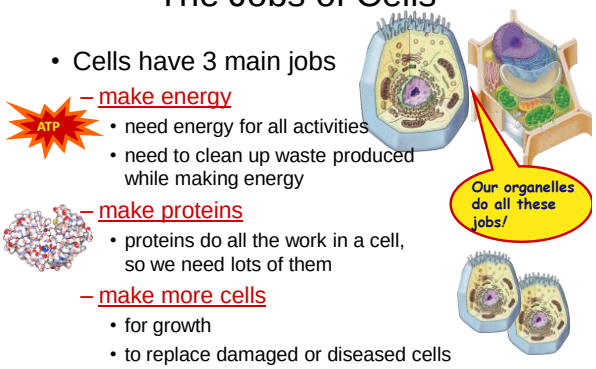
Making Energy

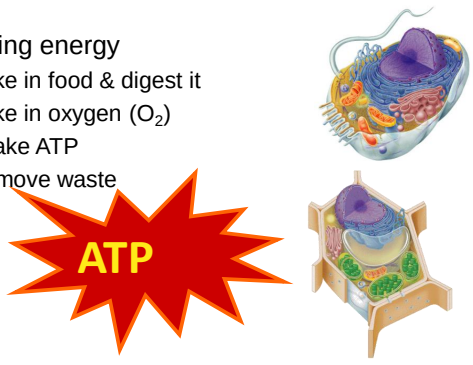
The Jobs of Cells

- Cells have 3 main jobs
  - make energy
    - need energy for all activities
    - need to clean up waste produced while making energy
  - make proteins
    - proteins do all the work in a cell, so we need lots of them
  - make more cells
    - for growth
    - to replace damaged or diseased cells



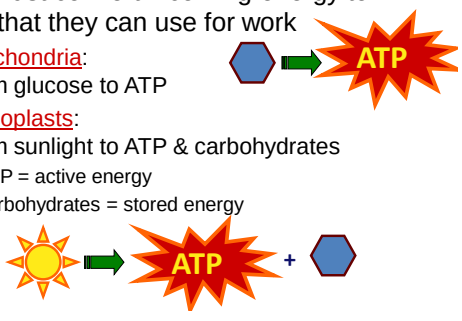
Cells need power!

- Making energy
  - take in food & digest it
  - take in oxygen (O_2)
  - make ATP
  - remove waste



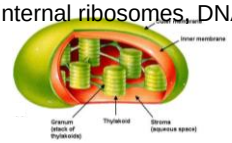
Making Energy

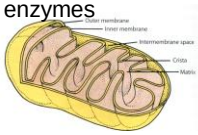
- Cells must convert incoming energy to forms that they can use for work
  - mitochondria: from glucose to ATP
  - chloroplasts: from sunlight to ATP & carbohydrates
    - ATP = active energy
    - carbohydrates = stored energy



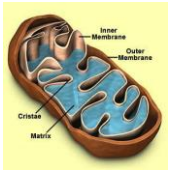
Mitochondria & Chloroplasts

- Important to see the similarities
  - transform energy
    - generate ATP
  - double membranes = 2 membranes
  - semi-autonomous organelles
    - move, change shape, divide
  - internal ribosomes, DNA & enzymes





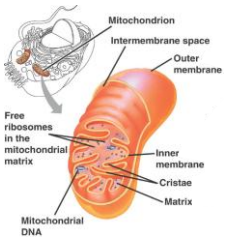
Mitochondria



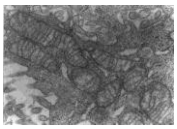
- Function
  - cellular respiration
  - generate ATP
    - from breakdown of sugars, fats & other fuels
    - in the presence of oxygen
      - break down larger molecules into smaller to generate energy = catabolism
      - generate energy in presence of O_2 = aerobic respiration

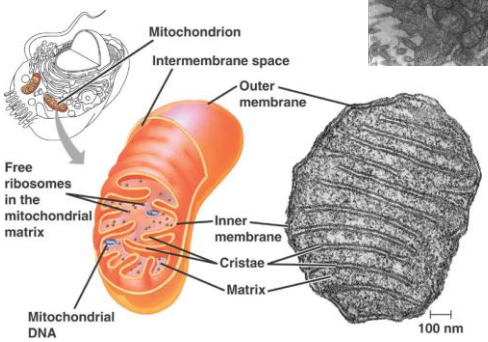
Mitochondria

- Structure
  - 2 membranes
    - smooth outer membrane
    - highly folded inner membrane
      - cristae
  - fluid-filled space between 2 membranes
  - internal fluid-filled space
    - mitochondrial matrix
    - DNA, ribosomes & enzymes

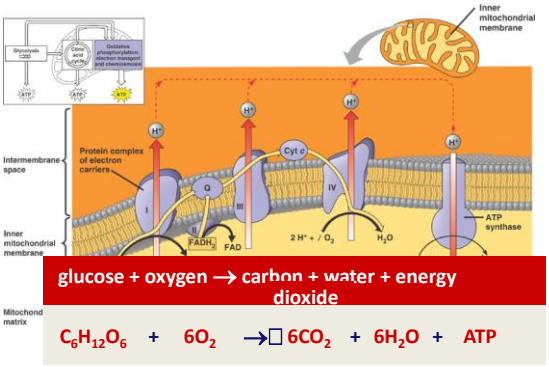


Mitochondria





Membrane-bound Enzymes

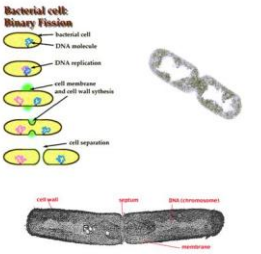


glucose + oxygen → carbon dioxide + water + energy

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

Dividing Mitochondria

Who else divides like that?



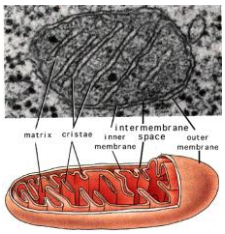
What does this tell us about the evolution of eukaryotes?

Mitochondria

- Almost all eukaryotic cells have mitochondria
  - there may be 1 very large mitochondrion or 100s to 1000s of individual mitochondria
  - number of mitochondria is correlated with aerobic metabolic activity
    - more activity = more energy needed = more mitochondria

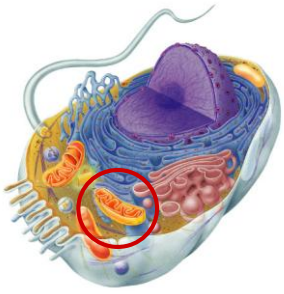
What cells would have a lot of mitochondria?

active cells:
- **muscle cells**
- **nerve cells**

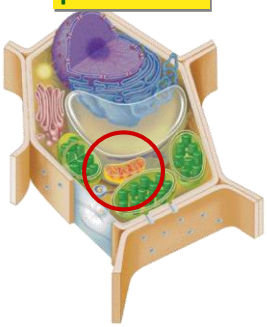


Mitochondria are everywhere!

animal cells

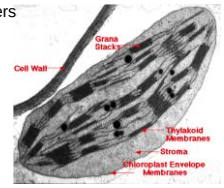


plant cells

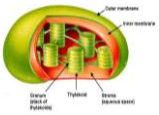


Chloroplasts

- Chloroplasts are plant organelles
  - class of plant structures = plastids
    - amyloplasts
      - store starch in roots & tubers
    - chromoplasts
      - store pigments for fruits & flowers
    - chloroplasts
      - store chlorophyll & function in photosynthesis
      - in leaves, other green structures of plants & in eukaryotic algae



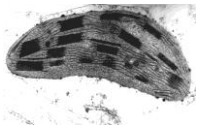
Chloroplasts



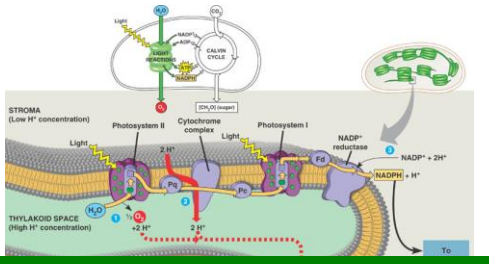
- Structure
  - 2 membranes
  - stroma = internal fluid-filled space
    - DNA, ribosomes & enzymes
    - thylakoids = membranous sacs where ATP is made
    - grana = stacks of thylakoids

Why internal sac membranes?

increase surface area for membrane-bound enzymes that synthesize ATP



Membrane-bound Enzymes



carbon dioxide + water + energy → glucose + oxygen

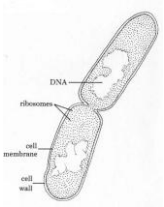
$6CO_2 + 6H_2O + \text{light energy} \rightarrow C_6H_{12}O_6 + 6O_2$

Chloroplasts

- Function
  - photosynthesis
  - generate ATP & synthesize sugars
    - transform solar energy into chemical energy
    - produce sugars from CO_2 & H_2O
- Semi-autonomous
  - moving, changing shape & dividing
  - can reproduce by pinching in two

Who else divides like that?

bacteria!

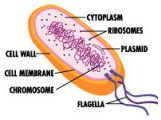


Mitochondria & chloroplasts are different

- Organelles not part of endomembrane system
- Grow & reproduce
  - semi-autonomous organelles
- Proteins primarily from free ribosomes in cytosol & a few from their own ribosomes
- Own circular chromosome
  - directs synthesis of proteins produced by own internal ribosomes
    - ribosomes like bacterial ribosomes

Who else has a circular chromosome not bound within a nucleus?

bacteria



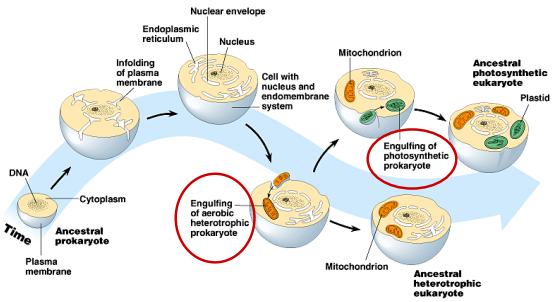
Endosymbiosis theory

- Mitochondria & chloroplasts were once free living bacteria
  - engulfed by ancestral eukaryote
- Endosymbiont
  - cell that lives within another cell (host)
    - as a partnership
    - evolutionary advantage for both
      - one supplies energy
      - the other supplies raw materials & protection

Lynn Margulis
U of M, Amherst

Endosymbiosis theory

Evolution of eukaryotes



Compare the equations

Photosynthesis

carbon dioxide + water + energy → glucose + oxygen

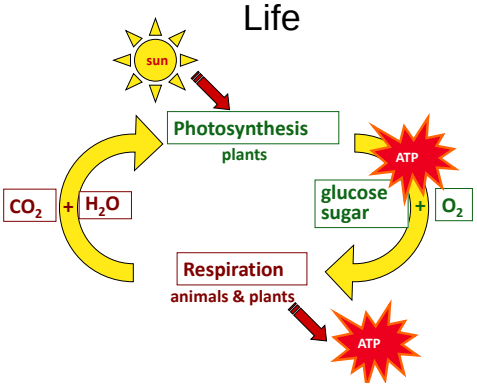
$6CO_2 + 6H_2O + \text{light energy} \rightarrow C_6H_{12}O_6 + 6O_2$

Respiration

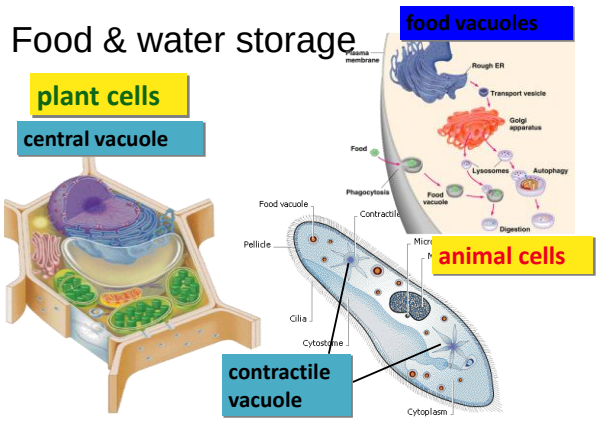
glucose + oxygen → carbon dioxide + water + energy

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

The Great ENERGY Circle of Life

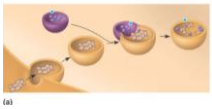


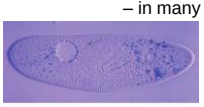
Food & water storage

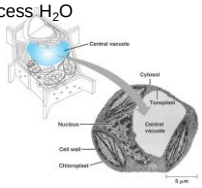


Vacuoles & vesicles

- Function
  - little "transfer ships"
    - Food vacuoles
      - phagocytosis, fuse with lysosomes
    - Contractile vacuoles
      - in freshwater protists, pump excess H_2O out of cell
    - Central vacuoles
      - in many mature plant cells

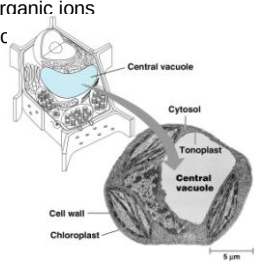






Vacuoles in plants

- Functions
  - storage
    - stockpiling proteins or inorganic ions
    - depositing metabolic byprc
    - storing pigments
    - storing defensive compounds against herbivores
    - selective membrane
      - control what comes in or goes out



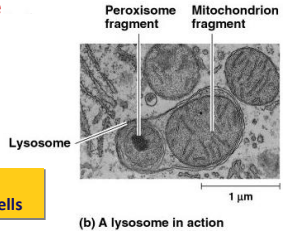
Lysosomes

Where old organelles go to die!

- Function
  - little "stomach" of the cell
    - digests macromolecules
  - "clean up crew" of the
    - cleans up broken down organelles
- Structure
  - vesicles of digestive enzymes

synthesized by rER, transferred to Golgi

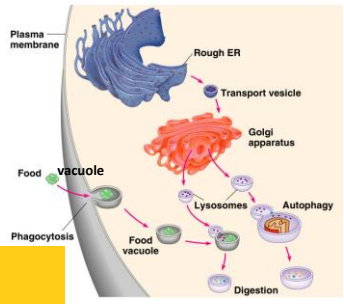
only in animal cells



(b) A lysosome in action

Cellular digestion

- Lysosomes fuse with food vacuoles
  - polymers digested into monomers
    - pass to cytosol to become nutrients of cell



- lyso– = breaking things apart
- –some = body

Lysosomal enzymes

- Lysosomal enzymes work best at pH 5
  - organelle creates custom pH
  - how?
    - proteins in lysosomal membrane pump H^+ ions from the cytosol into lysosome
  - why?
    - enzymes are very sensitive to pH
  - why?
    - enzymes are proteins — pH affects structure
  - why evolve digestive enzymes which function at pH different from cytosol?
    - digestive enzymes won't function well if some leak into cytosol = don't want to digest yourself!

When things go bad…

- Diseases of lysosomes are often fatal
  - digestive enzyme not working in lysosome
  - picks up biomolecules, but can't digest one
    - lysosomes fill up with undigested material
  - grow larger & larger until disrupts cell & organ function
    - lysosomal storage diseases
      - more than 40 known diseases
    - example: Tay-Sachs disease build up undigested fat in brain cells

Lysosomal storage diseases

- Lipids
  - Gaucher's disease
  - Niemann-Pick disease
  - Tay Sachs
- Glycogen & other poylsaccharides
  - Farber disease
  - Krabbe disease
- Proteins
  - Schindler's disease

But sometimes cells *need* to die…

- Lysosomes can be used to kill cells when they are supposed to be destroyed
  - some cells have to die for proper development in an organism
    - apoptosis
      - "auto-destruct" process
      - lysosomes break open & kill cell
    - ex: tadpole tail gets re-absorbed when it turns into a frog
    - ex: loss of webbing between your fingers during fetal development

Apoptosis

- programmed destruction of cells in multi-cellular organisms
  - programmed development
  - control of cell growth
    - example:
      if cell grows uncontrollably this self-destruct mechanism is triggered to remove damaged cell
    - cancer must over-ride this to enable tumor growth