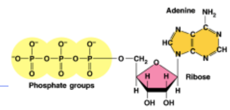
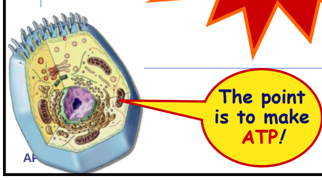
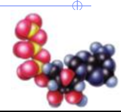
Making energy!

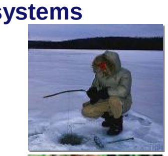






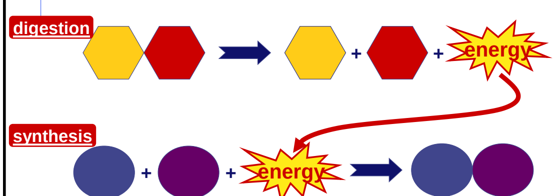
The energy needs of life

- Organisms are endergonic systems
  - What do we need energy for?
    - synthesis
      - building biomolecules
    - reproduction
    - movement
    - active transport
    - temperature regulation



Where do we get the energy from?

- Work of life is done by energy coupling
  - use exergonic (catabolic) reactions to fuel endergonic (anabolic) reactions

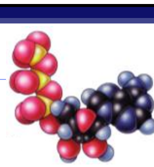


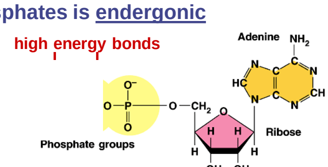
Living economy

- Fueling the body's economy
  - eat high energy organic molecules
    - food = carbohydrates, lipids, proteins, nucleic acids
  - break them down
    - digest = catabolism
  - capture released energy in a form the cell can use
- Need an energy currency
  - a way to pass energy around
  - need a short term energy storage molecule

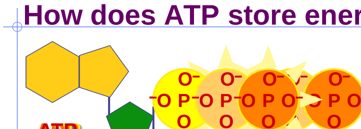
ATP

- Adenosine TriPhosphate
  - modified nucleotide
    - nucleotide = adenine + ribose + $P_i \rightarrow$ AMP
    - AMP + $P_i \rightarrow$ ADP
    - ADP + $P_i \rightarrow$ ATP
  - adding phosphates is endergonic





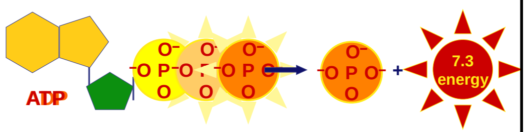
How does ATP store energy?



- Each negative PO_4 more difficult to add
  - a lot of stored energy in each bond
    - most energy stored in 3rd P_i
    - 3rd P_i is hardest group to keep bonded to molecule
- Bonding of negative P_i groups is unstable
  - *spring-loaded*
  - P_i groups "pop" off easily & release energy

Instability of its P bonds makes ATP an excellent energy donor

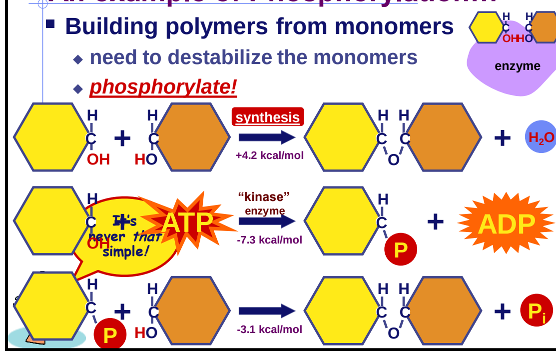
How does ATP transfer energy?



- ATP → ADP
  - releases energy
    - ΔG = -7.3 kcal/mole
- Fuel other reactions
- Phosphorylation
  - released P_i can transfer to other molecules
    - destabilizing the other molecules
  - enzyme that phosphorylates = "kinase"

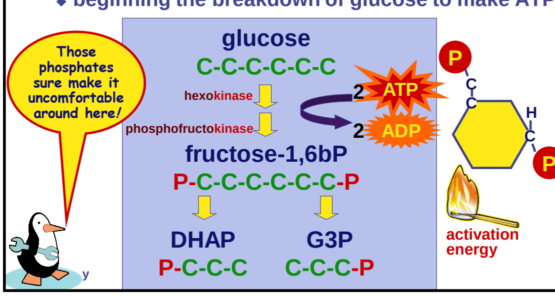
An example of Phosphorylation…

- Building polymers from monomers
  - need to destabilize the monomers
  - *phosphorylate!*



Another example of Phosphorylation…

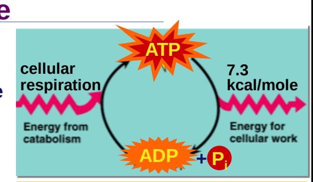
- The first steps of cellular respiration
  - beginning the breakdown of glucose to make ATP



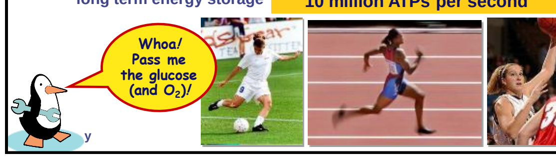
ATP / ADP cycle

Can't store ATP

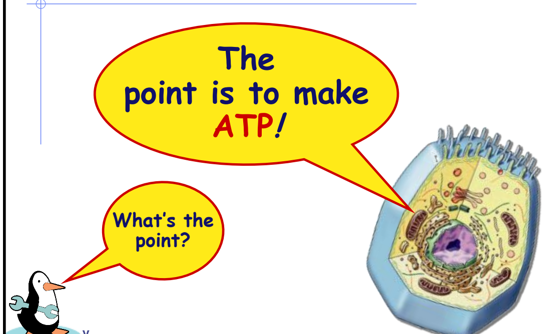
- good energy donor, not good energy storage
  - ✓ too reactive
  - ✓ transfers P_i too easily
  - ✓ only short term energy storage
    - carbohydrates & fats are long term energy storage



A working muscle recycles over 10 million ATPs per second

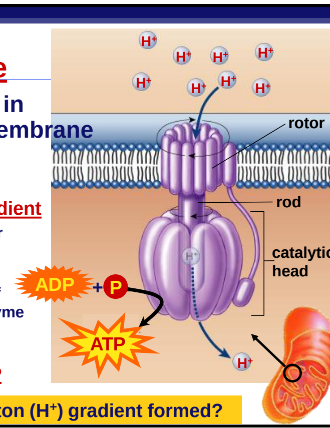


Cells spend a lot of time making ATP!

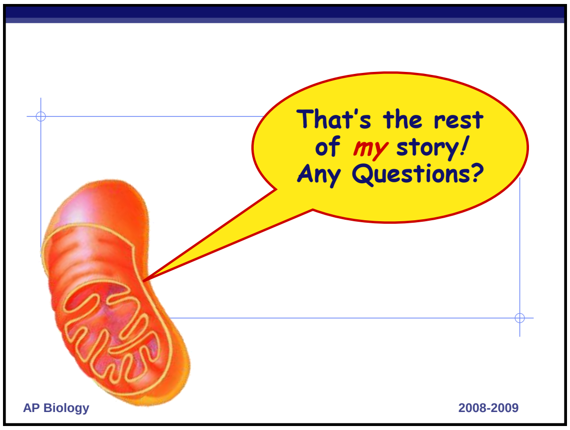


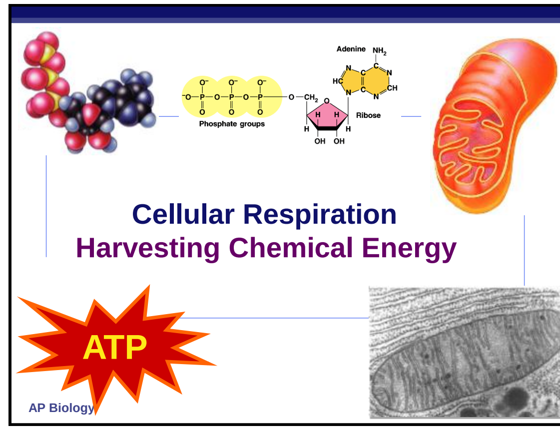
ATP synthase

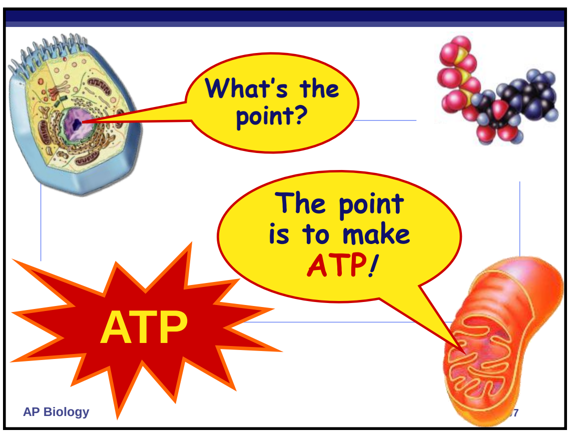
- Enzyme channel in mitochondrial membrane
  - permeable to H^+
  - H^+ flow down concentration gradient
    - flow like water over water wheel
    - flowing H+ cause change in shape of ATP synthase enzyme
    - powers bonding of P_i to ADP:
      $ADP + P_i \rightarrow ATP$

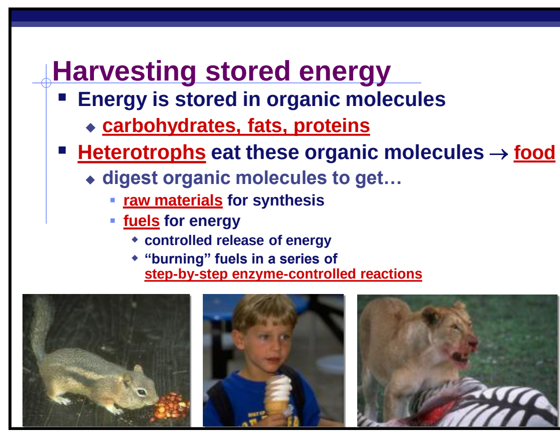


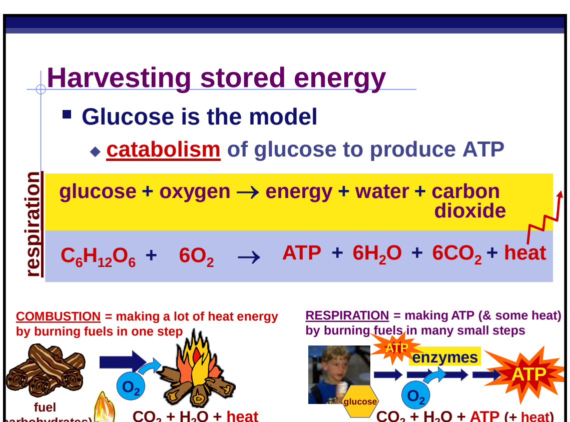
But… How is the proton (H^+) gradient formed?

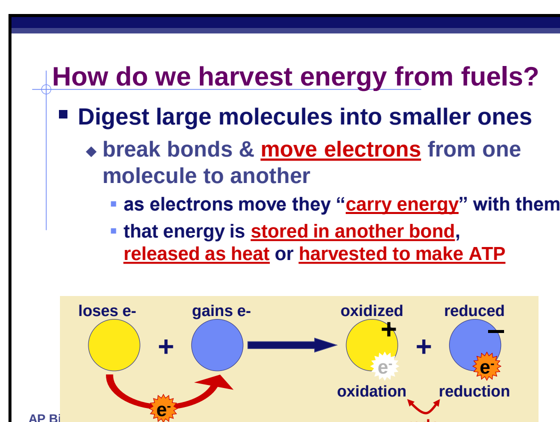

That's the rest of my story! Any Questions?
AP Biology
2008-2009


Adenine
Phosphate groups
Ribose
Cellular Respiration
Harvesting Chemical Energy
ATP
AP Biology


What's the point?
The point is to make ATP!
ATP
AP Biology

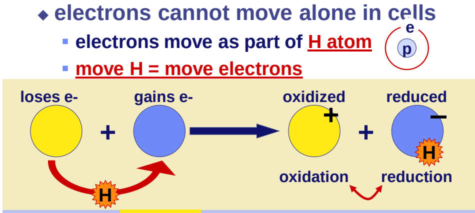

Harvesting stored energy
Energy is stored in organic molecules
carbohydrates, fats, proteins
Heterotrophs eat these organic molecules → food
digest organic molecules to get…
raw materials for synthesis
fuels for energy
controlled release of energy
"burning" fuels in a series of step-by-step enzyme-controlled reactions


Harvesting stored energy
Glucose is the model
catabolism of glucose to produce ATP
respiration
glucose + oxygen → energy + water + carbon dioxide
$C_6H_{12}O_6$ + $6O_2$ → ATP + $6H_2O$ + $6CO_2$ + heat
COMBUSTION = making a lot of heat energy by burning fuels in one step
fuel (carbohydrates)
O_2
CO_2 + H_2O + heat
RESPIRATION = making ATP (& some heat) by burning fuels in many small steps
ATP
enzymes
glucose
O_2
ATP
CO_2 + H_2O + ATP (+ heat)


How do we harvest energy from fuels?
Digest large molecules into smaller ones
break bonds & move electrons from one molecule to another
as electrons move they "carry energy" with them
that energy is stored in another bond, released as heat or harvested to make ATP
loses e-
gains e-
oxidized
reduced
+
+
oxidation
reduction
redox
e-
e-
e-

How do we move electrons in biology?

- Moving electrons in living systems
  - electrons cannot move alone in cells
    - electrons move as part of H atom
    - move H = move electrons



oxidation

$C_6H_{12}O_6$ + $6O_2$ → $6CO_2$ + $6H_2O$ + ATP

reduction

Coupling oxidation & reduction

- REDOX reactions in respiration
  - release energy as breakdown organic molecules
    - break C-C bonds
    - strip off electrons from C-H bonds by removing H atoms
      - $C_6H_{12}O_6 \rightarrow CO_2$ = the fuel has been oxidized
    - electrons attracted to more electronegative atoms
      - in biology, the most electronegative atom? O
      - $O_2 \rightarrow H_2O$ = oxygen has been reduced
  - couple REDOX reactions & use the released energy to synthesize ATP

oxidation

$C_6H_{12}O_6$ + $6O_2$ → $6CO_2$ + $6H_2O$ + ATP

reduction

Oxidation & reduction

- Oxidation
  - adding O
  - removing H
  - loss of electrons
  - releases energy
  - exergonic
- Reduction
  - removing O
  - adding H
  - gain of electrons
  - stores energy
  - endergonic

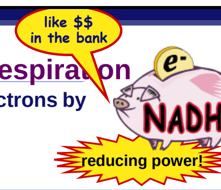
oxidation

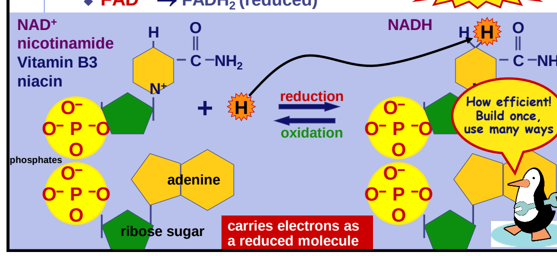
$C_6H_{12}O_6$ + $6O_2$ → $6CO_2$ + $6H_2O$ + ATP

reduction

Moving electrons in respiration

- Electron carriers move electrons by shuttling H atoms around
  - $NAD^+ \rightarrow$ NADH (reduced)
  - $FAD^{+2} \rightarrow FADH_2$ (reduced)

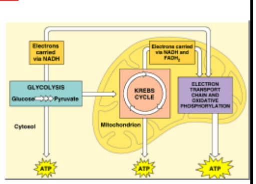




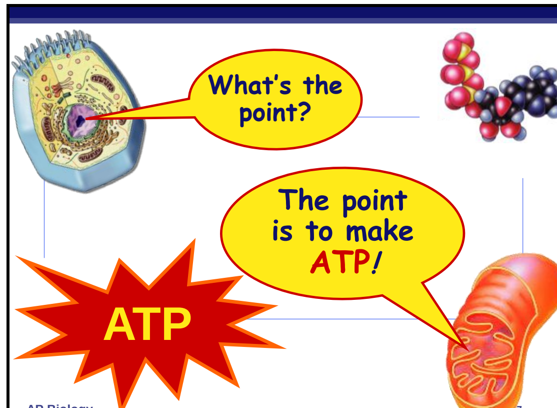
carries electrons as a reduced molecule

Overview of cellular respiration

- 4 metabolic stages
  - Anaerobic respiration
    1. Glycolysis
       - respiration without O_2
       - in cytosol
  - Aerobic respiration
       - respiration using O_2
       - in mitochondria
    2. Pyruvate oxidation
    3. Krebs cycle
    4. Electron transport chain

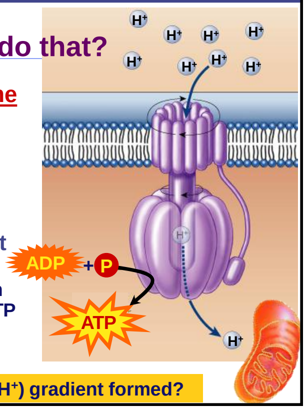


$C_6H_{12}O_6$ + $6O_2$ → ATP + $6H_2O$ + $6CO_2$ (+ heat)

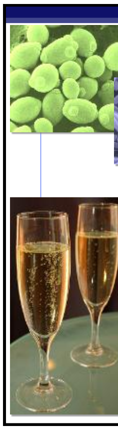


And how do we do that?

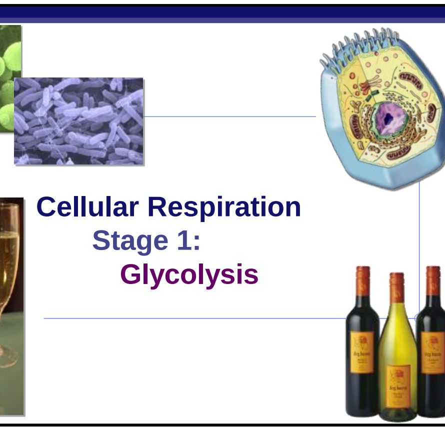
- ATP synthase enzyme
  - H^+ flows through it
    - conformational changes
    - bond P_i to ADP to make ATP
  - set up a H^+ gradient
    - allow the H^+ to flow down concentration gradient through ATP synthase
    - ADP + P_i → ATP

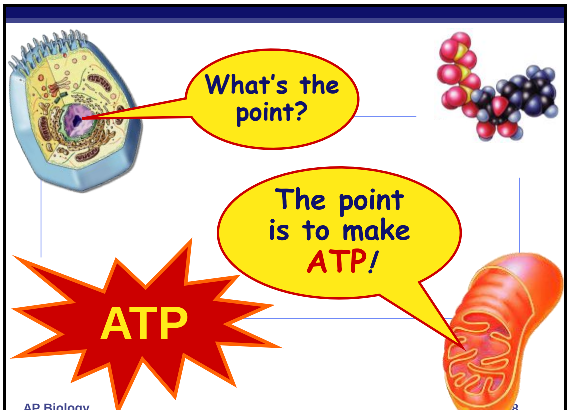


But… How is the proton (H^+) gradient formed?



Cellular Respiration
Stage 1: Glycolysis





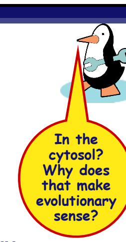
AP Biology

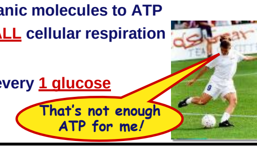
Glycolysis

- Breaking down glucose
  - "glyco – lysis" (splitting sugar)

glucose → → → → → pyruvate	
6C	2x 3C

  - ancient pathway which harvests energy
    - where energy transfer first evolved
    - transfer energy from organic molecules to ATP
    - still is starting point for ALL cellular respiration
  - but it's inefficient
    - generate only 2 ATP for every 1 glucose
  - occurs in cytosol

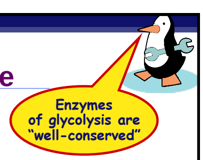




AP Biology

Evolutionary perspective

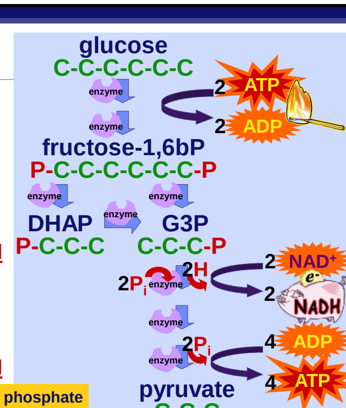
- Prokaryotes
  - first cells had no organelles
- Anaerobic atmosphere
  - life on Earth first evolved without free oxygen (O_2) in atmosphere
  - energy had to be captured from organic molecules in absence of O_2
- Prokaryotes that evolved glycolysis are ancestors of all modern life
  - ALL cells still utilize glycolysis



Overview

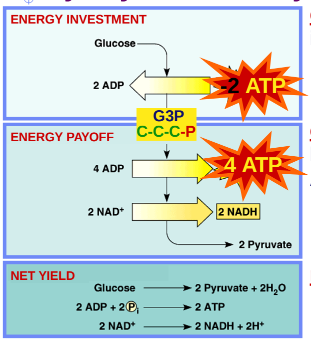
10 reactions

- convert glucose (6C) to 2 pyruvate (3C)
- produces: 4 ATP & 2 NADH
- consumes: 2 ATP
- net yield: 2 ATP & 2 NADH



DHAP = dihydroxyacetone phosphate
G3P = glyceraldehyde-3-phosphate

Glycolysis summary



endergonic
invest some ATP

exergonic
harvest a little ATP & a little NADH

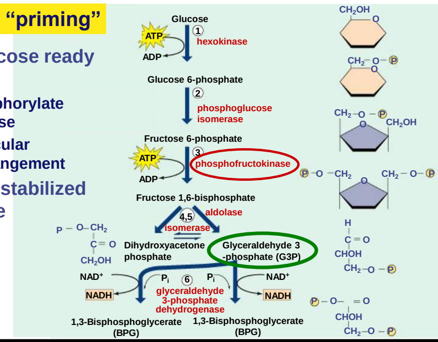
like $$ in the bank

net yield
✓2 ATP
✓2 NADH

1st half of glycolysis (5 reactions)

Glucose "priming"

- get glucose ready to split
  - phosphorylate glucose
  - molecular rearrangement
- split destabilized glucose

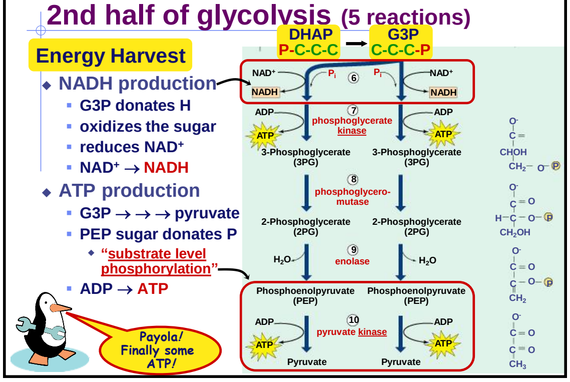


AP Biology

2nd half of glycolysis (5 reactions)

Energy Harvest

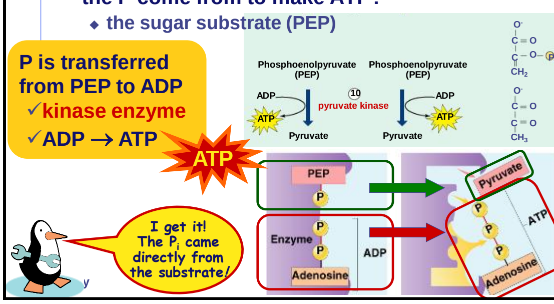
- NADH production
  - G3P donates H
  - oxidizes the sugar
  - reduces NAD+
  - NAD+ → NADH
- ATP production
  - G3P → → → pyruvate
  - PEP sugar donates P
    - "substrate level phosphorylation"
  - ADP → ATP



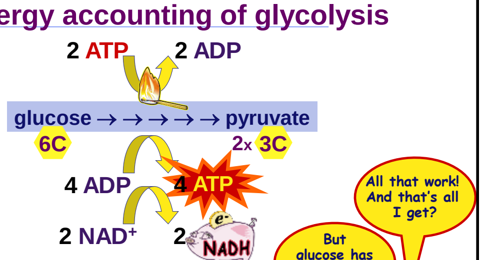
Substrate-level Phosphorylation

- In the last steps of glycolysis, where did the P come from to make ATP?
  - the sugar substrate (PEP)

P is transferred from PEP to ADP
✓kinase enzyme
✓ADP → ATP



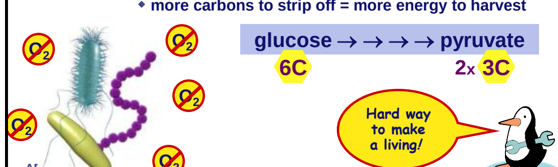
Energy accounting of glycolysis



- Net gain = 2 ATP + 2 NADH
  - some energy investment (-2 ATP)
  - small energy return (4 ATP + 2 NADH)
- 1 6C sugar → 2 3C sugars

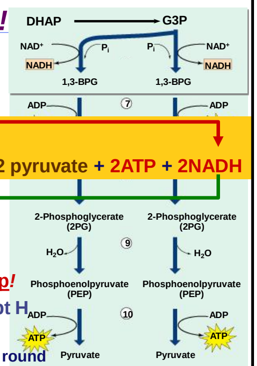
Is that all there is?

- Not a lot of energy…
  - for 1 billon years+ this is how life on Earth survived
    - no O_2 = slow growth, slow reproduction
    - only harvest 3.5% of energy stored in glucose
      - more carbons to strip off = more energy to harvest



But can't stop there!

raw materials → products



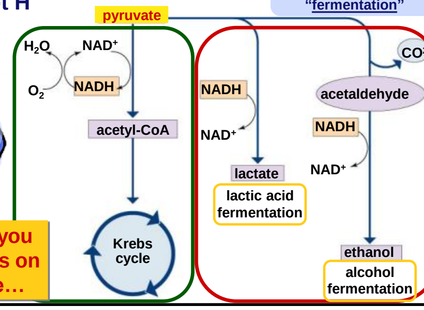
Glycolysis

glucose + 2ADP + 2P_i + 2 NAD^+ → 2 pyruvate + 2ATP + 2NADH

- Going to run out of NAD^+
  - without regenerating NAD^+, energy production would stop!
  - another molecule must accept H from NADH
    - so NAD^+ is freed up for another round

How is NADH recycled to NAD^+?

Another molecule must accept H from NADH



which path you use depends on who you are…

Fermentation (anaerobic)

- Bacteria, yeast

pyruvate → ethanol + CO_2
3C 2C 1C
NADH NAD^+ back to glycolysis→→

- beer, wine, bread

- Animals, some fungi

pyruvate → lactic acid
3C 3C
NADH NAD^+ back to glycolysis→→

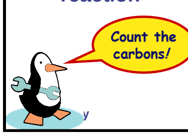
- cheese, anaerobic exercise (no O_2)

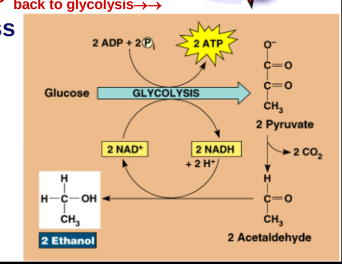
Alcohol Fermentation

bacteria
yeast

pyruvate → ethanol + CO_2
3C 2C 1C
NADH NAD^+ back to glycolysis→→

- Dead end process
  - at ~12% ethanol, kills yeast
  - can't reverse the reaction



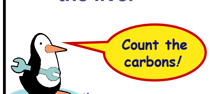


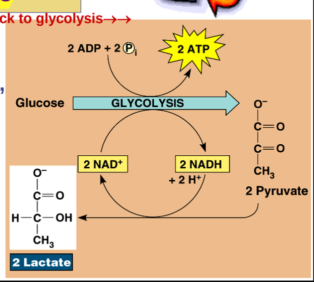
Lactic Acid Fermentation

animals
some fungi

pyruvate ↔ lactic acid O_2
3C 3C
NADH NAD^+ back to glycolysis→→

- Reversible process
  - once O_2 is available, lactate is converted back to pyruvate by the liver





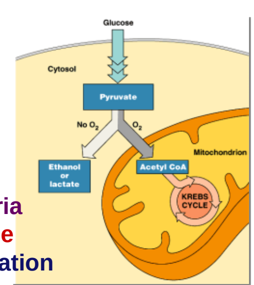
Pyruvate is a branching point

Pyruvate

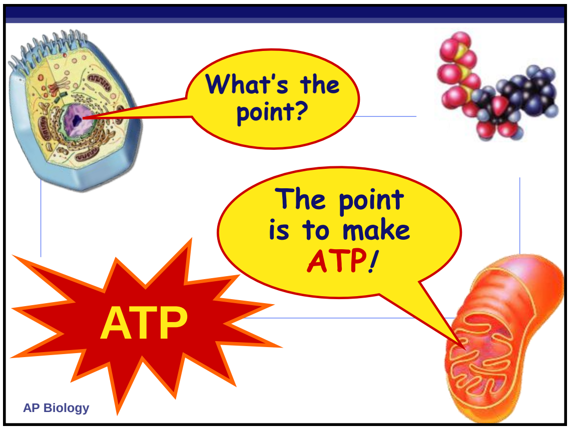
O_2 O_2

fermentation
anaerobic respiration

mitochondria
Krebs cycle
aerobic respiration



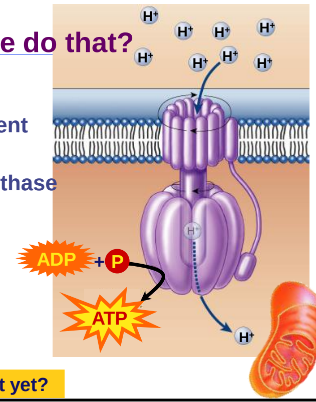
AP Biology



And how do we do that?

- ATP synthase
  - set up a H^+ gradient
  - allow H^+ to flow through ATP synthase
  - powers bonding of P_i to ADP

ADP + P_i → ATP

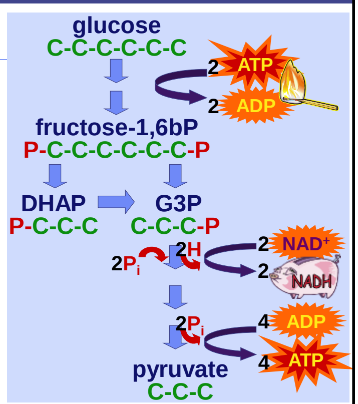


But… Have we done that yet?

Overview

10 reactions

- convert glucose (6C) to 2 pyruvate (3C)
- produces: 4 ATP & 2 NADH
- consumes: 2 ATP
- net: 2 ATP & 2 NADH



Cellular Respiration

Stage 2 & 3:

Oxidation of Pyruvate

Krebs Cycle

Glycolysis is only the start

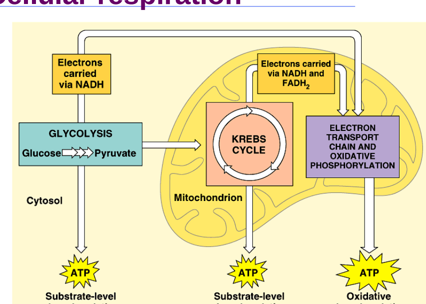
- Glycolysis

glucose → → → → → pyruvate
6C 2x 3C

- Pyruvate has more energy to yield
  - 3 more C to strip off (to oxidize)
  - if O_2 is available, pyruvate enters mitochondria
  - enzymes of Krebs cycle complete the full oxidation of sugar to CO_2

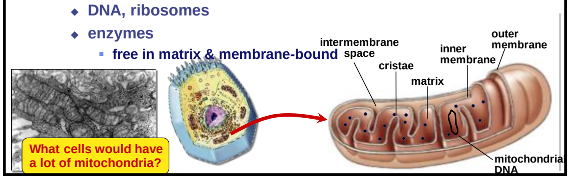
pyruvate → → → → → → CO_2
3C 1C

Cellular respiration



Mitochondria — Structure

- Double membrane energy harvesting organelle
  - smooth outer membrane
  - highly folded inner membrane
    - cristae
  - intermembrane space
    - fluid-filled space between membranes
  - matrix
    - inner fluid-filled space
  - DNA, ribosomes
  - enzymes
    - free in matrix & membrane-bound



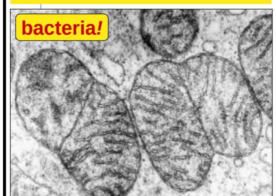
What cells would have a lot of mitochondria?

Mitochondria – Function

Oooooh! Form fits function!

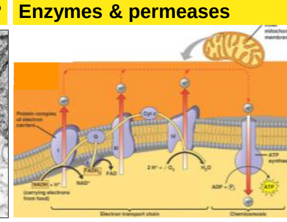
Dividing mitochondria
Who else divides like that?

bacteria!



What does this tell us about the evolution of eukaryotes?
Endosymbiosis!

Membrane-bound proteins
Enzymes & permeases



Advantage of highly folded inner membrane?
More surface area for membrane-bound enzymes & permeases

Oxidation of pyruvate

- Pyruvate enters mitochondrial matrix

$$2x\left[\text{pyruvate} \rightarrow\rightarrow\rightarrow \text{acetyl CoA} + CO_2\right]$$

3C — 2C — 1C

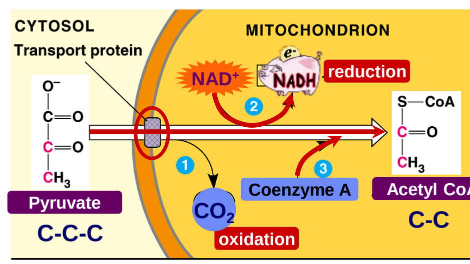
NAD → NADH

Where does the CO_2 go? Exhale!

- 3 step oxidation process
- releases 2 CO_2 (count the carbons!)
- reduces 2 NAD → 2 NADH (moves e⁻)
- produces 2 acetyl CoA

- Acetyl CoA enters Krebs cycle

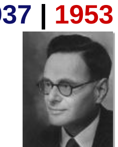
Pyruvate oxidized to Acetyl CoA



2 x [Yield = 2C sugar + NADH + CO_2]

Krebs cycle

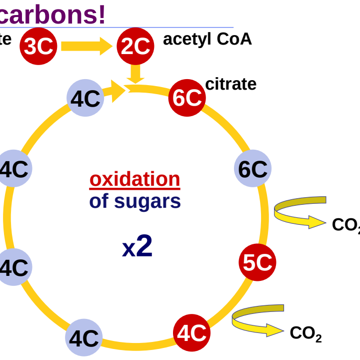
1937 | 1953



Hans Krebs
1900-1981

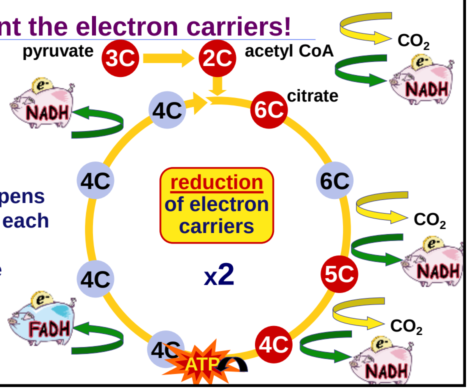
- aka Citric Acid Cycle
  - in mitochondrial matrix
  - 8 step pathway
    - each catalyzed by specific enzyme
    - step-wise catabolism of 6C citrate molecule
- Evolved later than glycolysis
  - does that make evolutionary sense?
    - bacteria →3.5 billion years ago (glycolysis)
    - free O_2 →2.7 billion years ago (photosynthesis)
    - eukaryotes →1.5 billion years ago (aerobic respiration = organelles → mitochondria)

Count the carbons!



This happens twice for each glucose molecule

Count the electron carriers!



This happens twice for each glucose molecule

AP Biology

Whassup?

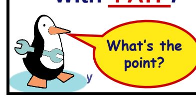
So we fully oxidized glucose

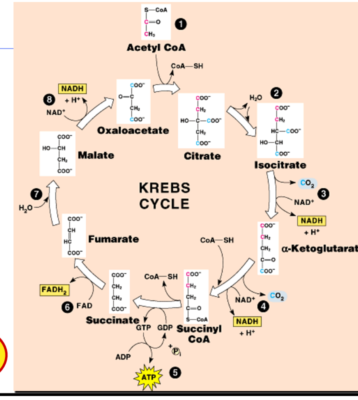
$C_6H_{12}O_6$

↓

CO_2

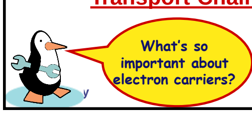
& ended up with 4 ATP!

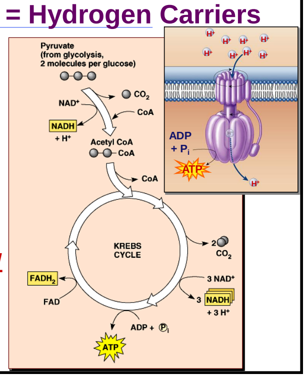




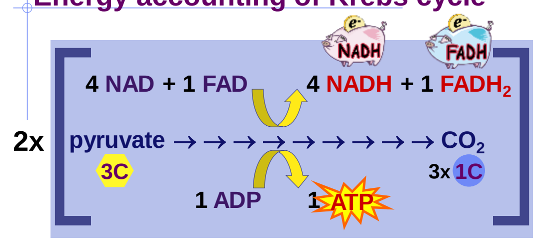
Electron Carriers = Hydrogen Carriers

- Krebs cycle produces large quantities of electron carriers
  - NADH
  - $FADH_2$
  - go to Electron Transport Chain!





Energy accounting of Krebs cycle



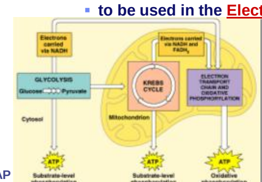
Net gain = 2 ATP

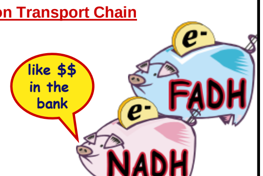
= 8 NADH + 2 $FADH_2$

AP Biology

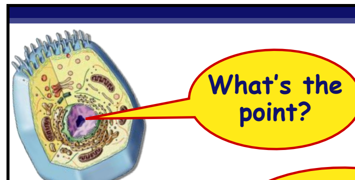
Value of Krebs cycle?

- If the yield is only 2 ATP then how was the Krebs cycle an adaptation?
  - value of NADH & $FADH_2$
    - electron carriers & H carriers
      - reduced molecules move electrons
      - reduced molecules move H^+ ions
    - to be used in the Electron Transport Chain

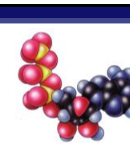




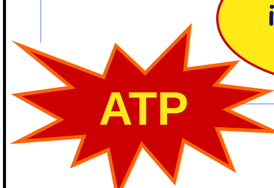
AP

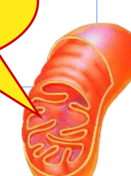


What's the point?



The point is to make ATP!



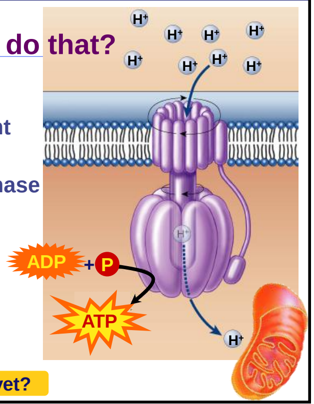


AP Biology

And how do we do that?

- ATP synthase
  - set up a H^+ gradient
  - allow H^+ to flow through ATP synthase
  - powers bonding of P_i to ADP

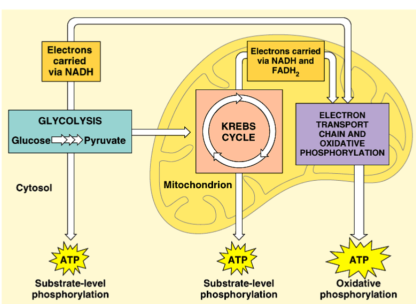
ADP + P_i → ATP

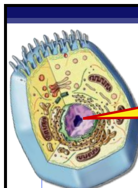


But… Have we done that yet?

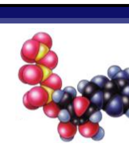
Cellular Respiration
Stage 4:
Electron Transport Chain

Cellular respiration

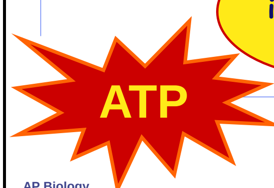




What's the point?



The point is to make ATP!

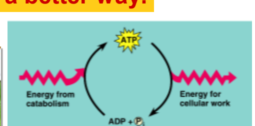


ATP accounting so far…

- Glycolysis → 2 ATP
- Kreb's cycle → 2 ATP
- Life takes a lot of energy to run, need to extract more energy than 4 ATP!

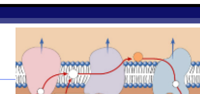
There's got to be a better way!

I need a lot more ATP!

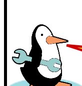


A working muscle recycles over 10 million ATPs per second

There *is* a better way!



- Electron Transport Chain
  - series of proteins built into <u>inner mitochondrial membrane</u>
    - along <u>cristae</u>
    - transport proteins & enzymes
  - transport of electrons down ETC linked to pumping of H^+ to create H^+ gradient
  - yields <u>~36 ATP</u> from 1 glucose!
  - only in presence of O_2 (<u>aerobic respiration</u>)

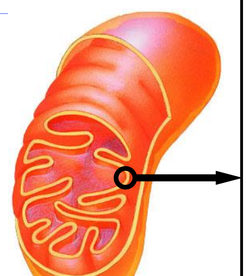


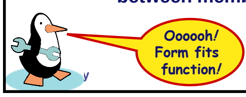
That sounds more like it!

O_2

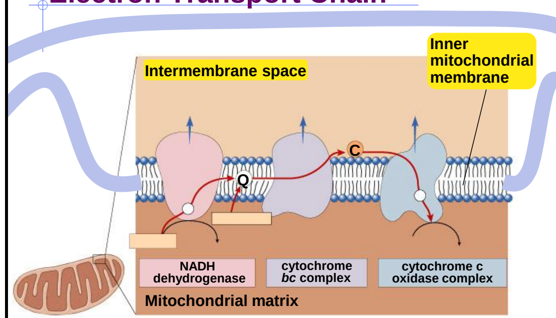
Mitochondria

- Double membrane
  - outer membrane
  - inner membrane
    - highly folded cristae
    - enzymes & transport proteins
  - intermembrane space
    - fluid-filled space between membranes



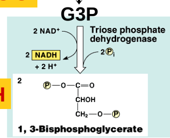


Electron Transport Chain



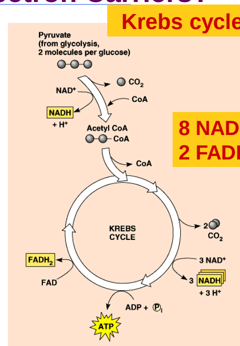
Remember the Electron Carriers?

Glycolysis

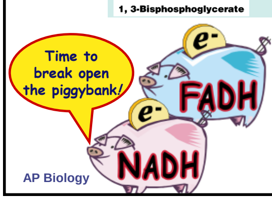


2 NADH

Krebs cycle



8 NADH
2 $FADH_2$

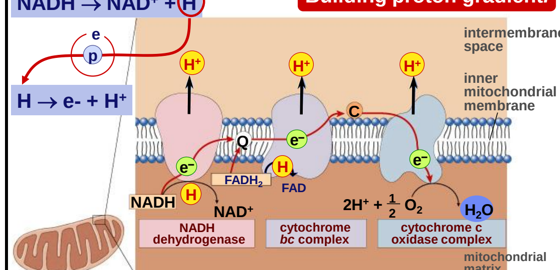


Electron Transport Chain

NADH → NAD^+ + H

Building proton gradient!

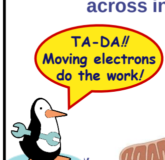
H → e- + H^+

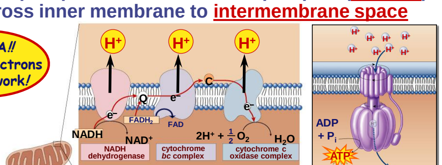


What powers the proton (H^+) pumps?…

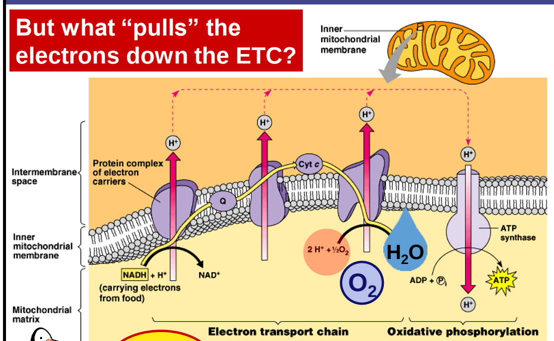
Stripping H from Electron Carriers

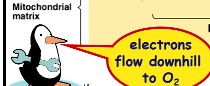
- Electron carriers pass electrons & H^+ to ETC
  - H cleaved off NADH & $FADH_2$
  - electrons stripped from H atoms → H^+ (protons)
    - electrons passed from one electron carrier to next in mitochondrial membrane (ETC)
    - flowing electrons = energy to do work
  - transport proteins in membrane pump H^+ (protons) across inner membrane to intermembrane space





But what "pulls" the electrons down the ETC?

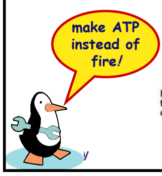


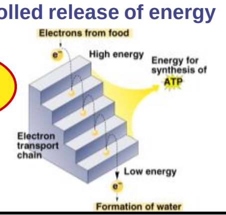


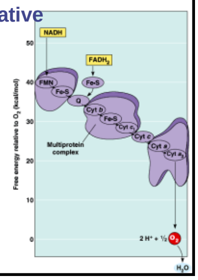
oxidative phosphorylation

Electrons flow downhill

- Electrons move in steps from carrier to carrier downhill to oxygen
  - each carrier more electronegative
  - controlled oxidation
  - controlled release of energy





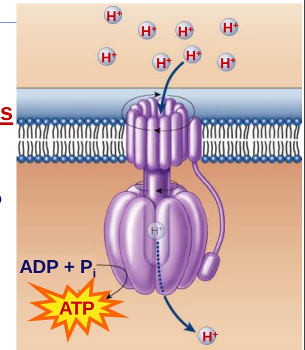


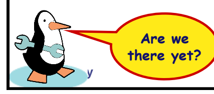
We did it!

"proton-motive" force

- Set up a H^+ gradient
- Allow the protons to flow through ATP synthase
- Synthesizes ATP

ADP + $P_i \rightarrow$ ATP

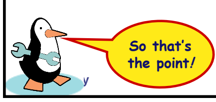


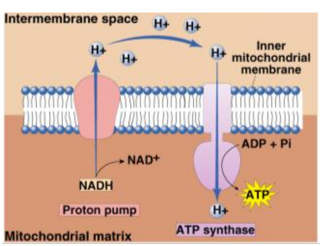


Chemiosmosis

- The diffusion of ions across a membrane
  - build up of proton gradient just so H+ could flow through ATP synthase enzyme to build ATP

Chemiosmosis links the Electron Transport Chain to ATP synthesis

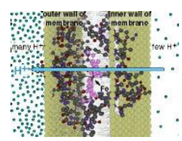




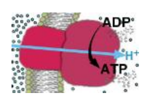
Peter Mitchell

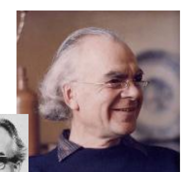
1961 | 1978

- Proposed chemiosmotic hypothesis
  - revolutionary idea at the time



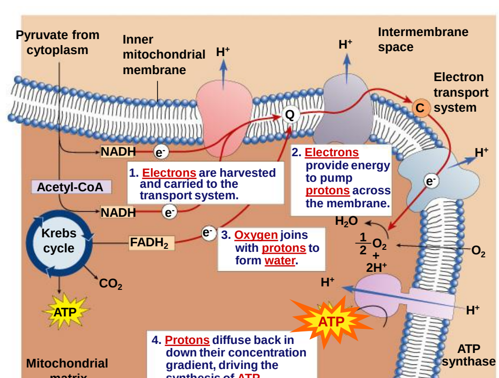
proton motive force



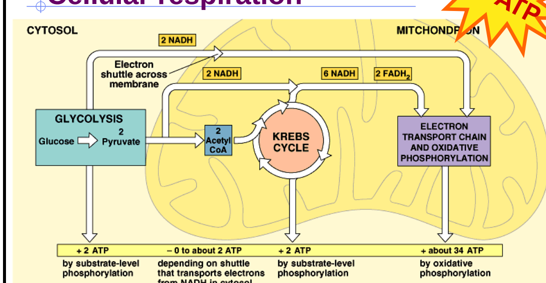


1920-1992

AP Biology



Cellular respiration



2 ATP + 2 ATP + ~34 ATP

AP Biology

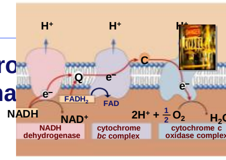
Summary of cellular respiration

$C_6H_{12}O_6$ + $6O_2$ → $6CO_2$ + $6H_2O$ + ~38 ATP

- Where did the glucose come from?
- Where did the O_2 come from?
- Where did the CO_2 come from?
- Where did the CO_2 go?
- Where did the H_2O come from?
- Where did the ATP come from?
- What else is produced that is not listed in this equation?
- Why do we breathe?

Taking it beyond…

- What is the final electro Electron Transport Cha

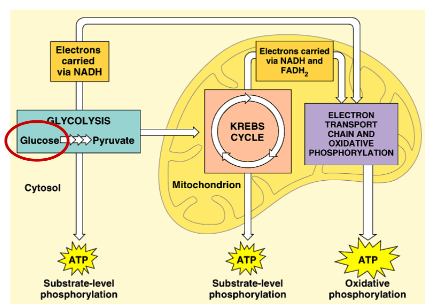


O_2

- So what happens if O_2 unavailable?
  - ETC backs up
    - nothing to pull electrons down chain
    - NADH & $FADH_2$ can't unload H
  - ATP production ceases
  - cells run out of energy
  - and you die!

Cellular Respiration
Other Metabolites & Control of Respiration

Cellular respiration



Beyond glucose: Other carbohydrates

- Glycolysis accepts a wide range of carbohydrates fuels

polysaccharides $\xrightarrow{\text{hydrolysis}}$ → → glucose

- ex. starch, glycogen

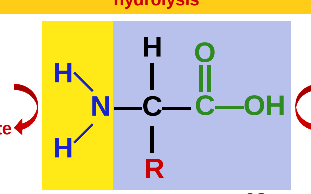
other 6C sugars $\xrightarrow{\text{modified}}$ → → glucose

- ex. galactose, fructose

Beyond glucose: Proteins

proteins $\xrightarrow{\text{hydrolysis}}$ → → → → amino acids

waste



glycolysis
Krebs cycle

amino group = waste product excreted as ammonia, urea, or uric acid

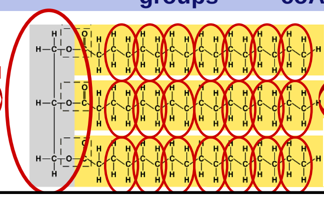
2C sugar = carbon skeleton = enters glycolysis or Krebs cycle at different stages

Beyond glucose: Fats

fats → → → → → glycerol + fatty acids
hydrolysis

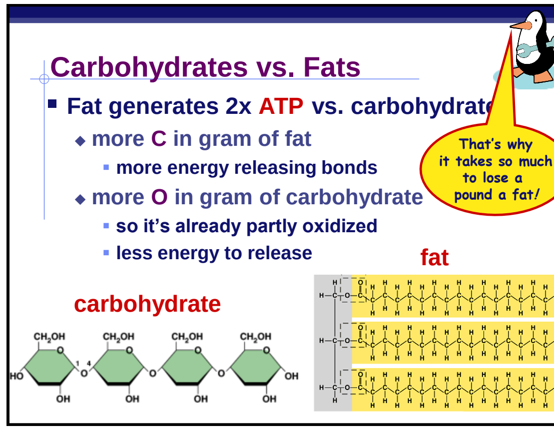
glycerol (3C) → → G3P → → glycolysis

fatty acids → 2C acetyl groups → acetyl coA → Krebs cycle



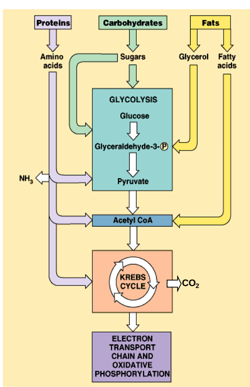
Carbohydrates vs. Fats

- Fat generates 2x ATP vs. carbohydrate
  - more C in gram of fat
    - more energy releasing bonds
  - more O in gram of carbohydrate
    - so it's already partly oxidized
    - less energy to release



Metabolism

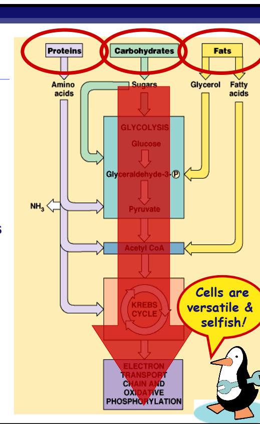
- Coordination of chemical processes across whole organism
  - digestion
    - catabolism when organism needs energy or needs raw materials
  - synthesis
    - anabolism when organism has enough energy & a supply of raw materials
  - by regulating enzymes
    - feedback mechanisms
    - raw materials stimulate production
    - products inhibit further production



AP Biology

Metabolism

- Digestion
  - digestion of carbohydrates, fats & proteins
    - all catabolized through same pathways
    - enter at different points
  - cell extracts energy from every source



AP Biology

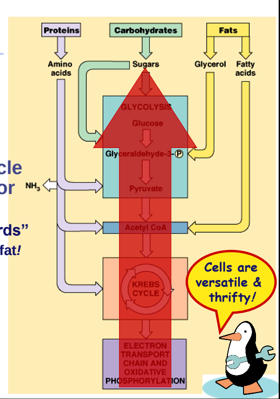
Metabolism

- Synthesis
  - enough energy? build stuff!
  - cell uses points in glycolysis & Krebs cycle as links to pathways for synthesis
    - run pathways "backwards"
      - have extra fuel, build fat!

pyruvate → → glucose

Krebs cycle intermediaries → → amino acids

acetyl CoA → → fatty acids

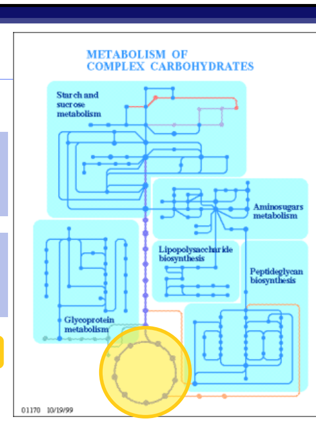


Carbohydrate Metabolism

The many stops on the Carbohydrate Line

from Krebs cycle back through glycolysis

"gluconeogenesis"

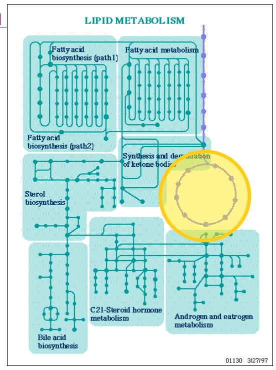


AP Biology

Lipid Metabolism

The many stops on the Lipid Line

from Krebs cycle (acetyl CoA) to a variety of lipid synthesis pathways

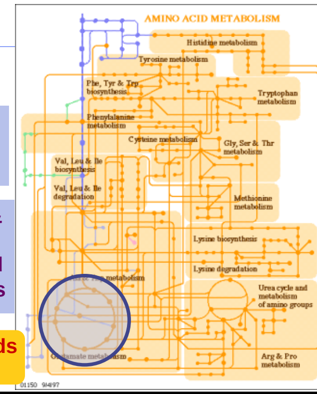


AP Biology

Amino Acid Metabolism

The many stops on the Amino Acid Line

from Krebs cycle & glycolysis to an array of amino acid synthesis pathways



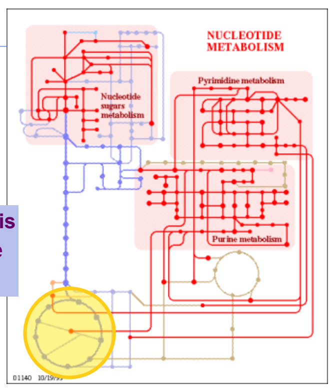
8 essential amino acids
12 synthesized aa's

AP Biology

Nucleotide Metabolism

The many stops on the GATC Line

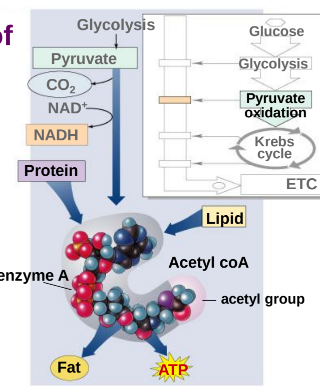
- sugar from glycolysis
- phosphate & N-base from Krebs cycle



AP Biology

Central Role of Acetyl CoA

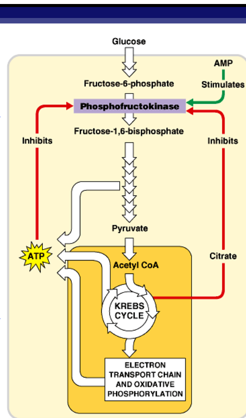
- Acetyl CoA is central to both energy production & biomolecule synthesis
- Depending on organism's need
  - build ATP
    - immediate use
  - build fat
    - stored energy



AP Biology

Control of Respiration

Feedback Control



AP Biology

Feedback Inhibition

- Regulation & coordination of production
  - final product is inhibitor of earlier step
    - allosteric inhibitor of earlier enzyme
  - no unnecessary accumulation of product
  - production is self-limiting

A → B → C → D → E → F → G

enzyme 1, enzyme 2, enzyme 3, enzyme 4, enzyme 5, enzyme 6

allosteric inhibitor of enzyme 1

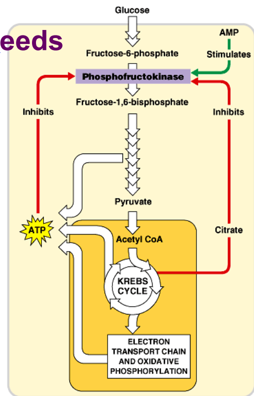
AP Biology

Respond to cell's needs

- Key point of control
  - phosphofructokinase
    - allosteric regulation of enzyme
      - why here?
        "can't turn back" step before splitting glucose
    - AMP & ADP stimulate
    - ATP inhibits
    - citrate inhibits

Why is this regulation important?

Balancing act:
availability of raw materials vs.
energy demands vs. synthesis



A Metabolic economy

- Basic principles of supply & demand regulate metabolic economy
  - balance the supply of raw materials with the products produced
  - these molecules become feedback regulators
    - they control enzymes at strategic points in glycolysis & Krebs cycle
      - levels of AMP, ADP, ATP
        - regulation by final products & raw materials
      - levels of intermediates compounds in pathways
        - regulation of earlier steps in pathways
      - levels of other biomolecules in body
        - regulates rate of siphoning off to synthesis pathways

AP Biology

It's a Balancing Act

- Balancing synthesis with availability of both energy & raw materials is essential for survival!
  - do it well & you survive longer
  - you survive longer & you have more offspring
  - you have more offspring & you get to "take over the world"