813 (16.95); ethanol with no oxidant -14.6 (3.50).
Assignment 19 Q7a: the next highest energy yield is glucose with nitrate (NO3-) as oxidant, -2,774 kJ/mol.
Assignment 19 Q7b: 2,774 / 2,883 = about 96% of the aerobic energy yield.

Reduction potential –

Energetics of oxidation-reduction reactions can be reported as a reduction potential (E°′).
Reduction potential is inversely proportional to free energy (ΔG).
ΔG°′ = -nFΔE°′, or ΔE°′ = -ΔG°′/nF.
A negative E°′ goes with a positive ΔG; a positive E°′ goes with a negative ΔG.
Table 13.4 (acceptor → donor: E°′ mV, ΔG°′ kJ): 2H+ → H2 -420, +81; NAD+ → NADH -320, +62; FAD → FADH2 -220, +42; FMN → FMNH2 -190, +37.
Table 13.4, more: menaquinone → menaquinol -74, +14; fumarate → succinate +33, -6; ubiquinone → ubiquinol +110, -21; NO3- → NO2- +420, -81; ½O2 → H2O +820, -158.
Table 14.1 (the electron tower) adds: CO2 → [CH2O] glucose -430, +166; S0 → HS- -280, +27; CO2 → CH4 -240, +46; SO4 2- → H2S -220, +170.
Table 14.1, more: Fe3+ → Fe2+ (pH 7) +200, -19; NO2- → NH4+ +440, -255; MnO2 → Mn2+ +460, -89; NO3- → ½N2 +740, -357; Fe3+ → Fe2+ (pH 2) +770, -74.
A half reaction can be reversed so it goes the other way; reversed, its ΔG changes sign.
Assignment 20 Q1a: reduction of NAD+ to NADH has ΔG of +62 kJ (unfavorable).
Assignment 20 Q1b: the half reaction coupled to it must be more favorable, so its ΔG must be more negative than -62 kJ.
Assignment 20 Q2: oxidizing one glucose carbon to CO2 (-166 kJ, the first reaction reversed) plus reducing O2 to H2O (-158 kJ) gives about -324 kJ.
Assignment 20 Q3: three half reactions more negative than -166 kJ: H2S oxidized to SO4 2- (-170, reversed), NO2- reduced to NH4+ (-255), NO3- reduced to N2 (-357).

Factors that affect the Gibbs Free Energy and reduction potential value

ΔH: change in enthalpy (heat energy in chemicals); release of heat (more oxidized) gives a negative ΔH.
T: temperature in Kelvin (273 + °C); higher temperatures promote the reaction.
ΔS: entropy (disorder) change; if the products are more disordered, ΔS is positive and ΔG more negative.
ΔG is also affected by the concentration of substrates (A and B) and products (C and D).
If the product concentration [C][D] is less than the substrate concentration [A][B], the log is a negative number and ΔG gets more negative.

Table 13.2, ratio of products to reactants: 10^-4 → -23 kJ/mol and 10^-2 → -11 (products increase); 1 → 0 (ΔG = ΔG°); 10^2 → +11 and 10^4 → +23 (reactants increase).
Removing a product as fast as it is made can change a reaction's ΔG to a negative value.
Standard reduction potentials are for all concentrations at 1 M, 25°C and pH 7.
A tenfold ratio of products to reactants subtracts about 60 mV from E (makes it less favorable).
Free FAD is -220 mV; FAD bound to a protein has a different E°′ that depends on its protein environment.

C. Energy Carriers: Ways cells capture and store energy

Energy is captured and stored in three different ways.
1. High energy phosphoryl bonds (ATP).
2. Reduced electron carriers (NADH).
3. Transmembrane ion gradients: proton motive force (H+ gradient).
All three are interconvertible.

1. High energy phosphate bonds

Bonds to the 2nd and 3rd phosphates in nucleotides (ATP).
Bonds of phosphate in some organic molecules (PEP, 1,3-bisphosphoglycerate).
Generated by two means: a. substrate level phosphorylation; b. ATP synthase driven by the transmembrane proton gradient.
Substrate level phosphorylation occurs during a step in glycolysis and in the TCA cycle.
It is usually made by a coupled reaction: Molecule-PO3 + ADP → Molecule + ATP.
Glycolysis step: 1,3-bisphosphoglycerate loses its phosphoryl group to ADP, forming ATP and 3-phosphoglycerate (enzyme phosphoglycerate kinase).
TCA step: succinyl-CoA becomes succinate + CoA-SH while ADP + Pi becomes ATP (enzyme succinyl-CoA synthetase); some microbes make GTP.
ATP synthase adds a high energy phosphate bond to ADP using energy from the proton motive force (protons flowing back into the cell).
The ETS (electron transport system) pumps H+ out of the cell as electrons go from RH2 to O2 (making H2O), leaving the outside + and the inside -.
The H+ gradient drives ATP production by F1Fo ATP synthase (3 H+ flow in per ATP) and powers active transport.
PEP has the highest hydrolysis energy (-62 kJ/mol); ATP → ADP is -31 kJ/mol.

2. Reduced Electron carriers

Reduced electron carriers: NADH, NADPH and FADH2.
Electron carriers can exist in an oxidized (NAD+) or a reduced state (NADH).
The reduced form carries two electrons and stores more energy.
NAD+ (NADP+) takes 2 e- + 2 H+ from hydrogens in food molecules, forming NADH (NADPH) + H+.
The nicotinamide ring accepts the electrons; its reduced, nonaromatic form has higher energy.
NADP+ is NAD+ with an extra phosphate on the adenosine part.
Reduced electron carriers (NADH) can be generated by oxidation of chemical substrates.
Oxidation releases energy; reduction captures energy.
Example: NAD+ + R-CH(OH)-R′ ⇌ NADH + R-C(=O)-R′ + H+.
Chemoheterotrophs generate NADH from the oxidation of carbons in glucose.
As glucose is oxidized step by step, hydrogens with electrons go to NADH, the carbon skeleton ends as CO2, and the energy is captured as ATP.
In aerobic metabolism the electrons and hydrogens end on O2 (the final electron acceptor), making water.
Reduced electron carriers can power biosynthetic reactions or make membrane potential (proton motive force) through an electron transport system (ETS).
NADH gives electrons to the ETS in the membrane, which pumps protons outside, creating proton motive force or membrane potential.
ETS parts: NADH dehydrogenase, FMN, coenzyme Q, cytochromes b, c1, c, a and a3; FADH2 also feeds in electrons; O2 is reduced to H2O.
The protons flow back in through ATP synthase, making ATP.

Oxidation-reduction reactions, reduction potential

Oxidation-reduction reactions change the redox state of carbon atoms in an organic molecule; the reduced form has more energy.
Example: pyruvic acid + NADH + H+ → lactic acid + NAD+ (the C=O carbon becomes H-C-OH, so it is reduced).
Carbon redox state rule: count +1 for each bond to oxygen and -1 for each bond to hydrogen; carbon-carbon bonds are neutral.
Assignment 19 Q8: methane (CH4) = -4.
Fatty acid carbon (2 H, 2 C) = -2.
Alcohol carbon (2 H, 1 O, 1 C) = -1.
Sugar carbon (1 H, 1 O, 2 C) = 0.
Carboxylic acid carbon (C=O plus O-H, 1 C) = +3.
Carbon dioxide (CO2) = +4.
More negative = more reduced (more energy, toward CH4); more positive = more oxidized (toward CO2).

Reduction potential (E°′) reports the energetics of these reactions; it is inversely proportional to ΔG (ΔG°′ = -nFΔE°′).
Some TCA reactions can be run backwards and would then use up NADH or FADH2; reduction potential can analyze their energetics.
Table for Assignment 20 Q4 (E′0 in V): succinate + CO_2 → α-ketoglutarate -0.670; acetate → acetaldehyde -0.580; $2H^+$ → H_2 -0.421; α-ketoglutarate + CO_2 → isocitrate -0.380; cystine → 2 cysteine -0.340.
More: NAD^+ → NADH -0.320; $NADP^+$ → NADPH -0.324; acetaldehyde → ethanol -0.197; pyruvate → lactate -0.185; oxaloacetate → malate -0.166; FAD → FADH2 -0.040.
More: fumarate → succinate +0.031; ubiquinone → ubiquinol +0.045; cytochrome b +0.070; cytochrome c +0.254; cytochrome a3 +0.385; ½O_2 → H_2O +0.816.

3. Transmembrane gradients

Can store energy by creating a charge and/or concentration difference on the two sides of a membrane.
Usually with protons, but other ions can be used (Na^+).
This creates a membrane potential (ΔΨ).
Often created by electron transport chains, which usually transport H^+ (protons) across the membrane.
Ions want to flow across the membrane to equalize the charge and/or concentration difference: this is the proton motive force.
A reductant (electron donor) gives electrons to a membrane-bound electron transport chain that ends at an oxidant (electron acceptor); the H^+ pumped out flow back through ATP synthase to make ATP.

Proton Motive Force -

Proton motive force (Δp) consists of two differences (potentials) across the membrane.
1) Electrical potential (ΔΨ) = total charge difference, including all ions.
2) pH difference (ΔpH) = log of the difference in pH outside vs inside.
Δp = ΔΨ - (2.3 R x T / F) ΔpH; (2.3 x R x T / F) = 60 at 30°C.
So Δp = ΔΨ - 60 x ΔpH, in mV.
At neutral pH, Δp, ΔΨ and -60ΔpH are usually all negative, which drives protons inward.
ΔΨ is about -50 to -150 mV for many bacteria, and a ΔpH of 1.0 (inside 7.5, outside 6.5) adds about -60 mV.
So Δp = about -110 to -210 mV with a ΔpH of 1.0.
Cells can adjust the proton motive force value by adjusting the charge difference (ΔΨ) and/or the pH difference (ΔpH).
A: charge gradient and pH gradient (acid and + charge outside, base and - charge inside): Δp = ΔΨ - 60ΔpH.
B: charge gradient with no pH gradient (K^+ ions outside): Δp = ΔΨ, ΔpH = 0.
C: pH gradient with no charge gradient (K^+ ions inside balance the charge): Δp = -60ΔpH, ΔΨ = 0.
Membrane potential (proton motive force) can be used to power 1) ATP synthesis, 2) transport across the membrane, 3) turning of flagella (bacteria).
ATP synthesis is by F1Fo ATP synthase; flagellar rotation is driven by H^+ flowing in.
Transport by PMF: antiport (Na^+ out, H^+ in), uniport (K^+ in), symport (an anion A^- in with H^+) and a drug efflux pump (drug out, H^+ in).

D. Overview of Catabolism and Metabolic pathways (13.3 5-6/e)

Not covered yet (Lecture 25+)

General features of Catabolism

For metabolic pathways - Know # of energy rich molecules (ATPs, NADHs, etc) and carbon end-products produced by each (Assignment 10)

Know if pathway generates Precursor metabolites

How each differs from other similar pathways – unique steps, metabolites, # of energy rich metabolites produced

E. Glucose breakdown (13.4 5-6/e)

Not covered yet (Lecture 25+)

1. Glycolysis or EMP pathway

2. Entner-Doudoroff (ED) pathway

3. Pentose phosphate pathway (PPP)

4. Gluconeogenesis

F. Fermentation (13.4 5-6/e)

Not covered yet (Lecture 25+)

Features of fermentation in general and why cells do this pathway
Fermentation pathways of gut bacteria and production of short chain fatty acids
1. **Alcoholic**
2. **Homolactic**
3. **Heterolactic**
4. **Mixed acid**
5. **Acetic acid fermentation**
6. **Propionate acid fermentation via acrylate or succinate pathways**
7. **Butyrate fermentation**
8. **Butandiol fermentation**
9. **Foods generated by fermentation and type of fermentation involved**
   Production of different alcohols via alcohol fermentation
   Fermentation of vegetables and milk

G. Tricarboxylic acid cycle (13.4 5-6/e)

Not covered yet (Lecture 25+)
1. **Typical Bacterial**
2. **Incomplete TCA cycle**
3. **Glycoxylate bypass**
4. **Reductive TCA**
5. **Links between TCA and Glycolysis**

H. Electron Transport (Chapter 14.1 – 14.2 5/e)

Not covered yet (Lecture 25+)
Features of Electron Transport Systems
Types of electron carriers and the features of each
Organization and minimum components of electron transport chains
Variations in electron transport chains observed and why
How do protons get moved across the membrane?
Proton motive force – two components in calculation (charge and pH difference)
ATP synthesis – ATP synthase

I. Respiration

Not covered yet (Lecture 25+)
1. **Aerobic respiration – overall reaction and role on electron transport in it**
2. **Anaerobic Respiration (Chapter 14.3 5-6/e)**
   a. **How it differs from aerobic respiration**
   b. **Types of molecules that can be used as electron acceptors**
   c. **Difference between dissimilatory and assimilatory**
   d. **What is the electron acceptor and what does it get reduced to?**
      1) **Denitrification**
      2) **Nitrate reduction**
      3) **Sulfate reduction**
      4) **Metal reduction**
   e. **Nitrogen cycle: nitrogen fixing and nitrogen Assimilation (15.4 5-6/e)**

J. Lithotrophy (14.5 6/e)

Not covered yet (Lecture 25+)
Features
Nitrification – reactions
Sulfur and metal oxidation – example reactions
Hydrogenotrophy – what it is and how used for
Dehalorespiration and Methanogenesis

K. Phototrophy (14.6 and 18.2 6/e)

Not covered yet (Lecture 25+)

a. Overview: Oxygenic vs Anoxygenic
Types observed and features of each
b. Structure/components of light harvesting structures
Photosynthetic Pigments – Role in photosynthesis and how
Bacteriorhodopsin
Chlorophyll, bacteriochlorophyll
Carotenoids, Phycobilins
Structure of Antenna complex and reaction center
Features of different types of phototrophic bacteria
Cyanobacteria
Purple Sulfur bacteria
Purple Non-sulfur bacteria
Green Sulfur bacteria
Green non-sulfur bacteria
C. Photosystems (what cyclic vs non-cyclic means)
Anaerobic photosystem I
Anaerobic photosystem II
Oxygenic Z pathway

L. Carbon fixation – (15.1 – 15.2 6/e)

Not covered yet (Lecture 25+)
Basic features of each pathway and what types use them
1. Calvin cycle – features of pathway and how CO2 fixed
2. Reductive TCA
3. Acetyl-CoA pathway
4. 3-Hydroxypropionate cycle

M. Analysis of predicted metabolic pathways in Metacyc (Assignment 12)

Not covered yet (Lecture 25+)
1. Know how to interpret Pathway and Glyph diagrams from Metacyc website
2. Know reasons why Metacyc pathway prediction may be wrong
Should be able to name metabolic pathways listed on Assignment 11 Part A from overall reaction
Should be able to determine the products from a shown metabolic pathway and how to balance reactions

Other slide facts (Lectures 23-24)

Lecture 23 (10/21/26) is Metabolism Part 1; Lecture 24 (10/23/26) is Metabolism Part 2.
Assignment 16 (Lecture 21 in-class) due 10/21; Assignment 17 (Structures Microbe) due 10/25; Assignment 18 (Lecture 22 questions) due 10/23.
Assignment 19 (Lecture 23 questions) due 10/30; Assignment 20 covers Lecture 24.
No lecture on Monday 10/26 (4644 lab students need to do a procedure); Exam 2 was Wednesday Oct 28 (study guide and old exam posted).
The slides call this unit Unit 4, Diversity of Microbial Metabolism: basic concepts and the diversity of metabolism in microbes.
Unit outline: A. Overview of Metabolism, B. Energetics, C. Energy Carriers, D. Overview of Catabolism, E. Glucose Breakdown, F. Fermentation, G. TCA Cycle.
Unit outline, continued: H. Electron Transport Systems, I. Respiration (aerobic and anaerobic), J. Lithotrophy, K. CO2 fixation, L. Phototrophy.
Overview topics: 1. catabolism, anabolism and energy; 2. elements to acquire; 3. sources of electrons; 4. energy and carbon acquisition schemes; 5. central pathways; 6. precursor metabolites; 7. alternative pathways; 8. oxidation-reduction reactions.