There are a lot of diagrams here. DO NOT, I repeat, DO NOT get overly anxious or excited about them. We will go through them again slowly!!

Read the slides, read the book, DO NOT TAKE NOTES. Take a break. REPEAT

Read the book and take notes with the slides
Metabolism

- Transfer of food energy to chemical energy
- Energy for chemical reactions comes from the bonds of the macronutrients
- Includes anabolic and catabolic reactions
- The cell is the metabolic processing center
- The type and extent of metabolic activities depends on the type of cell
Metabolism Definitions

- Anabolism/Catabolism
- Aerobic
- Anaerobic
- ATP and ADP
- Cytosol
- Mitochondria
- Glycolysis
- Pyruvate
- Lactic Acid
- Cori Cycle
- Acetyl CoA
- Coenzymes (CoA)
- NAD and FAD
- Krebs Cycle
- Electron Transport Chain
- Gluconeogenesis
- Fatty Acid Oxidation (Beta Oxidation)
- Deamination
- Oxaloacetate
Food Energy to Cellular Energy

- Digestion, absorption, transportation
- Glycolysis (cytosol)
- Krebs Cycle (TCA or Citric Acid Cycle) (mitochondria)
- Electron Transport Chain (inner membrane of mitochondria)
All of the energy-yielding nutrients—protein, carbohydrate, and fat—can be broken down to acetyl CoA.

Acetyl CoA can enter the TCA cycle.

Most of the reactions above release hydrogen atoms with their electrons, which are carried by coenzymes to the electron transport chain.

ATP is synthesized.

Hydrogen atoms react with oxygen to produce water.
A typical cell

A mitochondrion

Outer compartment
Outer membrane (site of fatty acid activation)

Cytosol (site of glycolysis)

Inner compartment (site of pyruvate-to-acetyl CoA, fatty acid oxidation, and TCA cycle)

Inner membrane (site of electron transport chain)
Chemical Reactions in Metabolism

- **Catabolic:**
  - Breakdown reactions that release energy
    - Glycogen $\rightarrow$ Glucose
    - Triglycerides $\rightarrow$ Fatty Acids + Glycerol
    - Proteins $\rightarrow$ Amino Acids

- **Anabolic:**
  - Building reactions that require energy
    - Glucose $\rightarrow$ Glycogen
    - Fatty Acids + Glycerol $\rightarrow$ Triglycerides
    - Amino Acids $\rightarrow$ Proteins
ANABOLIC REACTIONS

Glycogen

Uses energy

Glucose + Glucose

Triglycerides

Uses energy

Glycerol + Fatty acids

Protein

Uses energy

Amino acids + Amino acids

Anabolic reactions include the making of glycogen, triglycerides, and protein; these reactions require differing amounts of energy.

CATABOLIC REACTIONS

Glycogen

Yields energy

Glucose

Triglycerides

Yields energy

Glycerol

Fatty acids

Yields energy

Protein

Yields energy

Amino acids

Catabolic reactions include the breakdown of glycogen, triglycerides, and protein; the further catabolism of glucose, glycerol, fatty acids, and amino acids releases differing amounts of energy. Much of the energy released is captured in the bonds of adenosine triphosphate (ATP).

NOTE: You need not memorize a color code to understand the figures in this chapter, but you may find it helpful to know that blue is used for carbohydrates, yellow for fats, and red for proteins.
Energy Transfer Reactions

- **ATP**
  - Energy release during breakdown of macronutrients is captured as ATP
  - Energy molecule used to power cellular functions

- **ADP**
  - When ATP used, a phosphate is removed becomes lower energy form
  - ADP will receive an additional phosphate from breakdown of macronutrients to recharge

- **Enzymes and Coenzymes**
  - Metabolic reactions require enzymes to act
  - Coenzymes (From B Vitamins) NAD from niacin – NADH
    - FAD from riboflavin -FADH
    - Carry hydrogens to ETC for synthesis of ATP
Energy is released when a high-energy phosphate bond in ATP is broken. Just as a battery can be used to provide energy for a variety of uses, the energy from ATP can be used to do most of the body’s work—contract muscles, transport compounds, make new molecules, and more. With the loss of a phosphate group, high-energy ATP (charged battery) becomes low-energy ADP (used battery).

Energy is required when a phosphate group is attached to ADP, making ATP. Just as a used battery needs energy from an electrical outlet to get recharged, ADP (used battery) needs energy from the breakdown of carbohydrate, fat, and protein to make ATP (recharged battery).
Macronutrient Use in Metabolism

- **To obtain energy**
  - Mostly carbs (glucose) and fatty acids;
  - Limited Amino Acids

- **To make glucose**
  - Carbs
  - Some amino acids
  - Fatty Acids (5% of the triglyceride molecule)

- **To make proteins**
  - Amino acids needed
  - Some can be made from glucose and glycerol *when* nitrogen is available

- Energy consumption > need = body fat stores
Nutrient Metabolism

- During metabolism, the body separates atoms from energy yielding nutrients
- Net result:
  - Carbs $\rightarrow$ glucose
  - Lipids $\rightarrow$ glycerol + fatty acids
  - Proteins $\rightarrow$ amino acids
- These compounds are further broken down to the atoms:
  - carbon (C)
  - oxygen (O)
  - hydrogen (H)
  - nitrogen (N)
Carbon Backbones of Energy Yielding Nutrients

3 carbon compounds can make glucose

Glucose

Some amino acids

2 carbon compounds cannot make glucose

Fatty Acids

Some amino acids
The Importance of Glucose

- **Pyruvate**
  - Breakdown of glucose (6C) to 2 (3C) units
  - Some amino acids (glucogenic aa)
  - Glycerol
  - Reversible step
  - Needed to make energy for those cells that only use glucose (RBC, nervous system)

- **Acetyl Co-A**
  - 2 carbon compound with Coenzyme attached
All of the energy-yielding nutrients—protein, carbohydrate, and fat—can be broken down to acetyl CoA.

Acetyl CoA can enter the TCA cycle.

Most of the reactions above release hydrogen atoms with their electrons, which are carried by coenzymes to the electron transport chain.

ATP is synthesized.

Hydrogen atoms react with oxygen to produce water.
Review

- What is metabolism?
- Where does the energy come from?
- How are macronutrients used in metabolism?
- Where do the metabolic reactions take place?
- What Compounds Can Make Glucose and why?
  - Glucose
  - Glycerol
  - Fatty Acids
  - Amino Acids
- What will happen if dietary carbohydrate consumption is insufficient?
Stages Of Metabolism

- Digestion
  - Macronutrients to individual components
  - Absorbed into cells
- Glycolysis (cytosol of the cell)
  - Anaerobic
  - Creates (2) 3 carbon units
- Citric Acid Cycle, TCA Cycle, Krebs(mitochondria of the cell)
  - Aerobic
  - Reaction produces CO2 and electrons, NADH
  - Extracts most energy to power generation of ATP
- Electron Transport Chain (inner mitochondria of the cell)
  - Most ATP produced here
  - NADH and FADH deliver high energy electrons
  - At the end of the chain, O2 + electrons + H = H2O
Metabolism of Nutrients: Carbohydrates

- Cells extract energy from carbs in 4 ways
  - Glycolysis (anaerobic)
  - Pyruvate to Acetyl-CoA (aerobic)
  - Krebs (Citric Acid or TCA cycle) (aerobic)
  - Electron Transport Chain (aerobic)
- End products CO2, H2O, ATP
Glycolysis: Glucose to Pyruvate

**Glucose (6C)**
- Breakdown to 2 (3C) units
- Coenzyme delivers hydrogens/electrons to the ETC
- Some CO2 expelled
- Reversible step
Pyruvate’s Options

- **Anaerobic** – produces Lactate in muscles –
  - Cori cycle: converts muscle lactate to glucose in the liver
  - Muscle can then obtain glucose to make ATP if oxygen is present

- **Aerobic** – Proceed to AcetylCoA

Source: http://physiwiki.wetpaint.com/page/Cell%20Respiration%20and%20Metabolism
Pyruvate to Lactate: Anaerobic

Working muscles break down most of their glucose molecules anaerobically to pyruvate. If the cells lack sufficient mitochondria or in the absence of sufficient oxygen, pyruvate can accept the hydrogens from glucose breakdown and become lactate. This conversion frees the coenzymes so that glycolysis can continue.

NOTE: Other figures in this chapter focus narrowly on the carbons of pyruvate. Its oxygen group is included in this figure to more clearly illustrate this reaction. See definitions for the chemical structures of pyruvate and lactate.

Liver enzymes can convert lactate to glucose, but this reaction requires energy. The process of converting lactate from the muscles to glucose in the liver that can be returned to the muscles is known as the Cori cycle.
Glycolysis: Pyruvate to Acetyl CoA

If cells need energy AND oxygen is available, pyruvate enters the mitochondria.

Irreversible step:
Carbon removed
3 C now becomes a 2 C
Can it make glucose??

Each pyruvate loses a carbon as carbon dioxide and picks up a molecule of CoA, becoming acetyl CoA. The arrow goes only one way (down) because the step is not reversible.
What Does Acetyl CoA Do?

- Generate ATP
- Synthesize fat
  - Available to use in the future
  - Any macronutrient in consumed in excess of energy needs can be used to make fat
Pyruvate and Acetyl CoA Pathways

NOTE: Amino acids that can be used to make glucose are called *glucogenic*; amino acids that are converted to acetyl CoA are called *ketogenic*. 
Metabolism of Nutrients: Lipids

**Glycerol**
- can make glucose
- can enter TCA cycle
- 3 Carbon Unit
- 5% of TG can make glucose

**Fatty acids:**
- Beta oxidation
  - Cleave f/a 2 C’s at a time
  - Each 2C combines with Acetyl CoA
  - 95% of TG cannot make glucose
The fatty acid is first activated by coenzyme A.

As each carbon-carbon bond is cleaved, hydrogens and their electrons are released, and coenzymes pick them up.

Another CoA joins the chain, and the bond at the second carbon (the beta-carbon) weakens. Acetyl CoA splits off, leaving a fatty acid that is two carbons shorter.

The shorter fatty acid enters the pathway and the cycle repeats, releasing more hydrogens with their electrons and more acetyl CoA. The molecules of acetyl CoA enter the TCA cycle, and the coenzymes carry the hydrogens and their electrons to the electron transport chain.

Net result from a 16-C fatty acid: 14-C fatty acid CoA + 1 acetyl CoA
Cycle repeats, leaving: 12-C fatty acid CoA + 2 acetyl CoA
Cycle repeats, leaving: 10-C fatty acid CoA + 3 acetyl CoA
Cycle repeats, leaving: 8-C fatty acid CoA + 4 acetyl CoA
Cycle repeats, leaving: 6-C fatty acid CoA + 5 acetyl CoA
Cycle repeats, leaving: 4-C fatty acid CoA + 6 acetyl CoA
Cycle repeats, leaving: 2-C fatty acid CoA + 7 acetyl CoA

*Notice that 2-C fatty acid CoA = acetyl CoA, so that the final yield from a 16-C fatty acid is 8 acetyl CoA.
Glycerol enters the glycolysis pathway about midway between glucose and pyruvate. Fatty acids are broken down into 2-carbon fragments that combine with CoA to form acetyl CoA (shown in Figure 7-11).

**IN SUMMARY** A 16-carbon fatty acid yields 8 acetyl CoA.
Metabolism of Nutrients: Proteins

- Deamination – Nitrogen removed
  - Liver converts ammonia to Urea
  - Carbon skeletons provide energy, glucose or convert to fat
    - 2 carbon units: directly into AcetylCoA
    - 3 carbon units: can make glucose
    - 3 carbon units: directly into TCA cycle
  - Kidney excretes Urea from body
Most amino acids can be used to synthesize glucose; they are glucogenic.

Some amino acids are converted directly to acetyl CoA; they are ketogenic.

Some amino acids can enter the TCA cycle directly; they are glucogenic.

NOTE: Deamination and the synthesis of urea are discussed and illustrated in Chapter 6, Figure 6-13 (p. 186). The arrows from pyruvate and the TCA cycle to amino acids are possible only for nonessential amino acids; remember, the body cannot make essential amino acids.
Krebs, TCA, Citric Acid Cycle

- **Set of reactions that breakdown AcetylCoA to CO2 and H**
- **See Page 220**
- Cycle:
  - Acetyl CoA not regenerated – breakdown to CO2 and CoA
  - Oxaloacetate = 4 C compound that cycles
    - **must** be present for Acetyl CoA to enter TCA and make energy
    - Made primarily from pyruvate (some amino acids also)
    - Cannot be made from fat
- Bottom line – oxaloacetate must be present to allow AcetylCoA to enter Krebs cycle and make ATP!
- Underscores the need for carbohydrate for adequate metabolism – need a 3 C unit to start (from pyruvate or AA)
  - Without carbs cycle slows down

- [http://www.youtube.com/watch?v=p-k0biO1DT8&feature=related](http://www.youtube.com/watch?v=p-k0biO1DT8&feature=related)
NOTE: Knowing that glucose produces pyruvate during glycolysis and that oxaloacetate must be available to start the TCA cycle, you can understand why the complete oxidation of fat requires carbohydrate.
Electron Transport Chain

- Coenzymes deliver hydrogens and electrons from the TCA cycle, glycolysis and beta oxidation to a carrier.
- Inner membrane of the mitochondria
  - Carrier passes them to another carrier
  - Oxygen accepts electrons combines with hydrogen = water
- During electron transfer energy released to move H to outer compartment of mitochondria
- Hydrogen ions float “downhill” – inner compartment
- ATP synthesized
- ATP leaves mitochondria, enters cytoplasm, used for energy
**Electron Transport Chain**

Passing electrons from carrier to carrier along the chain releases enough energy to pump hydrogen ions across the membrane.

**ATP Synthesis**

Hydrogen ions flow "downhill"—from an area of high concentration to an area of low concentration—through a special protein complex that powers the synthesis of ATP.

---

Coenzymes deliver hydrogen and high-energy electrons to the electron transport chain from the TCA cycle.

Oxygen accepts the electrons and combines with hydrogen ions to form water.

\[
\text{ADP} + \text{P} \rightarrow \text{ATP}
\]
IN SUMMARY

- All of the energy-yielding nutrients—protein, carbohydrates, and fat—can be broken down to acetyl CoA.
- Acetyl CoA can enter the TCA cycle or it can make fat.
- Many of these reactions release hydrogen atoms with their electrons, which are carried by coenzymes to the electron transport chain.
- In the end, oxygen is consumed, water and carbon dioxide are produced, and energy is captured in ATP.
- Some amino acids, pyruvate, and glycerol can be used to make glucose.
- Fatty acids cannot be used to make glucose.
Feasting

- Metabolism favors fat formation
  - Dietary fat to body fat is most direct and efficient conversion
  - Carbohydrate and protein have other roles to fulfill before conversion to body fat
- Overall, excess consumption of any nutrient leads to fat formation
The Body’s Response to Feasting

When a person overeats (feasting):

- **Food component:**
  - Carbohydrate
  - Fat
  - Protein

- **Is broken down in the body to:**
  - Carbohydrate: Glucose
  - Fat: Fatty acids
  - Protein: Amino acids (first used to replace body proteins)

- **And then ends up as:**
  - Liver and muscle glycogen stores
  - Body fat stores
  - Nitrogen lost in urine
Fasting

- Catabolic State
  - All nutrients eventually used for energy
  - Glycogen from liver and fatty acids from adipose tissue yield Acetyl CoA and provide energy for cells
    - Glucose – needed for brain, RBC and nerves
    - Protein – 3 carbon can provide glucose – body protein must be broken down to provide these
    - Ketosis – produced by Acetyl CoA fragments
      - Can provide fuel for some brain cells
      - Suppresses appetite
      - Changes acid/base balance of body
  - Metabolism slows – lean tissue shrinks – muscles do less work - less calorie demands
When a person draws on stores (fasting):

**Storage component:**
- Liver and muscle glycogen stores
- Body fat stores

**Is broken down in the body to:**
- Glucose
- Fatty acids

**And then used for:**
- Energy
If the fast continues beyond glycogen depletion:

**Body component:**
- Body protein
- Body fat

**Is broken down in the body to:**
- Amino acids
- Fatty acids

**And then converted to:**
- Glucose
  - Nitrogen and some ketone bodies lost in urine
  - Ketone bodies

**Energy**
What About Low Carb Diets?

- Metabolism similar to fasting
  - Uses glycogen stores first
  - Gluconeogenesis when glycogen is depleted
    - Body tissues used somewhat even when protein provided in diet
- Urine monitoring
- Ketosis
Alcohol in the Body

- Alcohol’s special privileges
  - No digestion
  - Quick absorption
    - Slowing absorption
- Stomach
  - Alcohol dehydrogenase
- Small intestine
  - Priority over nutrients
Alcohol Arrives in the Liver

- Liver cells
  - First to receive alcohol-laden blood
- Alcohol dehydrogenase
- Disrupts liver activity
- Can permanently change liver cell structure
- Rate of alcohol metabolism
  - Acetaldehyde
  - Acetate
The conversion of alcohol to acetyl CoA requires the B vitamin niacin in its role as the coenzyme NAD. When the enzymes oxidize alcohol, they remove H atoms and attach them to NAD. Thus NAD is used up and NADH accumulates. (Note: More accurately, NAD+ is converted to NADH + H+.)
Acetyl CoA molecules are blocked from getting into the TCA cycle by the high level of NADH. Instead of being used for energy, the acetyl CoA molecules become building blocks for fatty acids.

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Alcohol Problems

- Alcohol Poisoning
  - If passed out from excess, still absorbed and levels in bloodstream rise
  - Overdose can cause irreversible brain damage
- Poor Diet
- Vitamin Deficiencies
- Fatty Liver
- Elevated Triglycerides
- Body Weight
Alcohol Arrives in the Brain

- Sedates inhibitory nerves
  - Acts as central nervous system depressant
- Blood alcohol levels and brain responses
- Death of liver and brain cells
- Depression of antidiuretic hormone (ADH)
  - Loss of body water
    - Loss of important minerals
Alcohol Arrives in the Brain

1. Judgment and reasoning centers are most sensitive to alcohol. When alcohol flows to the brain, it first sedates the frontal lobe, the center of all conscious activity. As the alcohol molecules diffuse into the cells of these lobes, they interfere with reasoning and judgment.

2. Speech and vision centers in the midbrain are affected next. If the drinker drinks faster than the rate at which the liver can oxidize the alcohol, blood alcohol concentrations rise: the speech and vision centers of the brain become sedated.

3. Voluntary muscular control is then affected. At still higher concentrations, the cells in the cerebellum responsible for coordination of voluntary muscles are affected, including those used in speech, eye-hand coordination, and limb movements. At this point people under the influence stagger or weave when they try to walk, or they may slur their speech.

4. Respiration and heart action are the last to be affected. Finally, the conscious brain is completely subdued, and the person passes out. Now the person can drink no more; this is fortunate because higher doses would anesthetize the deepest brain centers that control breathing and heartbeat, causing death.
## Alcohol Arrives in the Brain

<table>
<thead>
<tr>
<th>Blood Alcohol Concentration</th>
<th>Effect on Brain</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.05</td>
<td>Impaired judgment, relaxed inhibitions, altered mood, increased heart rate</td>
</tr>
<tr>
<td>0.10</td>
<td>Impaired coordination, delayed reaction time, exaggerated emotions, impaired peripheral vision, impaired ability to operate a vehicle</td>
</tr>
<tr>
<td>0.15</td>
<td>Slurred speech, blurred vision, staggered walk, seriously impaired coordination and judgment</td>
</tr>
<tr>
<td>0.20</td>
<td>Double vision, inability to walk</td>
</tr>
<tr>
<td>0.30</td>
<td>Uninhibited behavior, stupor, confusion, inability to comprehend</td>
</tr>
<tr>
<td>0.40 to 0.60</td>
<td>Unconsciousness, shock, coma, death (cardiac or respiratory failure)</td>
</tr>
</tbody>
</table>

**NOTE:** Blood alcohol concentration depends on a number of factors, including alcohol in the beverage, the rate of consumption, the person's gender, and body weight. For example, a 100-pound female can become legally drunk (≥0.10 concentration) by drinking three beers in an hour, whereas a 220-pound male consuming that amount at the same rate would have a 0.05 blood alcohol concentration.
Alcohol and Malnutrition

- Can contribute to body fat and weight gain
  - 1 ounce of alcohol represents 0.5 ounce of fat
  - Central obesity
- Substituted energy
  - 7 kcalories per gram
- Nutrient displacement
  - B vitamins
Alcohol Benefits

- U shaped curve for mortality rates
  - 1-2 drinks per day same as nondrinkers
  - >3 increased death rate

- Heart Disease
  - Beer, wine, spirits all equal in protection
  - Raise HDL
  - May inhibit blood clots

- Cancer
Energy Drinks

- Beverages marketed to enhance or boost energy
- General Contents of many energy drinks
  - Caffeine
  - Guarana
  - Ginseng
  - Taurine
  - B Vitamins
  - Glucuronolactone
  - Sugar
Energy Drinks

- Concerns
  - Stimulant
  - Diuretic
  - Alcohol
Other helpful video links

- http://www.youtube.com/watch?v=m4Mx-oQ-jrk&feature=related
- http://www.youtube.com/watch?v=hw5nWB0xN0Y&feature=related