Fish Feeding

Dr.A.Y.Al-Dubakel

Fish Feeding – Syllabus

1- Introduction

2- Feeding and Digestion

3- Nutrient Metabolism

4- Nutrition Physiology

5- Sensory Organs

6- Anatomy and Diet

7- Control and Regulation of Digestion

8- Digestion and Metabolism

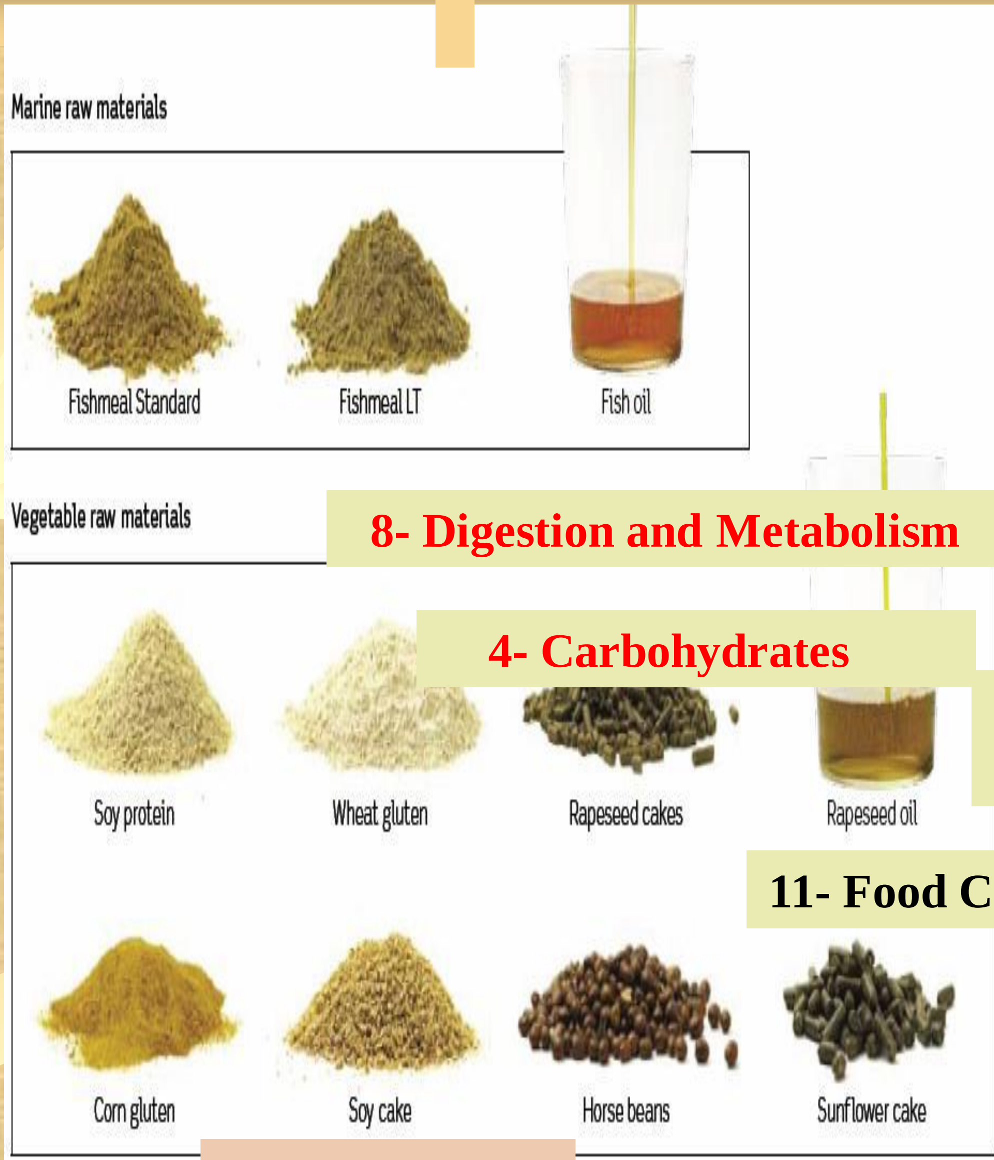
4- Carbohydrates

11- Food Capture Structures and Organs

10- Diet and Fish Husbandry

11- Feeding Methods

12- Fish Feeding Experiments

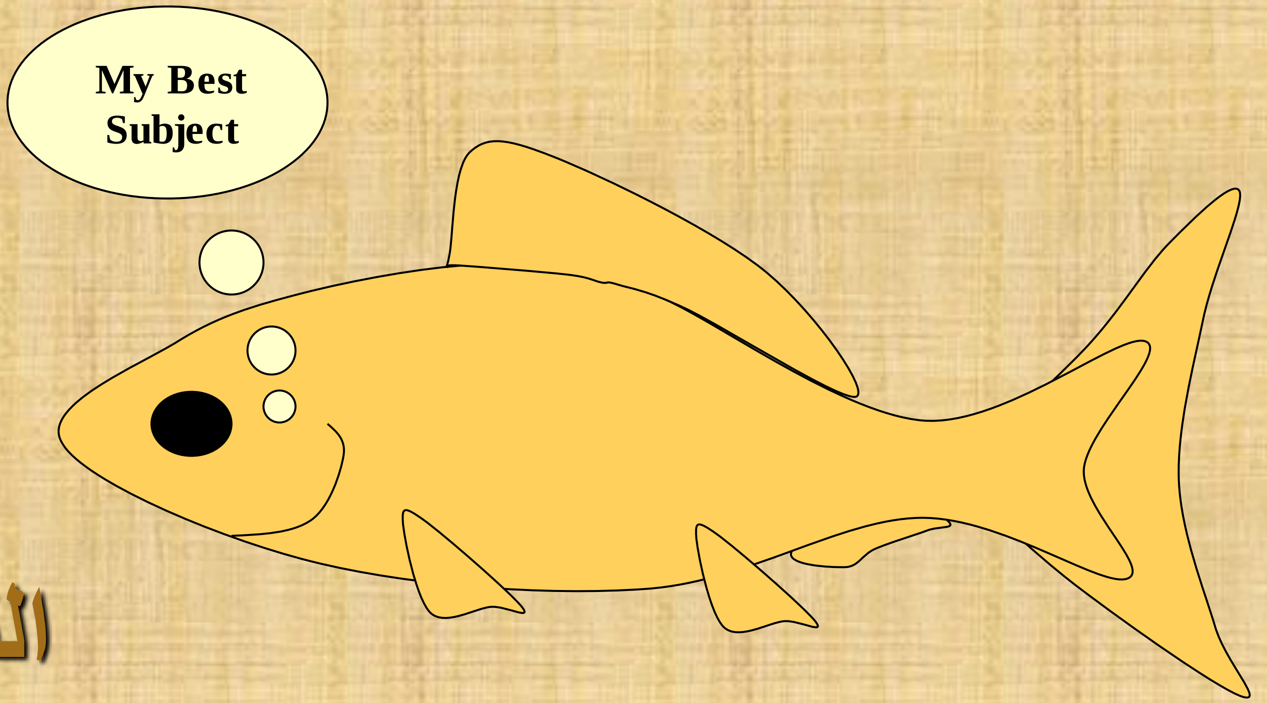


Feed materials

Report on Fish feedin

Ref.(Halver,2002)&Hepher,1988)

التغذية والهضم Feeding and Digestion



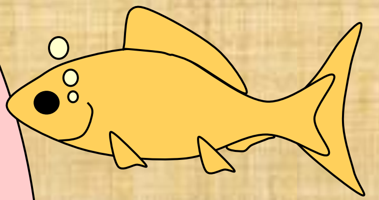
التغذية

Feeding

توازن الطاقة Energy Budgets

Intake (I = Income)

- Macronutrients
  - Carbohydrates
  - Fats/Oils
  - Proteins
- Micronutrients
  - Vitamins
  - Essential
  - Fatty Acids
  - Amino Acids
  - Sugars



Energy Use (E = Expenditure)

- Respiration
- Osmoregulation
- Movement
- Feeding
- Digestion
- Reproduction

If اذا

I = E Growth = 0

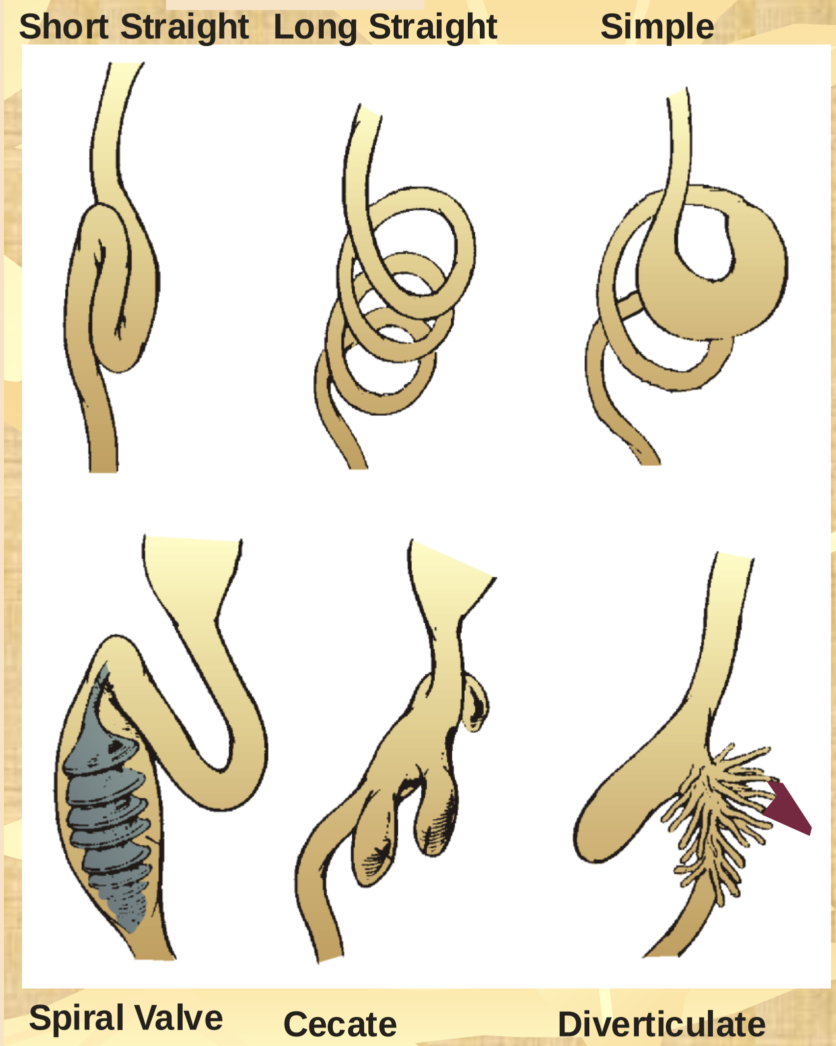
Growth = − I < E

Growth = + I > E

Stomach - Modifications

- Agastric
  - Short Straight – Carnivores
  - Long Straight – Herbivores
  - Simple - Carnivores
- Gastric
  - Spiral Valves – Elasmobranchs
  - Cecate – Herbivores
  - Diverticulate – Herbivores and Carnivores

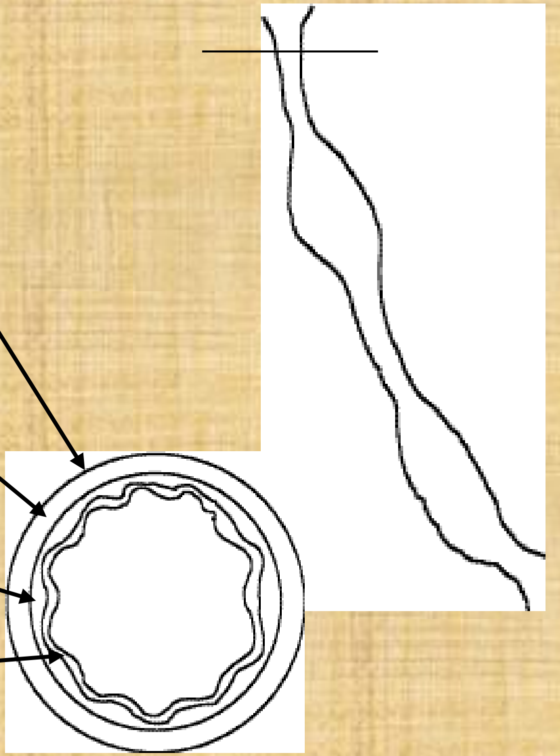
Agastric



Gastric

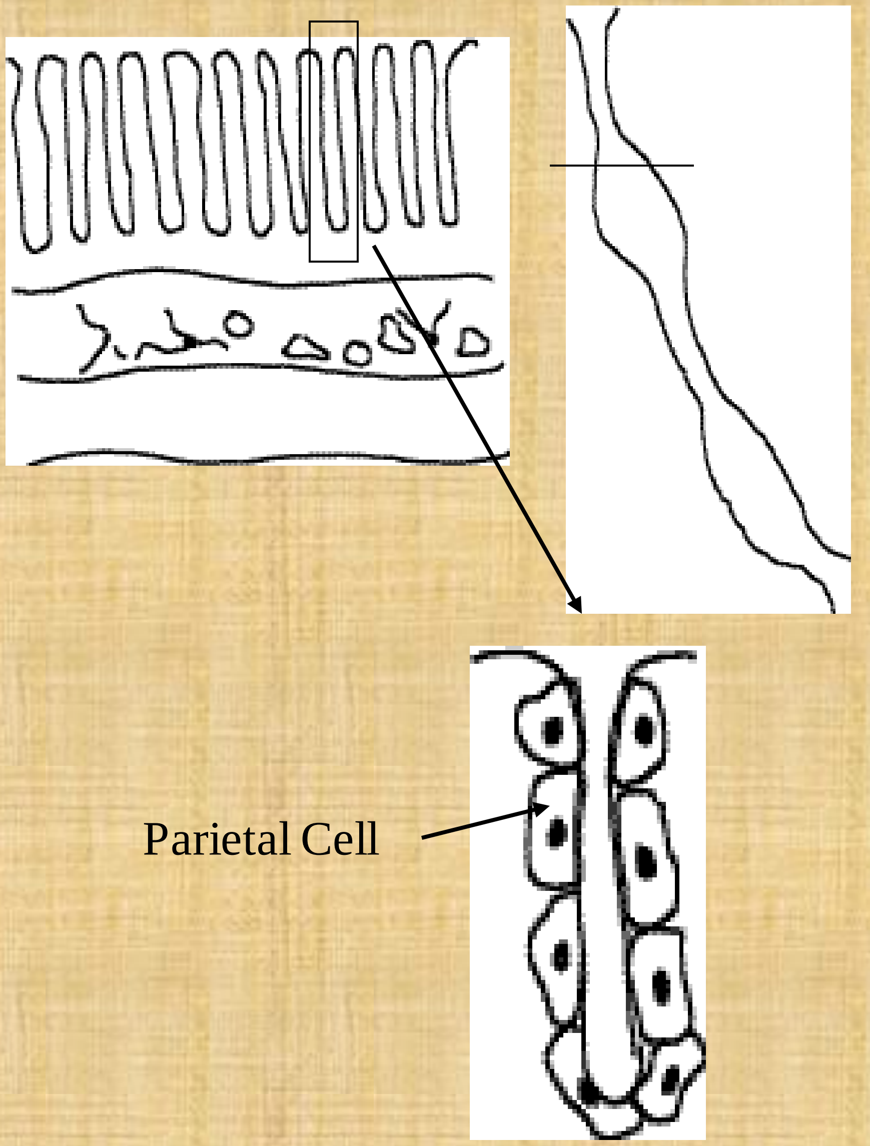
The Esophagus

- Serosa/Adventitia – A transition
- Muscularis – Muscles More Spiral and in Opposition
- SubMucosa – Thin
- Mucosa – Stratified squamous to cuboidal



The Stomach- Anterior or Fundic

- Adventitia to Serosa
- Muscularis – Arranged as Spiral Bands in Opposition
- Submucosa – Thick
- Mucosa – Cuboidal to Columnar with Deep Pits Lined by Parietal Cells – Secrete HCl



Stomach - Modifications

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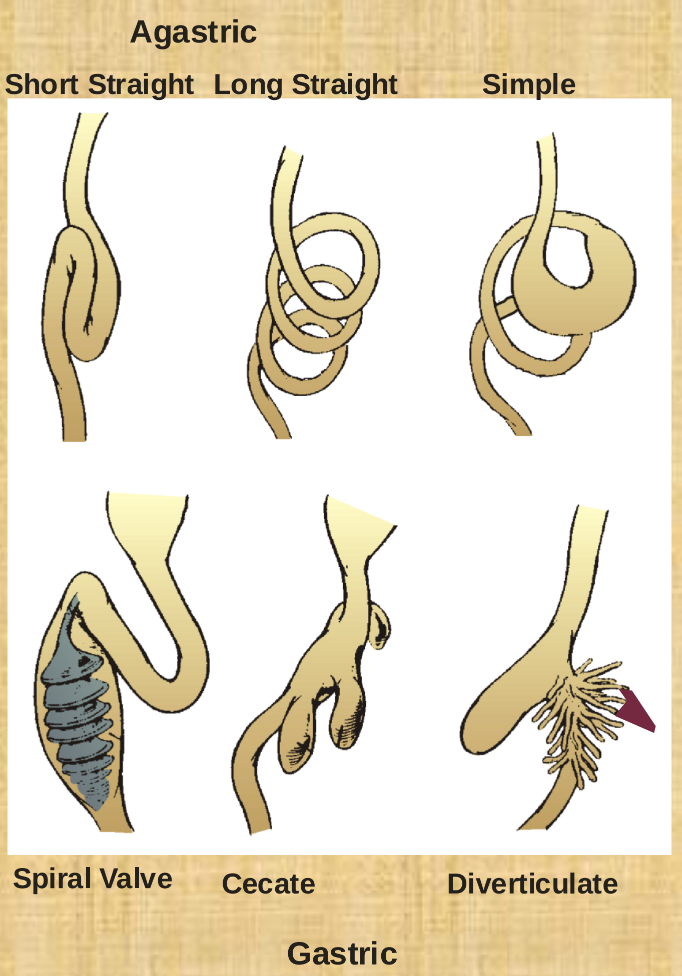
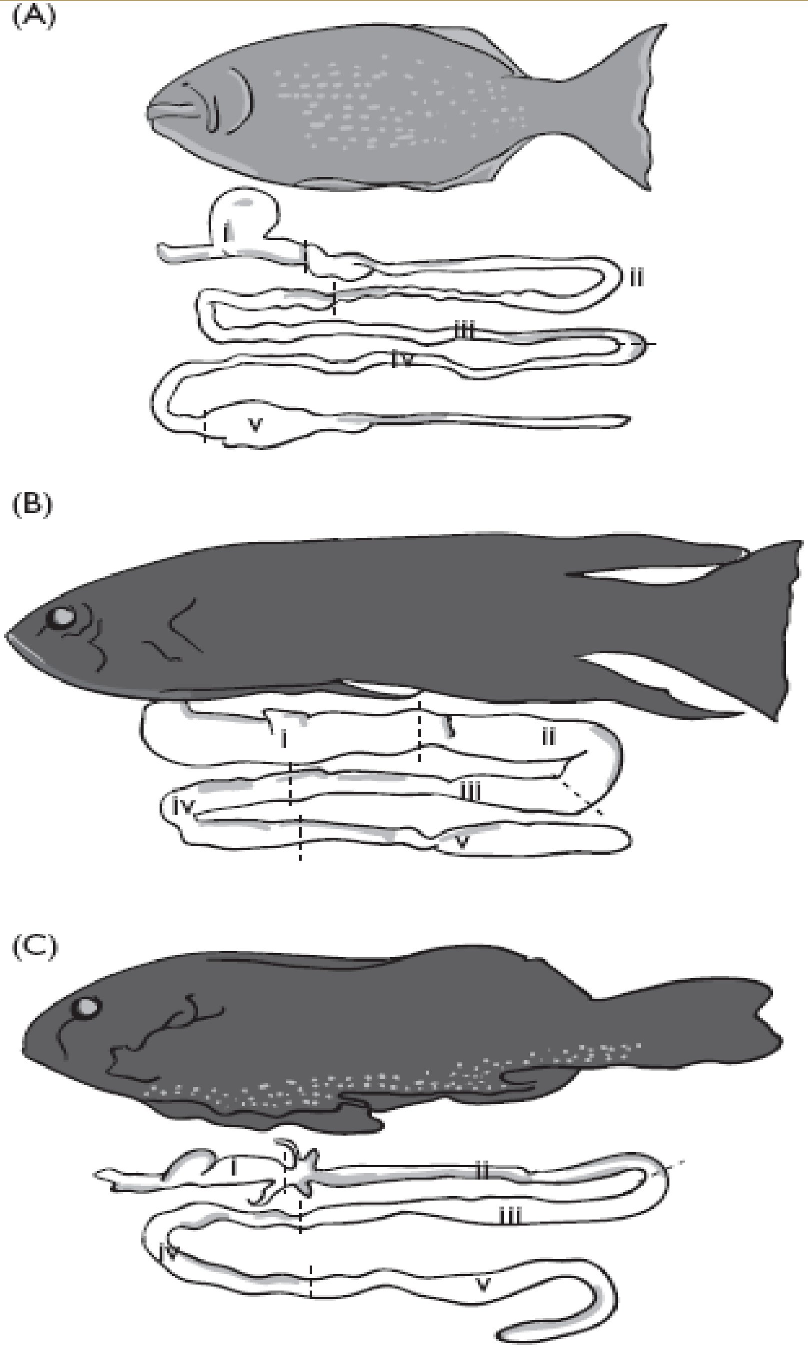
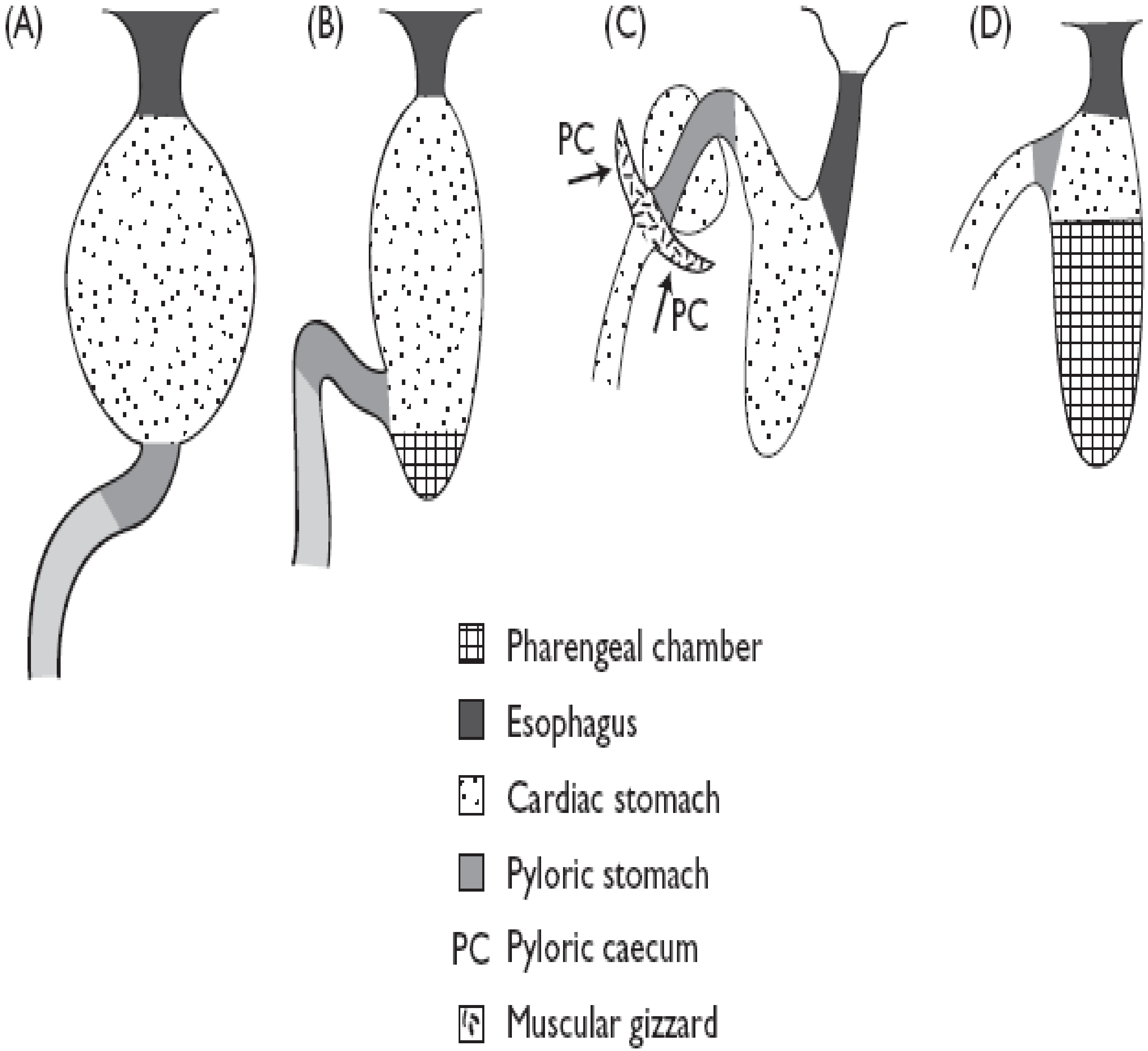
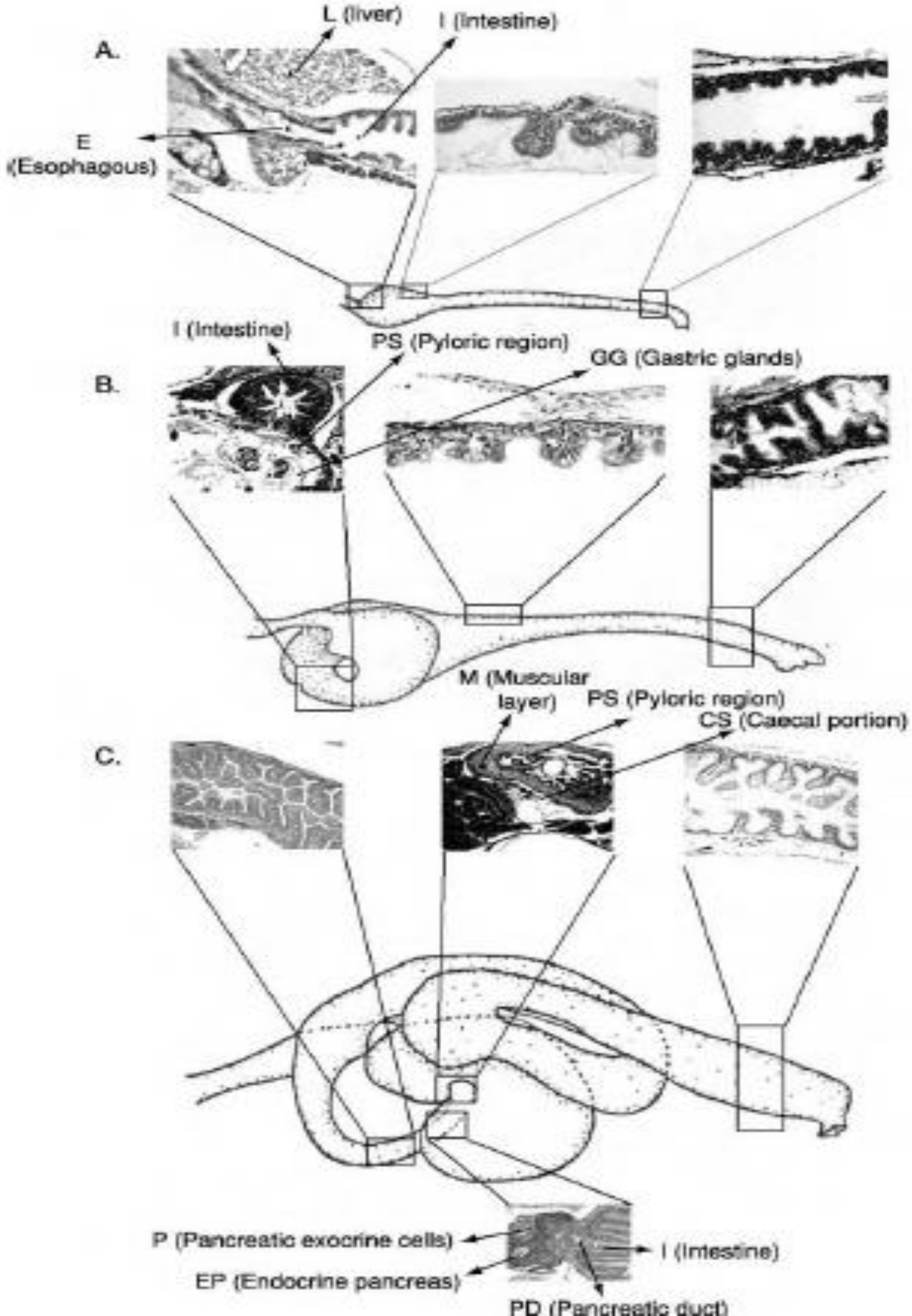




Intestines of three herbivorous fishes. Roman numerals i–v designate segments in which differences in biochemical activities were analyzed. Drawings based on photographs of *K. sydneyanus* (A), *O. pullus* (B), and *A. arctidens* (C)



A variety of stomach types found in fishes: contrasting the “straight” stomach of *Esox* (A) with “typical” J-shape in *Anguilla* (B), the heavy walled “gizzard” in *Mugil* (C) and “T” shape in *Alcolapia grahami* (D).



Digestive tract changes in ontogenesis of pacu (*Piaractus mesopotamicus*). A, B, and C
refer to fish sizes of 6, 12, and 22 min in length, respectively

Digestion

Digestion: the preparation of food by the animal for absorption

involves the following processes:

1) mechanical reduction of particle size;
2) enzyme solubilization of organics;
3) pH solubilization of inorganic;
4) emulsification of fats

Absorption: various processes that allow ions and molecules to pass through membranes of the intestinal tract into the blood, lymph, hemolymph, etc. to be metabolized by the animal

Fish Digestion: anatomy

Two major groups: w/stomach, w/out

w/out stomach: cyprinids (carps)

w/stomach: cold-water salmonids, warm-water catfish, tilapia, eels, grouper

note: all "pure" predators have a stomach and teeth

relative gut length (RGL): gut:body length

high RGL = species consuming detritus, algae (high proportion of indigestible matter)

Trans-Membrane Transport of Macromolecules

- 1 Attachement of molecule to receptor or surface
- 2 Involution of surface
- 3 Engulfment of molecule
- 4 Pinching off and import of macromolecule into the cell

Digestive anatomy: stomach

Channel catfish: have true stomach that secretes HCl and pepsinogen (enzyme)

Common carp: no stomach; however, "bulb" at anterior end of digestive tract, bile and pancreatic secretions empty into intestine posterior to cardiac sphincter, no secretion of gastrin (low pH)

Tilapia: modified stomach, secretes HCl, well-defined pocket, pH varies w/digestal flow, has pyloric sphincter

Shrimp: cardiac/pyloric sections, gastric secretions, gastric mill, straight shot to midgut

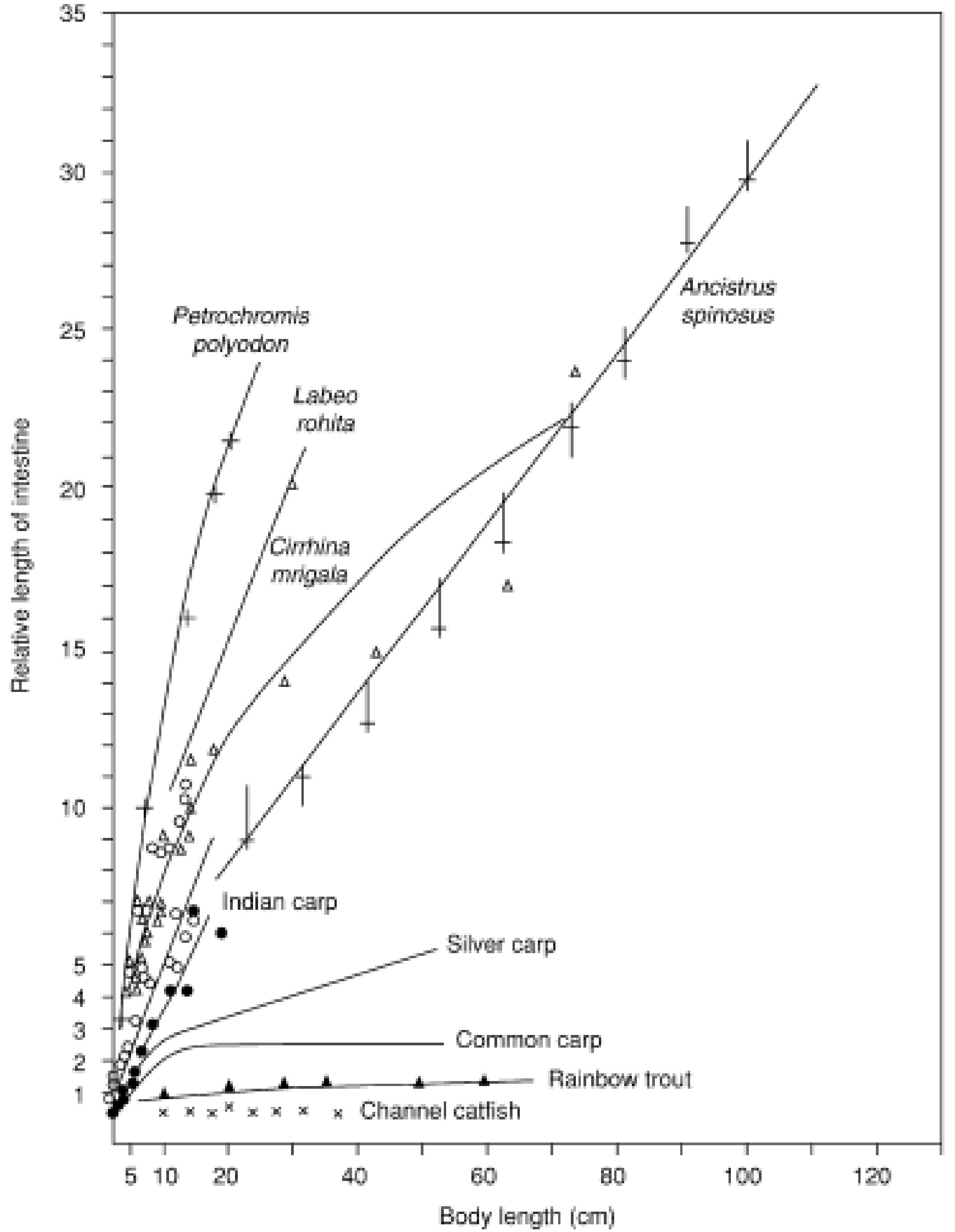
Digestive anatomy: intestine

Channel catfish: length less than whole body, no large/small version, slightly basic pH, digestive secretions, nutrient absorption, many folds for absorption

Common carp: digestive tract is 3x whole body length, similar in activity to that of channel catfish

Tilapia: tract is 6-8x that of body length, activities similar to that of other species

Shrimp: short midgut w/midgut gland used for absorption/secretion/storage of nutrients, enzymes), slightly basic, blind tubules



Changes in the relative length of intestine (expressed in body lengths) in several fish species

Digestive Anatomy: liver and pancreas (fish)

Both organs produce digestive secretions

liver produces bile but is also the primary organ for synthesis, detoxification and storage of many nutrients

pancreas is primary source of digestive enzymes in most animals

it also produces **zymogens** (precursors to enzymes)

Digestive Anatomy: midgut gland (shrimp)

Also referred to as "**hepatopancreas**"

not an accurate descriptor because function not exactly similar

located as a diversion off of midgut

specialized cells for storage, secretion

good indicator of dietary lipid source

very susceptible to disease infection

Digestive Processes: fish stomach

We will use the catfish as an example, since it's digestive processes are similar to that of most monogastric animals

Step 1: food enters stomach, neural and hormonal processes stimulate digestive secretions

as stomach distends, parietal cells in lining secrete **gastrin**, assisting in digestion

gastrin converts the zymogen **pepsinogen** to **pepsin** (a major proteolytic enzyme)

some fish have **cirulein** instead of gastrin

Digestive processes: fish stomach

Flow of **digesta** out of stomach is controlled by the pyloric sphincter

pepsin has pH optimum and lyses protein into small peptides for easier absorption

minerals are solubilized; however, no lipid or COH is modified

mixture of gastric juices, digesta, mucous is known as **chyme**

Digestive Processes: fish intestine

Chyme entering the small intestine stimulates secretions from the pancreas and gall bladder (**bile**)

bile contains salts, cholestrol, phospholipids, pigments, etc.

pancreatic secretions include bicarbonates which buffer acidity of the chyme

zymogens for proteins, COH, lipids, chitin and nucleotides are secreted

e.g., **enterokinase** (trypsinogen --> trypsin)

others: chymotrypsin, carboxypeptidase, aminopeptidase, chitinase

Digestive Processes: intestine

Digestion of COH's is via **amylase**, which hydrolyzes starch

others: **nuclease**, **lipase**

cellulase: interesting in that it is not secreted by pancreas, but rather produced by gut bacteria

note: intestinal mucosa also secretes digestive enzymes

Amino acids

Teleosts excrete a mixture of nitrogenous compounds

most nitrogenous waste excreted thru gills

Rem: excretion of ammonia requires less energy than urea because urea is synthesized

further, excretion of ammonia does not require movement of water across membrane (ie., easy passage)

Digestive processes: absorption

Most nutrient absorption occurs in the intestine

a cross-section of the intestinal luma shows that it is highly convoluted, increasing surface area

absorption through membrane is either by **passive diffusion** (concentration gradient)

or by **active transport** (requires ATP)

or via **pinocytosis** (particle engulfed)

nutrients absorbed by passive diffusion include: electrolytes, monosaccharides, some vitamins, smaller amino acids

Digestion - Chemical

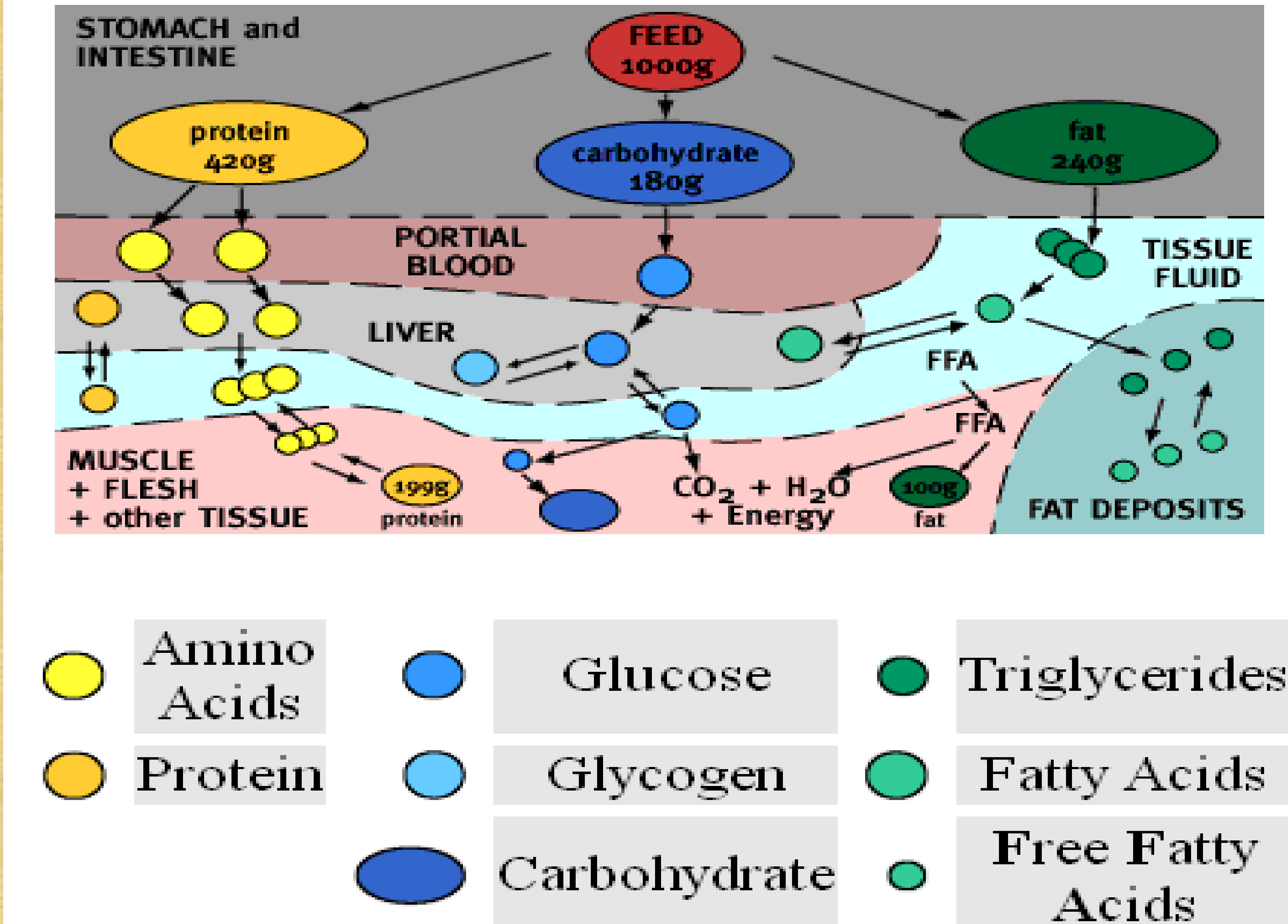
Enzyme	Site of Secretion	Site of Action	Substrate	Products
Pepsin	Stomach	Stomach	Protein	Peptides
Trypsin	Pancreas	Intestine	Protein/Peptides	Peptides
Chymotripsin	Pancreas	Intestine	Protein/Peptides	Peptides
Carboxypeptidase	Pancreas	Intestine	Protein/Peptides	AAs, Peptides
Aminopeptidase	Intestine	Intestine	Protein/Peptides	AAs, Peptides
Di-/tripeptidases	Intestine	Intestine	Protein/Peptides	AAs
Lipase	Pancreas	Intestine	Triglycerides	Fatty Acids, Monoacylglycerols
Esterase	Pancreas	Intestine	Esters	Alcohols, Fatty Acids
Amylase	Pancreas	Intestine	Starches	Disaccharides
Disaccharidases	Intestine	Intestine	Disaccharides	Monosaccharides
Chitinases	Pancreas/Gut Microflora	Intestine	Chitin	N-Acetyl-glucosamine
Cellulase	Gut Microflora	Intestine	Cellulose	Saccharides

Summary of Digestive Enzymes

Gastric secretions	Fluid/enzyme	Function/notes
Stomach	HCl	Reduces gut pH, pepsiongen
	Zymogen, pepsinogen, HCl	Proteolysis
		COH's
	Amylase	Lipids
	Lipase	Esters
	Esterase	Chitin
	Chitinase	
Pancreas	HCO_3	Neutralizes HCl
	Proteases	Cleave peptide linkages
	Amylase	COH's
	Lipase	Lipids
	Chitinase	Chitin
Liver/bile	Bile salts, cholestrol	Increase pH, emulsify lipids
Intestine	Aminopeptidases	Split nucleosides
	Lecithinase	Phospholipids to glycerol + fatty acids

Digestive enzymes: Substrates and actions

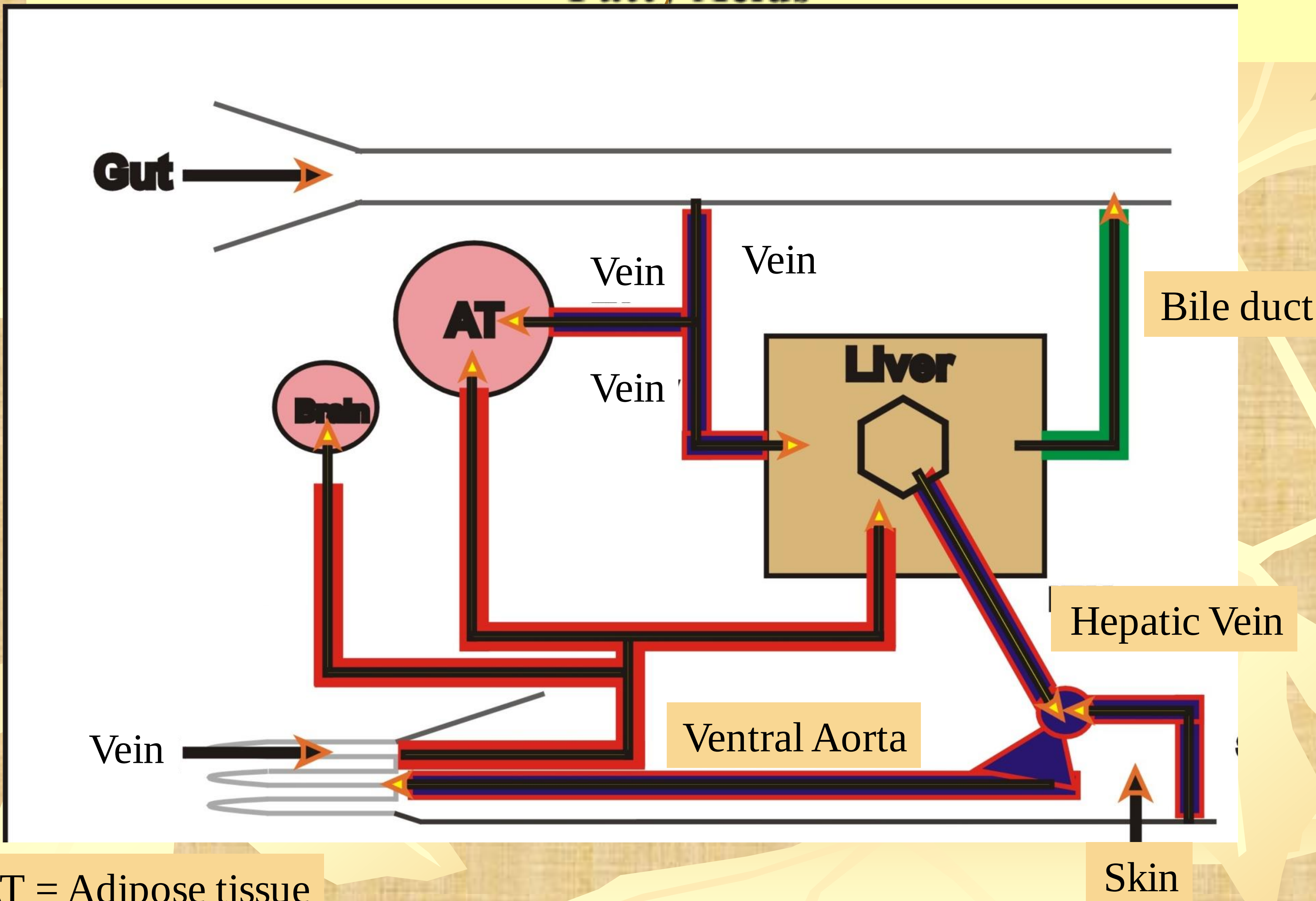
Macronutrient substrate	Chemical bond	Digestive enzyme	Site of production	Site of action
Carbohydrates	Glycosidic	**Carbohydrases**		
		Amylase	Pancreas	Intestine
		Cellulase	Gut bacteria	Intestine
		Chitinase	Gut bacteria	Intestine
Lipids (Fats)	Ester	**Lipase/Esterase**		
		Lipase	Pancreas	Intestine
		Esterase	Pancreas	Intestine
		Phospholipase	Pancreas	Intestine
Proteins	Peptide	**Proteases/Peptidases**		
		Pepsin(ogen)	Stomach	Stomach
		Trypsin(ogen)	Pancreas	Intestine
		Chymotrypsin(ogen)	Pancreas	Intestine
		Peptidases	Pancreas/Intestine	Intestine


STOMACH and INTESTINE
FEED 1000g
protein 420g
carbohydrate 180g
fat 240g
PORTIAL BLOOD
TISSUE FLUID
LIVER
FFA
FFA
MUSCLE + FLESH + other TISSUE
199g protein
CO2 + H2O + Energy
100g fat
FAT DEPOSITS
Amino Acids
Glucose
Triglycerides
Protein
Glycogen
Fatty Acids
Carbohydrate
Free Fatty Acids

Absorption
Lipids

- Lipids
  - Bile Emulsification
  - Absorption
  - Conversion to Lipoproteins (Complex Aggregates of Macromolecules)
  - Volatile Fatty Acids Directly Absorbed (Small Sized Molecules with polar/nonpolar groups

Absorption (Continued) Absorption and Mobilization of Fatty Acids



AT = Adipose tissue

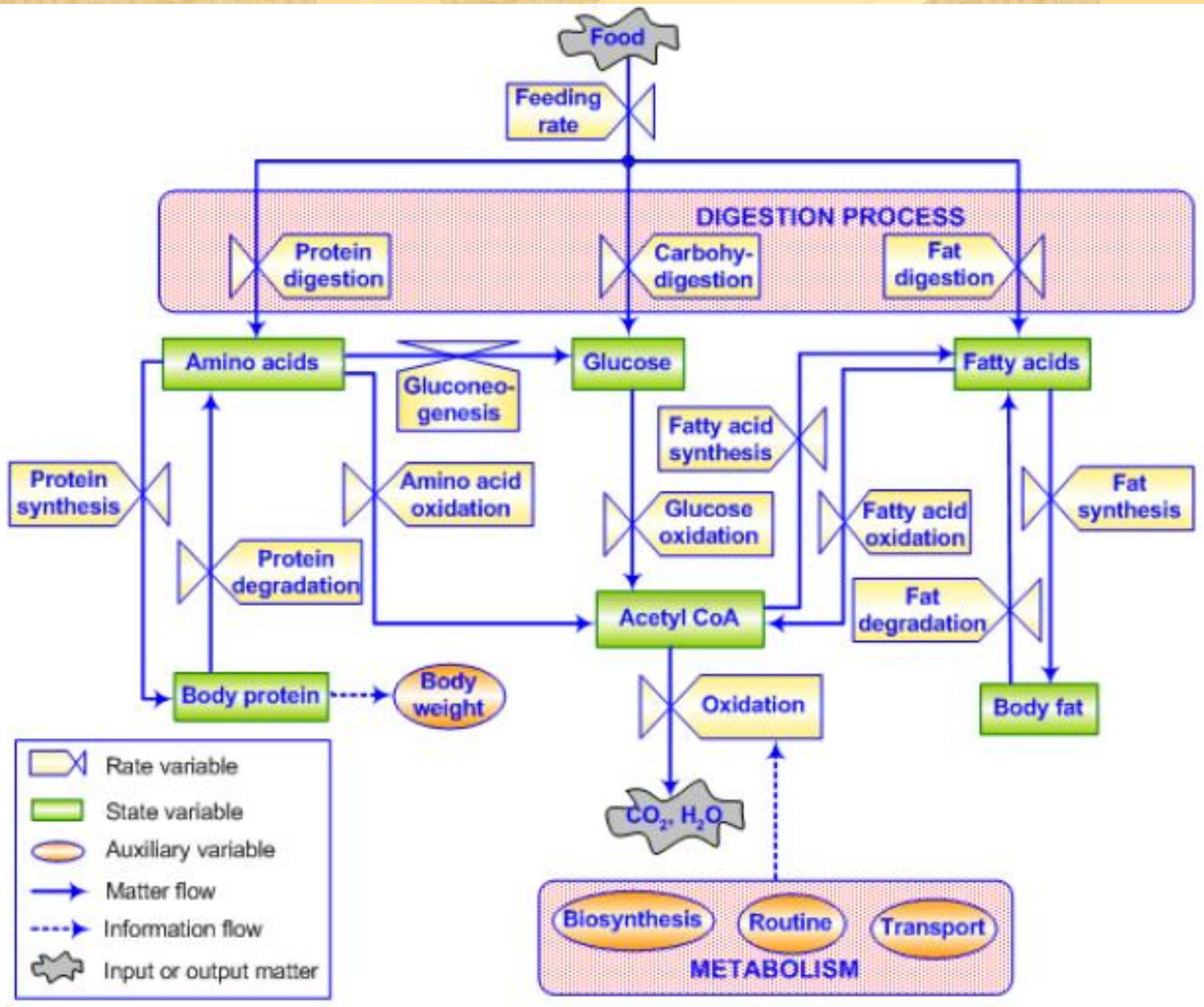


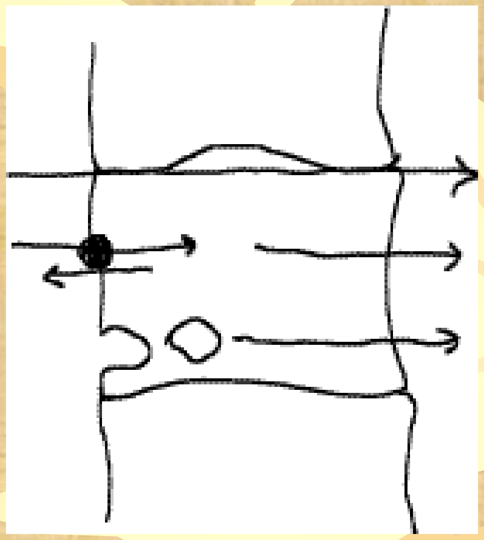
Figure 1. Schematic relational diagram of the model

Absorption (Continued) Carbohydrates

- Active Co-transport (Anti-port) of Simple Sugars
- Sodium Ion – Moves out Passively in Response to Solute Gradient
- If Protein Gates Saturated no Futher Absorption
- Cellulose, Though Complex Carbohydrate is Fermented into Volatile Fatty Acids

Absorption (Continued) Proteins

- Mono-peptides (Amino Acids)
  - CoTransport (Antiport) via Na Linked System
  - Movement Between Cells
- Di-peptides
  - CoTransport (Antiport)
  - Pinocytosis
- Poly-peptides
  - Pinocytosis



Part 2: Nutrient Metabolism

Metabolism: carbohydrates

Metabolism: the biological utilization of absorbed nutrients for synthesis (e.g., growth) and energy expenditure

as mentioned, for most aquatic species, the protein sparing effect of COH is good

however, COH metabolism has a long lag time associated with it

once COH is ingested/digested, blood levels quickly rise, but require extended periods to decline

Metabolism: carbohydrates

This lag response is considered similar in effect to that of diabetes

thus, turnover of COH by aquatics is much slower than that of land animals

explanation: aquatics often prefer to oxidize amino acids for energy

COH metabolic role: 1) immediate source of energy; 2) energy reserve (glycogen); 3) converted to triglyceride; 4) synthesis of non-essential amino acids

Metabolism: COH/energy

Normal pathway of converting COH to energy is known as **glycolysis**

1 mole of glucose converted to 2 moles of pyruvate = 6 ATP's

each mole of ATP represents 7.3 kcal energy

overall energy efficiency is 41% (fairly efficient transformation)

Metabolism: COH/energy

The entire oxidation of glucose utilizes two mechanisms: **Glycolysis** and **TCA** cycle

glycolysis takes place in cytosol, TCA in the mitochondria

TCA cycle utilizes a variety of substrates (e.g., amino acids, fatty acids, keto acids) for energy gain each turn on the TCA cycle = 15 ATP (w/2 molecules of pyruvate entering, this equals a total of 30 ATP

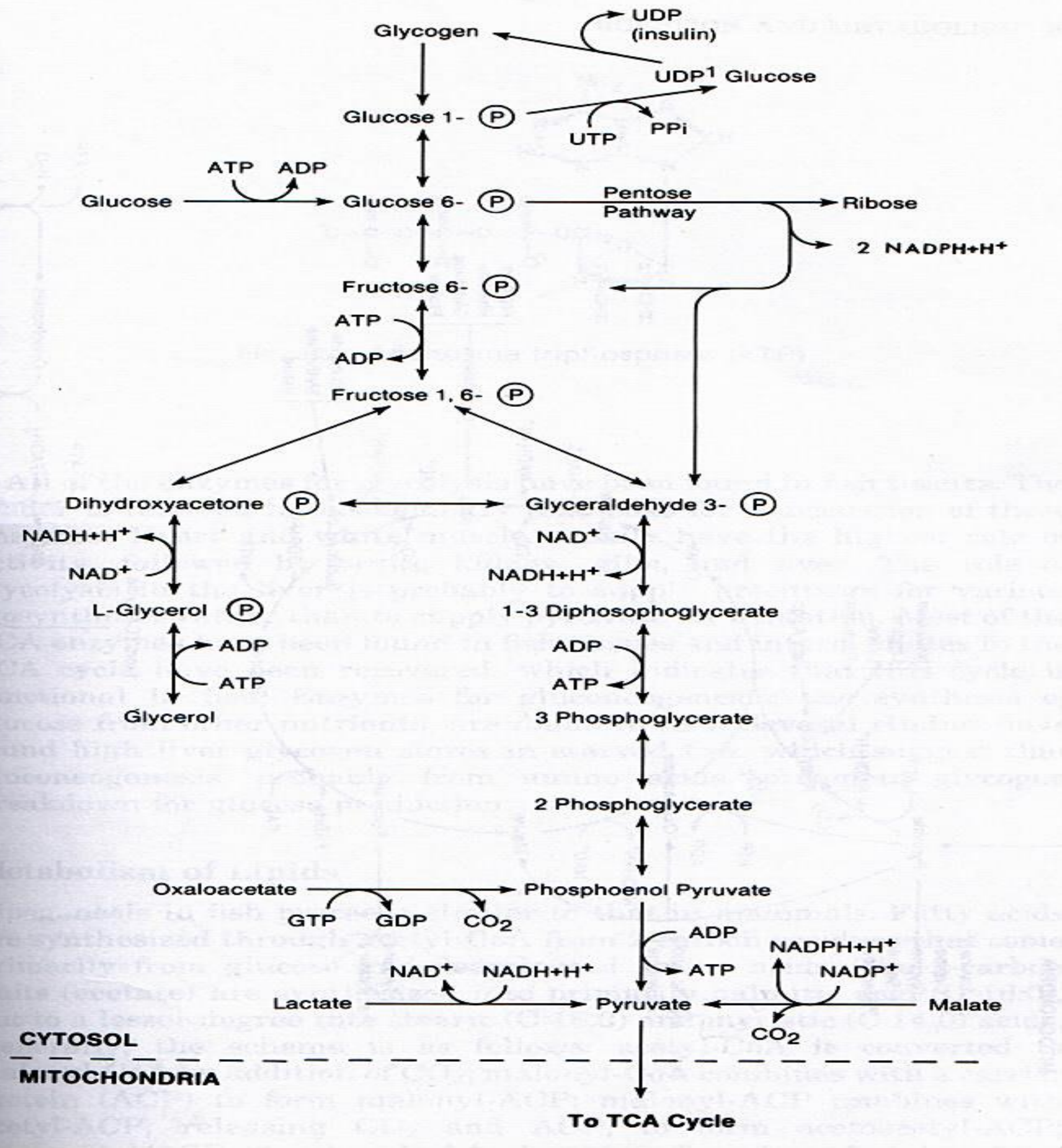
Metabolism: COH/energy

All the enzymes for glycolysis/TCA have been identified in fish tissues

those tissues showing highest enzyme activity are the heart and muscle tissue others include brain, kidney, gills, liver

gluconeogenesis: synthesis of glucose as a result of starvation

Glycolytic Pathway



Metabolism: lipids

Formation of lipids is known as **lipogenesis**

formation is through compound known as acetyl CoA (entering into TCA cycle)

fats are derived from the carbon skeleton found in all COH and non-essential amino acids

Step 1: COH, NEAA broken down into 2-carbon units known as acetate

Step 2: acetate converted to stearic acid or palmitic acid

responsible enzyme: fatty acid synthetase

Metabolism: fatty acids

Once palmitate (16 C) has been formed, it can be elongated and desaturated by enzymes in the mitochondria

the ability to chain elongate seldom exceeds 18 carbons in length

FA's (fatty acids) are added to glycerol phosphate (from glycolysis) to form a lipid

primary site for FA synthesis is in liver and adipose

Metabolism: fatty acids

Catabolism or oxidation of fatty acids in fish is similar to that of mammals

once you hydrolyze the fat (remove FA's) the glycerol moeity goes back into glycolytic pathway for energy production

release of triglycerides from adipose is under hormonal control

obesity: disease in which individual lacks ability to mobilize triglycerides

Metabolism: amino acids

Amino acids are "stored" in the body's amino acid pool

release is controlled by liver

sources: dietary and catabolism of proteins

protein metabolism: oxidation followed by energy release, carbon skeleton use for FA synthesis

amino acids, unlike lipids and COH, are not stored in the body

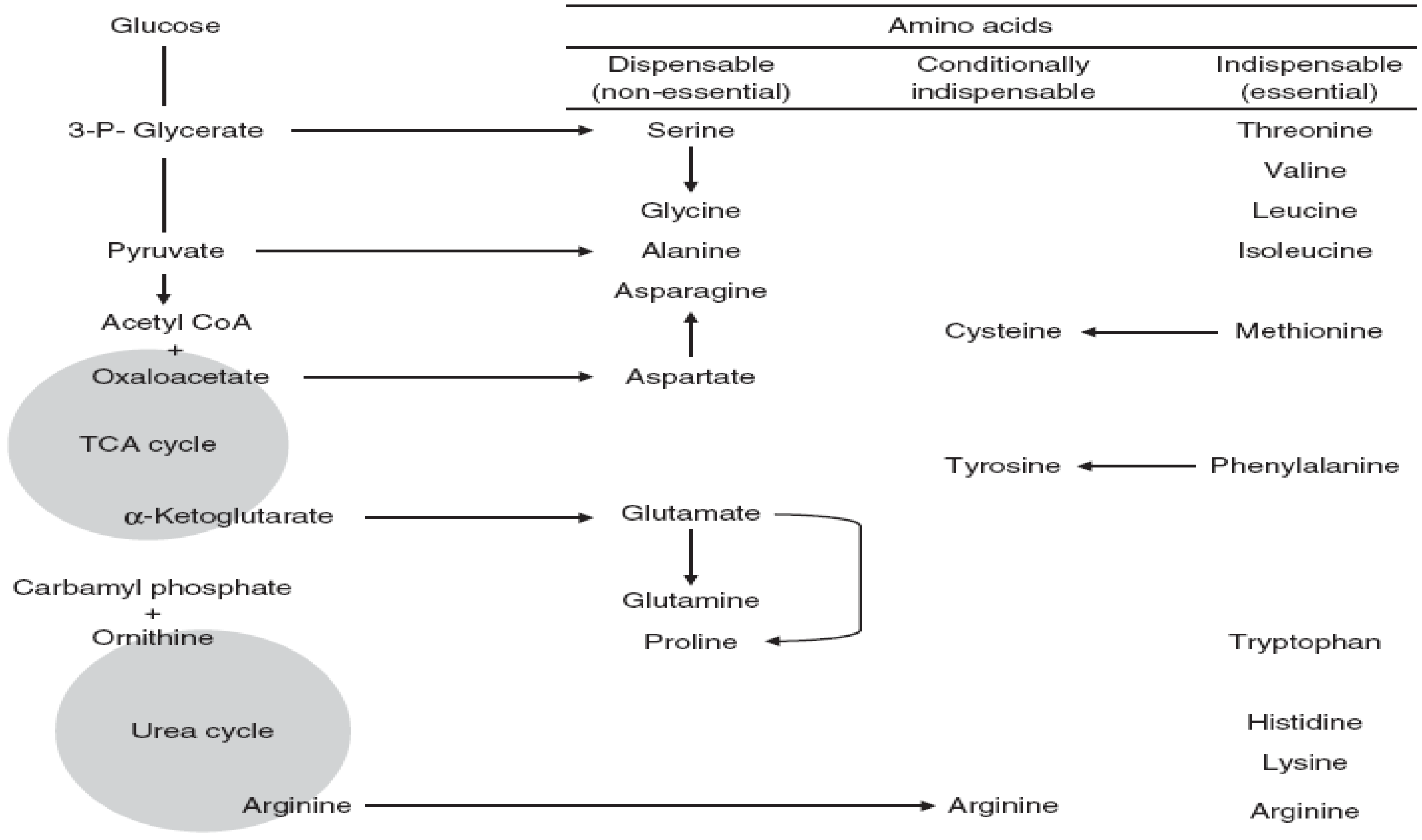
Metabolism: amino acids

Excesses of AA's (amino acids) in pool are deaminated and C-skel burnt for energy or converted to COH/lipid

where do the amino (NH_3) groups go?

They are transaminated (passed to a different C-skel) and eventually either excreted or used for subsequent AA synthesis

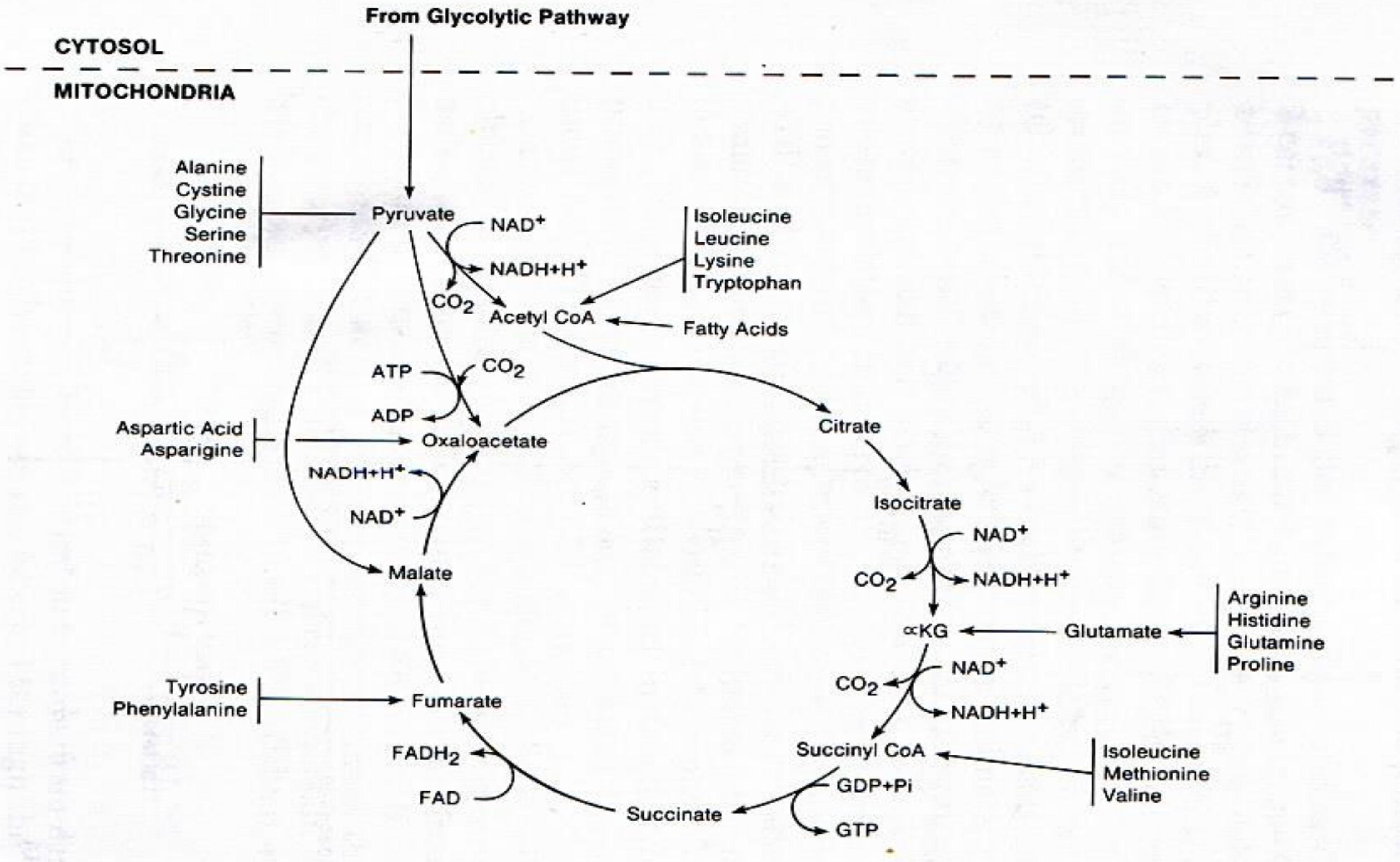
Terrestrials excrete urine, birds excrete uric acid, inverts/fish largely ammonia

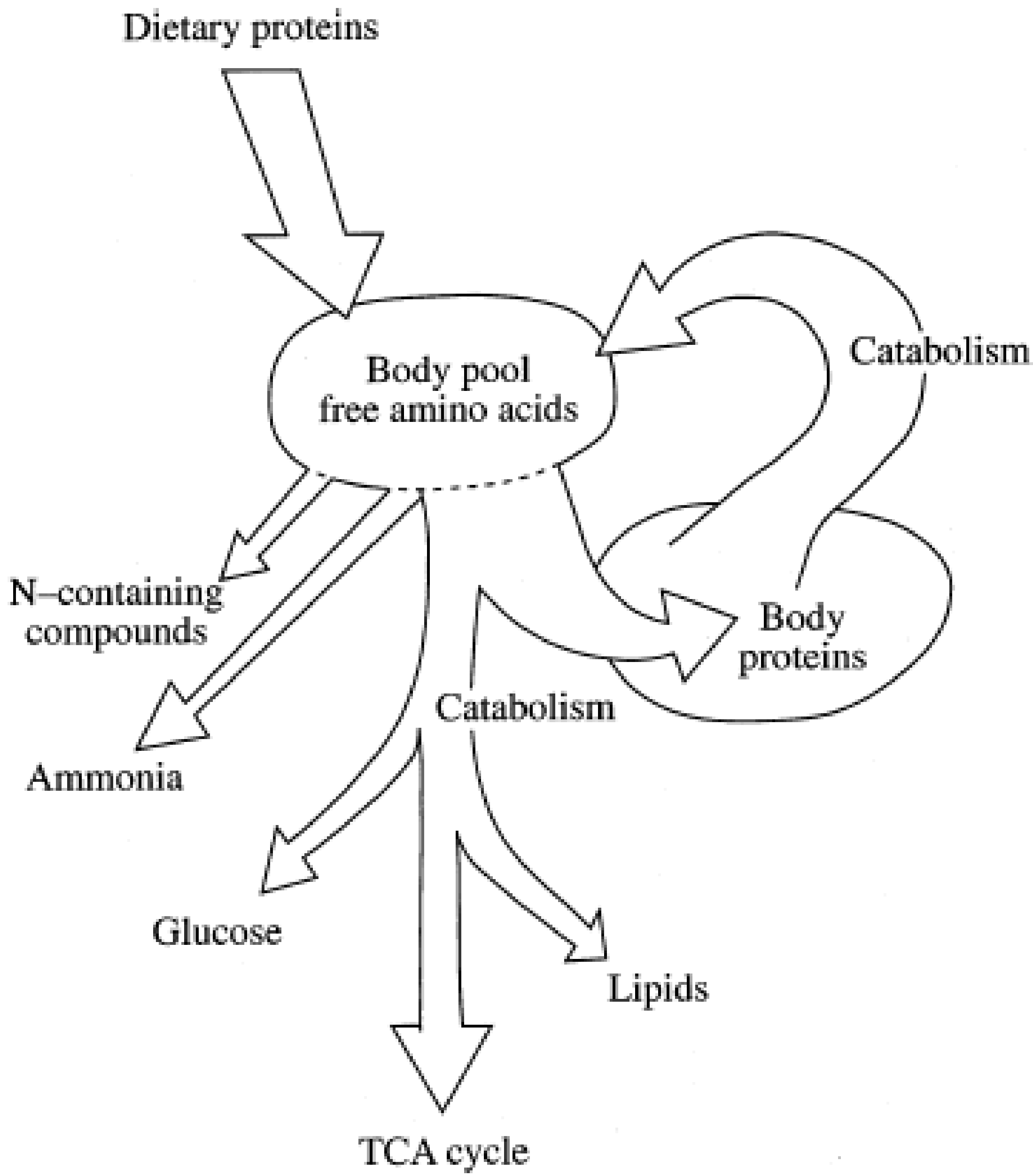


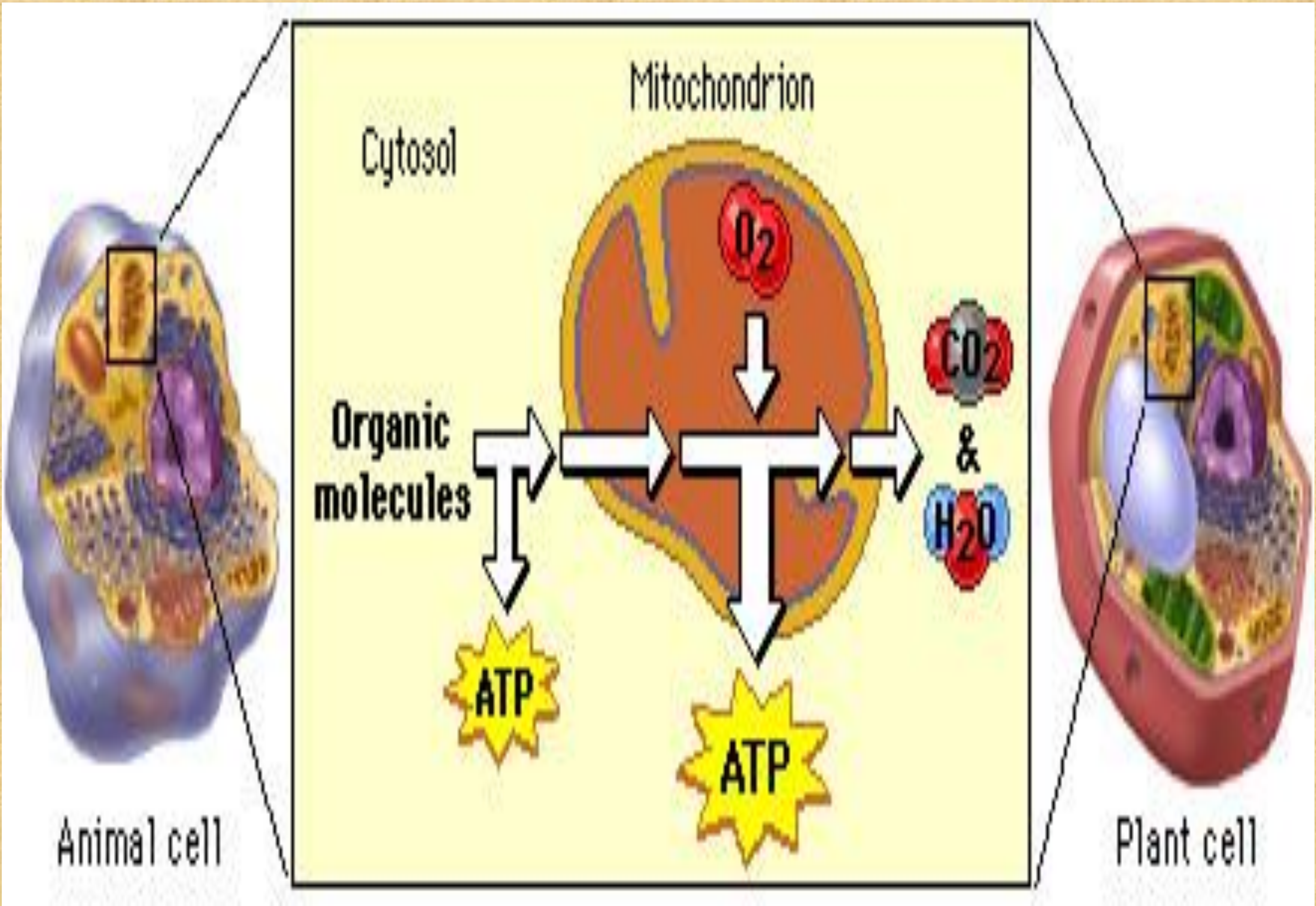
Pathways for amino acid synthesis, transformation and metabolism. An overview of the indispensable (essential), conditionally indispensable and dispensable (non-essential) amino acids is given. Conditionally, indispensable amino acids can be synthesized from indispensable amino acid precursors, whereas dispensable amino acids can be synthesized from a range of organic compounds. TCA cycle = tricarboxylic acid cycle.

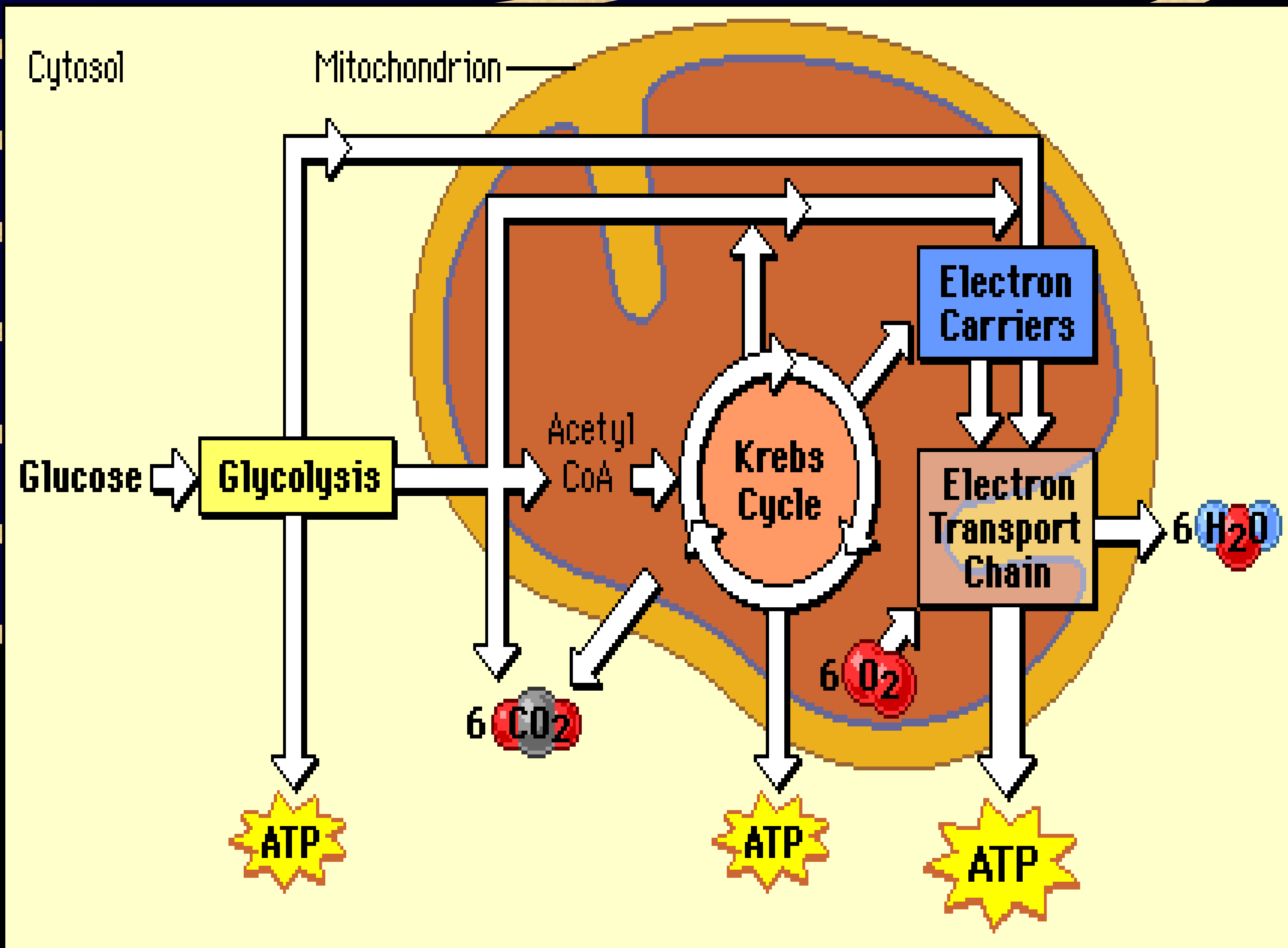
The majority of tissue in a fish, approximately 60% is the swimming musculature, of which fish have two primary types .Red (slow-twitch, oxidative) fibers are typically located in a superficial lateral wedge between the epaxial and hypaxial regions of white (fast-twitch, glycolytic) fibers. The red muscle is specialized for sustained, aerobic swimming contractions, while the white muscle has a high anaerobic capacity for powerful, short-duration bursts of activity. In tunas, the red muscle position is more internalized compared to ectothermic teleosts, extending from the superficial lateral region in toward the backbone. The lateral wedge in fish may contain red, white, or pink (intermediate, or fast, oxidative-glycolytic) fibers, depending on the species .The internalized position of the red muscle in fish is associated with vascular countercurrent heat exchangers which trap metabolic heat produced during muscle contractions, allowing fish to elevate red muscle temperature above ambient

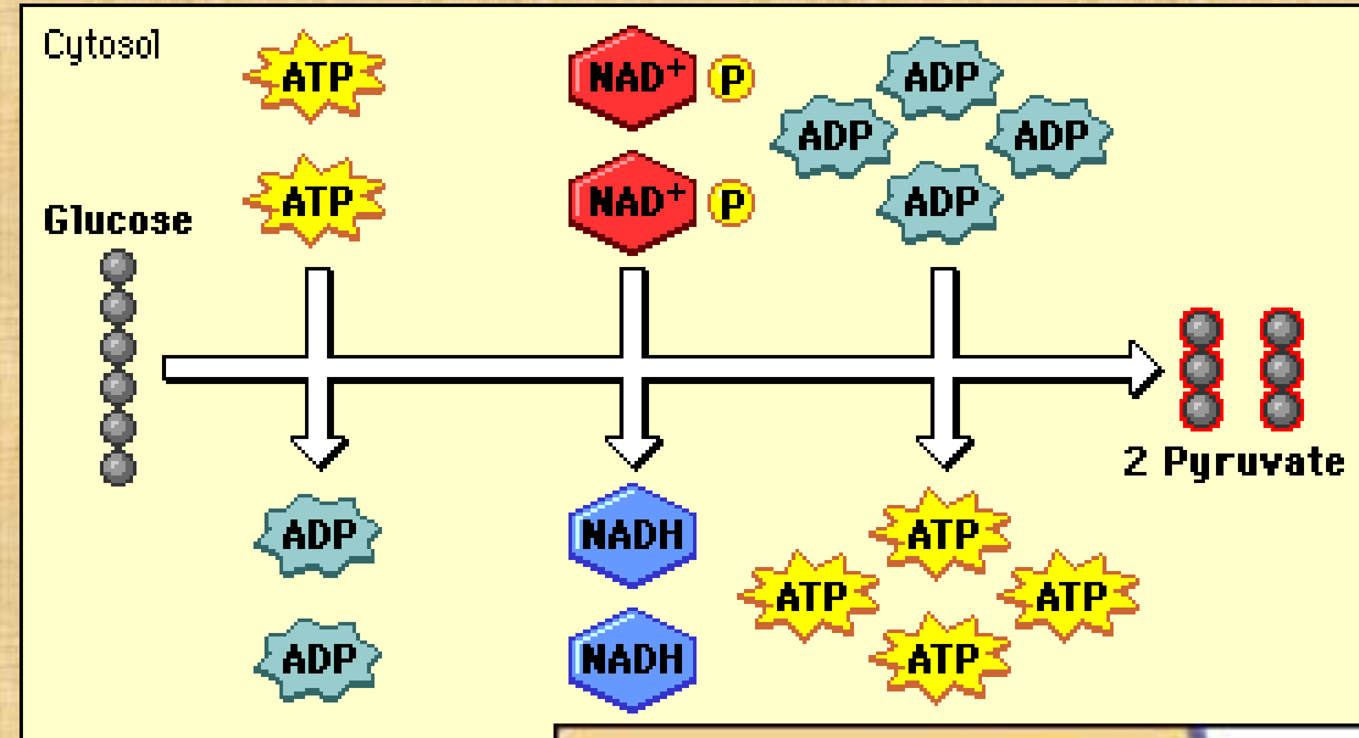
Tricarboxylic Acid Cycle

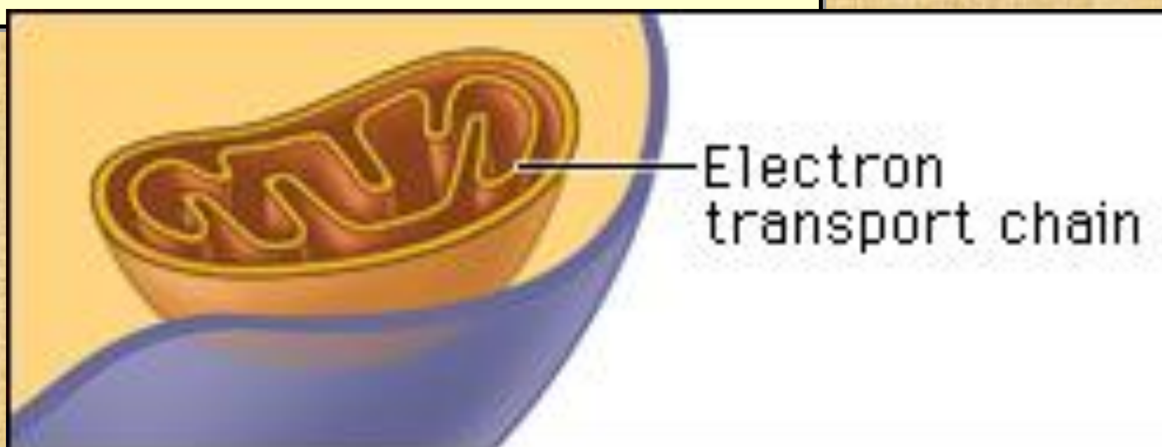



Dietary proteins
Body pool
free amino acids
Catabolism
N–containing
compounds
Body
proteins
Catabolism
Ammonia
Glucose
Lipids
TCA cycle


Mitochondrion
Cytosol
O_2
CO_2
&
H_2O
Organic molecules
ATP
ATP
Animal cell
Plant cell

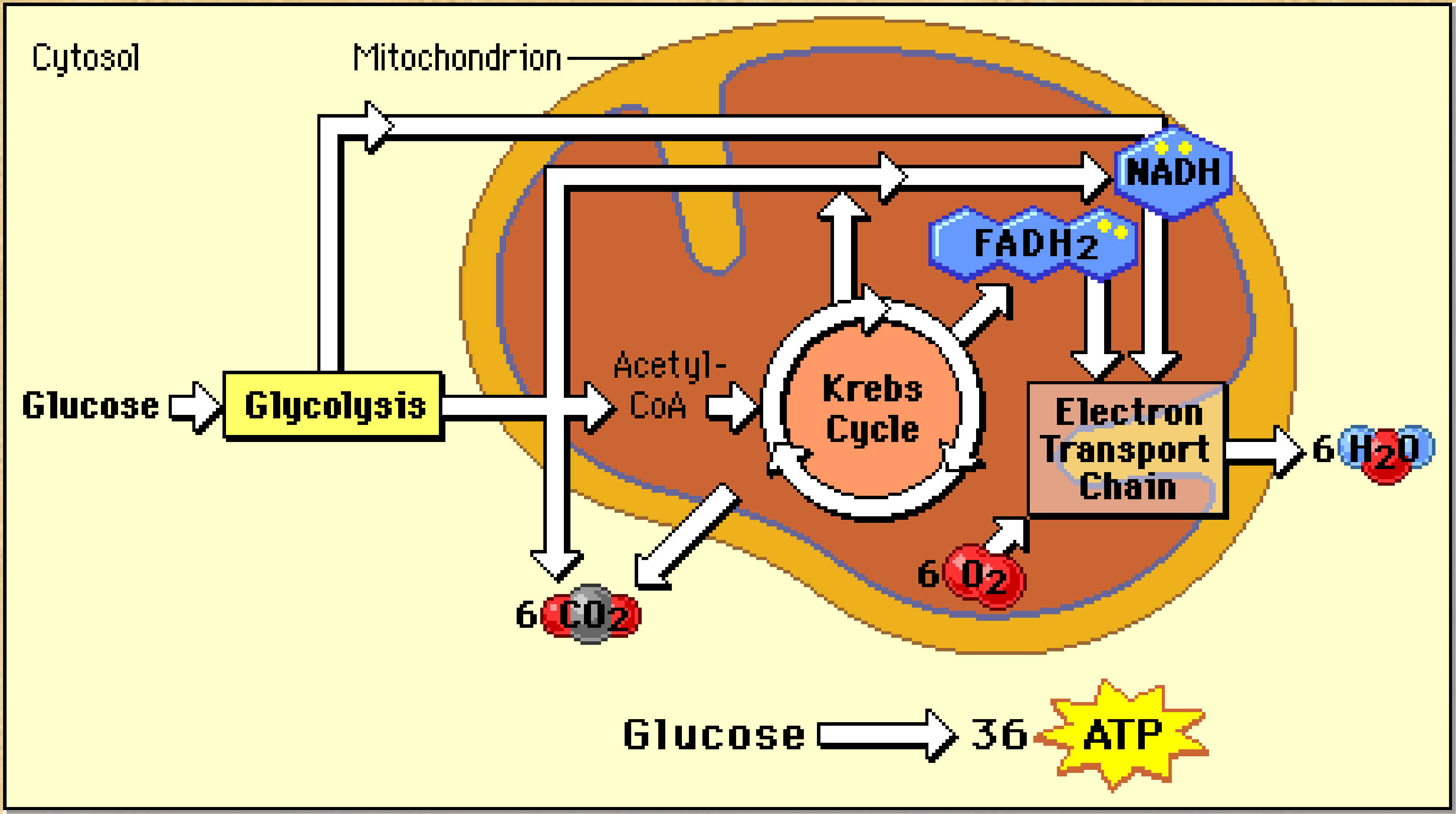

Cytosol
Mitochondrion
Glucose
Glycolysis
Acetyl CoA
Krebs Cycle
Electron Carriers
Electron Transport Chain
6 CO_2
6 O_2
6 H_2O
ATP
ATP
ATP

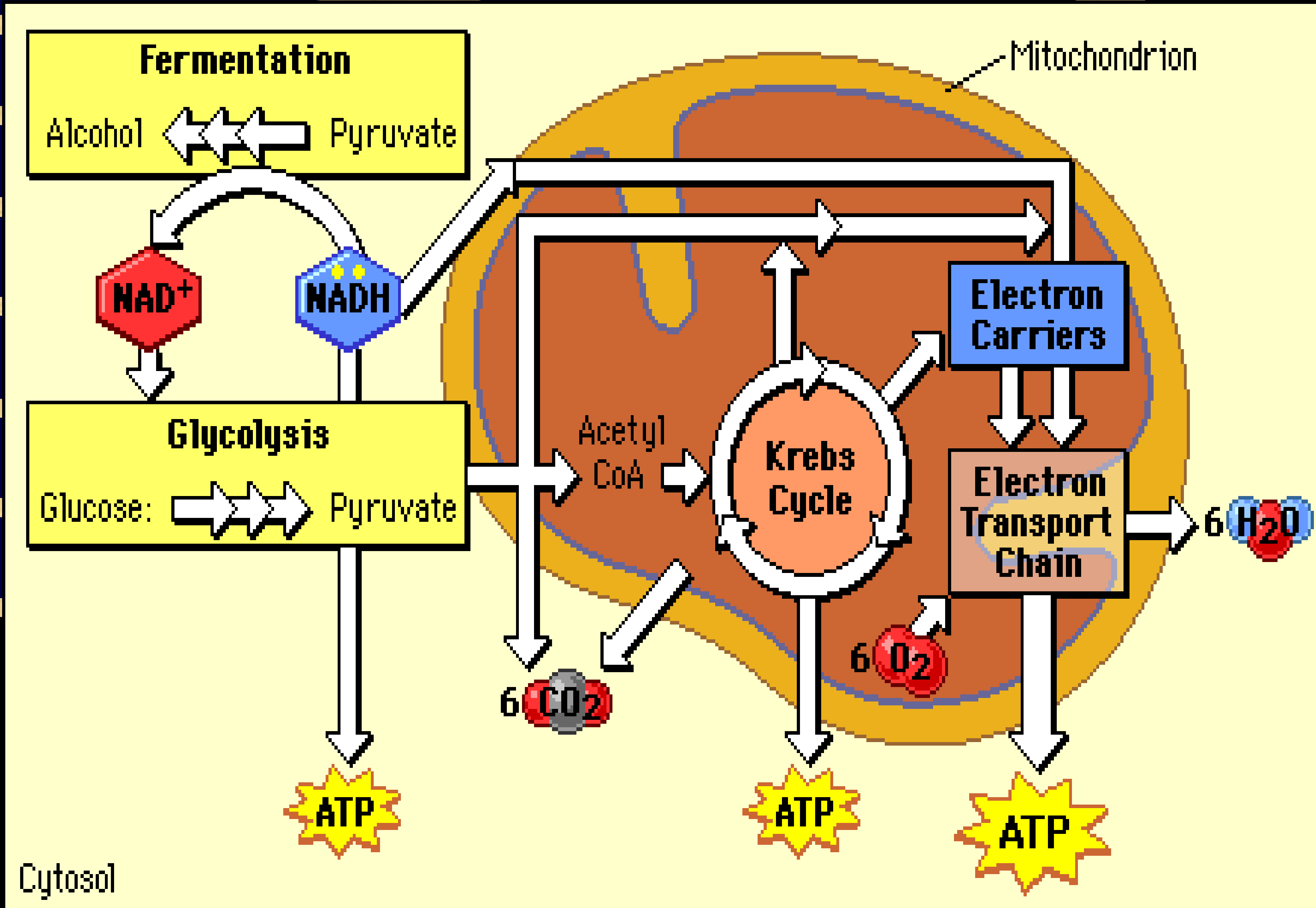


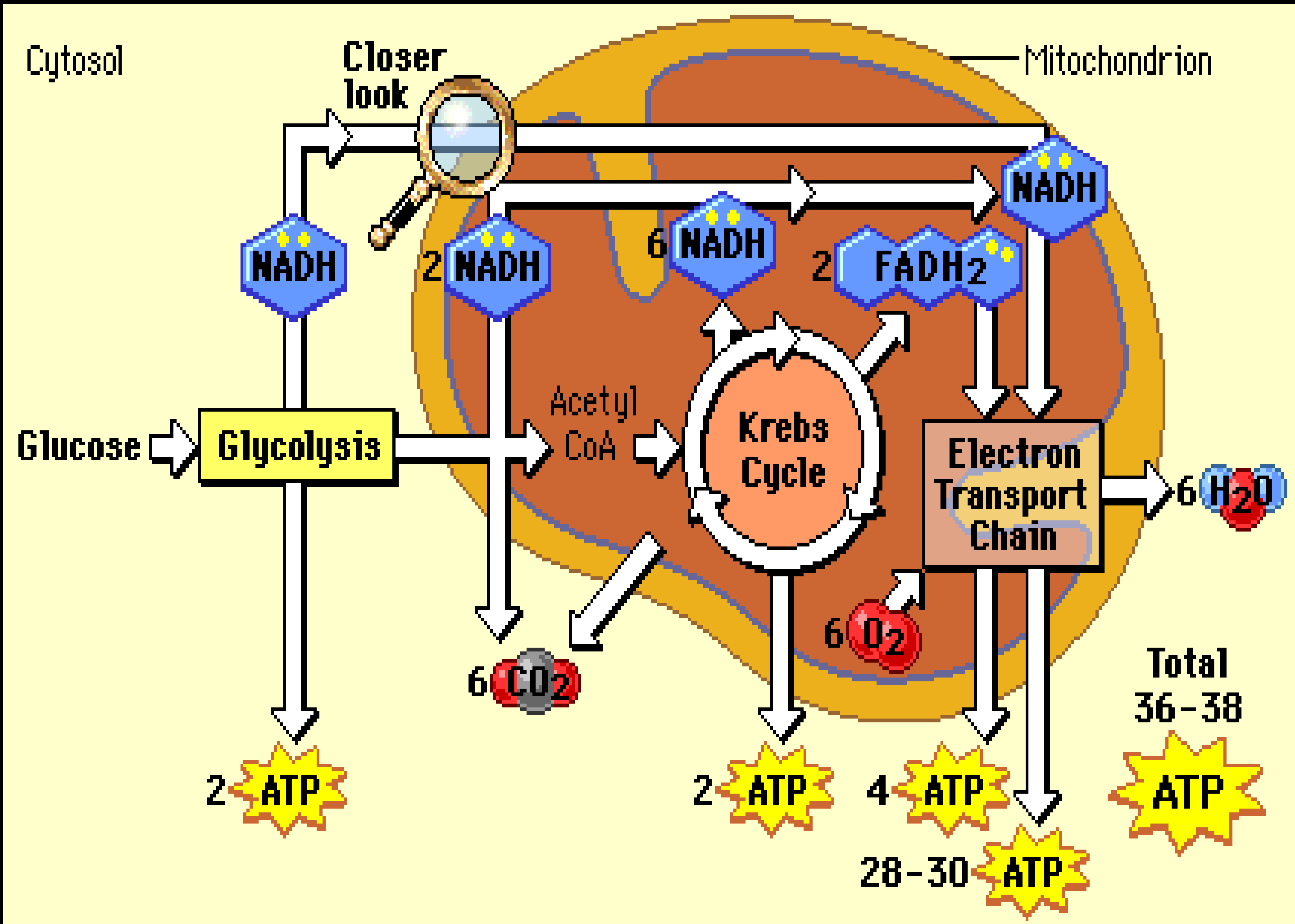


$$NADH + H^+ + 3\ ADP + 3\ Pi + 1/2\ O_2 \rightarrow NAD^+ + H_2O + 3\ ATP$$

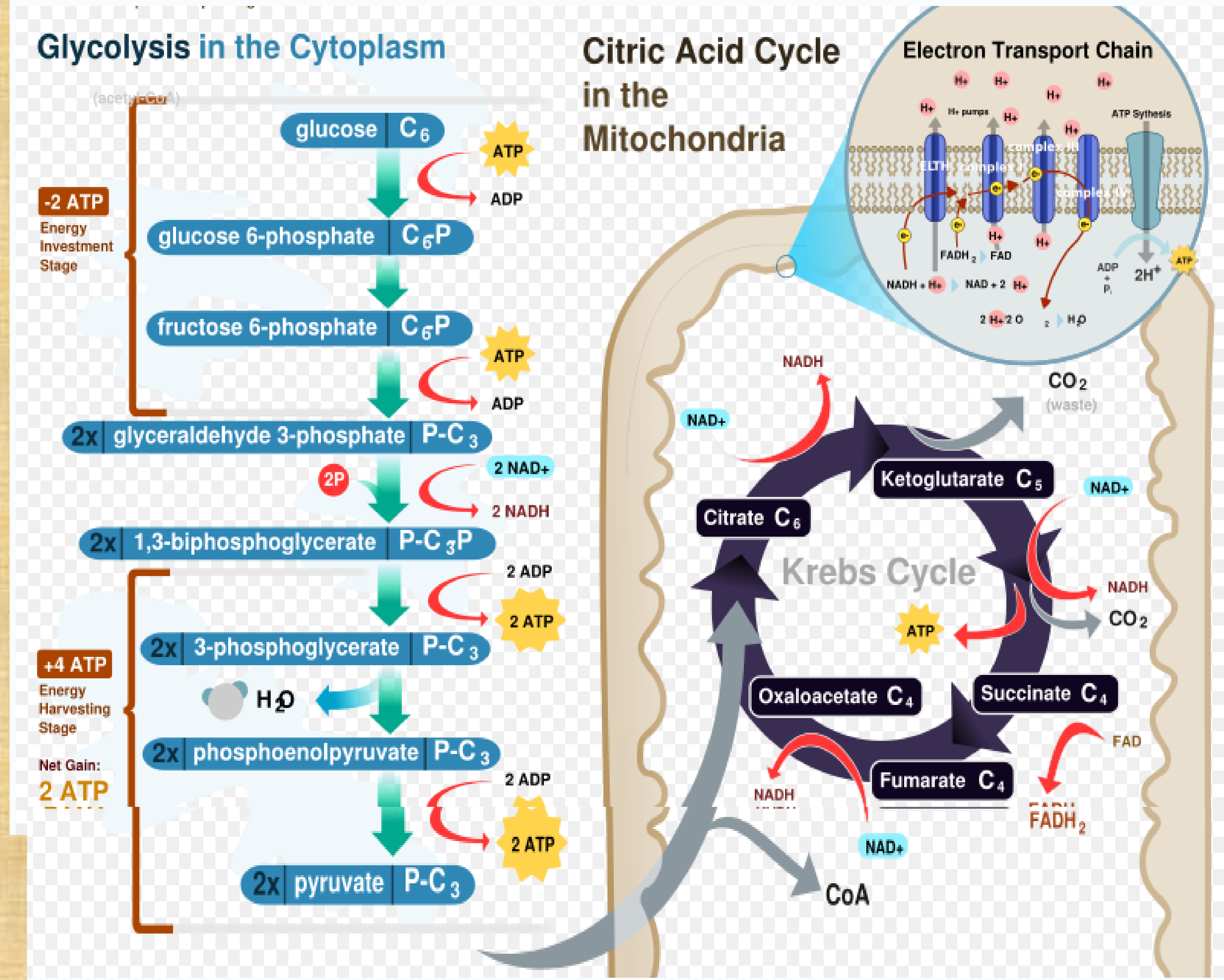
$$FADH_2 + 2\ ADP + 2\ Pi + 1/2\ O_2 \rightarrow FAD^+ + H_2O + 2\ ATP$$


Cytosol
Mitochondrion
Glucose
Glycolysis
NADH
FADH2
Acetyl-CoA
Krebs Cycle
Electron Transport Chain
6 H2O
6 O2
6 CO2
Glucose
36
ATP


Fermentation
Alcohol
Pyruvate
Mitochondrion
NAD+
NADH
Glycolysis
Glucose:
Pyruvate
Acetyl CoA
Krebs Cycle
Electron Carriers
Electron Transport Chain
6 H_2O
6 O_2
6 CO_2
ATP
ATP
ATP
Cytosol



Cytosol
Closer look
Mitochondrion
NADH
2 NADH
6 NADH
2 FADH2
NADH
Glucose
Glycolysis
Acetyl CoA
Krebs Cycle
Electron Transport Chain
6 H2O
6 O2
6 CO2
2 ATP
2 ATP
4 ATP
28-30 ATP
Total 36-38 ATP



Glycolysis in the Cytoplasm
(acetyl-CoA)
glucose C6
ATP
ADP
-2 ATP
Energy Investment Stage
glucose 6-phosphate C6P
fructose 6-phosphate C6P
ATP
ADP
2x glyceraldehyde 3-phosphate P-C3
2P
2 NAD+
2 NADH
2x 1,3-biphosphoglycerate P-C3P
2 ADP
2 ATP
2x 3-phosphoglycerate P-C3
+4 ATP
Energy Harvesting Stage
H2O
2x phosphoenolpyruvate P-C3
Net Gain:
2 ATP
2 ADP
2 ATP
2x pyruvate P-C3
Citric Acid Cycle in the Mitochondria
Electron Transport Chain
H+
H+ pumps
ATP Sythesis
complex III
complex I
complex IV
ELTH
FADH2
FAD
NADH + H+
NAD + 2 H+
2 H+ 2 O
H2O
ADP + Pi
2H+
ATP
NADH
NAD+
CO2
(waste)
Ketoglutarate C5
NAD+
Citrate C6
Krebs Cycle
NADH
CO2
ATP
Oxaloacetate C4
Succinate C4
FAD
Fumarate C4
NADH
FADH2
NAD+
CoA