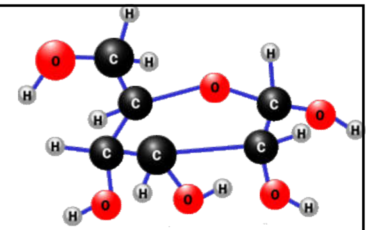
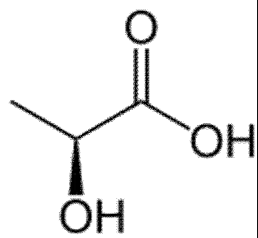
Anaerobic Pathways



- **Glycolysis**
  - Glucose + 2 ATP → 4 ATP + 2 Pyruvate
- No oxygen required
- Fairly low energy yield
- Lactate byproduct
  - Resting levels low
  - Tolerances 40 mmole/kg in humans, 200 mmole/kg in sea turtles
  - During strenuous exercise levels highest in muscle and liver tissue



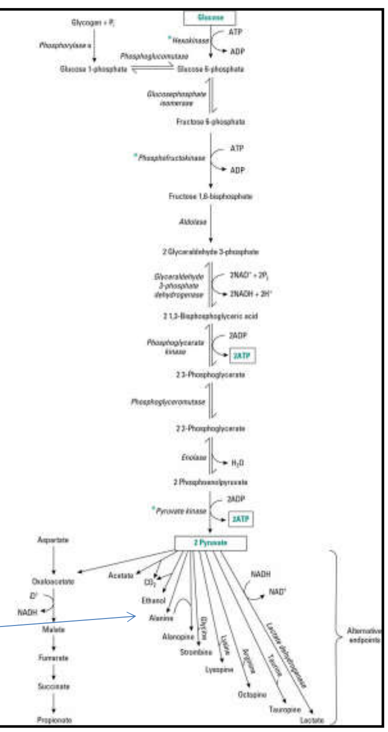
Glycolysis

- Lactate
  - common animal endpoint
  - not a waste product

Table 6.2 ATP yield from different fermentation routes.

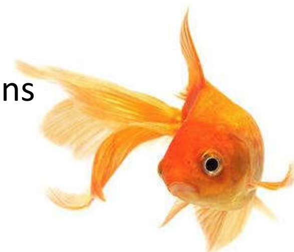
Substrate	Endpoints	mol ATP per mol substrate
Glucose	Lactate, octopine, alanopine or strombine	2
Glucose	Succinate	4
Glucose	Propionate	6
Aspartate or glutamate	Succinate	1
Aspartate or glutamate	Propionate	2
Branched-chain fatty acids	Volatile fatty acids	1

One alternative endpoint is Alanine. What organism uses that? When?



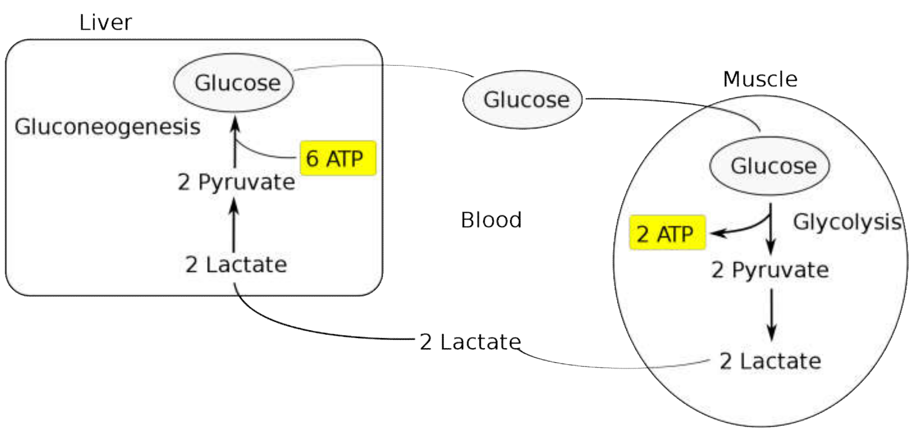
Alternate Endpoints

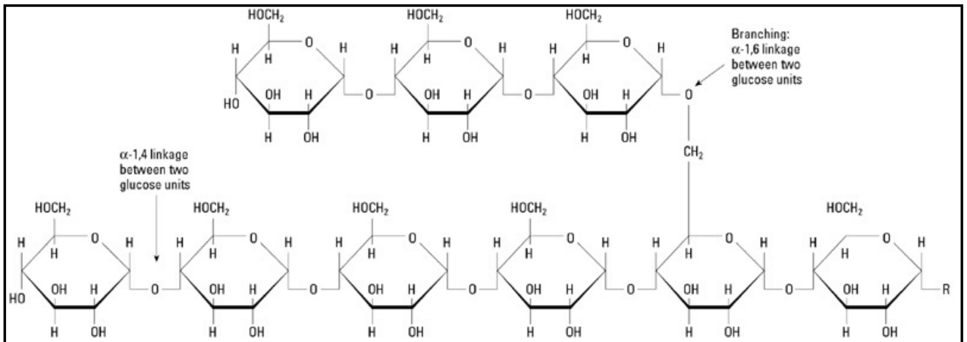
- Some animals use alternate endpoints under some conditions
  - Goldfish use ethanol in cold, anoxic conditions
  - Glucose → pyruvate → acetalaldehyde → ethanol
  - Ethanol is excreted



Gluconeogenesis – fate of end products

- Lactate transferred to liver, converted back into glucose
- Cost of 6 ATP
- Why bother?



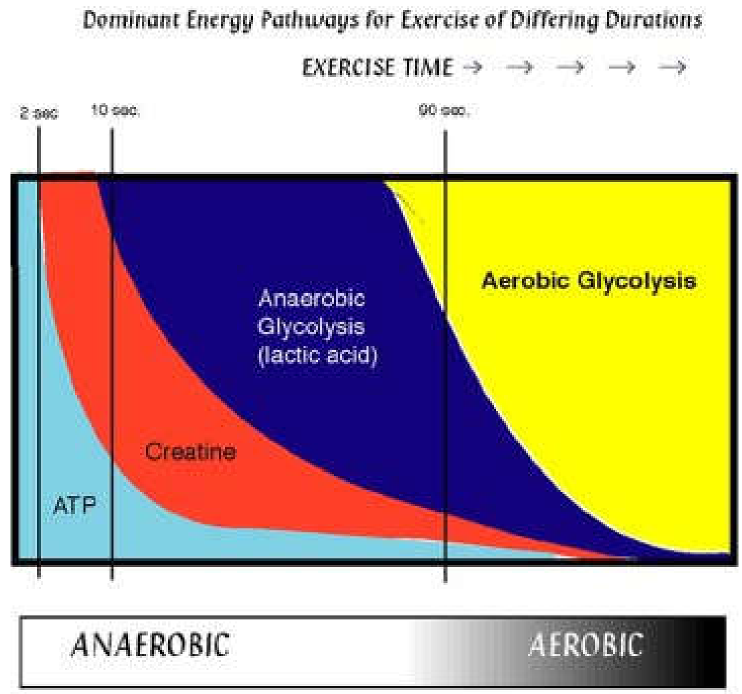


- Source and storage of glucose
- **Glycogen** – glucose polymer
  - Hormone control:
  - **Insulin** - stimulates storage of glucose in glycogen
  - **Glucagon** – reverse (**glycogenolysis**)

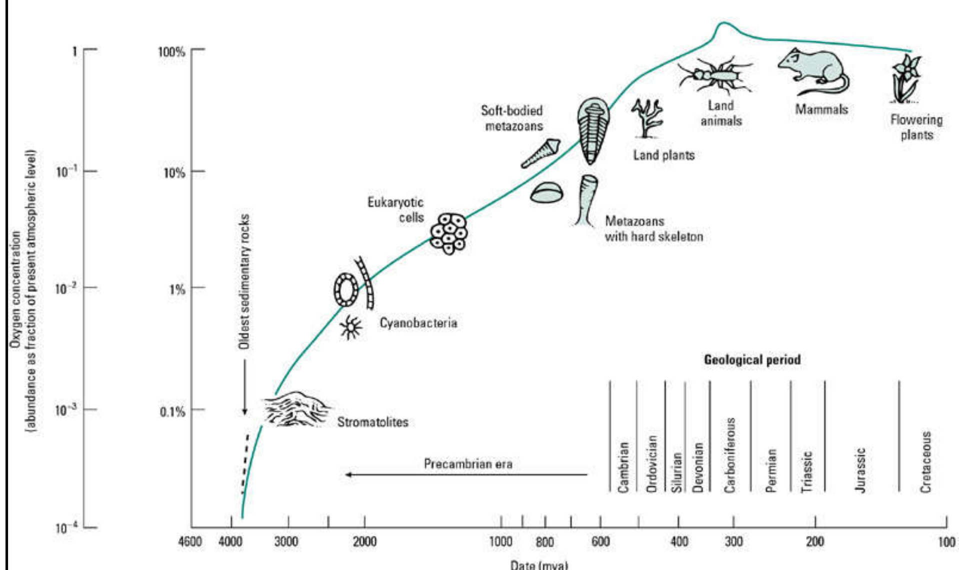
Review of some terms

- Catabolic processes
  - Glycolysis
  - Glycogenolysis
- Anabolic processes
  - Glycogenesis
  - Gluconeogenesis
- Molecules
  - Glucose
  - Glucagon
  - Pyruvate
  - Lactate
  - Creatine phosphate
- Hormones
  - Insulin
  - Glucagon

How does the Atkins diet “work”?

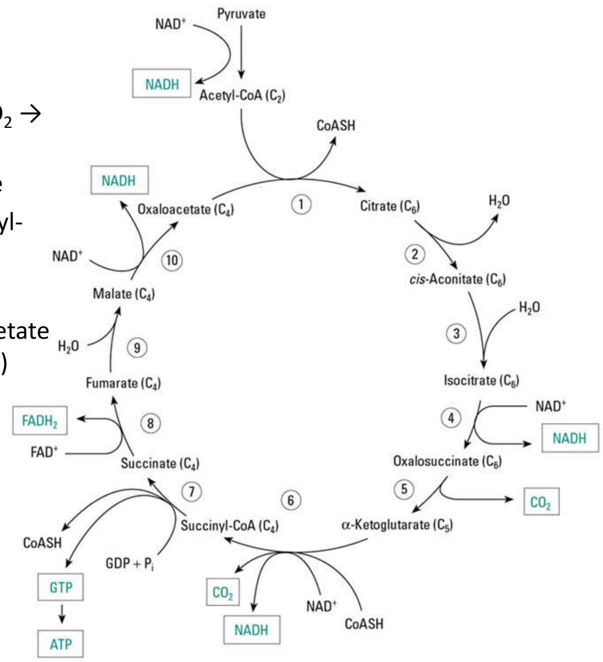


Oxygen in the Atmosphere



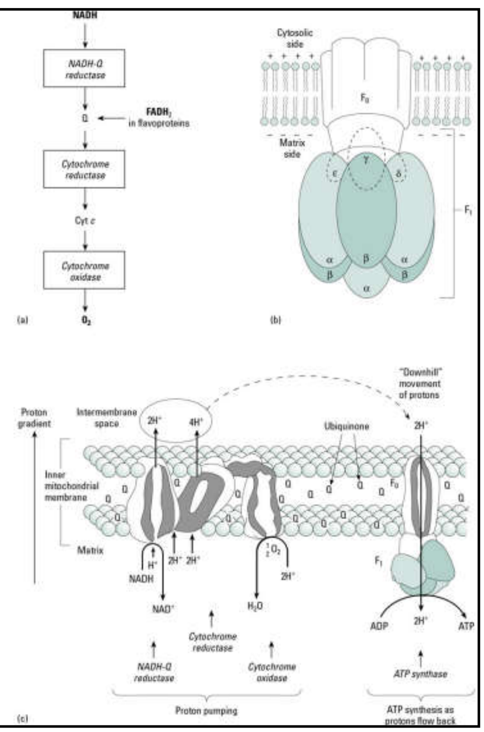
Aerobic pathway

- Overview
  - Glucose + 36 ADP + 6 O_2 → 36 ATP + 6 CO^2 + 6 H_2O
- Glycolysis yields 2 pyruvate
- Convert pyruvate into acetyl-CoA (C_2)
- **Citric Acid cycle**
  - Combine with Oxaloacetate (C_4) to make Citrate (C_6)
  - Break off two carbons (released as CO_2)
  - Yield (per pyruvate)
    - 2 CO_2
    - 3 NADH
    - 1 $FADH_2$
    - 1 GTP



Electron transfer system

- From Glycolysis, pyruvate oxidation and Citric Acid cycle
  - 1 glucose → 10 NADH + 2 $FADH_2$
- Electrons transferred to O_2, negatively charged oxygen combines with protons (**metabolic water**)
- Protons pumped out of mitochondrial matrix, setting up a gradient
- **ATP synthase** converts ADP → ATP as protons flow back into matrix

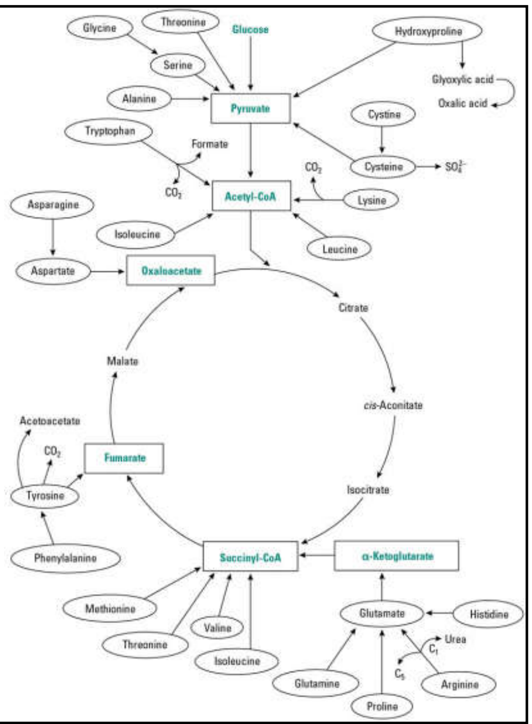


Overview, ATP yields

Reaction sequence	ATP yield per glucose	
Glycolysis (in cytoplasm)		
Phosphorylation of glucose	−1	
Phosphorylation of fructose 6-phosphate	−1	+2
Dephosphorylation of 2 molecules of 1,3-bisphosphoglycerate	+2	
Dephosphorylation of 2 molecules of phosphoenolpyruvate	+2	
(2 NADH are formed in the oxidation of 2 molecules of glyceraldehyde 3-phosphate)		
Conversion of pyruvate into acetyl-CoA feeding into Krebs cycle (in mitochondria)		
(2 NADH are formed)		
Krebs cycle (in mitochondria)		
2 molecules of GTP are formed from 2 molecules of succinyl-CoA	+2	+2
(6 NADH are formed in the oxidation of 2 molecules each of isocitrate, α-ketoglutarate, and malate)		
(2 $FADH_2$ are formed in the oxidation of 2 molecules of succinate)		
Oxidative phosphorylation (in mitochondria)		
2 NADH formed in glycolysis; each yields 2 ATP	+4	
2 NADH formed in the oxidative decarboxylation of pyruvate; each yields 3 ATP	+6	+32
2 $FADH_2$ formed in the Krebs cycle; each yields 2 ATP	+4	
6 NADH formed in the Krebs cycle; each yields 3 ATP	+18	
Net yield per glucose	+36	

Alternative Fuels

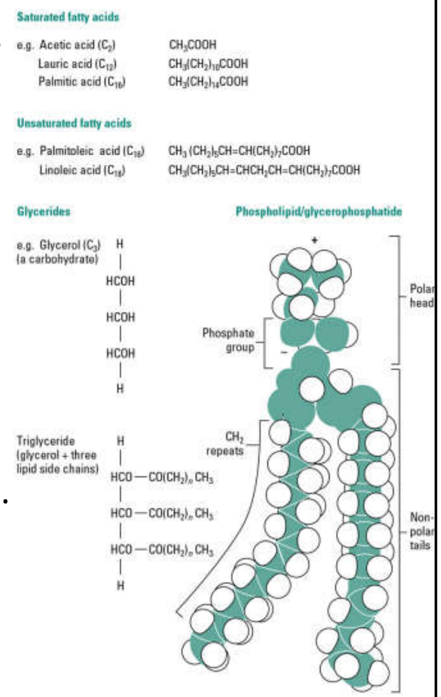
- Various amino acids can feed into parts of Citric Acid cycle
- Recall osmoregulation of intertidal copepod



Lipids - $(CH_2O)_3(CH_2)_{3n}(CO_2H)_3$

- Common fuel for aerobic metabolism
- Very high energy density
- Chain of CH_2 repeats
- Saturated vs. unsaturated

- Produces Acetyl-CoA (→ Citric Acid cycle) through **β-oxidation**.



Lipids - $(CH_2O)_3(CH_2)_{3n}(CO_2H)_3$

- Greater oxygen demand to produce ATP, measured as respiratory quotient (**RQ**)

- Carbohydrate metabolism
  - $C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O$
  - Ratio of CO_2 to O_2 is 1:1
  - **RQ** = 1.0

- Lipid metabolism (n=17)
  - $(CH_2O)_3(CH_2)_{51}(CO_2H)_3 \rightarrow 6\ CO_2 + 6\ H_2O$
  - $C_{57}H_{111}O_9 + 80\ O_2 \rightarrow 57\ CO_2 + 55\ H_2O$
  - Ratio of CO_2 to O_2 is 57:80 ~ 0.67
  - **RQ** = 0.7

Comparing fuels

Nutrient	Heat production: kJ per g consumed	Heat production: kJ per l O_2 consumed	RQ (CO_2 formed /O_2 used)	Metabolic water (g per g food)	Metabolic water (g per KJ)
Carbohydrates	17.4	20.9	1.00	0.56	0.032
Lipids	39.3	19.6	0.71	1.07	0.027
Proteins	17.8	18.6	0.80	0.4–0.5	0.022

- Carbohydrates
  - Fast ATP yield, high ATP per unit oxygen, low energy density
- Lipids
  - Slow ATP yield, low ATP per unit oxygen, high energy density

Patterns of Energy Use

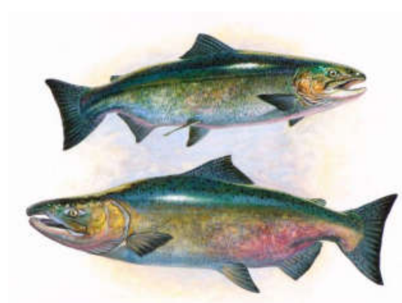
- The relative contribution of fuel types, duration and capacity are all variable.
- For example, general categories of muscle differ:
  - Red muscle
    - Lipid catabolism
    - High myoglobin, well supplied by vessels
    - Fatigue resistant
    - Slow acting
  - White muscle
    - Carbohydrate catabolism
    - Low myoglobin
    - Fatigue quickly
    - Fast acting

Ecological Implications

- Short distance, fast flying insects
  - Rely on carbohydrates
  - Fast start, fast metabolism
  - Low duration

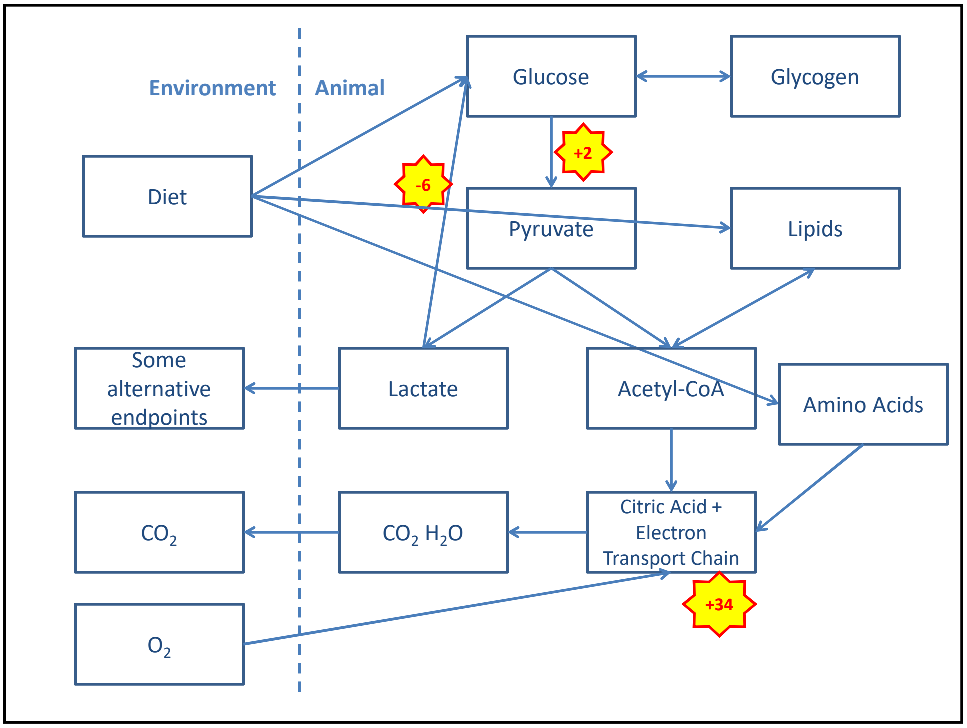
- Long distance, slow flyers
  - Lipids, more dense energy storage
  - Slower to metabolize

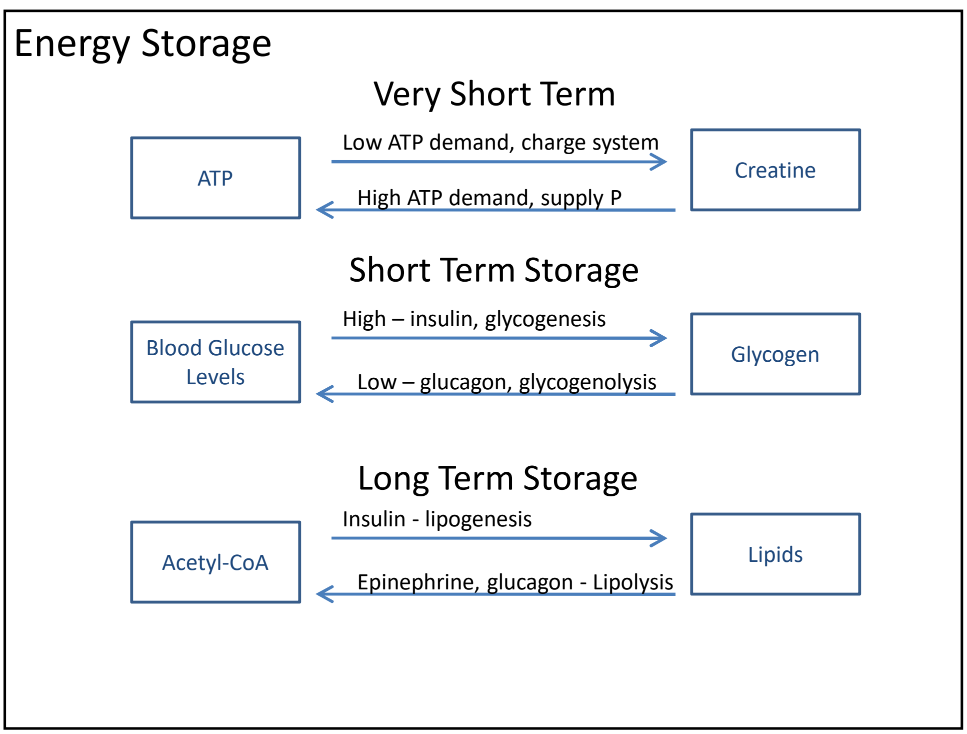
- Flying locust energy requirements
  - 500 mg per hour glycogen
  - 70 mg per hour lipid
  - Uses glycogen to initiate flight, switches to lipid



- Migrating salmon
  - Begin migration using lipid stores
  - Infrequent burst acceleration involves carbohydrates
  - Later in trip, protein catabolism

- Humans
  - High capacity for carbohydrate metabolism and lactate turnover
  - Carb-loading - maximize muscle glycogen stores


Environment
Animal
Diet
Glucose
Glycogen
+2
-6
Pyruvate
Lipids
Some alternative endpoints
Lactate
Acetyl-CoA
Amino Acids
CO_2
CO_2 H_2O
Citric Acid + Electron Transport Chain
+34
O_2


Energy Storage
Very Short Term
ATP
Low ATP demand, charge system
High ATP demand, supply P
Creatine
Short Term Storage
Blood Glucose Levels
High – insulin, glycogenesis
Low – glucagon, glycogenolysis
Glycogen
Long Term Storage
Acetyl-CoA
Insulin - lipogenesis
Epinephrine, glucagon - Lipolysis
Lipids