Life and Health Science

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What is a cell membrane made of & what does it do?

- All living things are composed of cells & all cells have a cell membrane
  - <u>Cell membranes have 3 components:</u>
    - Phospholipids
    - Cholesterol
    - Proteins

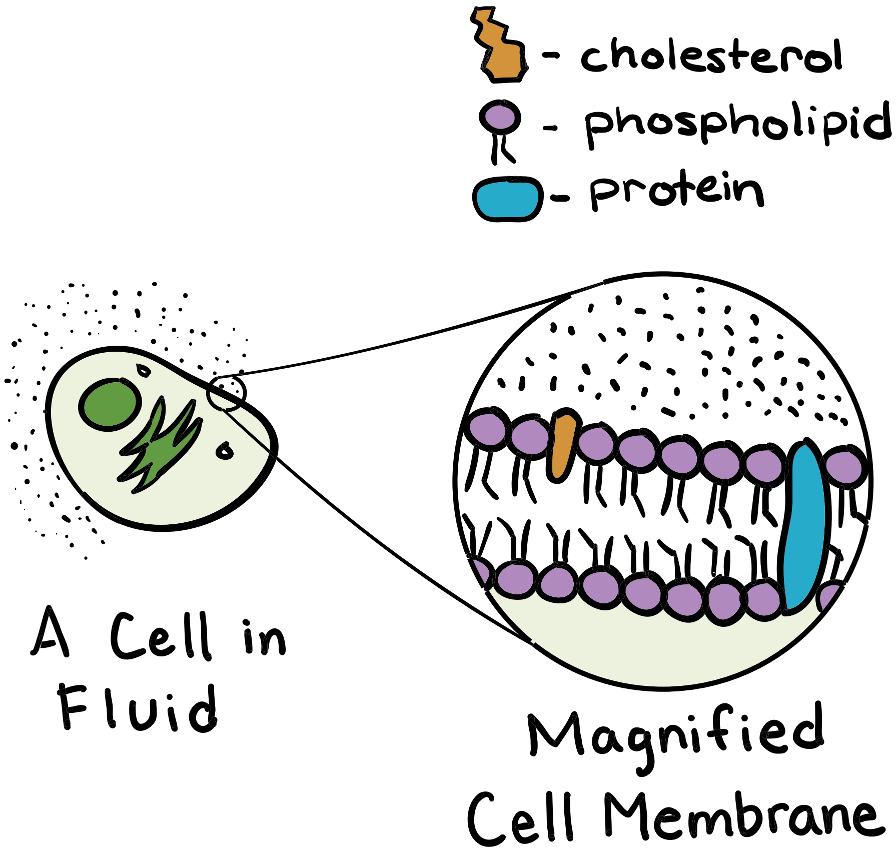
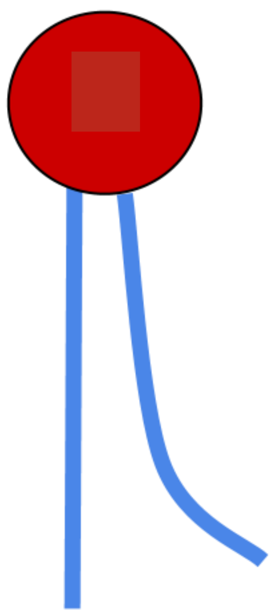


Figure: https://www.khanacademy.org/science/ap-biology/cell-structure-and-function/membrane-permeability/a/fluid-mosaic-model-cell-membranes-article

- Component 1: **Phospholipids** – a unique lipid
  - Remember: lipids are hydrophobic
    - However: **phospholipids** have hydrophobic AND hydrophilic portions



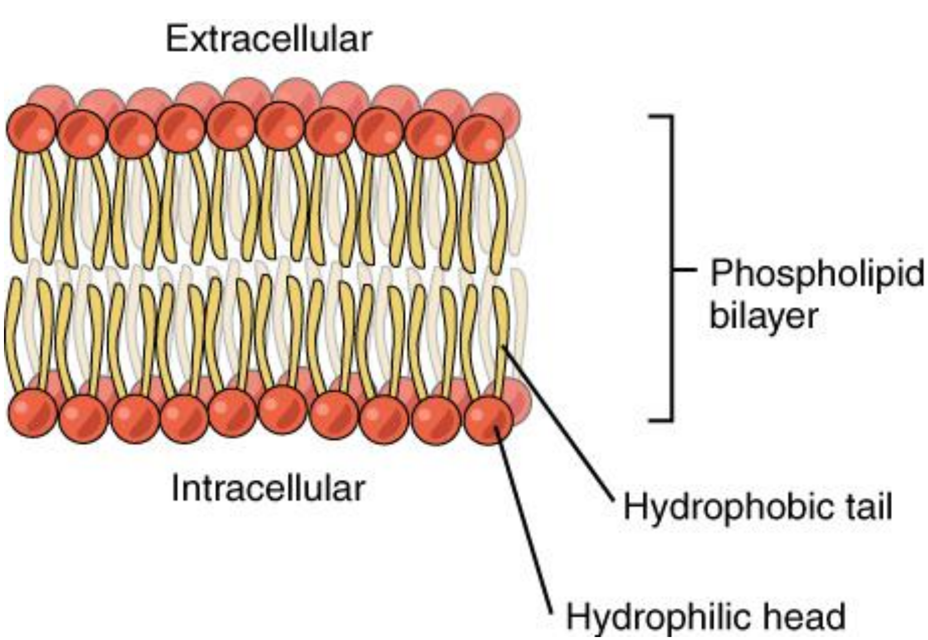
Hydrophilic head (attracted to water)

Hydrophobic fatty acid tails (repel water, attracted to other lipids: **lipophilic**)

A phospholipid with a hydrophilic head and a hydrophobic tail

Figure: https://commons.wikimedia.org/wiki/File:Phospholipid_Chemicalmakeup.png

- When placed in water, hydrophilic heads have no trouble, but hydrophobic tails clump together
  - – Cells have watery insides AND watery outsides, so phospholipid tails clump in such a way that 2 layers are formed: **phospholipid bilayer**



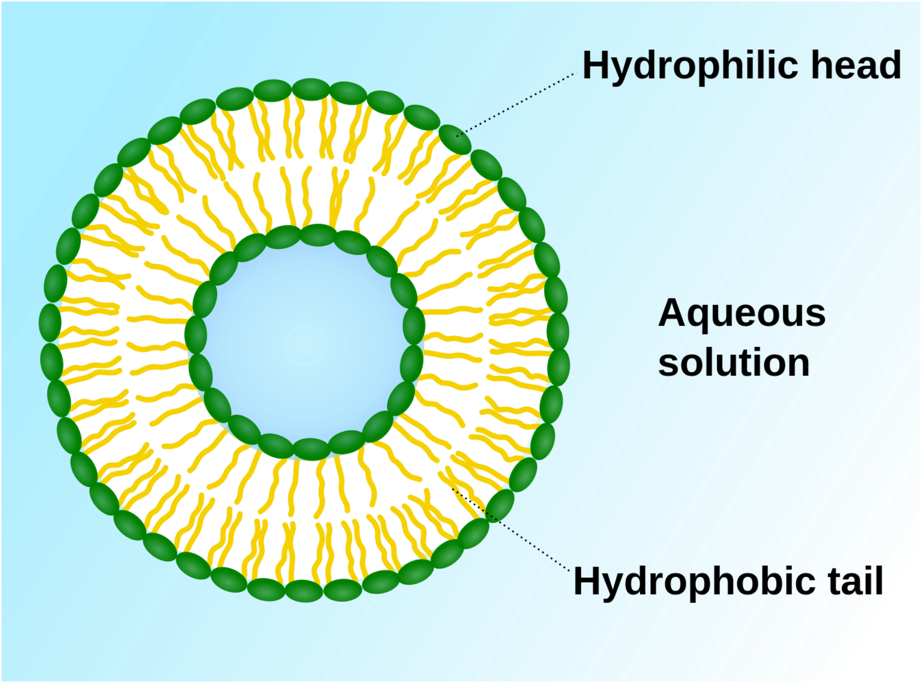


Figure: https://commons.wikimedia.org/wiki/File:0302_Phospholipid_Bilayer.jpg
Figure: https://commons.wikimedia.org/wiki/File:Liposome_scheme-en.svg

- Phospholipids are not bound together – they only take their shape because of the clumping of the tails

- The resulting phospholipid bilayer functions to <u>enclose the cell</u>
  - – the hydrophilic & hydrophobic layers restrict movement, keeping the insides in & the outsides out

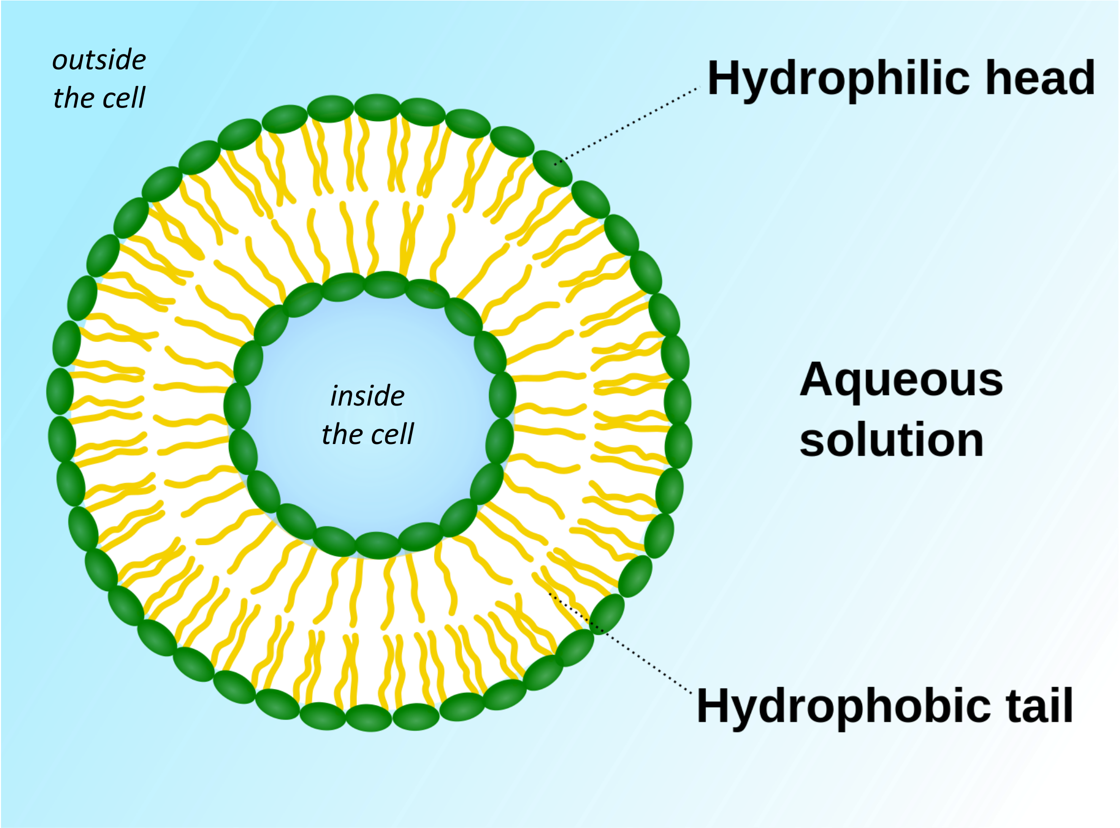
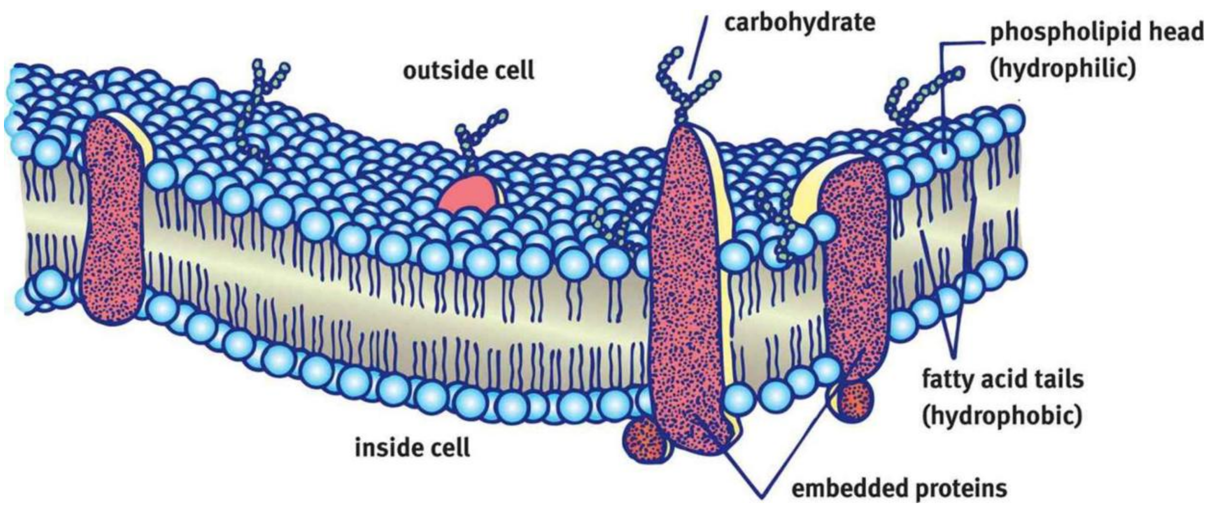


Figure: https://commons.wikimedia.org/wiki/File:Liposome_scheme-en.svg

- Because phospholipids are not bound together, the cell membrane is very flexible or “fluid” rather than a rigid, unmoving straight line



- The fatty acid tails of the phospholipids can alter how fluid or flexible the membrane is

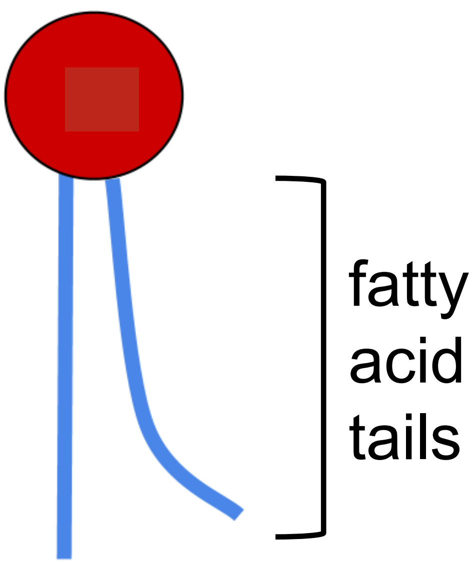


Figure: https://schoolbag.info/chemistry/mcat_biochemistry/47.html
Figure: https://commons.wikimedia.org/wiki/File:Phospholipid_Chemicalmakeup.png

- Remember: **saturated** fatty acids stack well next to each other – this makes phospholipids <u>more stiff</u>

- Remember: **unsaturated** fatty acids don’t line up well – this makes phospholipids <u>more flexible/fluid</u>

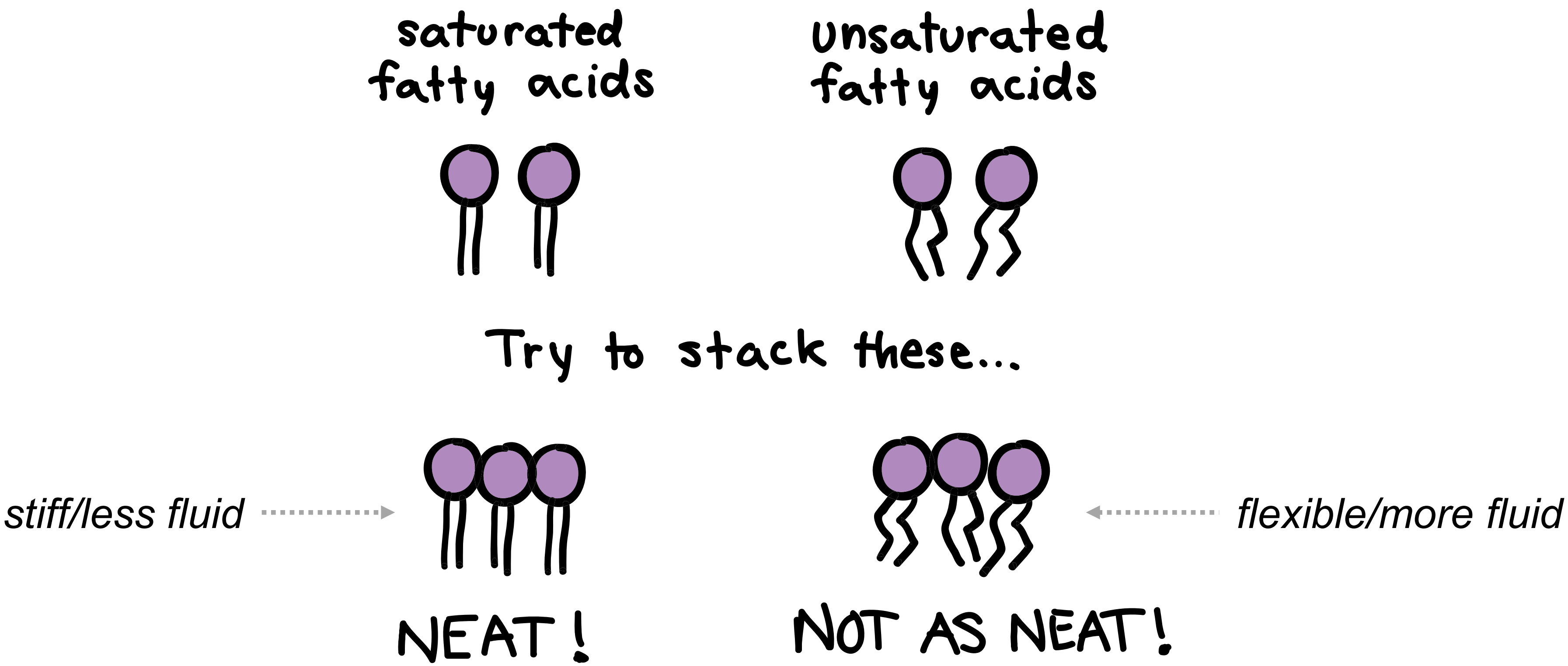
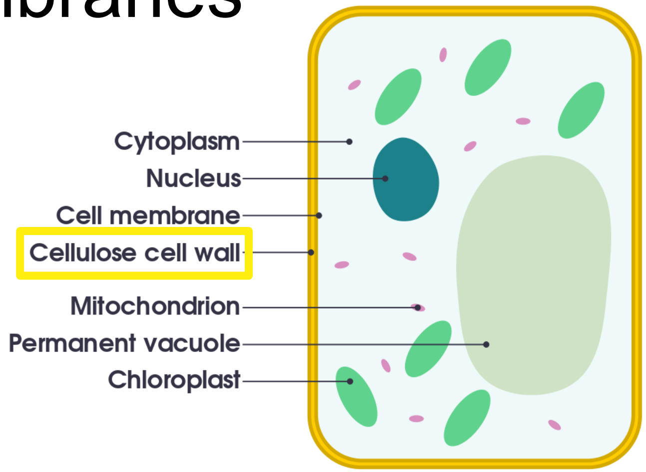


Figure: https://www.khanacademy.org/science/ap-biology/cell-structure-and-function/membrane-permeability/a/fluid-mosaic-model-cell-membranes-article

- Remember: plants make unsaturated fats
  - they have very flexible cell membranes
    - How do they stay rigid then?
      - Remember: they have cell walls for support



- Remember: animals don't have cell walls
  - How do they maintain structure then?
    - They make saturated fats to make their cell membranes more rigid & stiff
      - *Animals have 1 more thing that plants don't to help make their cell membranes more stiff…*

Figure: https://commons.wikimedia.org/wiki/File:Simple_diagram_of_plant_cell_(en).svg

Component 2: **Cholesterol**

- Remember: cholesterol is a hydrophobic lipid that animals make
  - wiggles in with the hydrophobic tails to make the cell membrane more stiff

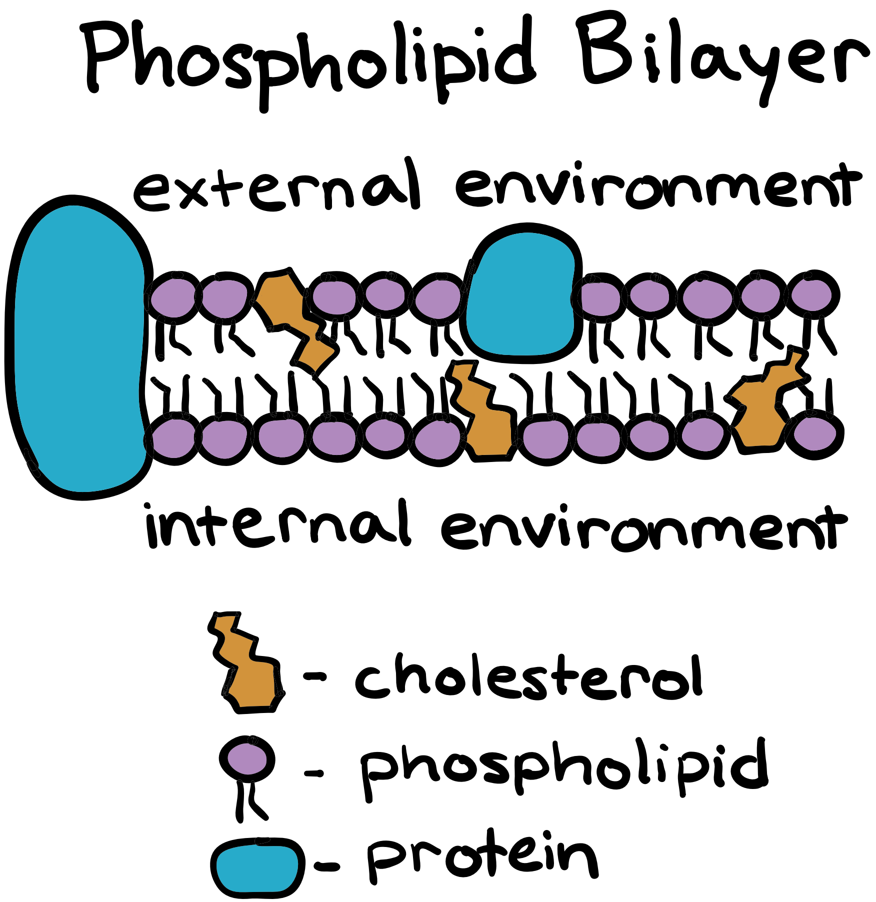


Figure: https://www.khanacademy.org/science/ap-biology/cell-structure-and-function/membrane-permeability/a/fluid-mosaic-model-cell-membranes-article

- Recap: cell membranes are fluid & flexible because the phospholipids that make them up are not bound to one another
  - we can increase fluidity (make it more flexible)
    - use unsaturated fatty acids
    - use no or very little cholesterol
  - or we can decrease fluidity (make it more stiff)
    - use saturated fatty acids
    - use plenty of cholesterol

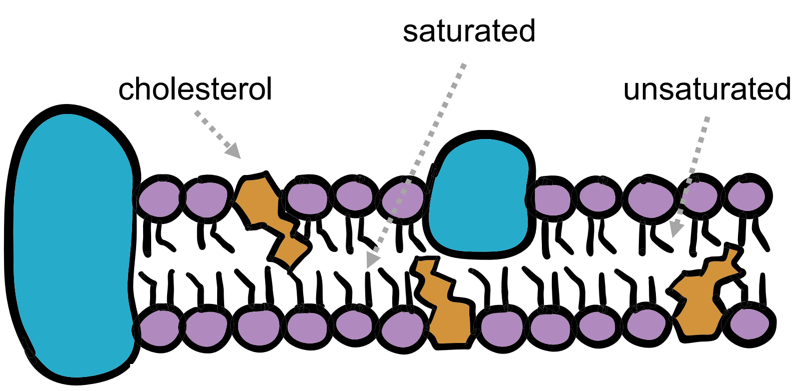


Figure: https://www.khanacademy.org/science/ap-biology/cell-structure-and-function/membrane-permeability/a/fluid-mosaic-model-cell-membranes-article

What molecules can & can not cross cell membranes on their own?

- Even though the phospholipid bilayer provides a barrier, some substances can still get across
  - Very small molecules like water & gases (CO_2 & O_2) can wiggle though the phospholipids

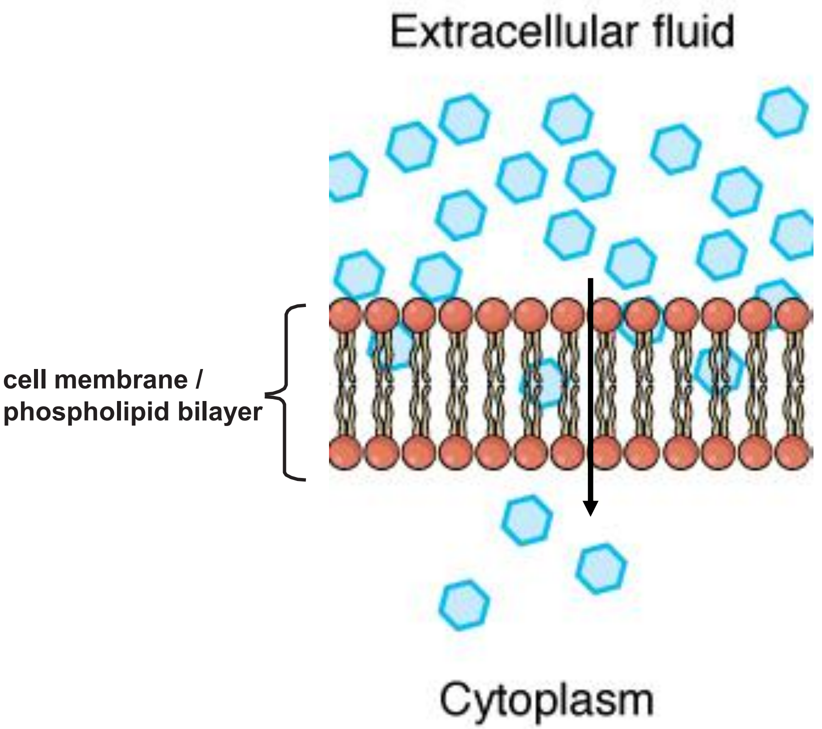
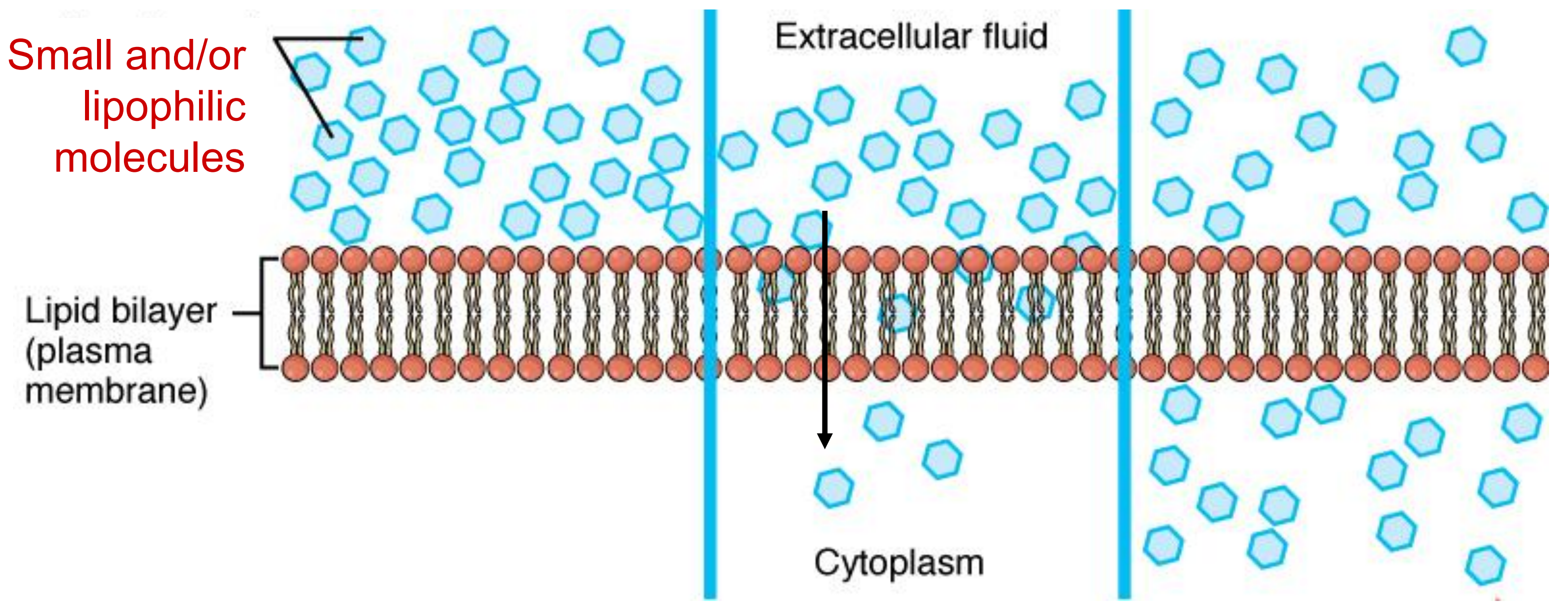


Figure: https://commons.wikimedia.org/wiki/File:0305_Simple_Diffusion_Across_Plasma_Membrane.jpg

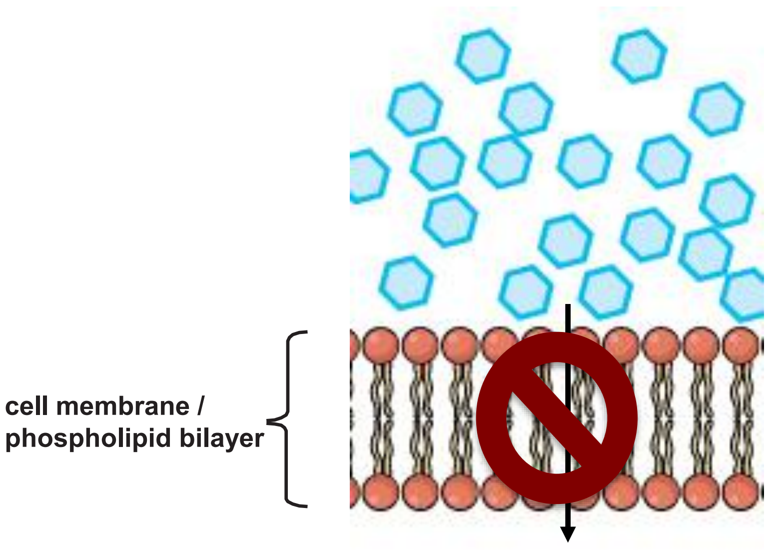
- Can also pass: hydrophobic molecules – also called "**lipophilic**" molecules
  - Lipophilic molecules are lipid-loving, so they are able to move easily through the fatty acid layer



Caffeine, hormones, & some vitamins are lipophilic (hydrophobic)

Figure: https://commons.wikimedia.org/wiki/File:0305_Simple_Diffusion_Across_Plasma_Membrane.jpg

- Even though some things can cross, the bilayer prevents many substances from crossing



  – Hydrophilic molecules can NOT cross the phospholipid bilayer
    - e.g. salts & sugars
  – Very large molecules also can NOT cross
    - e.g. polysaccharides

Figure: https://commons.wikimedia.org/wiki/File:0305_Simple_Diffusion_Across_Plasma_Membrane.jpg

- However: we need to get salts, sugars, polysaccharides, & other large or hydrophilic molecules inside our cells in order to stay alive
  - *Remember: life requires energy & nutrients*
- So how do we get these things across the cell membrane?
  - Using the 3rd component of membranes: **proteins**

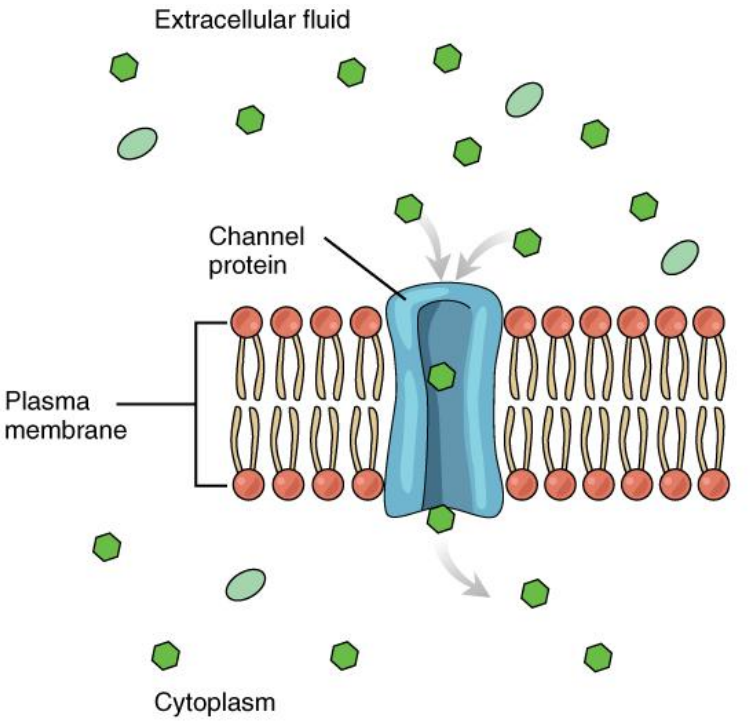


Figure: https://commons.wikimedia.org/wiki/File:0306_Facilitated_Diffusion.jpg

▪ Component 3: **Proteins**

– There are 5 types of proteins associated with the cell membrane: each has a different function

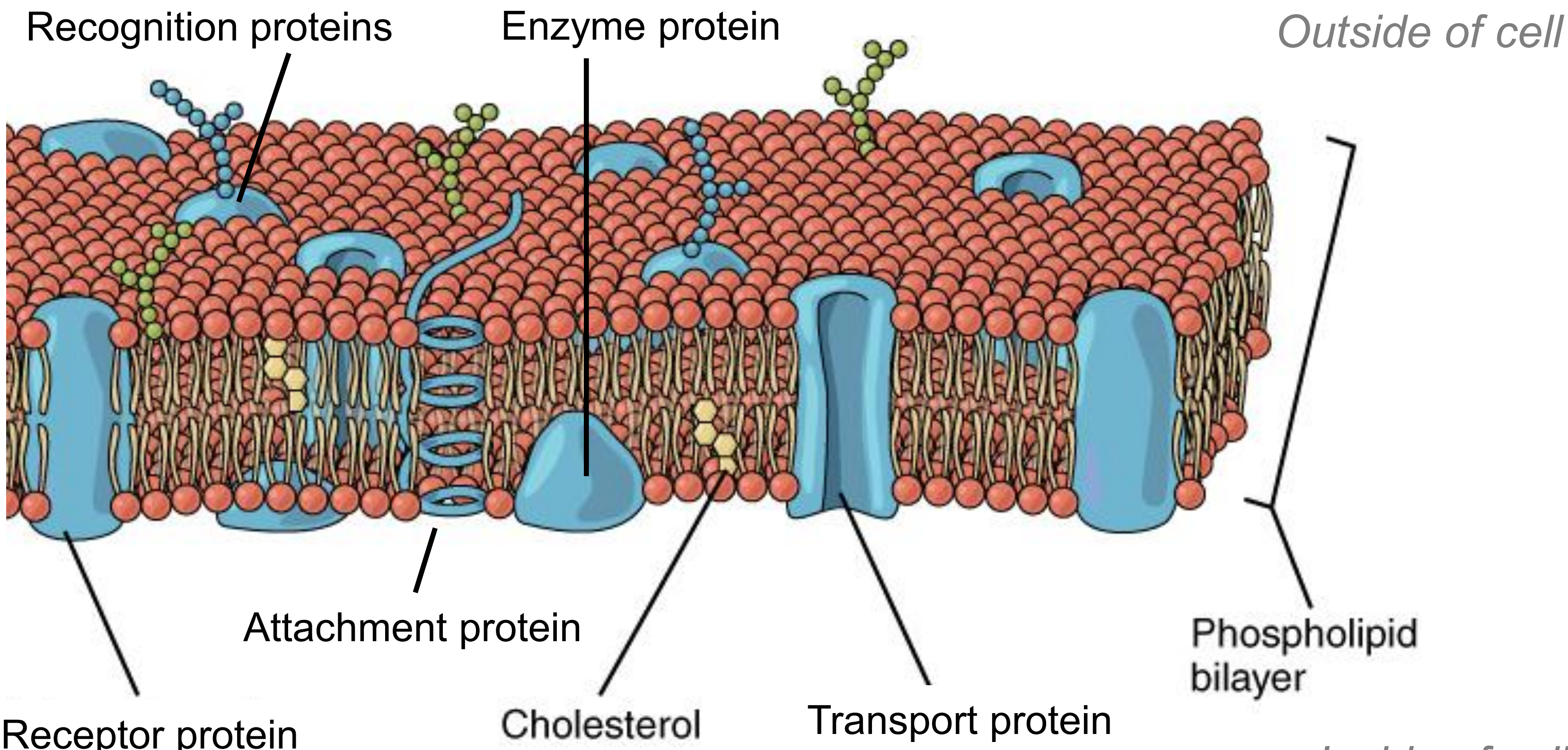
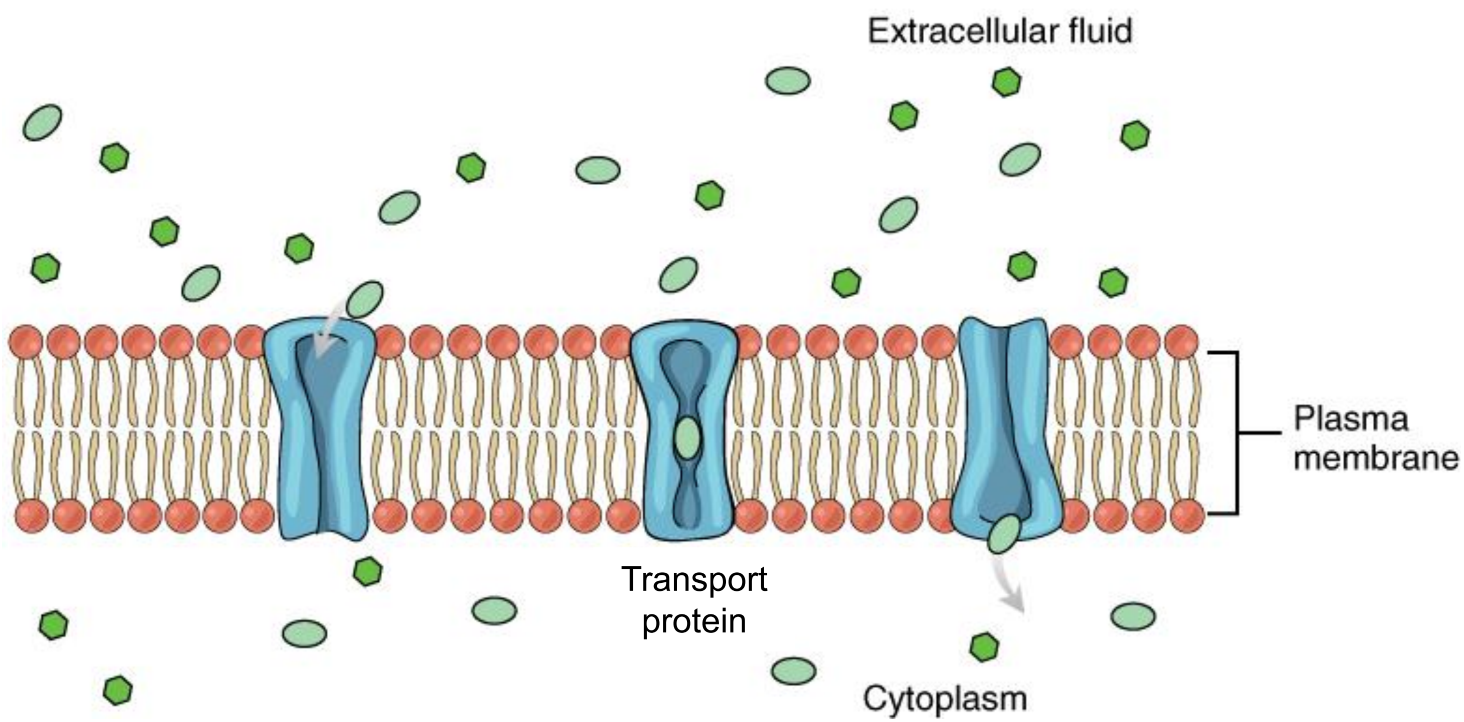


Figure: https://commons.wikimedia.org/wiki/File:0303_Lipid_Bilayer_With_Various_Components.jpg

- Type 1: **transport proteins**
  - Allow specific molecules to cross the membrane
  - e.g. a sodium transport protein ONLY lets sodium through



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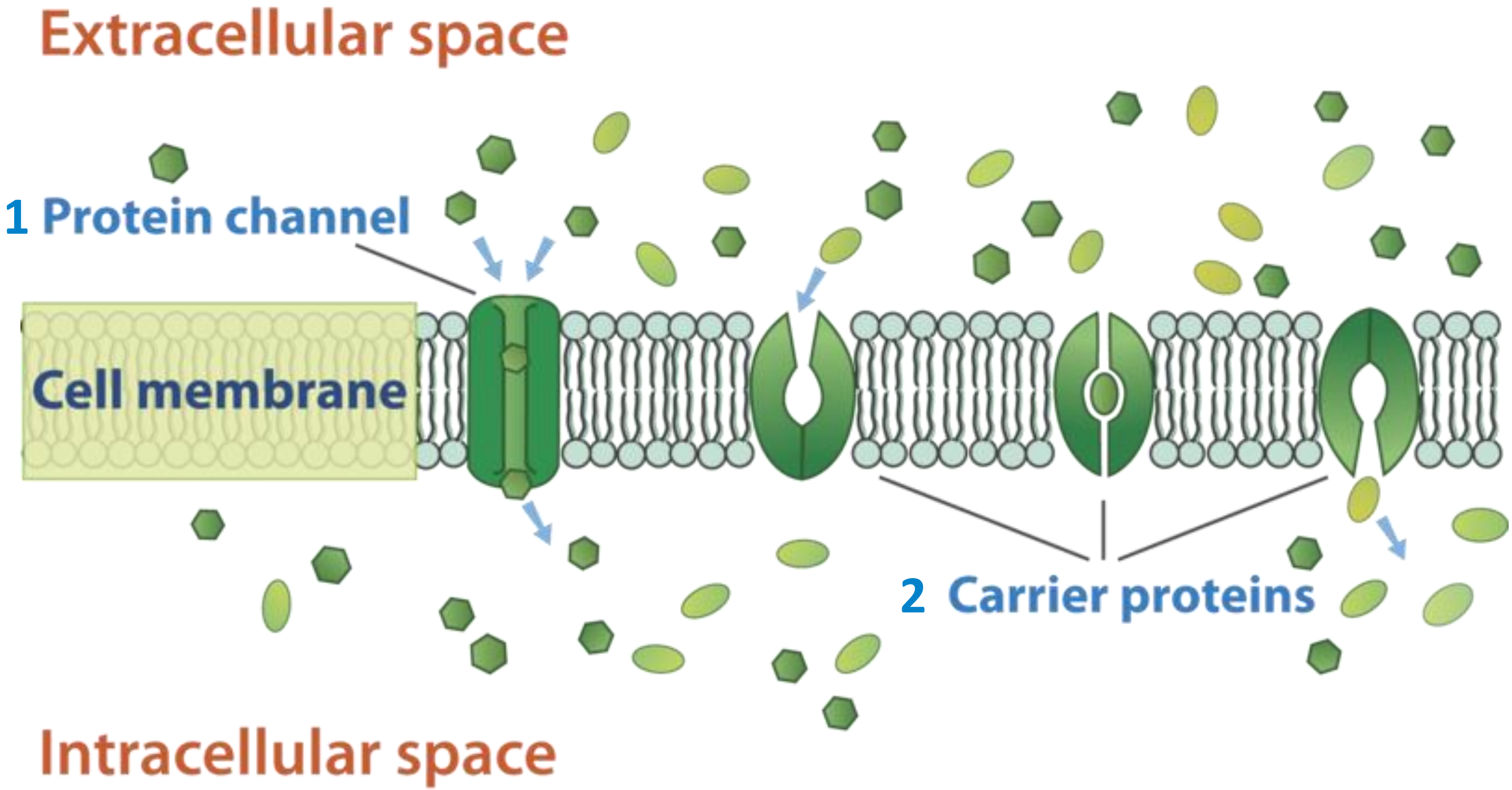

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- Type 2: **recognition proteins**
  - Serve as ID tags on the surface of a cell - this prevents the immune system from attacking it

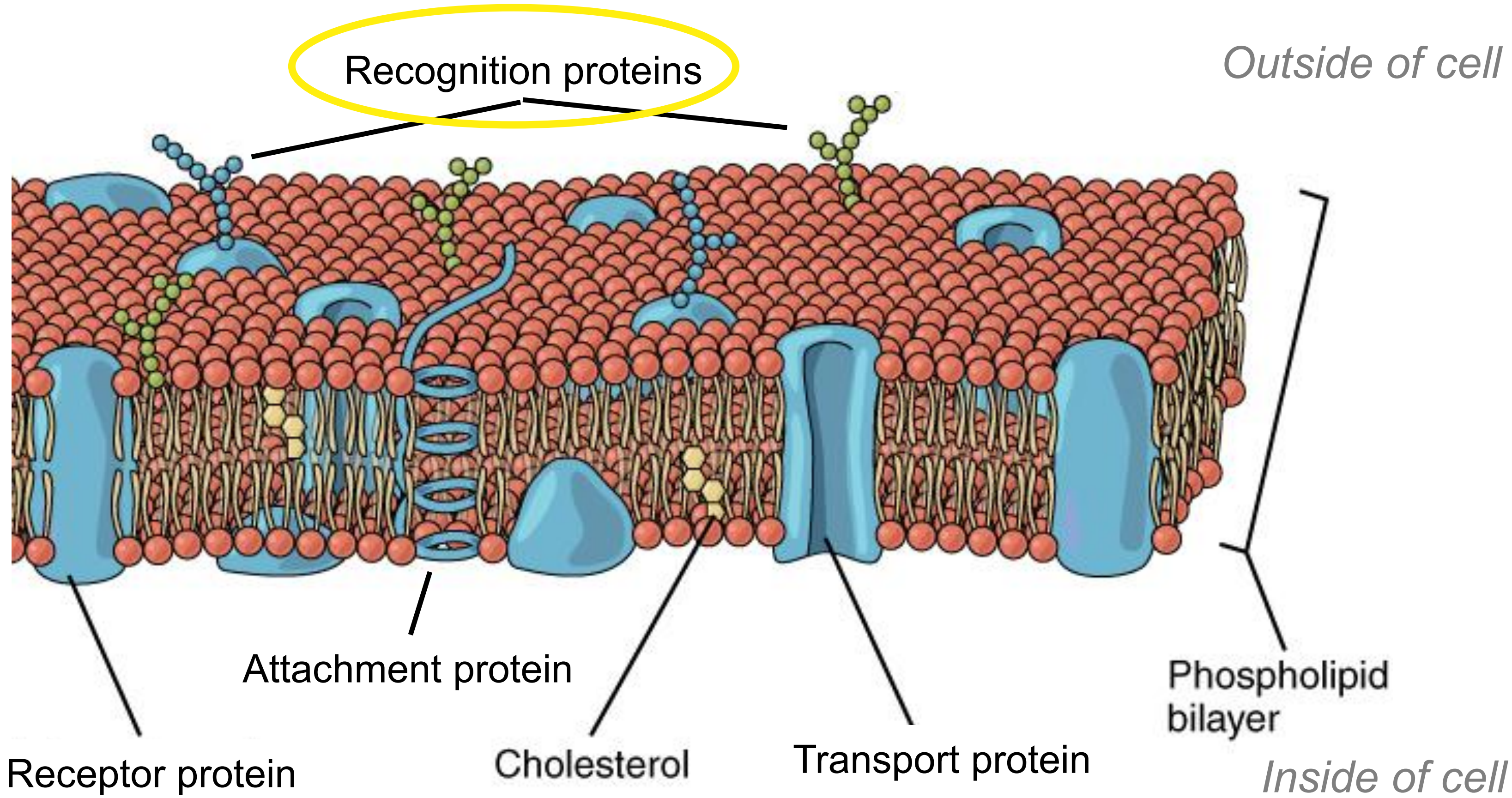
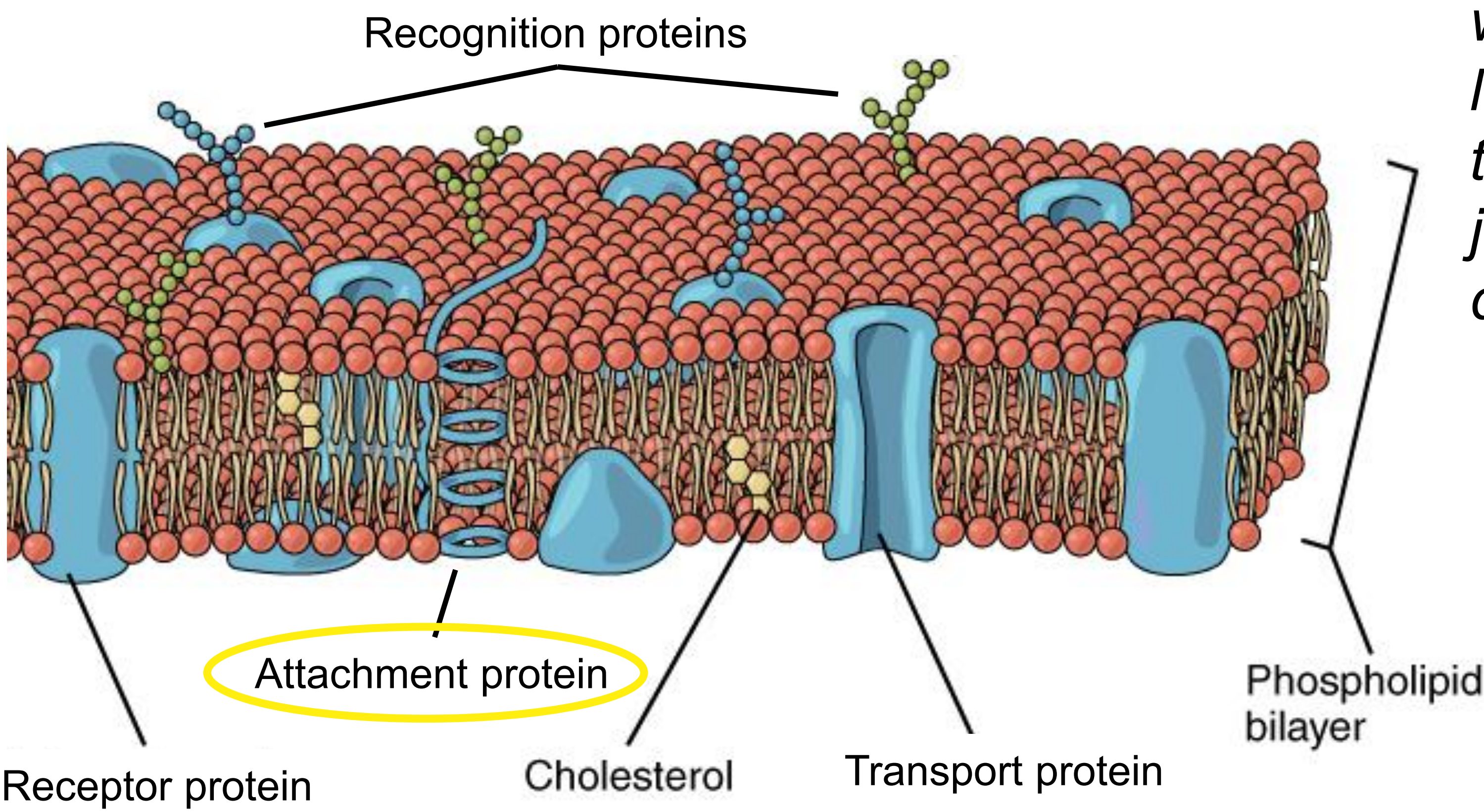


Figure: https://commons.wikimedia.org/wiki/File:0303_Lipid_Bilayer_With_Various_Components.jpg

▪ Type 3: **attachment proteins**

– Anchor & attach the cell membrane to the inner cytoskeleton & to other cells



Remember: we already learned about these - tight junctions & desmosomes

Figure: https://commons.wikimedia.org/wiki/File:0303_Lipid_Bilayer_With_Various_Components.jpg

▪ Type 4: **receptor proteins**

– Trigger cell responses when they bind to a specific molecule

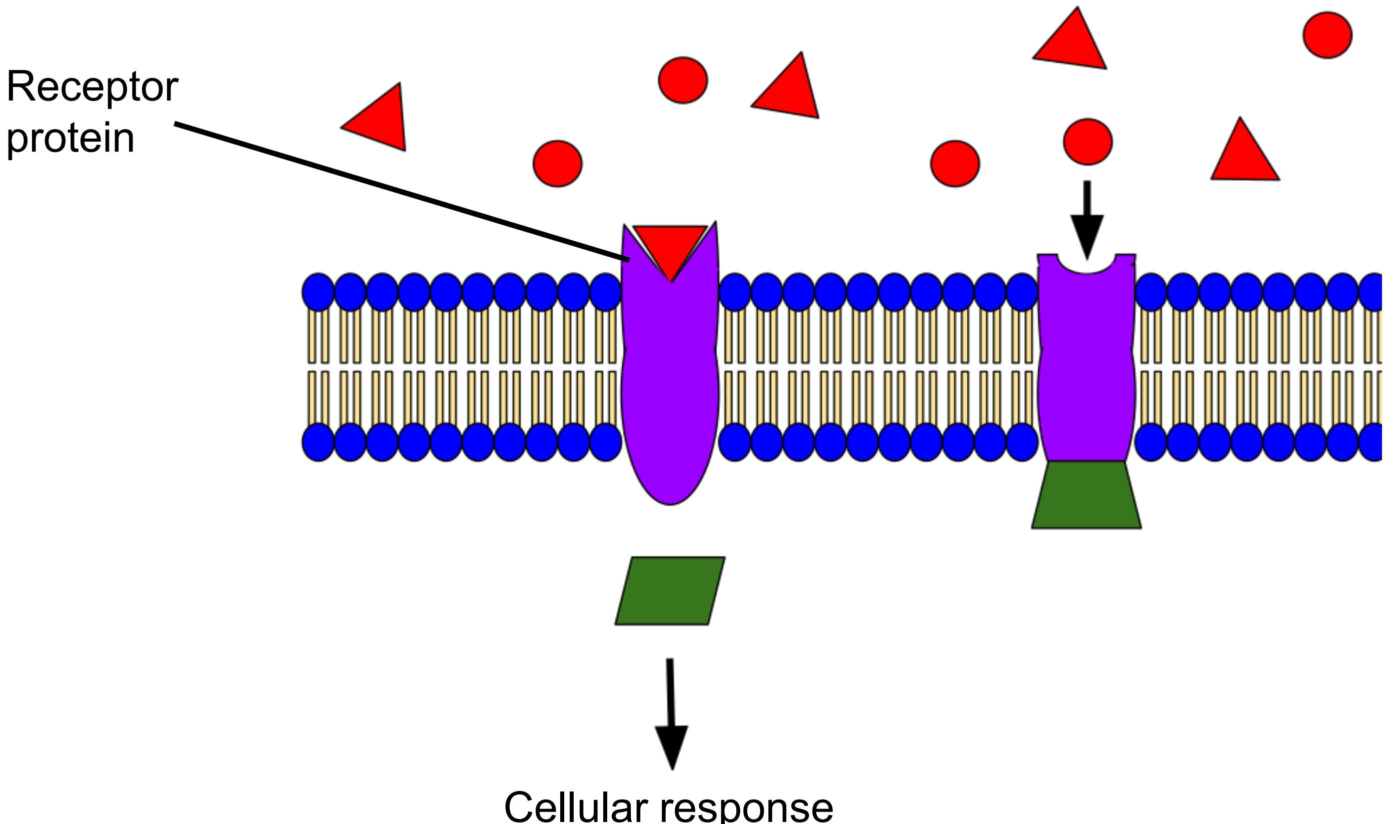
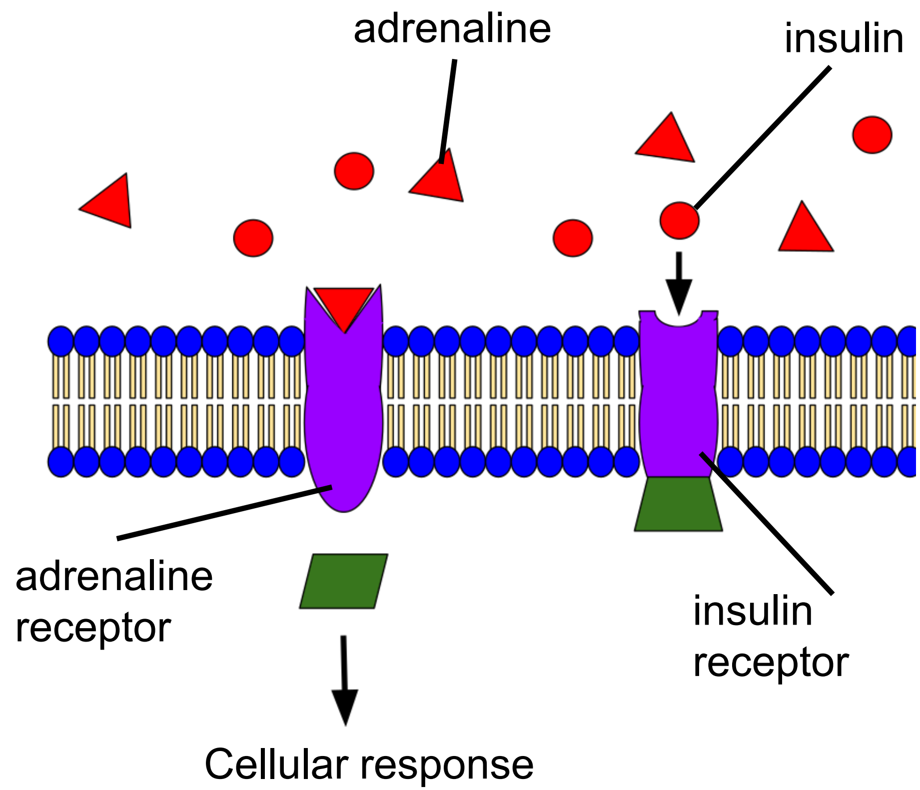


Figure: https://commons.wikimedia.org/wiki/File:Receptor_(Biochemistry).svg

- Receptor proteins trigger cell responses when they bind to a <u>specific</u> molecule
  - e.g. an insulin receptor will ONLY respond to the hormone insulin
  - molecule triggers a change in the cell, but never actually enters the cell



molecule can detach & go on to communicate with many other cells

Figure: https://commons.wikimedia.org/wiki/File:Receptor_(Biochemistry).svg

▪ Type 5: **enzymes**

– Regulate chemical reactions

– Not all enzymes are associated with the cell membrane

  • *more in the next chapter*

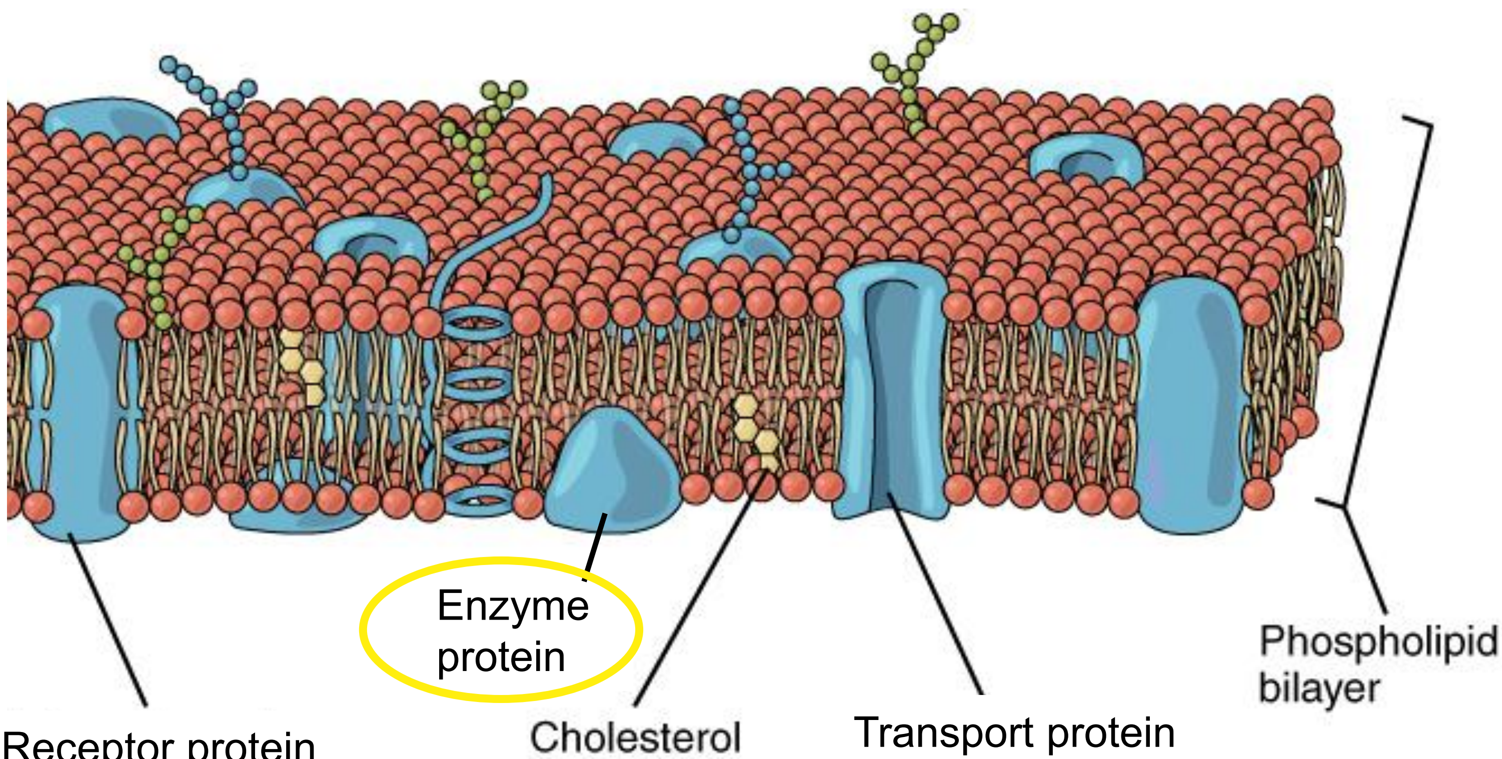


Figure: https://commons.wikimedia.org/wiki/File:0303_Lipid_Bilayer_With_Various_Components.jpg

Report 5

Submit to the same Email by 6th Dec.

Please conceptualize an artificial cell that incorporates a water-soluble anti-tumor compound, capable of specifically identifying and eliminating lung cancer cells. Provide a detailed description of the cell's structure, design principles, and functional mechanisms.

- We’ve now seen that there are several components to cell membranes, each with their own function
  - *Phospholipids enclose cells*
  - *Cholesterol adjusts cell membranes rigidity*
  - *5 proteins have 5 different functions*

- We also know some substances can move across the phospholipid bilayer by themselves, & some need transport proteins to get across
  - <u>So how do any of these molecules know whether to enter the cell, or to exit the cell?</u>

How do molecules know whether to move in or out of a cell?

- Technically, molecules don't "know" anything – but they reliably move according to the laws of physics
  – All molecules dissolved in water, or "**solutes,**" are in constant, random motion

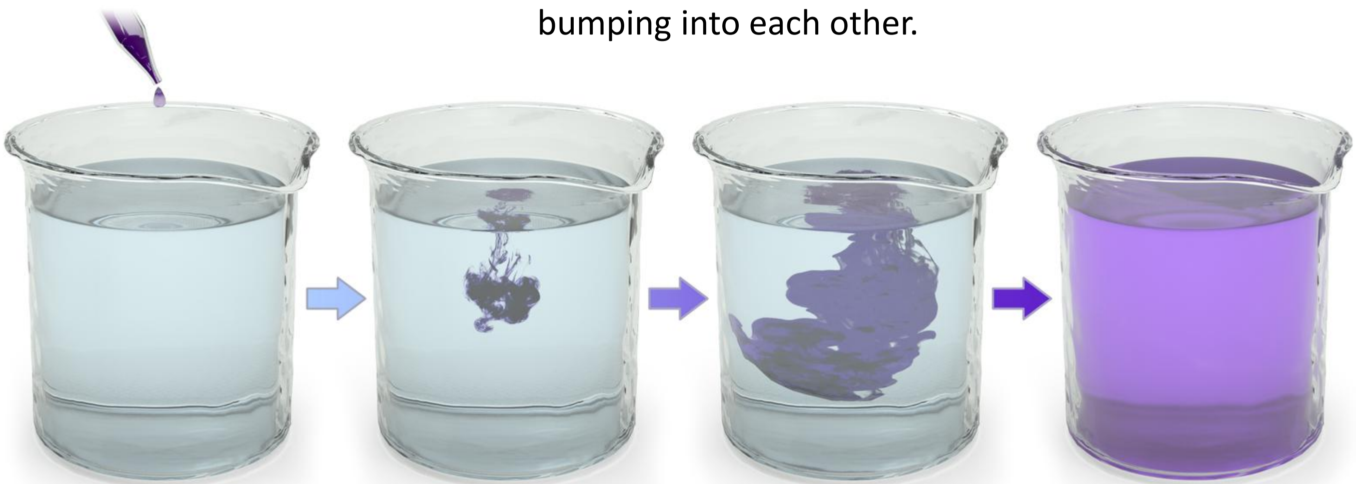
dye molecules are solutes

water molecules AND dye molecules are constantly moving around in the beaker

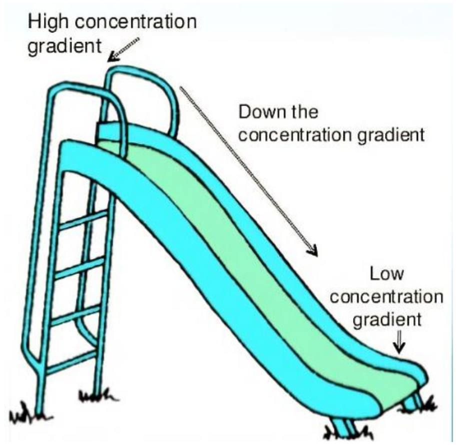
Figure: https://commons.wikimedia.org/wiki/File:Blausen_0315_Diffusion.png

- Even though solutes are moving randomly, we can statistically predict how they will move overall
  - We see here that even though solutes are moving randomly, they eventually become evenly distributed

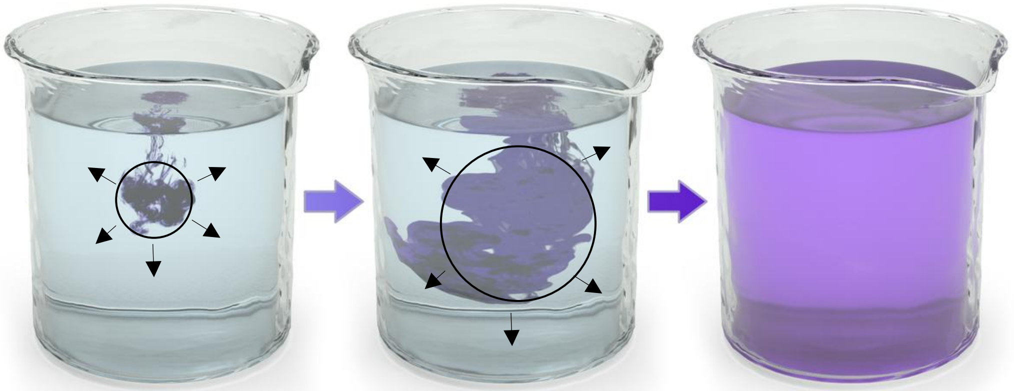
1. A solute, such as food coloring, is dropped into water.
2. Food-coloring molecules and water molecules move about randomly, bumping into each other.
3. The random motion of the Molecules causes them to end up evenly distributed.



- In other words, solutes are statistically more likely to move from where they are more highly concentrated to where there is a lower concentration
  - this random movement from high to low concentration = movement "down the **concentration gradient**"
  - eventually, this leads to **equilibrium**: an even distribution of solutes & water molecules

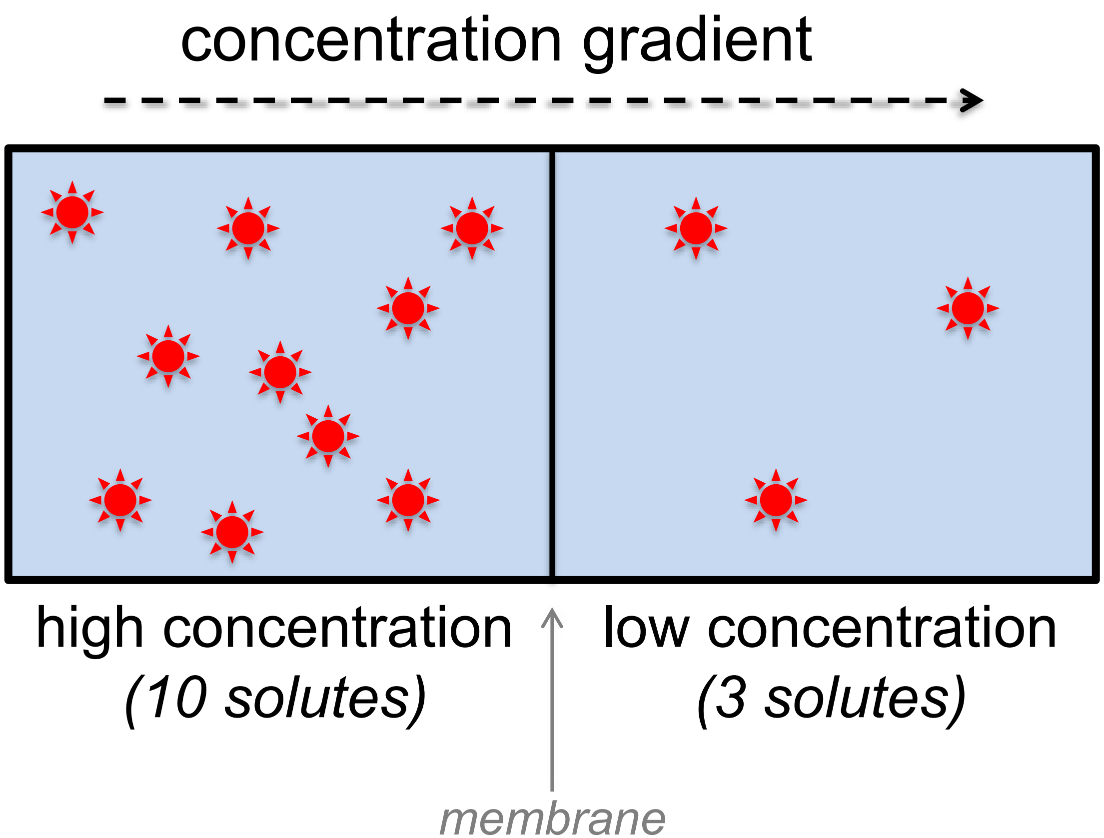


Dye is moving down the concentration gradient, with molecules moving from high to low concentration



Water and dye molecules have reached equilibrium

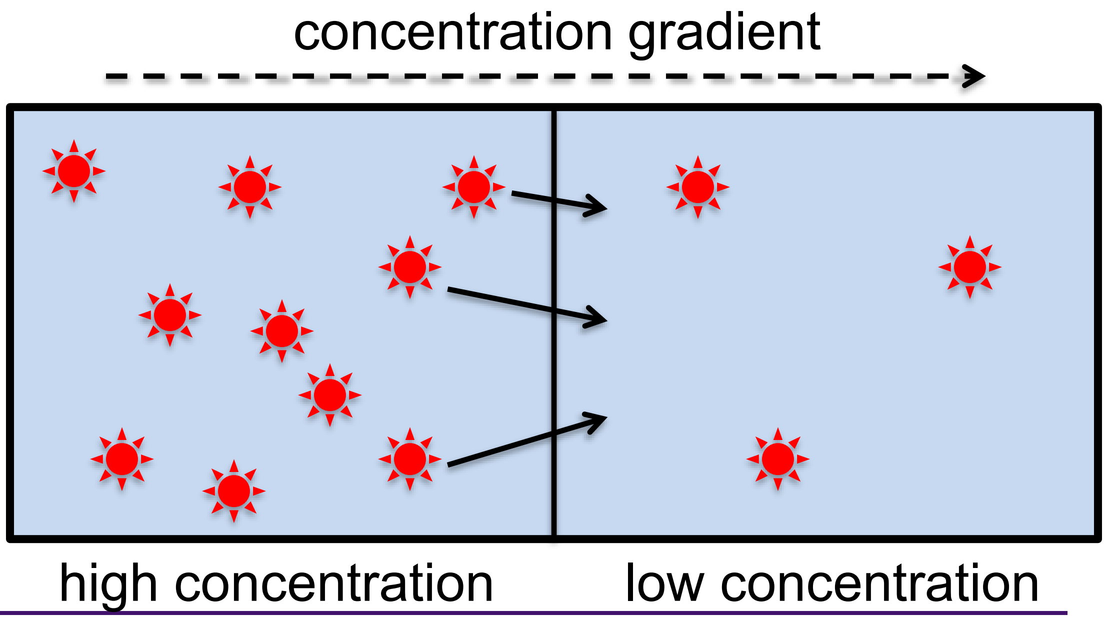
- Now let's consider what would happen if there were a membrane between 2 solutions:



10 solutes might move from left to right, but only 3 solutes might move in the opposite direction: this means statistically there will be a net movement of solutes from left to right, down the concentration gradient

- Since molecules move down their concentration gradient, we can now understand:
  – molecules will move IN to a cell if there is a lower concentration inside
  – molecules will move OUT of a cell if there is a lower concentration outside

- The movement of molecules down their concentration gradient = **diffusion**

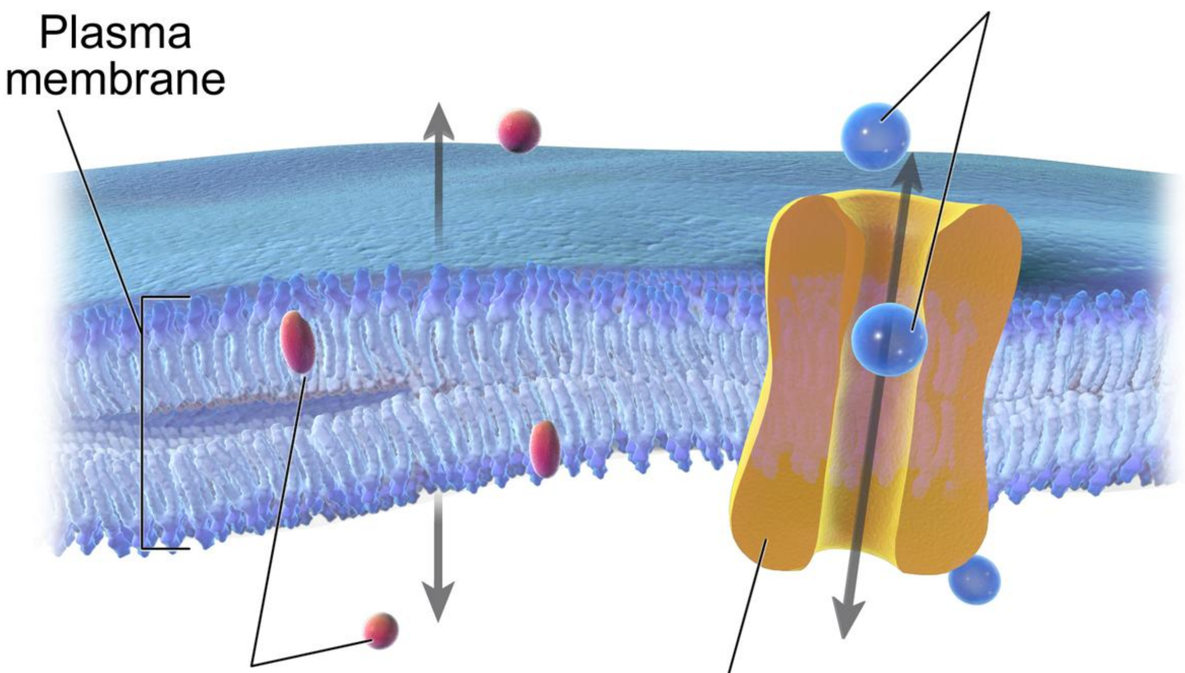


What are the possible ways to move across a cell membrane?

- There are 6 types of transport across cell membranes
  - 3 of them are called **passive transport**
    - Substances move down their concentration gradient (high to low)
    - No energy is needed
  - 3 of them are called **energy-requiring transport**
    - Energy is required

- **Passive transport** occurs when molecules move across a membrane without energy – they move down their concentration gradient

Molecules moving by *facilitated* diffusion or osmosis



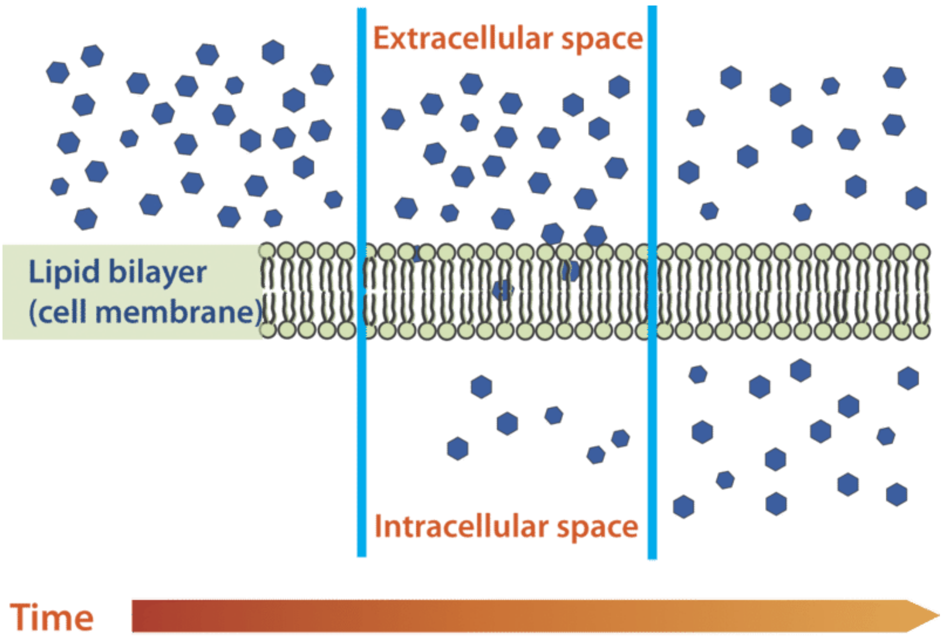
Molecules moving by *simple* diffusion or osmosis

Figure: https://commons.wikimedia.org/wiki/File:Blausen_0213_CellularDiffusion.png

▪ Simple diffusion

– Remember: small molecules & lipophilic molecules can pass through the phospholipid bilayer on their own

- they move directly across the membrane from high to low concentration
- no energy is needed or used = simple diffusion



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– Remember: hydrophilic molecules can NOT pass through the phospholipid bilayer on their own

- they need a protein to help them across the membrane from high to low concentration
- no energy is needed or used

= facilitated diffusion

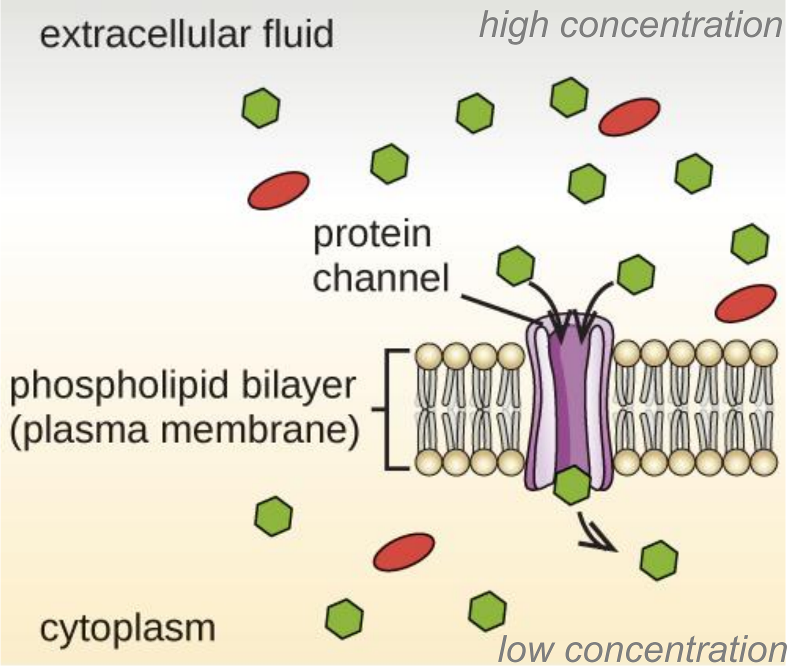


Figure: https://commons.wikimedia.org/wiki/File:OSC_Microbio_03_03_facdiff.jpg

▪ Osmosis

– Sometimes there is a concentration gradient, but solutes can <u>not</u> move past the membrane
  - *maybe they are too big, or transport proteins are closed*

– Water is small & <u>can</u> cross membranes: if solutes can't diffuse, water will move until each side of the membrane has equal concentrations (equilibrium)
  - **Osmosis** = movement of water across a membrane

OSMOSIS
Water molecules diffuse across a cell membrane until the concentration of water inside & outside the cell is equalized.

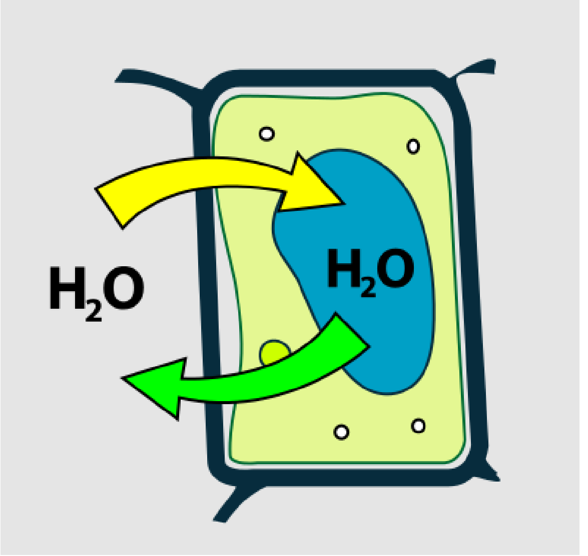
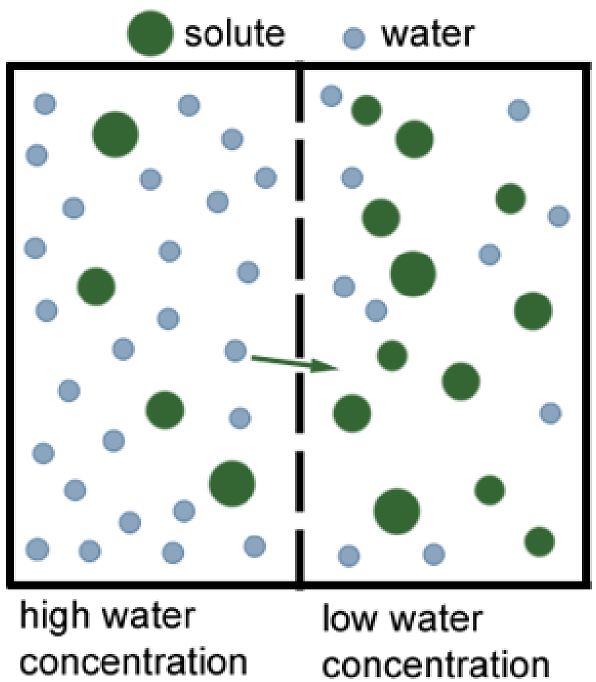


Figure: https://commons.wikimedia.org/wiki/File:Turgor_pressure_on_plant_cells_diagram.svg

- **Osmosis:** water technically moves by diffusion: from a region of high to low water concentration

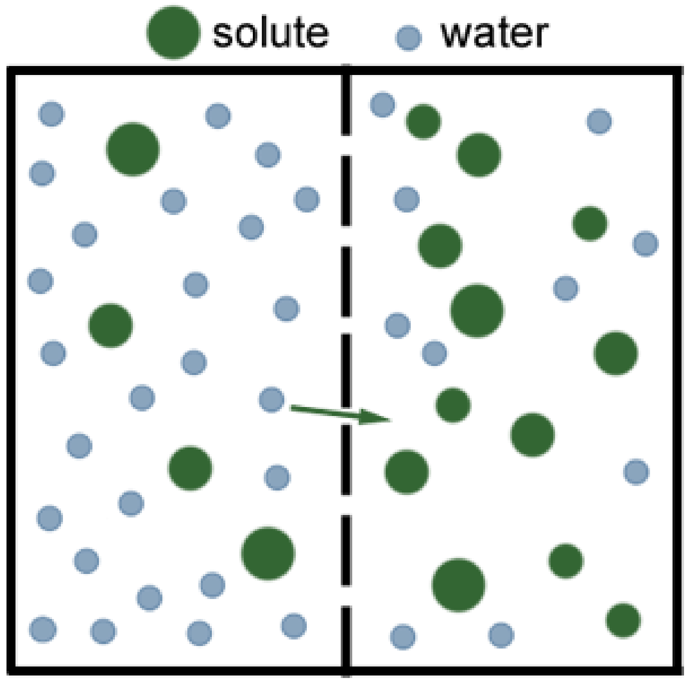


net movement of osmosis to the right

(water moves from high to low water)

Figure: https://scienceaid.net/biology/cell/osmosis.html

- However, it can be hard to determine which area has high vs. low water
  - to figure out which way water will move (osmosis) to help reach equilibrium, find the side that has high solutes – those must be diluted out to be closer to the concentration on the other side, so water will move toward them



5% solute
(lower solute concentration)

10% solute
(higher solute concentration)

net osmosis to the right
(water moves to dilute out the most concentrated solute)

Figure: https://scienceaid.net/biology/cell/osmosis.html

- The drive for equilibrium is so powerful that osmosis overcomes gravity:

Hypotonic solution (lower concentration)

Hypertonic solution (lower concentration)

Volumes are now different (and gravity is overcome), but equilibrium is reached, with equal concentrations on either side

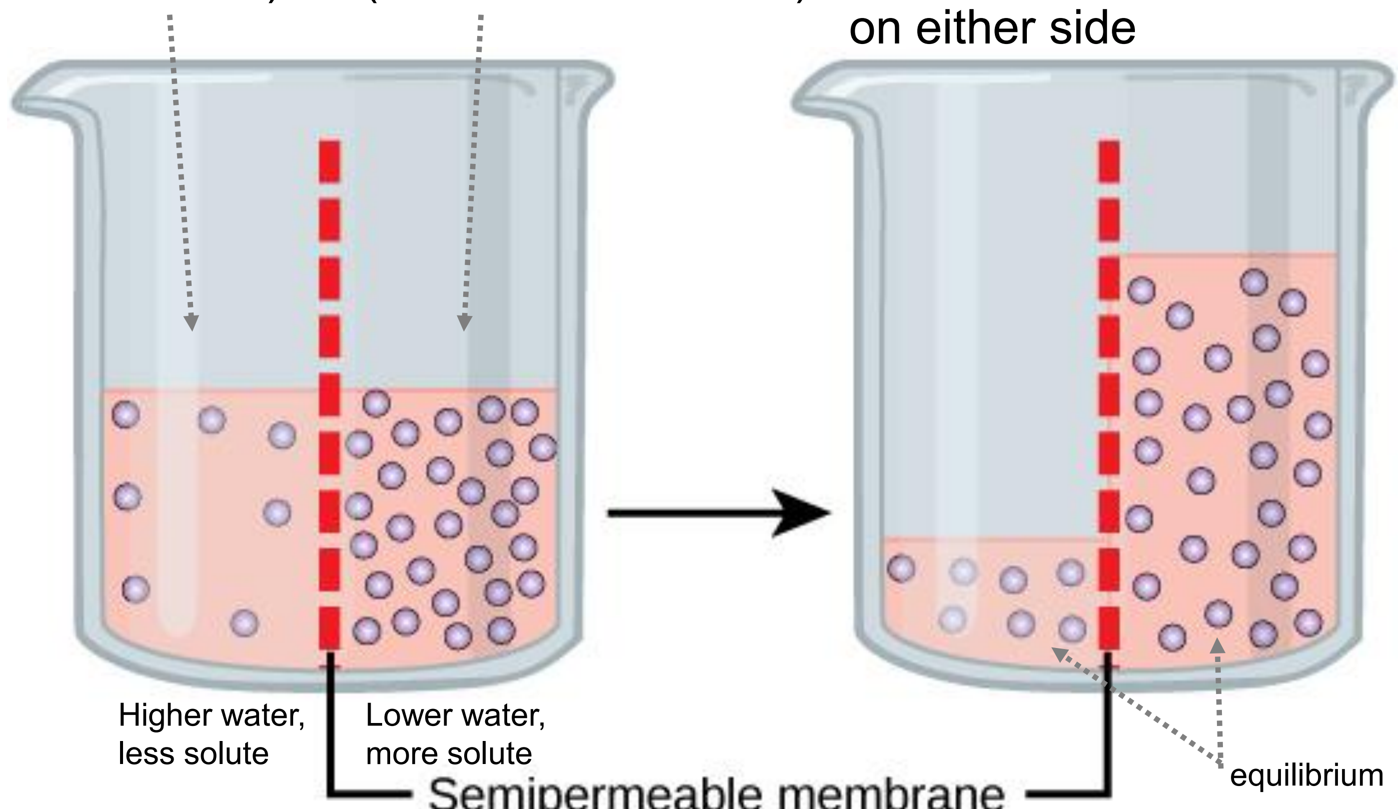
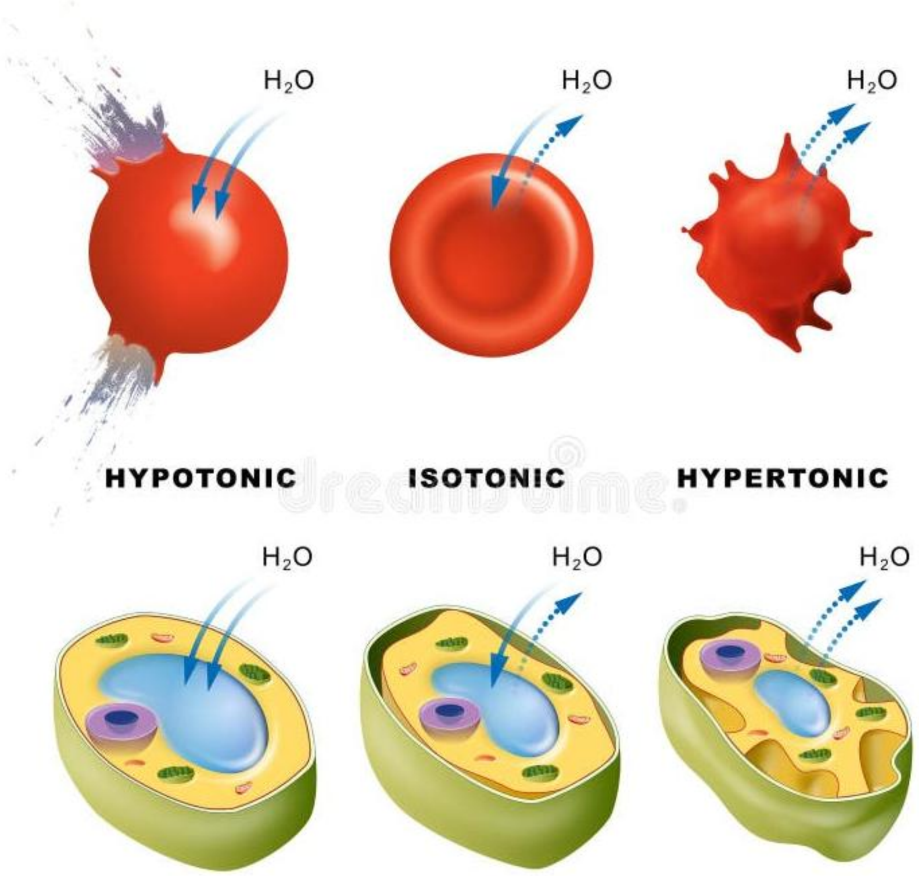


Figure: https://commons.wikimedia.org/wiki/File:Figure_05_02_06.jpg

- Cells are constantly filled with & surrounded by water: equilibrium is crucial, or life stops
  - Our cells can find themselves in 3 possible environments: <u>isotonic, hypertonic & hypotonic</u>



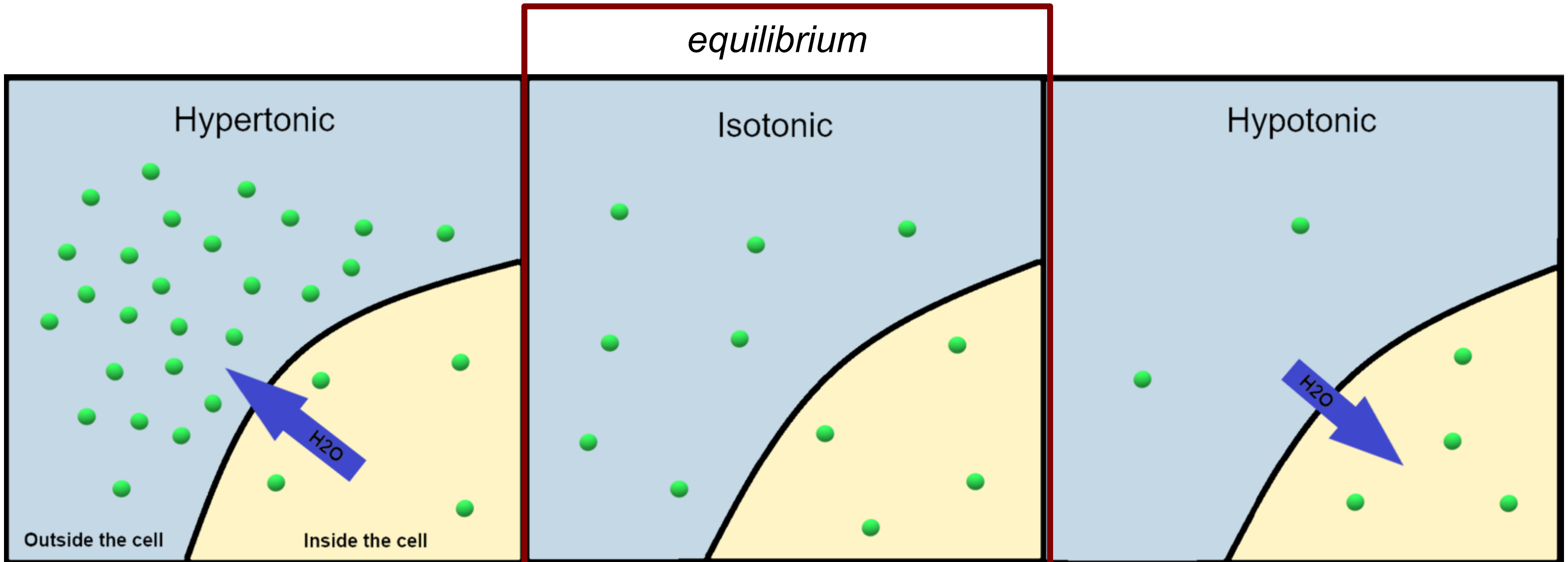
*A cell in a **hypertonic** solution loses water and shrinks*

*A cell in an **isotonic** solution remains healthy*

*A cell in a **hypotonic** solution gains water and can swell and burst*

https://thumbs.dreamstime.com/b/osmosis-animal-plant-cells-osmosis-affects-plant-animal-cells-differently-plant-animal-cells-can-tolerate-261982982.jpg

- **Isotonic** solutions: equal concentrations of water & solutes on either side of the membrane
  - No net water movement occurs



A cell in a **hypertonic** solution loses water and shrinks

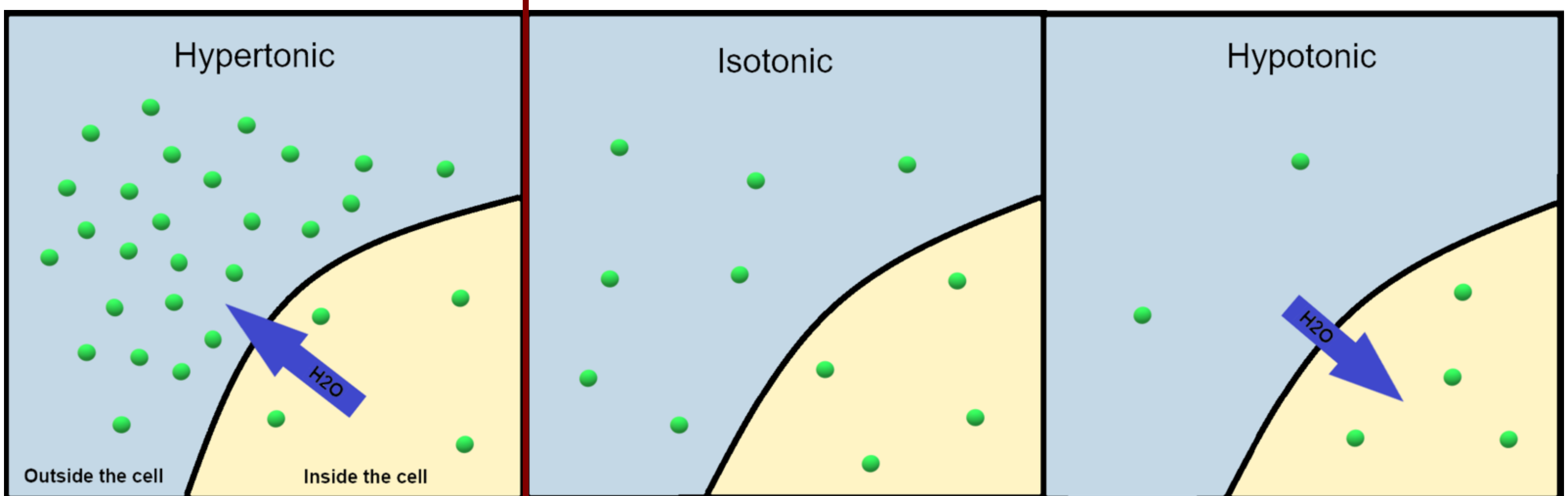
A cell in an **isotonic** solution remains healthy

A cell in a **hypotonic** solution gains water and can swell and burst

Figure: https://commons.wikimedia.org/wiki/File:Hypertonic_Isotonic_Hypotonic.png

- A **hypertonic** solution is one with a <u>greater solute</u> concentration relative to the cell
  - Water moves toward the more concentrated solutes outside the cell to dilute them: cell shrivels

equilibrium



A cell in a **hypertonic** solution loses water and shrinks

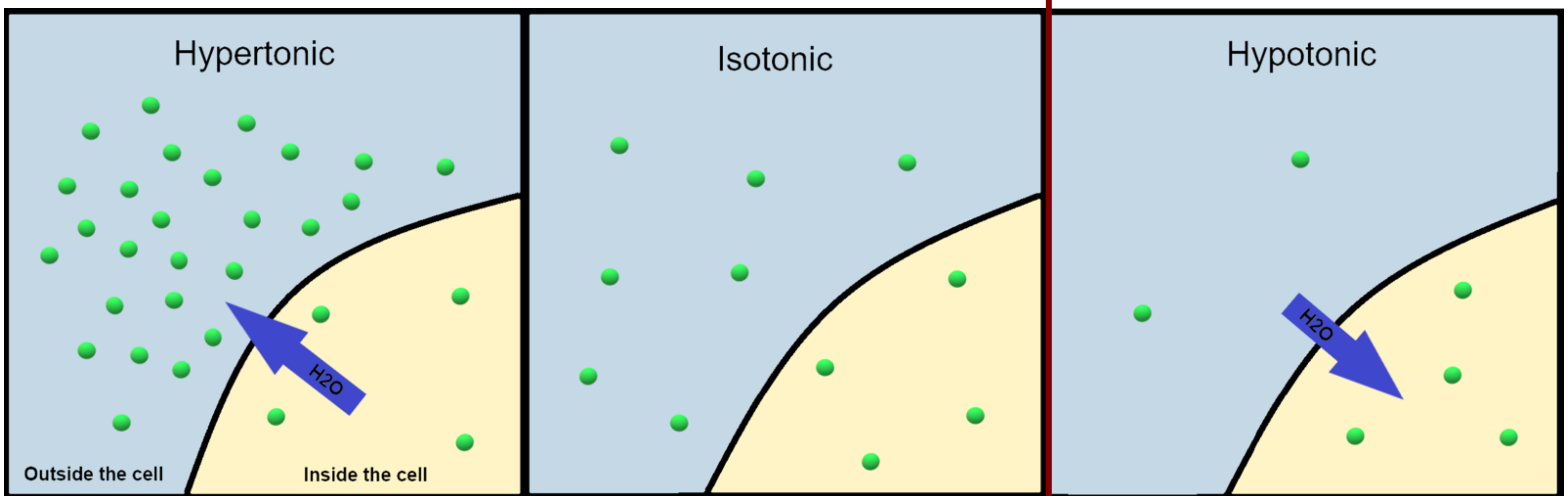
A cell in an **isotonic** solution remains healthy

A cell in a **hypotonic** solution gains water and can swell and burst

Figure: https://commons.wikimedia.org/wiki/File:Hypertonic_Isotonic_Hypotonic.png

- A **hypotonic** solution is one with a <u>lower solute</u> concentration relative to the cell
  - Water moves toward the more concentrated solutes inside the cell to dilute them: cell swells

equilibrium



A cell in a **hypertonic** solution loses water and shrinks

A cell in an **isotonic** solution remains healthy

A cell in a **hypotonic** solution gains water and can swell and burst

- <u>How these solutions affect our cells:</u>
  - Red blood cells are suspended in our watery blood
    - If our blood stream is **isotonic** relative to our cells, no net movement occurs – cells stay healthy

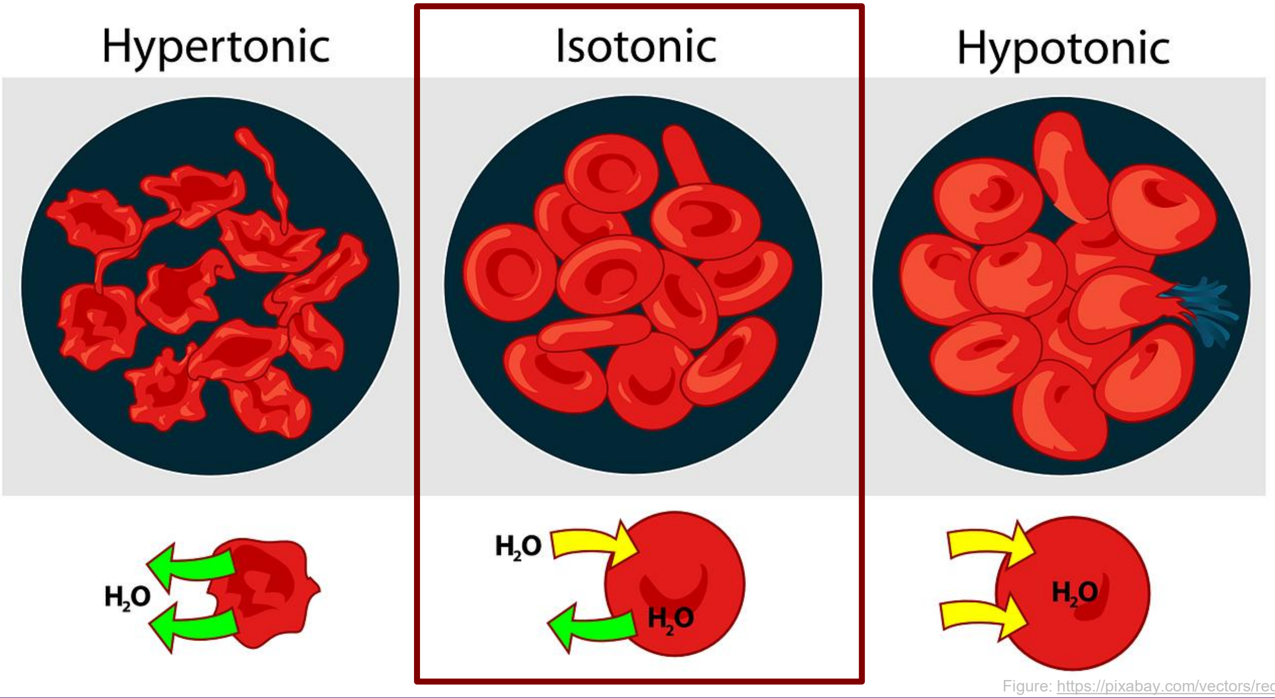
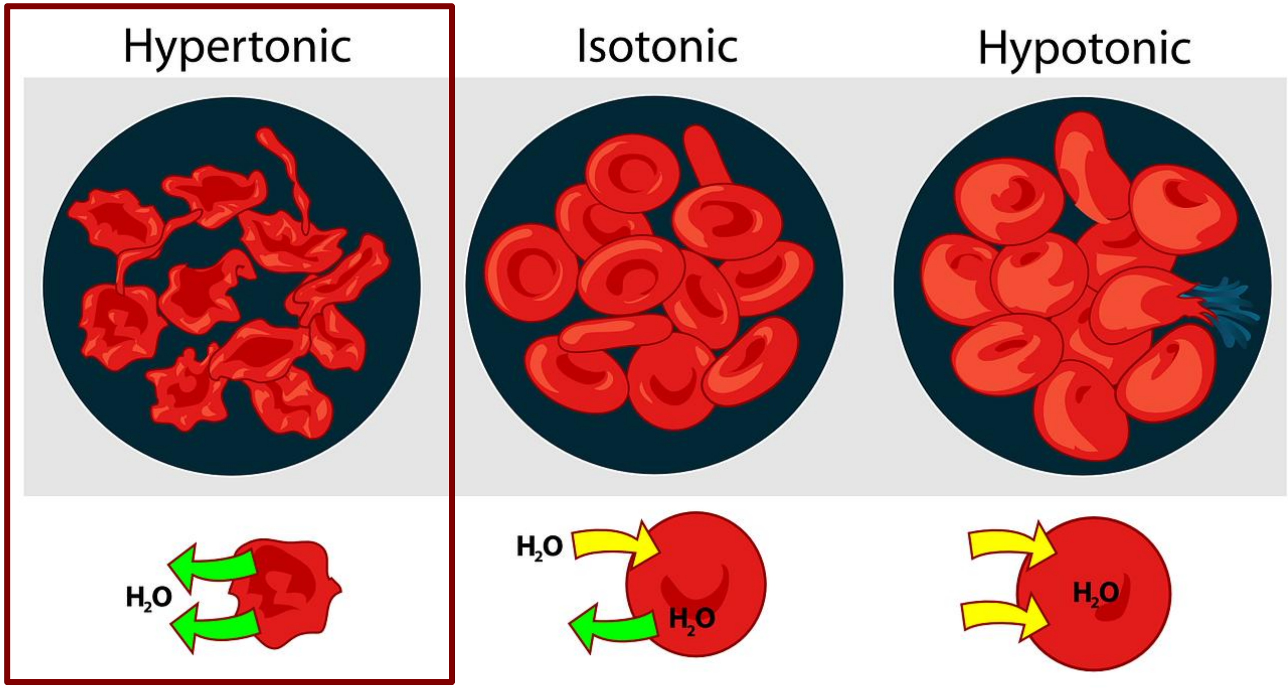
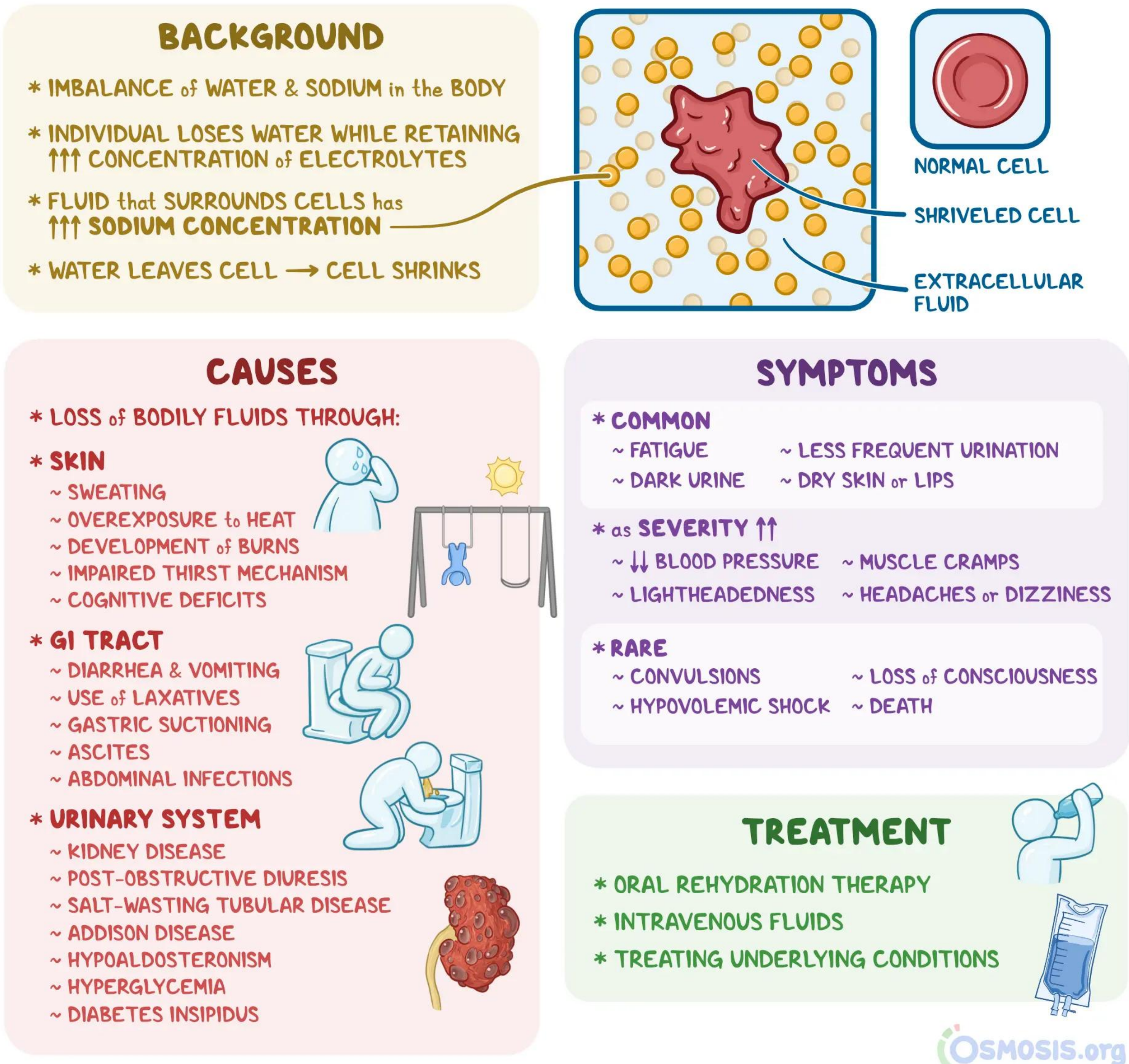


Figure: https://pixabay.com/vectors/red-science-diagram-cell-biology-41576/

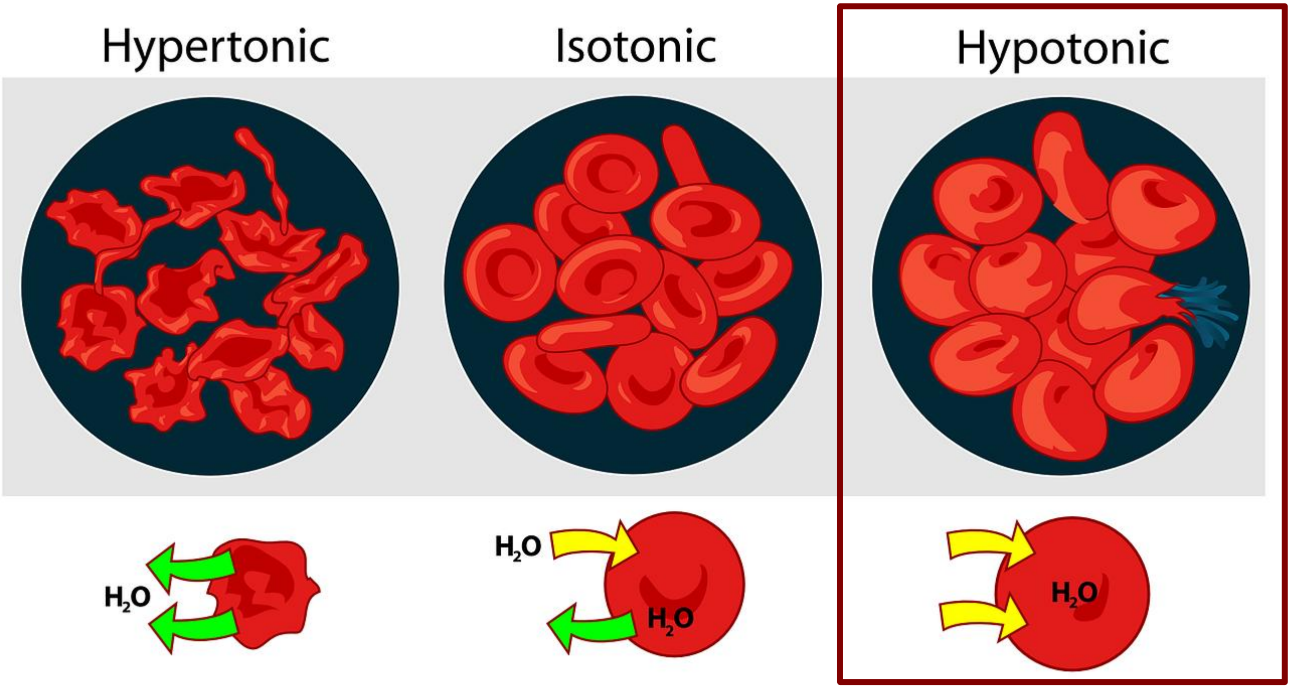
- <u>How these solutions affect our cells:</u>
  - If our blood stream is **hypertonic** relative to our cells, water moves out to dilute the blood stream
    - cells shrivel & can die



Hypertonic dehydration occurs when an individual excretes too much water without also excreting electrolytes, leaving the fluid that surrounds cells (i.e., extracellular fluid) with a high sodium concentration.



- <u>How these solutions affect our cells:</u>
  - If our blood stream is **hypotonic** relative to our cells, water moves in to dilute our cells
    - cells swell & can even burst (die)



Measure Serum Osmolality

Normal
(280-290 mOsm/kg)

Pseudohyponatremia
- Hyperlipidemia
- Hyperproteinemia

Low
(<280 mOsm/kg)

Asses Volume Status

Hypervolumic
- CHF
- Cirrhosis
- Nephrotic syndrome

Hypovolumic

Check Urinary Na^+

<15 mEq/L(Extrarenal loss)
- Vomitting, Diarrhea, fistulas
- Burns, sweating
- Pancreatitis, Peritonitis

>15 mEq/L(Renal loss)
- Recent diuretics
- Adrenal insufficiency
- Cerebral Salt wasting

Euvolumic
- SIADH(Urine Osm >100)
- Psycogenic polydipsia (Urine Osm <100)
- Hypothyroidism
- Cortisol deficiency

Elevated
(>290 mOsm/kg)

Hypertonic hyponatremia
- Hypeyglycemia
- Hypertonic infusions (mannitol, glycerie)

- <u>Osmosis regulates plant cells too:</u>
  - The inside of plant cells usually have more solutes than its surroundings, which are hypotonic
  - So water enters by osmosis, generating **turgor pressure**

turgor pressure in the central vacuole

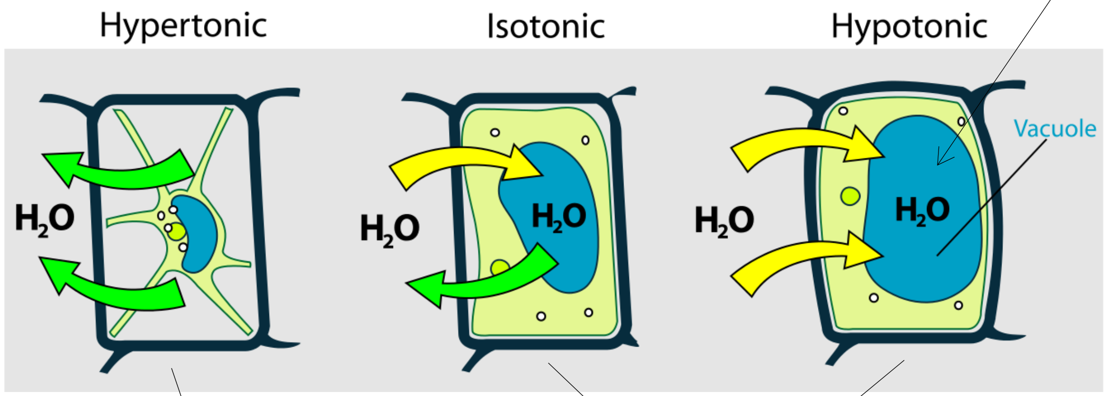
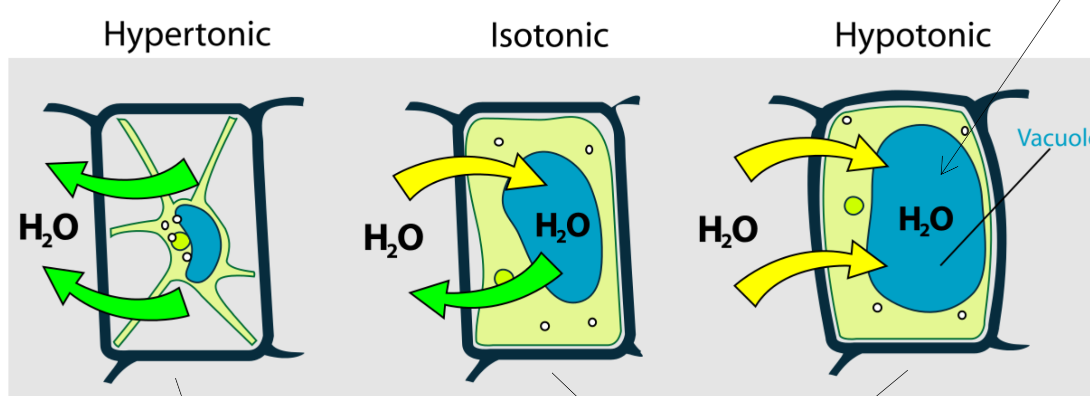


Figure: https://commons.wikimedia.org/wiki/File:Turgor_pressure_on_plant_cells_diagram.svg
Figure: https://botit.botany.wisc.edu/botany_130/anatomy/col1.html

– In a hypertonic environment (e.g. if you forget to water it), water leaves the cells instead

turgor pressure in the central vacuole

- turgor pressure is no longer supporting the cells – so the plant wilts



Osmosis vs. diffusion: which one will happen?

- 1st we need to know if solutes can cross
  - If so, diffusion will happen
  - If NOT, osmosis will happen
- What if both can cross?
  - Diffusion will happen until equilibrium is reached
    - Water no longer has to do any work = no osmosis

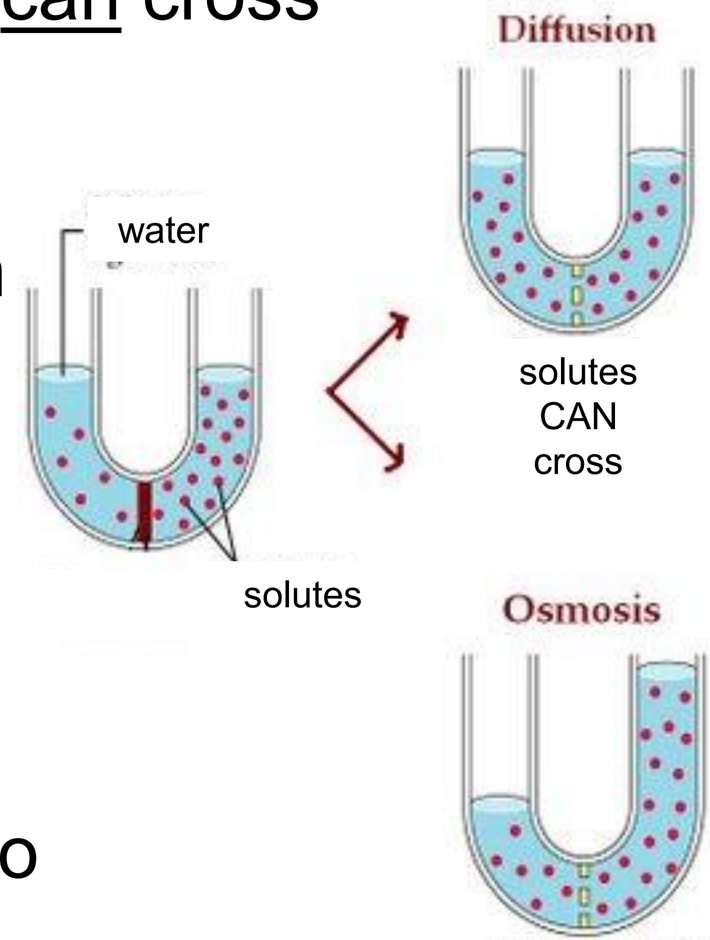


Figure: https://schsbiologyeocreview.weebly.com/picturesvideo.html

▪ **Energy-requiring transport**

– Sometimes a cell needs to move molecules <u>against their concentration gradient</u>

  - *e.g. too much calcium can poison a cell, so it actively pumps calcium out, even if it is at a higher concentration outside the cell*

– Sometimes a cell needs to move molecules <u>too big</u> to fit through proteins

  - *e.g. white blood cells of the immune system take in large bacterial cells to kill them*

▪ **Energy-requiring transport**:

– cells use energy for these 3 types of transport that either move molecules against their concentration gradient or that move large molecules

- Active transport
- Endocytosis
  - pinocytosis
  - phagocytosis
  - receptor-mediated
- Exocytosis

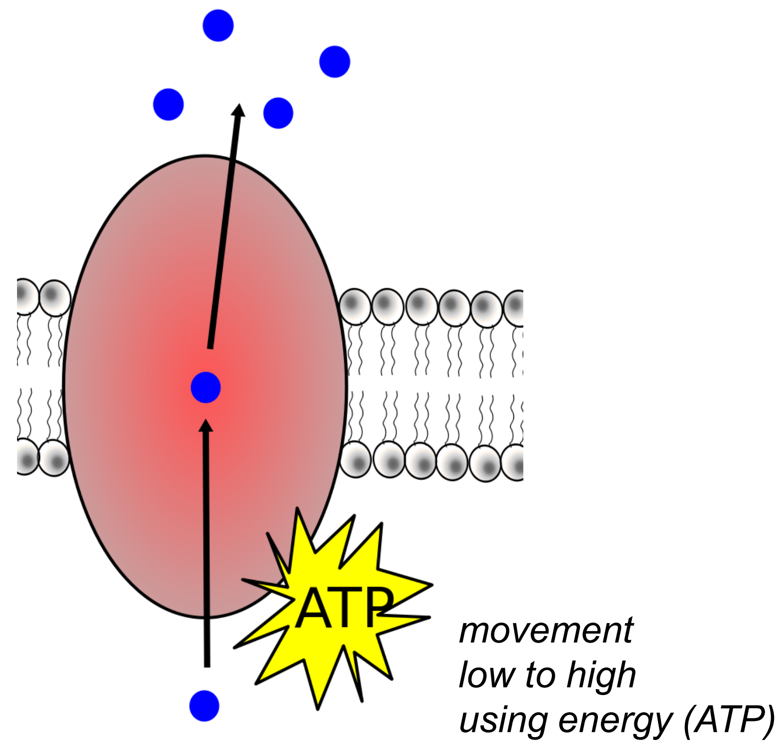


Figure: https://commons.wikimedia.org/wiki/File:Passief-actief-transport-in-cel.svg

▪ Active transport

– cells use a protein & energy (in ATP) to move molecules across cell membranes <u>against</u> their concentration gradients

too much calcium can poison a cell, so it actively pumps calcium out, even if it is at a higher concentration outside

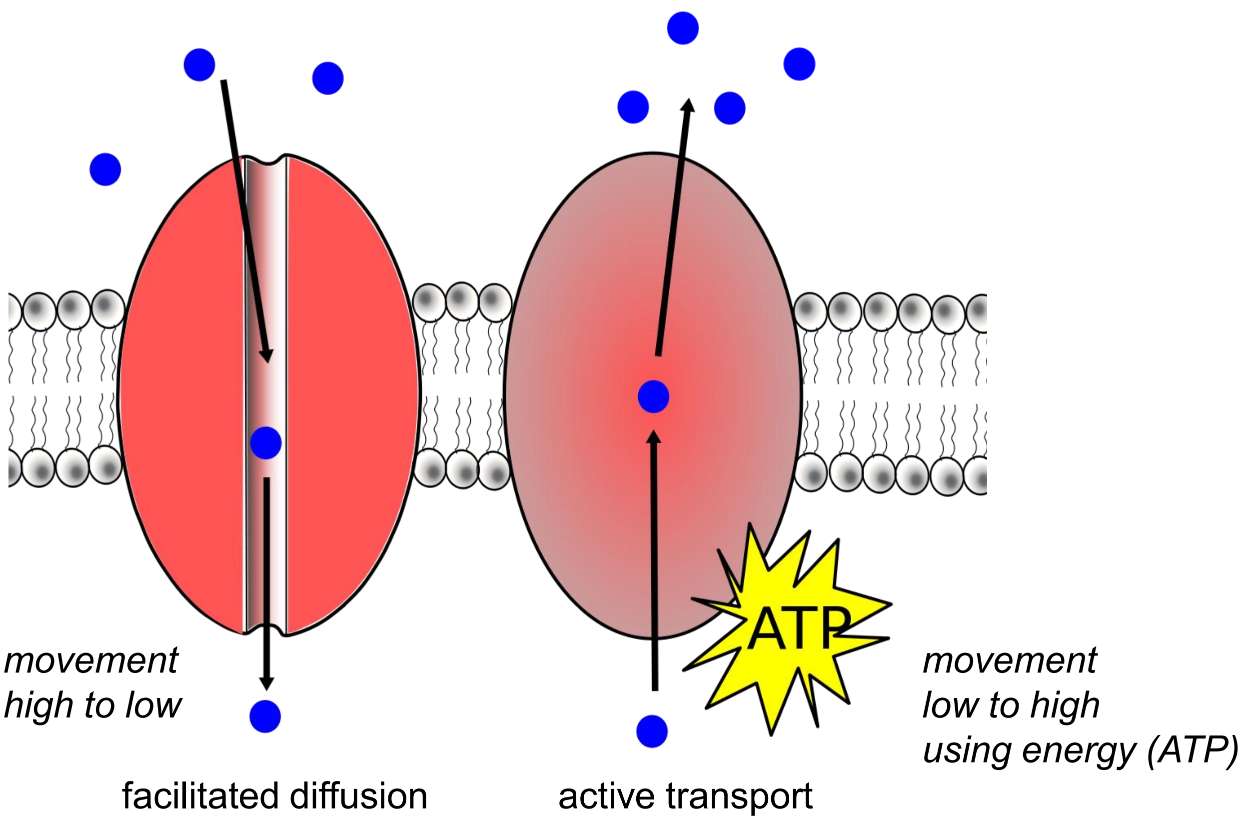
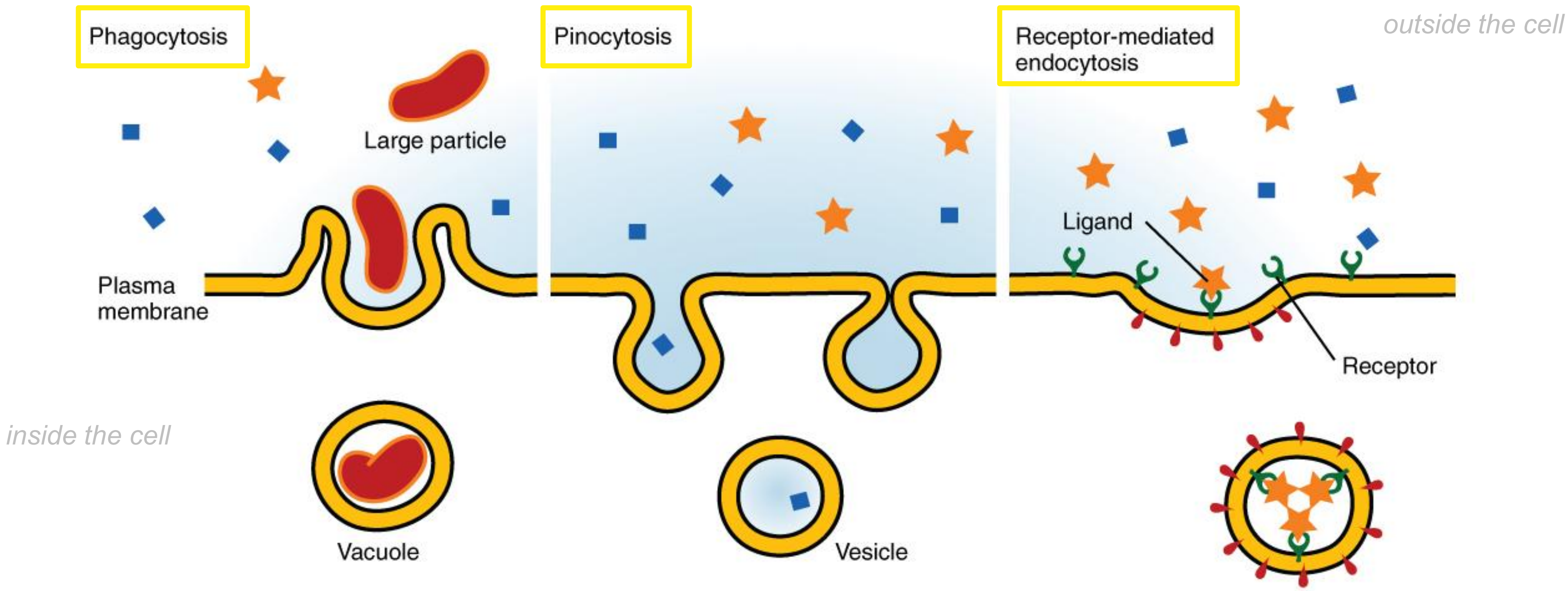


Figure: https://commons.wikimedia.org/wiki/File:Passief-actief-transport-in-cel.svg

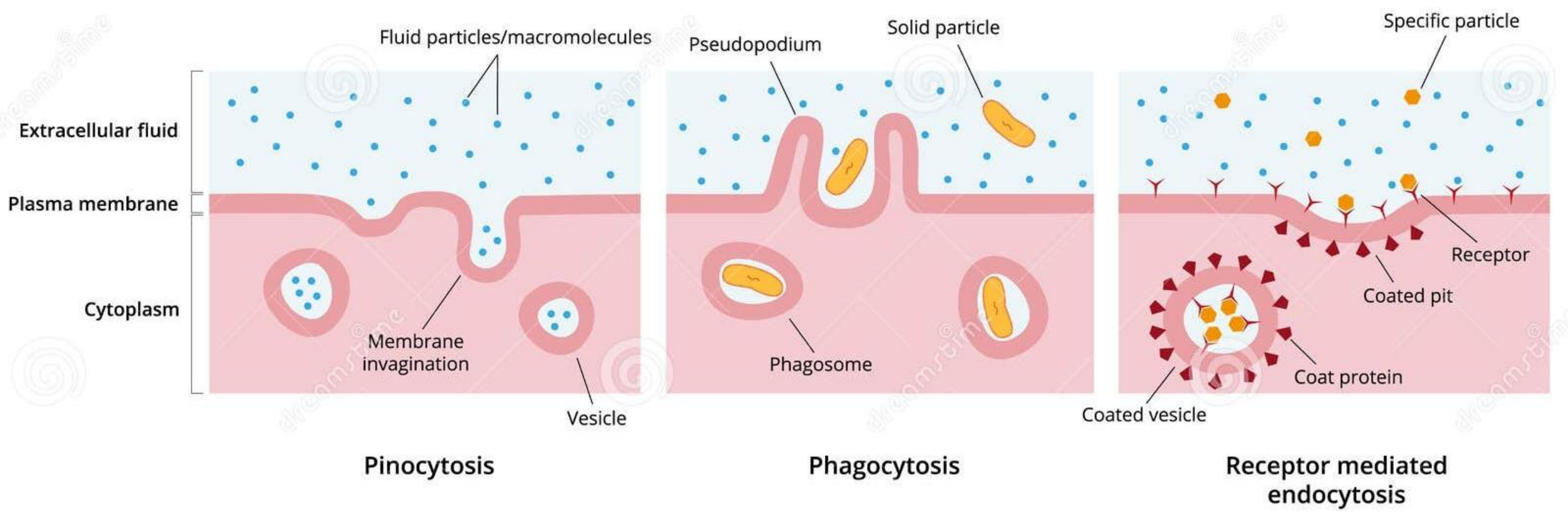
- **Endocytosis** = into the cell
  - cells take in large molecules, food particles, or large amounts of fluid by forming a vesicle



- *3 types of endocytosis: pinocytosis, phagocytosis, & receptor-mediated*

Figure: https://commons.wikimedia.org/wiki/File:0309_Three_Forms_of_Endocytosis.jpg

- Endocytosis 1. **Pinocytosis**: moves fluids into the cell – “cell drinking”
- Endocytosis 2. **Receptor-mediated**: moves <u>specific molecules</u> into the cell using receptor proteins



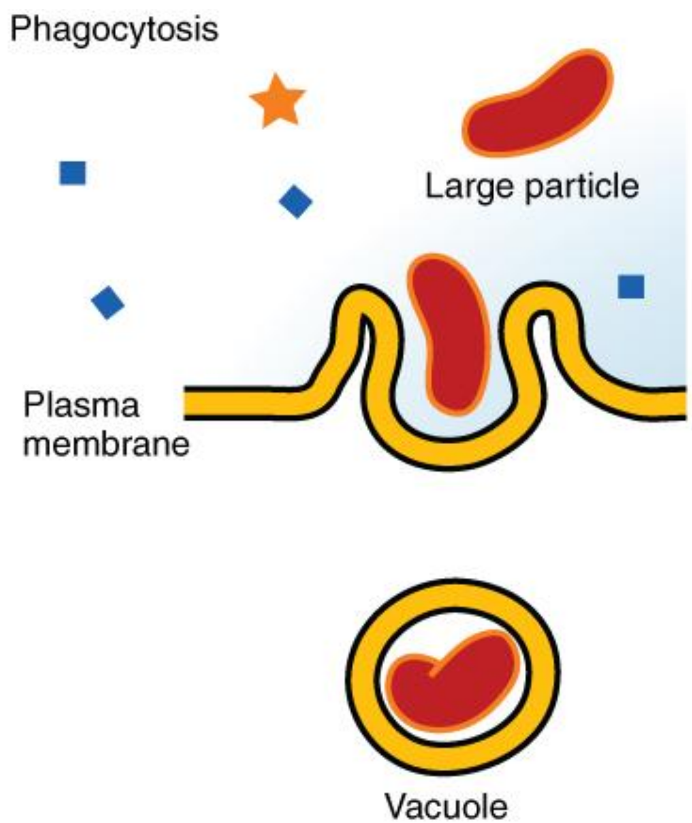
https://thumbs.dreamstime.com/z/illustration-types-endocytosis-process-engulfing-particles-eukaryotic-cells-phagocytosis-pinocytosis-receptor-mediated-254775236.jpg

- Endocytosis 3. **Phagocytosis**: moves large particles into the cell – “cell eating”

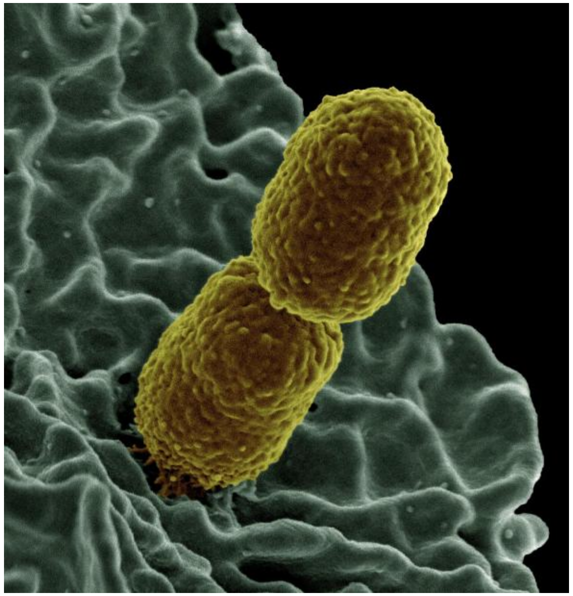
outside the cell

The cell membrane forms a pocket-like vesicle around a large particle.

The particle is transported into the cell in a vesicle.



inside the cell



A white blood cell taking in bacteria through phagocytosis

Figure: https://commons.wikimedia.org/wiki/File:0309_Three_Forms_of_Endocytosis.jpg

Figure: https://commons.wikimedia.org/wiki/File:Klebsiella_pneumoniae_Bacterium_(13383411493).jpg

- **Exocytosis** = out of the cell

  – cell uses energy to dispose of waste or secrete substances

vesicles containing the material move to & fuse with the cell membrane, then allow contents to empty out of the cell

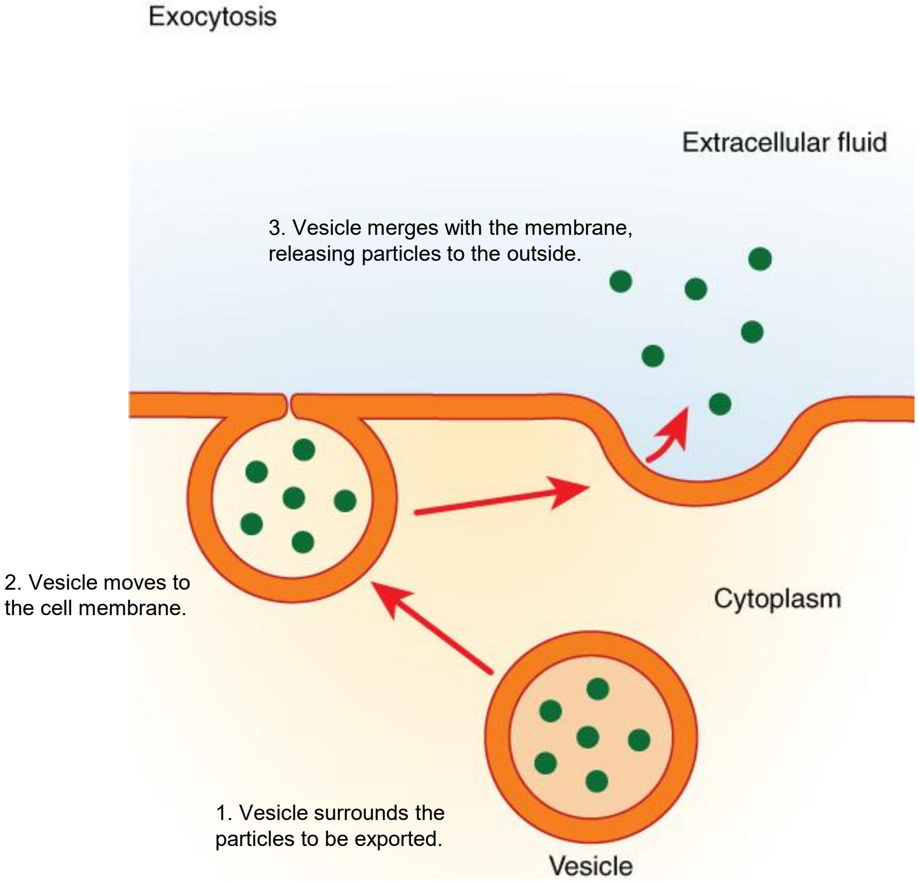


Figure: https://commons.wikimedia.org/wiki/File:0310_Exocytosis.jpg

– There are 5 types of proteins associated with the cell membrane: each has a different function

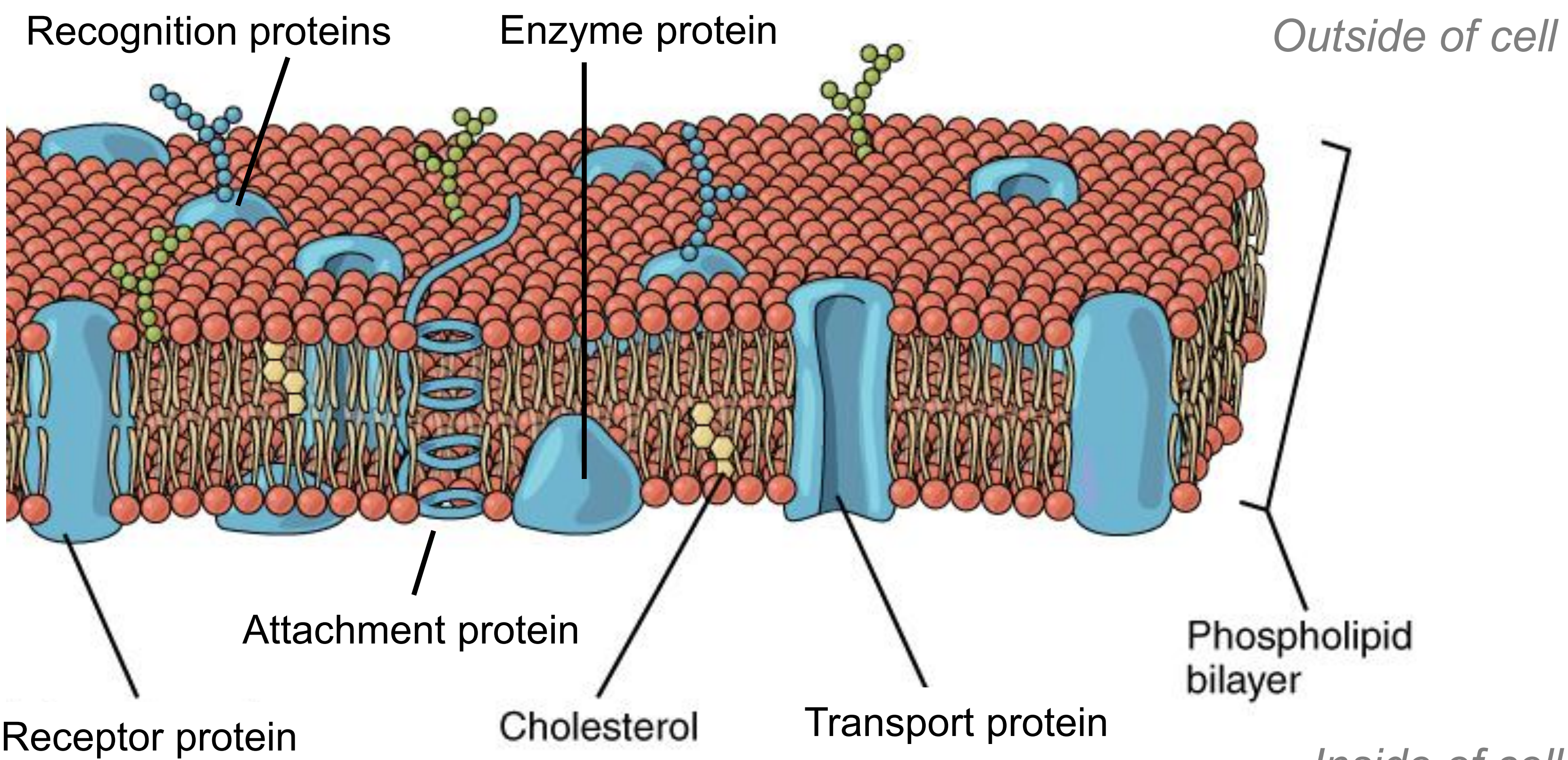


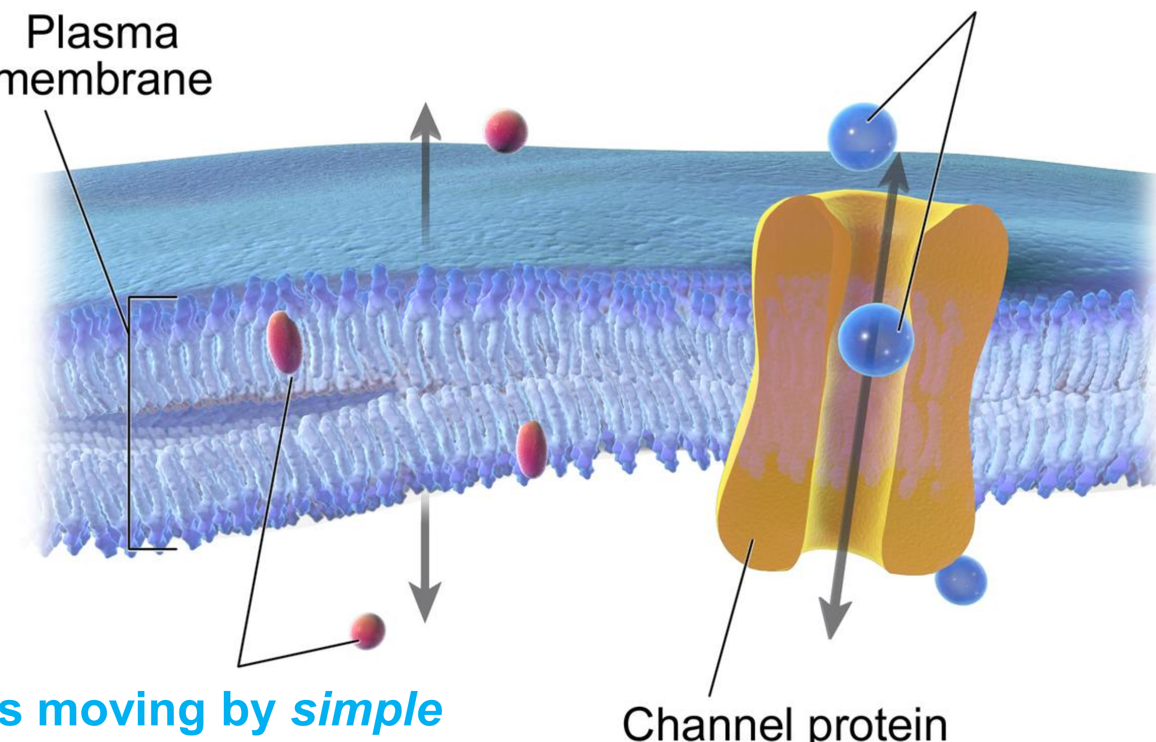
Figure: https://commons.wikimedia.org/wiki/File:0303_Lipid_Bilayer_With_Various_Components.jpg

What are the possible ways to move across a cell membrane?

- There are 6 types of transport across cell membranes
  - 3 of them are called **passive transport**
    - Substances move down their concentration gradient (high to low)
    - No energy is needed
  - 3 of them are called **energy-requiring transport**
    - Energy is required

- **Passive transport** occurs when molecules move across a membrane without energy – they move down their concentration gradient

Molecules moving by *facilitated* diffusion or osmosis

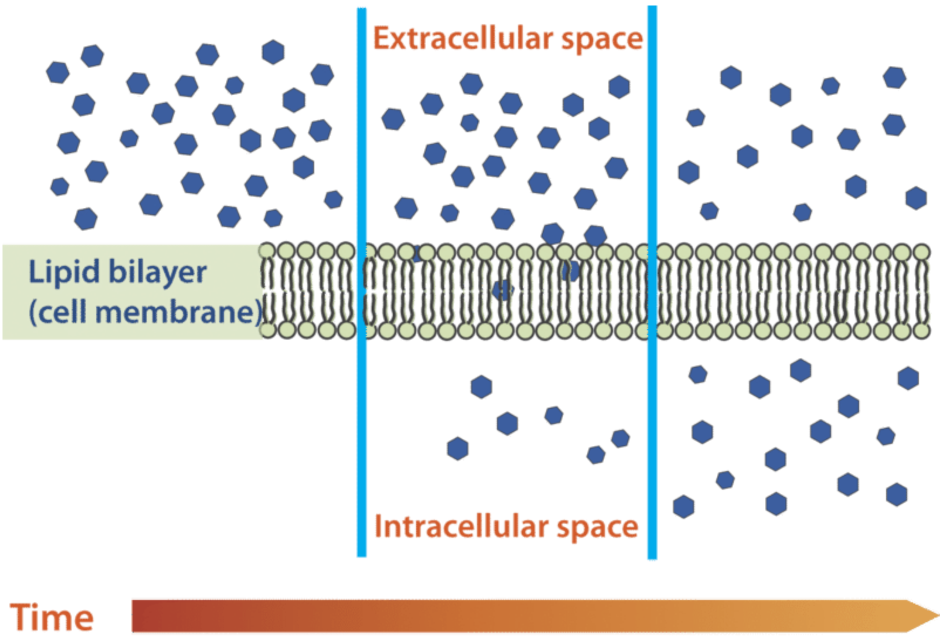


Molecules moving by *simple* diffusion or osmosis

Figure: https://commons.wikimedia.org/wiki/File:Blausen_0213_CellularDiffusion.png

Simple diffusion

- Remember: small molecules & lipophilic molecules can pass through the phospholipid bilayer on their own
  - they move directly across the membrane from high to low concentration
  - no energy is needed or used = <u>simple diffusion</u>



https://dr282zn36sxxg.cloudfront.net/datastreams/f-d%3A0fd776bc00c847e8fa8424cec9114242ae1ef6db139a5beda31bf309%2BIMAGE_TINY%2BIMAGE_TINY.1

– Remember: hydrophilic molecules can NOT pass through the phospholipid bilayer on their own

- they need a protein to help them across the membrane from high to low concentration

- no energy is needed or used

= <u>facilitated diffusion</u>

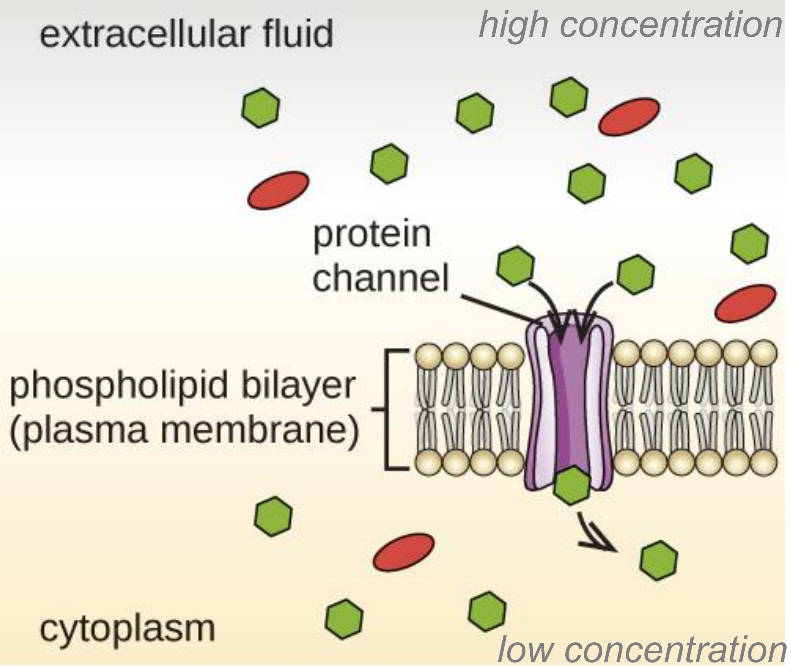


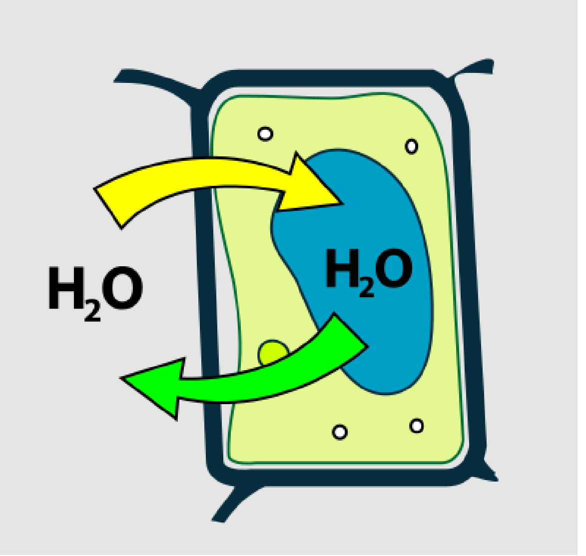
Figure: https://commons.wikimedia.org/wiki/File:OSC_Microbio_03_03_facdiff.jpg

Osmosis

- Sometimes there is a concentration gradient, but solutes can not move past the membrane
  - *maybe they are too big, or transport proteins are closed*
- Water is small & can cross membranes: if solutes can't diffuse, water will move until each side of the membrane has equal concentrations (equilibrium)
  - **Osmosis** = movement of water across a membrane

OSMOSIS

Water molecules diffuse across a cell membrane until the concentration of water inside & outside the cell is equalized.



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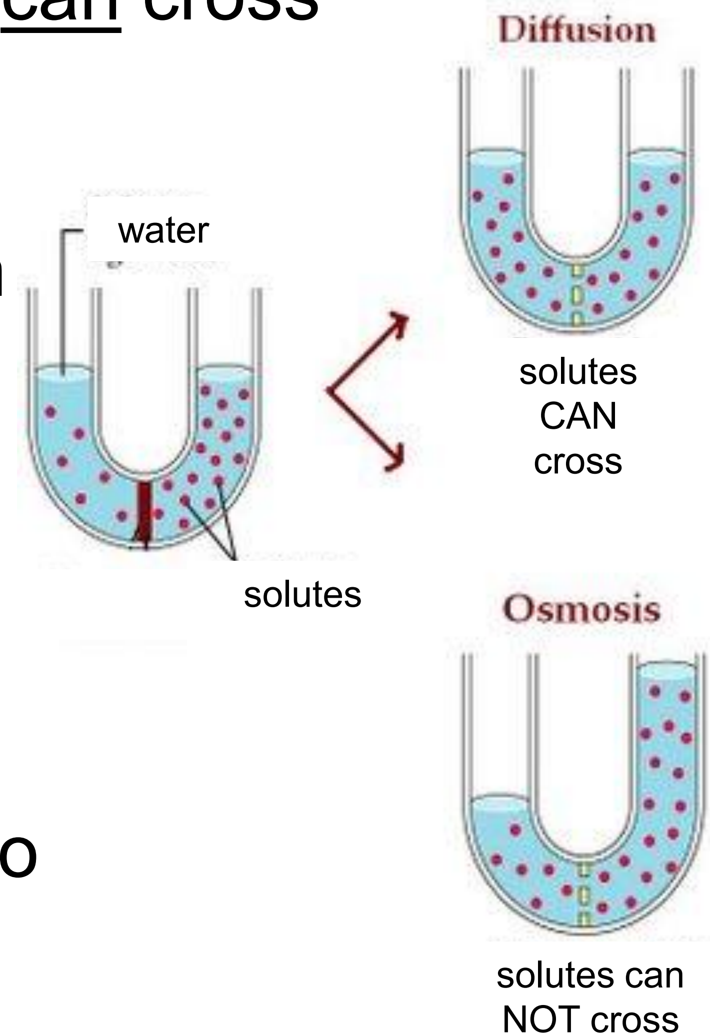

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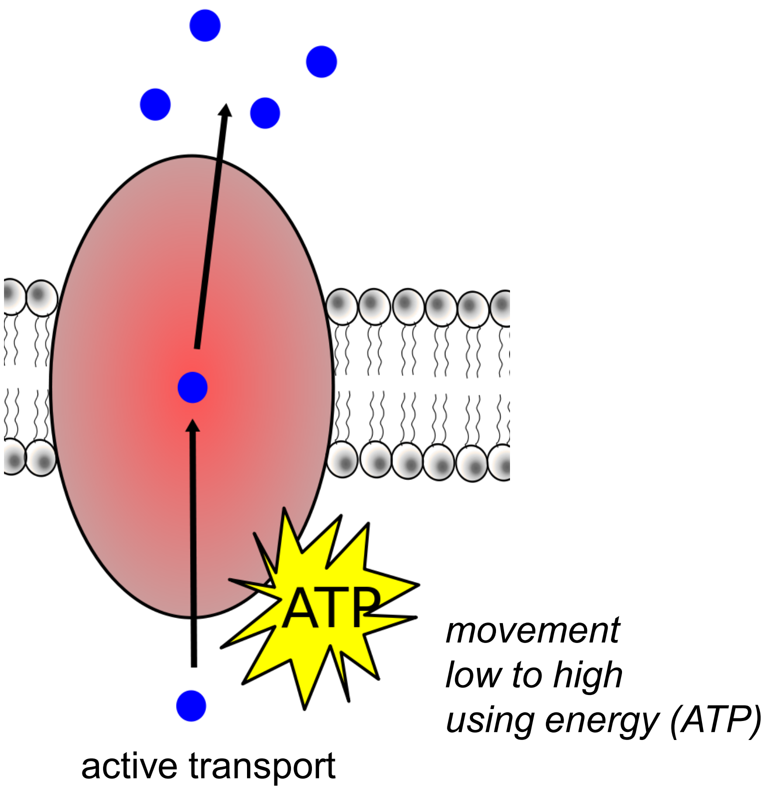

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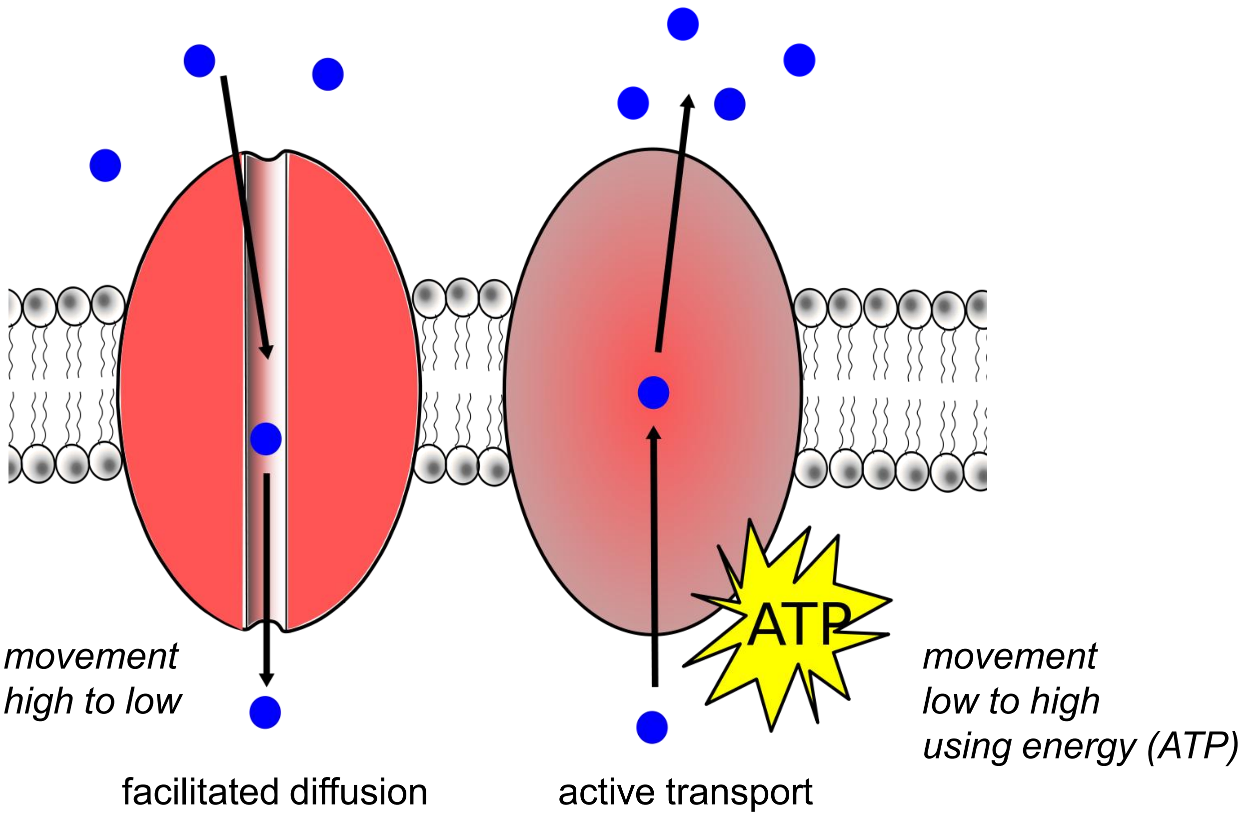

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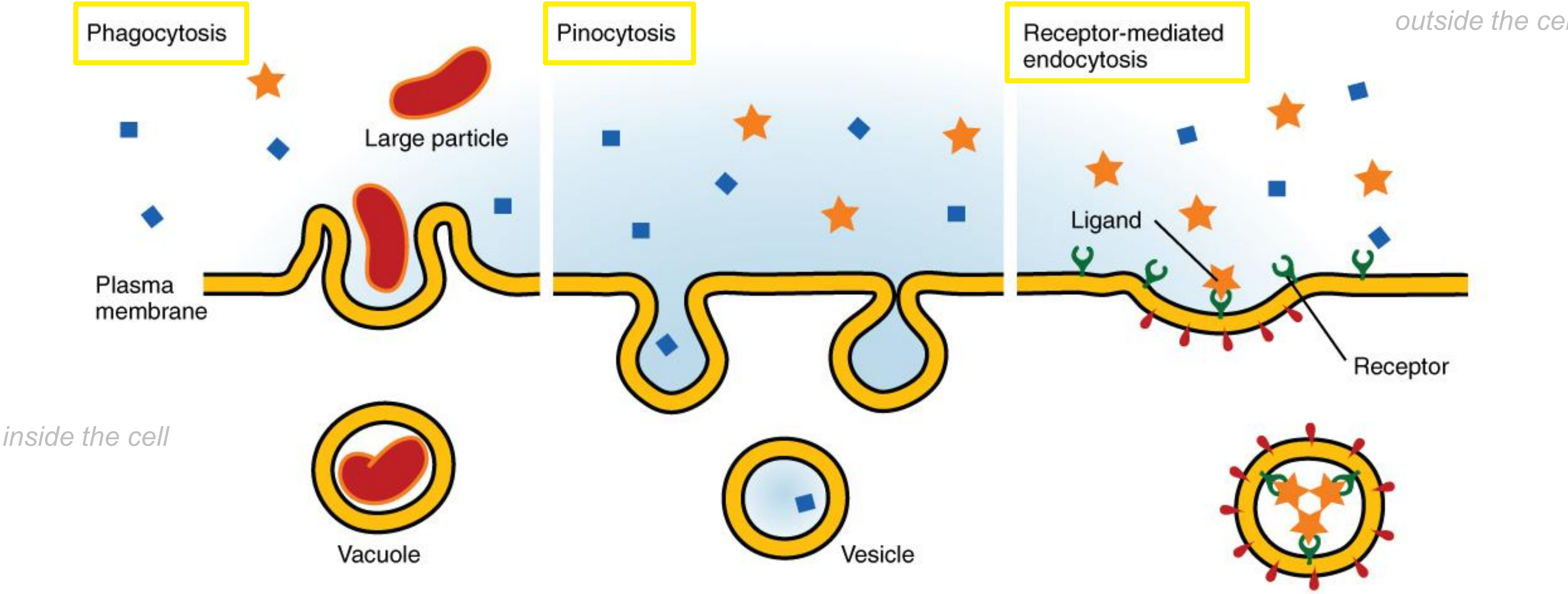

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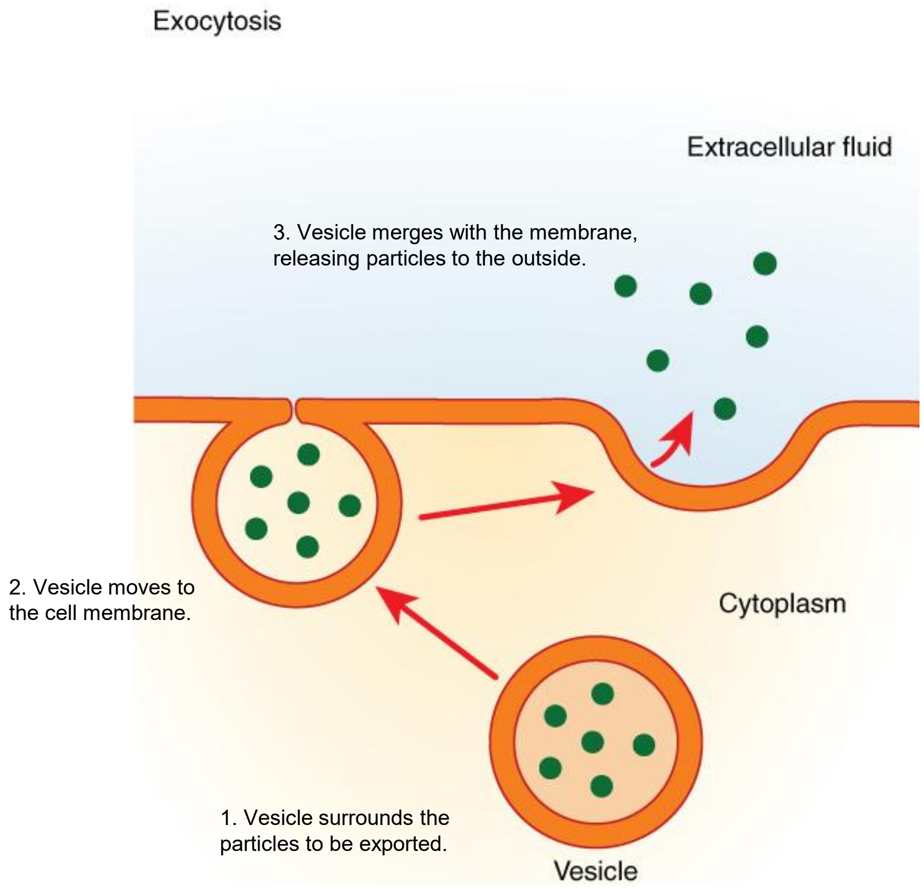


Figure: https://commons.wikimedia.org/wiki/File:0310_Exocytosis.jpg

- So then where do cells get the energy for energy-requiring transport…?
  - Coming up:
    - What is energy?
    - How do we capture energy on Earth?
    - How do we get energy out of food molecules?

Chapter 6: The Energy of Life

- What is energy?
- Chemical reactions capture & release energy
- What kind of energy is used in cells?
- Chemical reactions are regulated by enzymes
- How do we get usable energy on Earth?
- How do we release energy trapped in molecules?

Corresponds with OpenStax Biology 2e Chapters 6, 7, and 8

What is energy?

- **Energy** = the capacity to do *work*
  - To <u>work</u> means to <u>move</u> something – all of life depends on rearranging atoms & trafficking molecules, so life requires movement / work / energy
    - Energy comes in many different types: heat, light, electricity, chemical, radiation – all result from movement / work

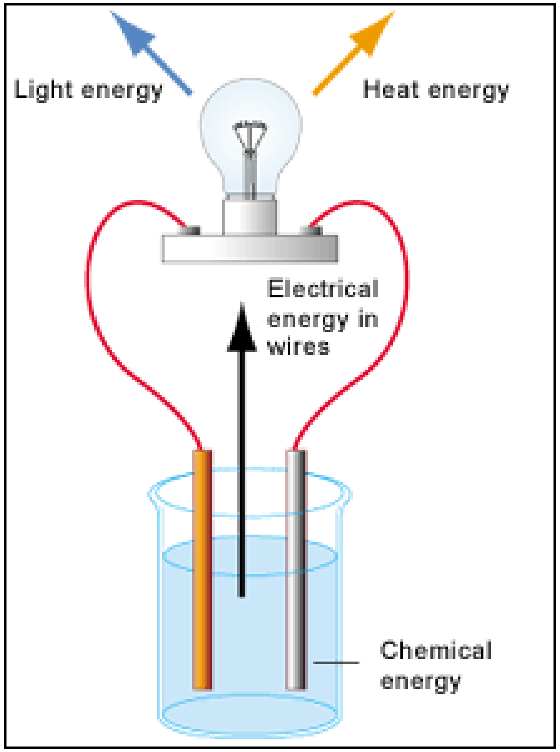
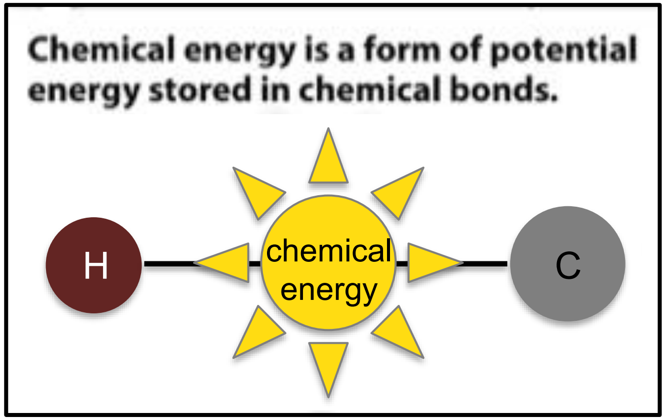


Figure: https://www1.curriculum.edu.au/sciencepd/energy/elec_activity.htm

- All types of energy can be in one of two forms
  - **Potential energy** = stored energy
    - e.g. an unburned molecule of gasoline contains potential energy that can be used by an engine
  - **Kinetic energy** = energy of motion or movement, used to do work
    - e.g. light (movement of photons)
    - e.g. heat (movement of molecules)
    - e.g. electricity (movement of ions)

- We **store chemical energy** (potential) by <u>building bonds</u> in molecules
  - e.g. gasoline, oil, & coal have their chemical bonds
  - e.g. sugars & fats have energy their chemical bonds

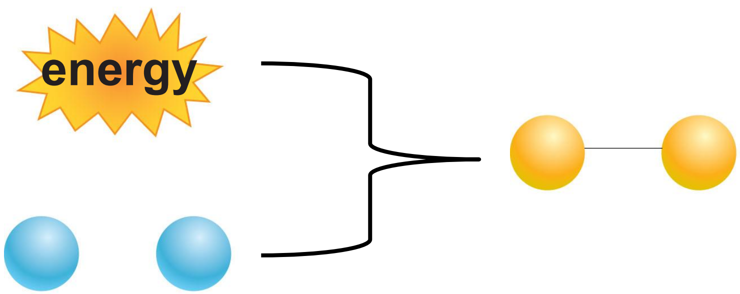


- We **release chemical energy** (kinetic – movement) by <u>breaking the bonds</u>
  - e.g. we power engines by breaking the bonds in gasoline molecules
  - e.g. we power our cells by breaking the bonds in sugars & fats

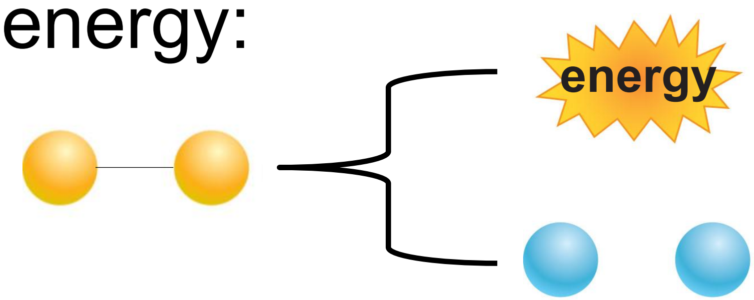
- <u>Energy can change forms:</u>
  - It can go from kinetic → potential *(storing energy)*
    - *we would **build** chemical bonds in a molecule to store energy*
  - It can go from potential → kinetic *(releasing energy)*
    - *we would **break** chemical bonds in a molecule to release energy*
    - Both of these are examples of **chemical reactions** = processes that build or break chemical bonds between atoms in a molecule

Chemical reactions capture & release energy

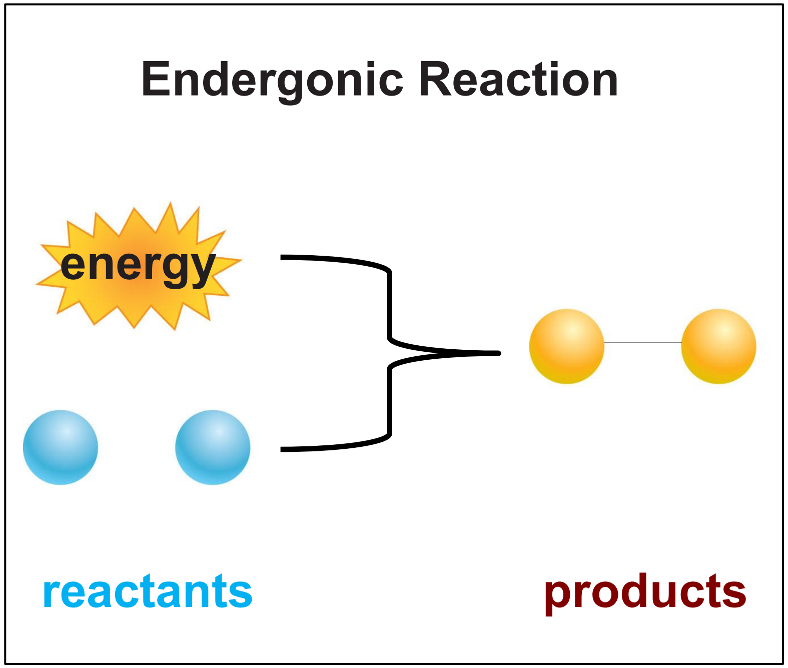
- <u>There are 2 kinds of chemical reactions</u>
  - – The reaction that stores energy: kinetic → potential = an **endergonic** reaction

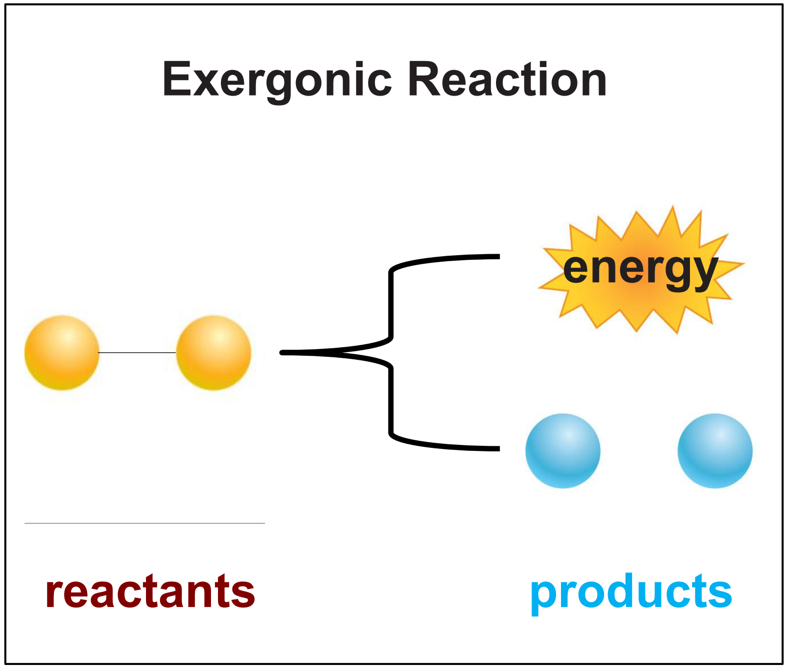


  - – The reaction that releases energy: potential → kinetic = an **exergonic** reaction

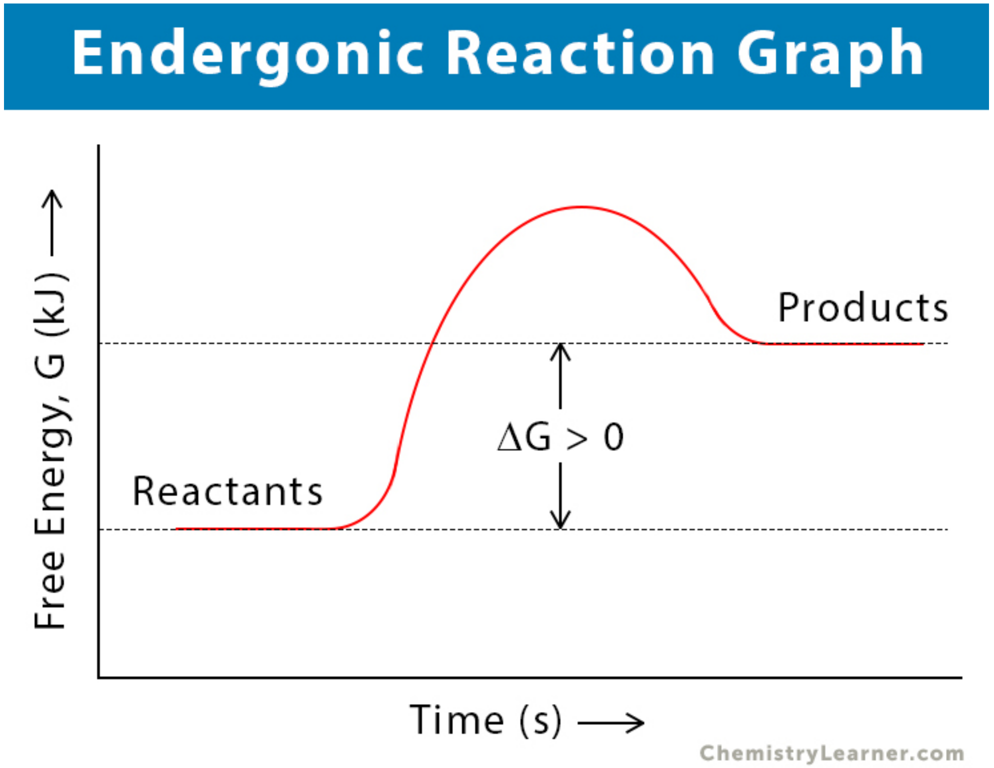


- In both kinds of chemical reactions we start with **reactants** & end with **products**



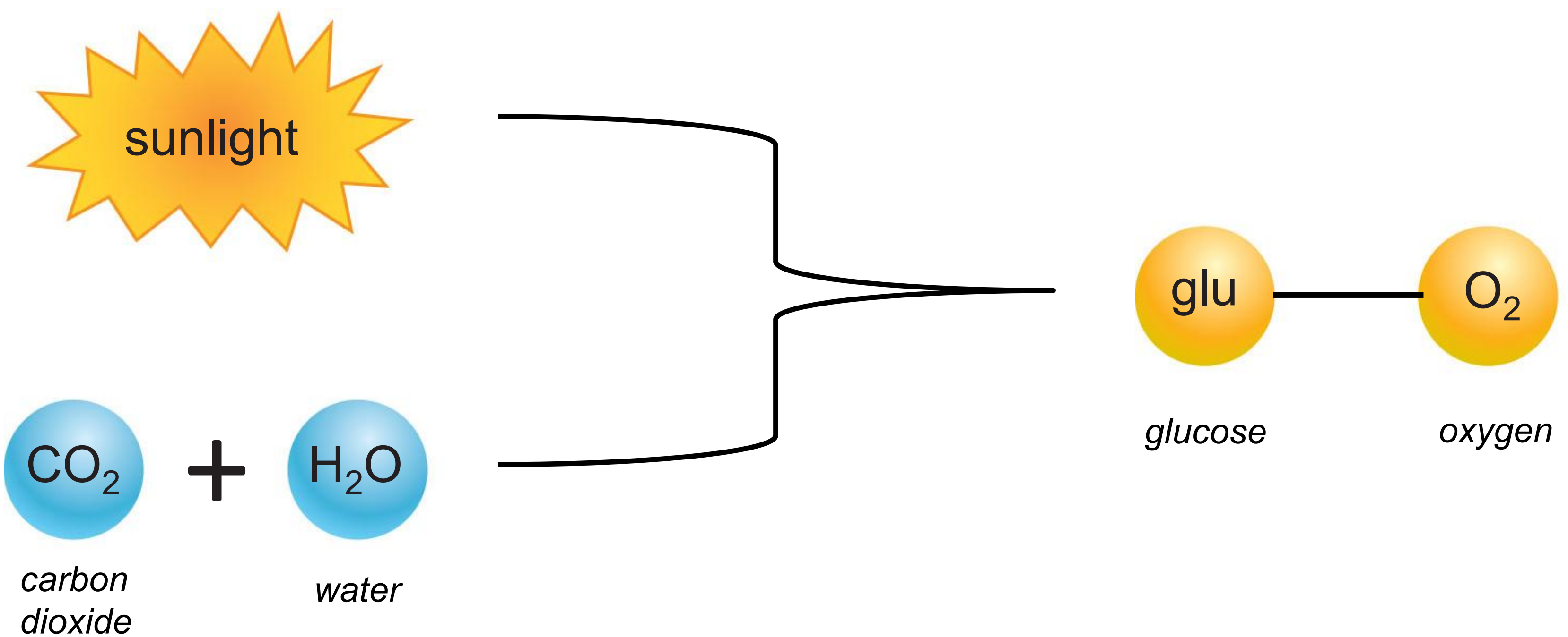


- <u>Endergonic reactions</u>
  - The reactants are low energy
  - The products are high energy
  - Kinetic energy comes in & is stored in bonds

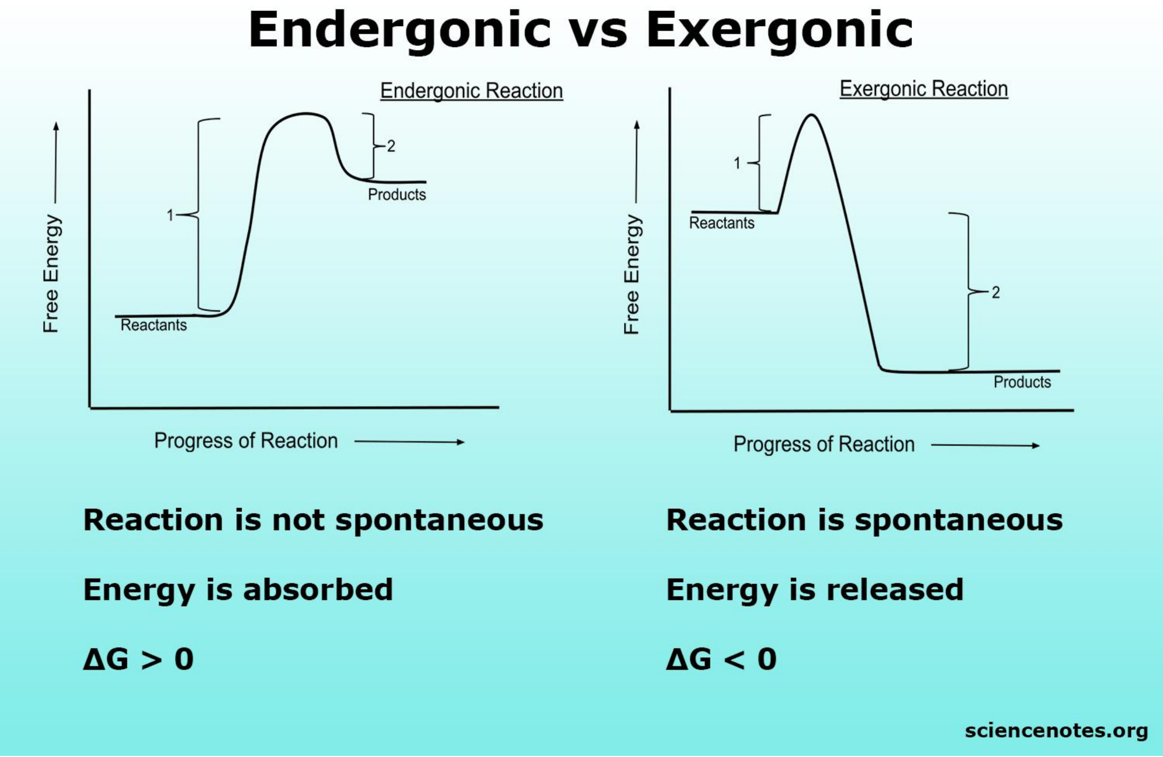


Example endergonic reaction = photosynthesis

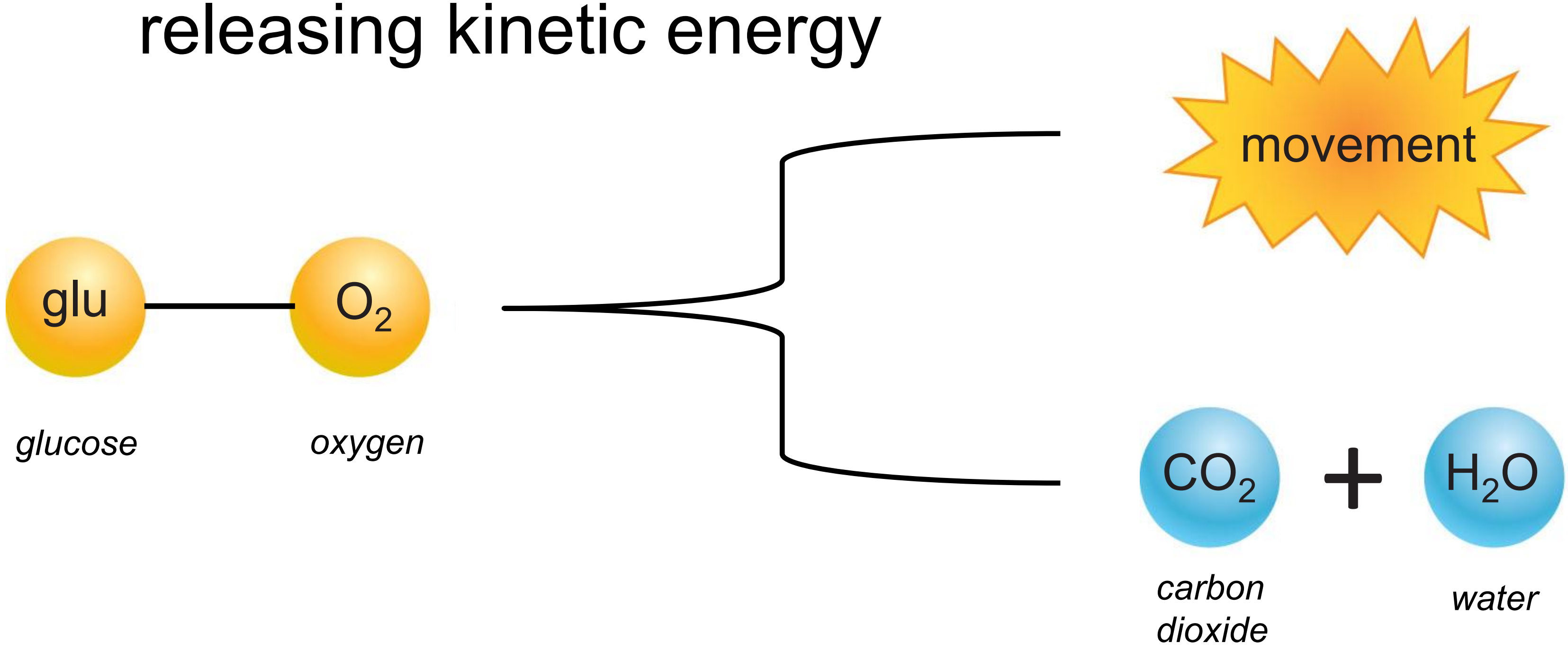
– kinetic energy of sunlight coming in + water & CO_2 (low energy reactants) = sugar & O_2 (high energy products)



- <u>Exergonic reactions</u>
  - The reactants are high energy
  - The products are low energy
  - Bonds are broken & kinetic energy comes out

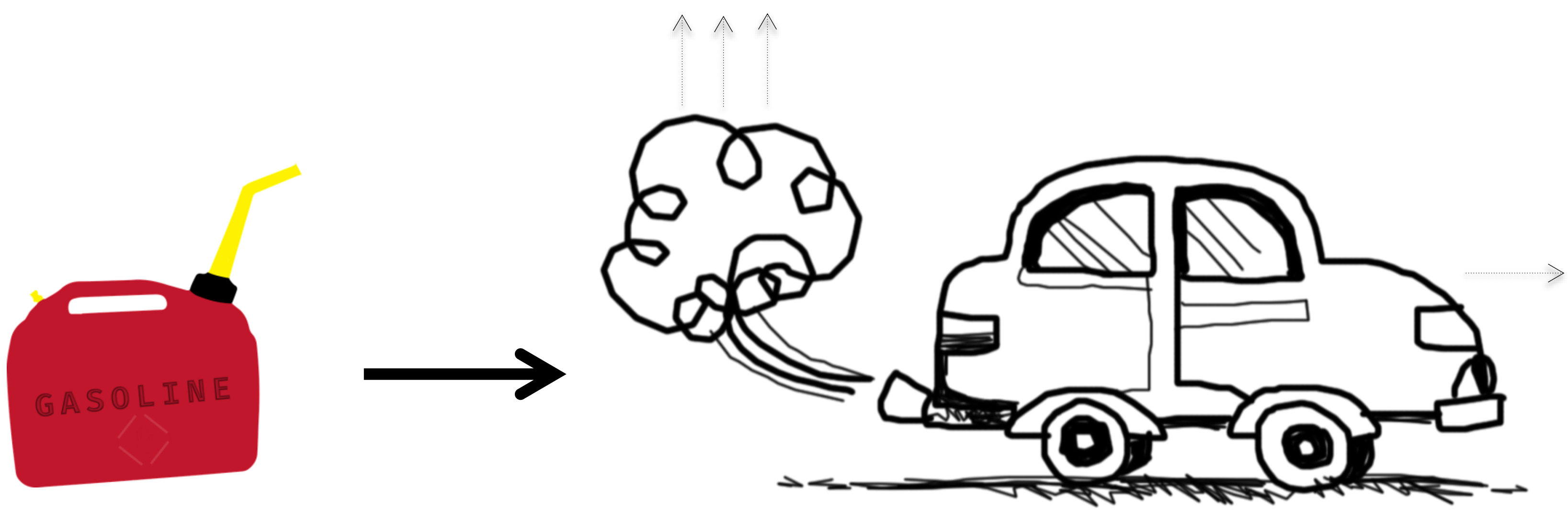


- <u>Example exergonic reaction = glucose breakdown</u>
  - as a glucose molecule is broken down, the sugar combines with O_2 (high energy reactants) to produce CO_2 & water (low energy products), releasing kinetic energy



Exergonic reactions are not efficient

– the conversion of potential energy to kinetic energy is not 100% efficient: waste product is **heat**



100 units chemical energy (concentrated) → **75 units heat energy** + **25 units kinetic energy (motion)**

Figure: https://www.maxpixel.net/Flammable-Red-Danger-Canister-Container-Gas-Fuel-4161953

Figure: https://www.maxpixel.net/Exhaust-Gases-Doodle-Auto-1388117

What kind of energy is used in cells?

- Living things are powered by breaking apart **glucose** molecules
    - *Remember: breaking a molecule apart = hydrolysis*

– However: the energy in glucose can't be used directly – must first transfer it to a middle man: **energy-carrier molecule**

= molecules that carry energy from breaking apart glucose to anywhere in the cell that needs it

– most common energy-carrier molecule = **ATP**

ATP is the most common energy-carrier molecule

- ATP carries energy (from breaking down carbohydrates like glucose) around the cell to where it's needed
- ATP = a nucleotide, which always have at least 1 phosphate, a sugar, & a base
- **ATP = adenosine triphosphate**:
  3 phosphates help the molecule carry energy

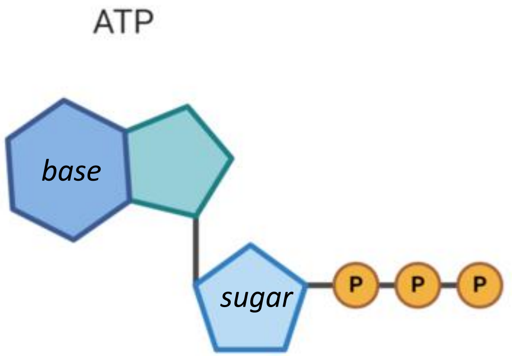
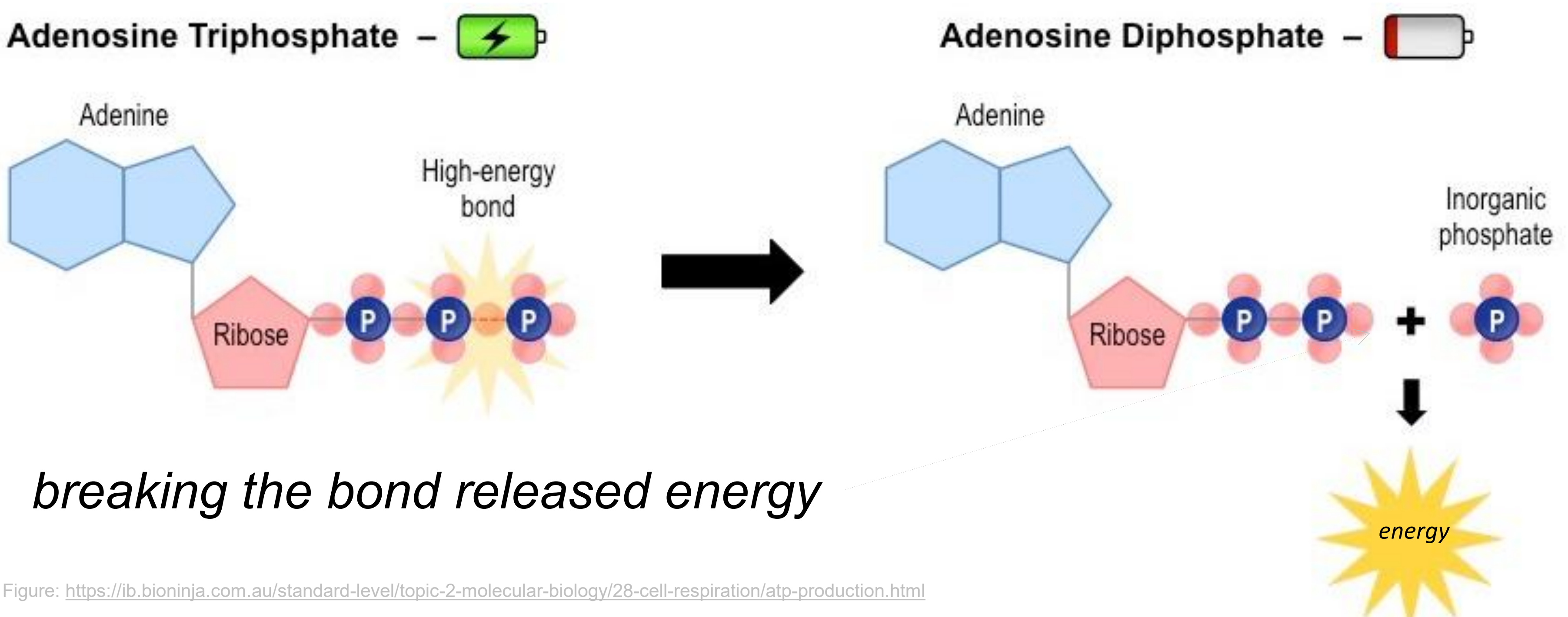


Figure: https://sml.snl.no/ATP

- To <u>release energy</u> from ATP (to fuel our cells), we must <u>break a bond</u> in the ATP molecule
  - The bond we break is between 2 phosphates
    - leaves **ADP** *(adenosine diphosphate)* & a **free phosphate**



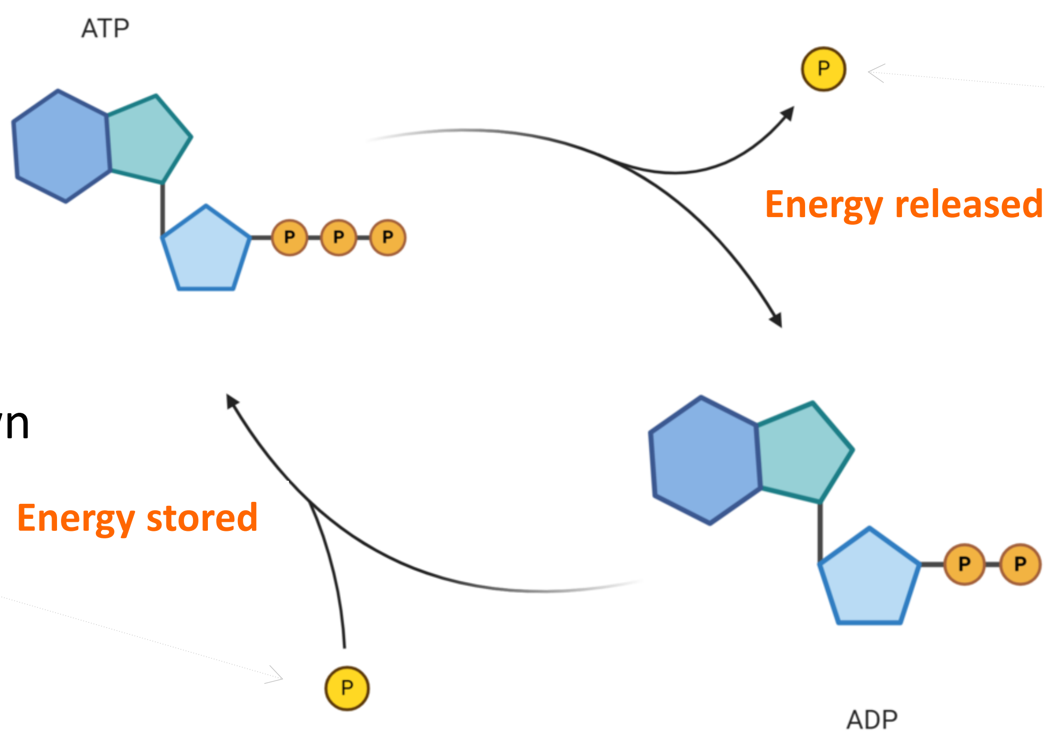
breaking the bond released energy

Figure: https://ib.bioninja.com.au/standard-level/topic-2-molecular-biology/28-cell-respiration/atp-production.html

- ADP & a free phosphate can be reconnected again (with **incoming kinetic energy** from glucose breakdown)

  = ATP, which is charged up again with energy

  - In this way, ATP acts like a rechargeable battery



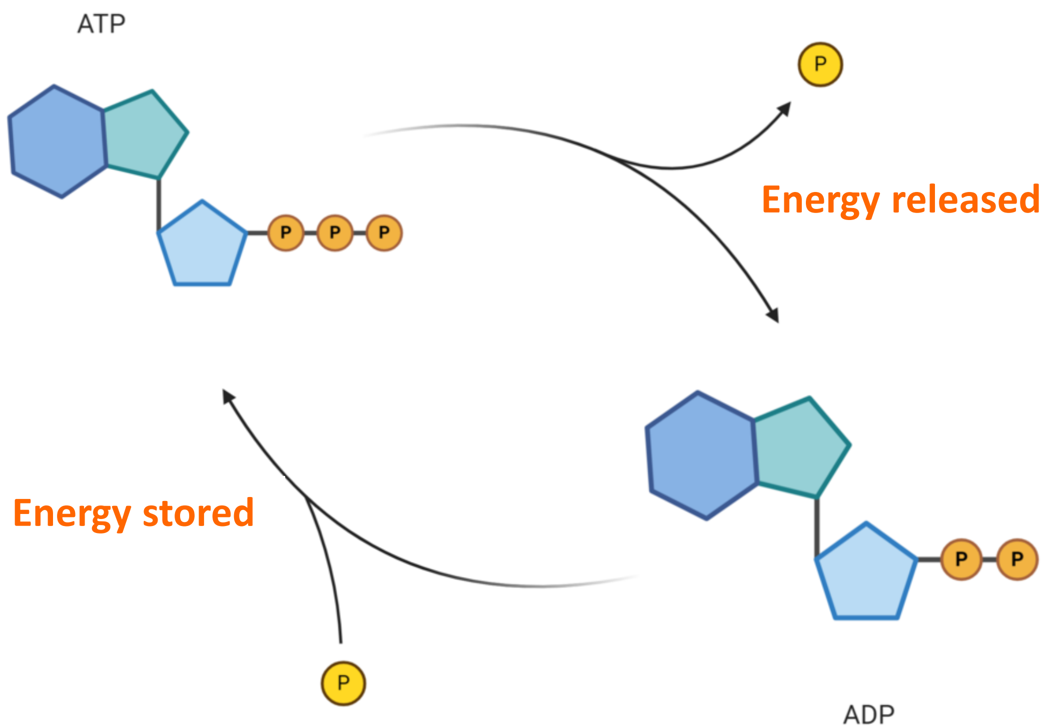
Energy is released as a phosphate is broken off from ATP.

An input of energy from the breakdown of sugar/glucose attaches ADP to P.

Figure: https://sml.snl.no/ATP

- **<u>1 molecule of ATP is recycled thousands of times</u>**
  - Building a bond between uncharged ADP & P = storing energy – <u>endergonic reaction</u>
  - Breaking the bond in ATP (to make ADP & P) = releasing energy – <u>exergonic reaction</u>

An input of energy from the breakdown of food attaches ADP to P: **endergonic**



Energy is released as a phosphate is broken off from ATP: **exergonic**

Don’t forget that there are so many great online resources to make this fun, like Amoeba Sisters!

https://www.amoebasisters.com/

https://www.youtube.com/user/AmoebaSisters

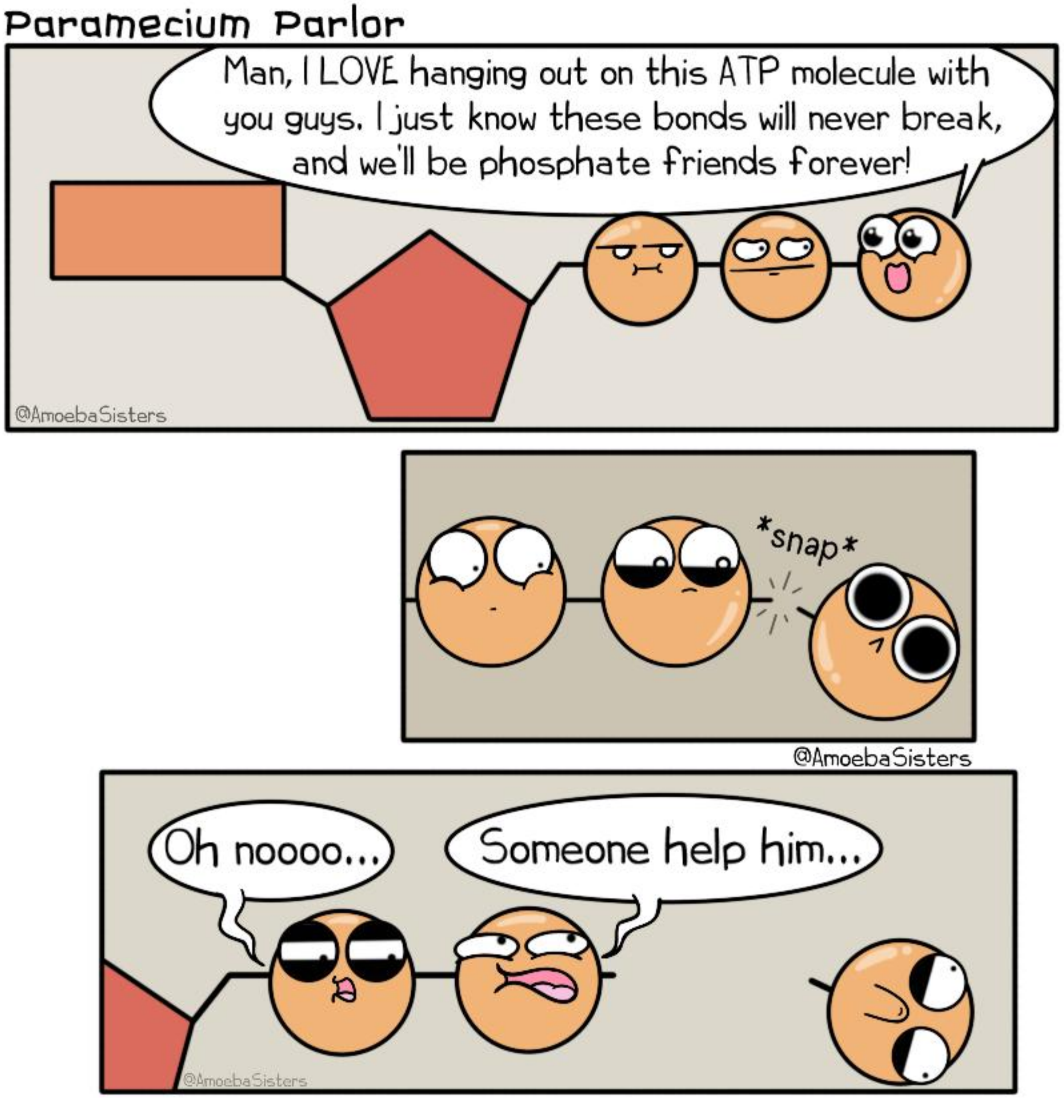


Figure: https://twitter.com/amoebasisters/status/1438293316240646148?s=21

Chemical reactions are regulated by enzymes

- Chemical reactions need a certain amount of energy to get started: **activation energy**
  - with no help, it can take too long for a chemical reaction to get over its activation energy: this means life can stop (death)

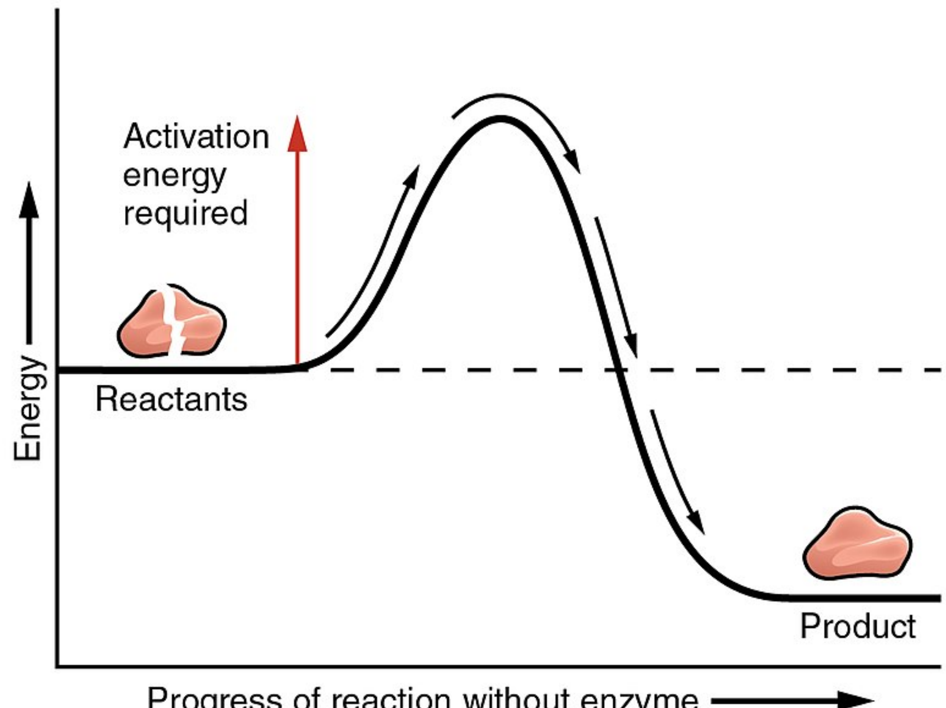


Figure: https://commons.wikimedia.org/wiki/File:212_Enzymes-01.jpg

- However, there are protein molecules that can give chemical reactions a "push" to help get them overcome their activation energy: **enzymes**
  – reactions can occur fast enough = staying alive

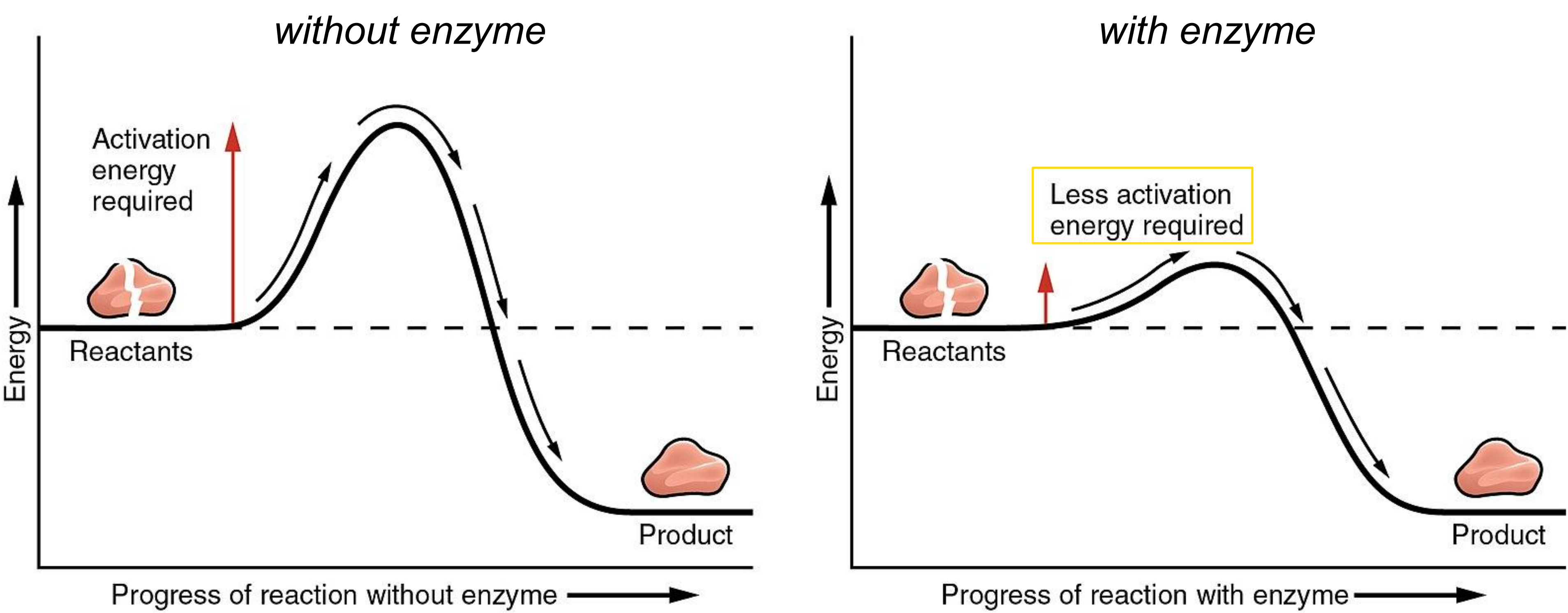


Figure: https://commons.wikimedia.org/wiki/File:212_Enzymes-01.jpg

- **Enzymes** speed up chemical reactions by <u>lowering the activation energy</u>
  - *Remember:* enzymes are proteins that are found associated with the cell membrane (to speed up chemical reactions there), but are also found in ALL parts of a cell, speeding up all chemical reactions

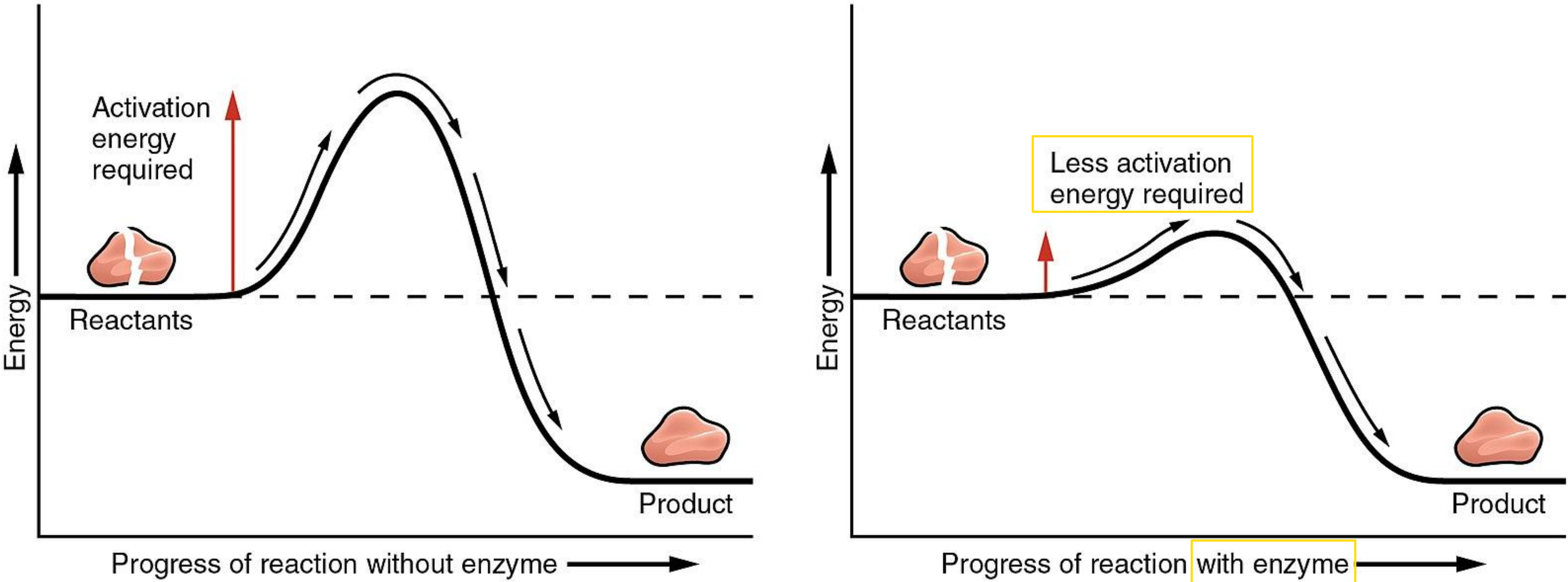
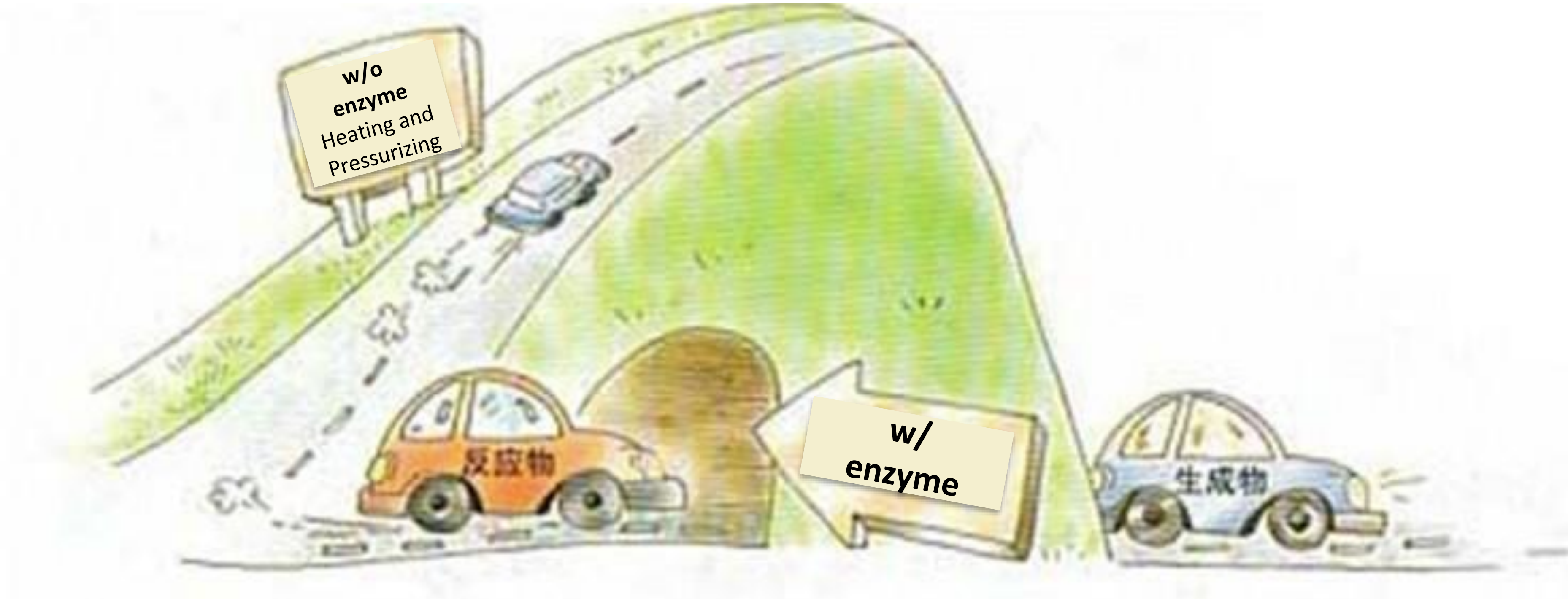


Figure: https://commons.wikimedia.org/wiki/File:212_Enzymes-01.jpg


w/o
enzyme
Heating and
Pressurizing
反应物
w/
enzyme
生成物

- *Remember*: all life requires energy
- *Remember*: to get energy, cells break apart glucose: exergonic chemical reaction
- *Remember*: to use the energy from glucose, cells store it in ATP: endergonic chemical reaction

Therefore: life is dependent on chemical reactions

- *Remember*: enzymes allow chemical reactions to occur fast enough to sustain life

Therefore: life is dependent on enzyme proteins

- Life is dependent on chemical reactions & enzymes
  - The rate of chemical reactions in a cell = **metabolism**
    - high metabolism = many reactions + moving quickly
    - low metabolism = few reactions + moving slowly
- Cells control metabolism by controlling enzymes
    - To speed up metabolism: make *more* enzymes & *activate* those that already exist
    - To slow down metabolism: make *less* enzymes & *de-activate* those that already exist

- Life is dependent on enzyme proteins: a problem with even one kind of enzyme can cause death
  - **Nerve gases** permanently block an enzyme responsible for muscle & brain activity: leads to paralysis & asphyxiation
    - e.g. Sarin gas attack in Syria, 2013

Figure: https://www.reuters.com/investigates/special-report/mideast-crisis-syria-chemicalweapons/

- **Arsenic** blocks an enzyme used to make ATP
  - No energy = cell death
  - Often used in pesticides = present in our food, soil, & water

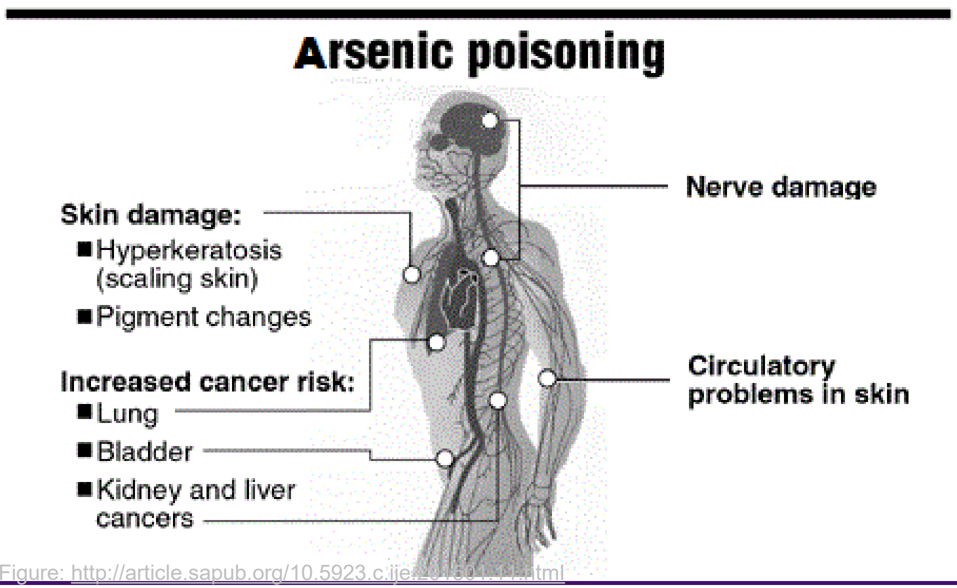


Figure: http://article.sapub.org/10.5923.c.ije.201601.11.html

Arsenic poisoning to the skin is common in gold miners

Figure: https://www.primehealthchannel.com/arsenic-poisoning.html

– **Lead** blocks an enzyme that maintains the cell membrane

- No membrane = cell death
- Used in pesticides & found in paints, food, soil, & water, some cosmetics, & even toys

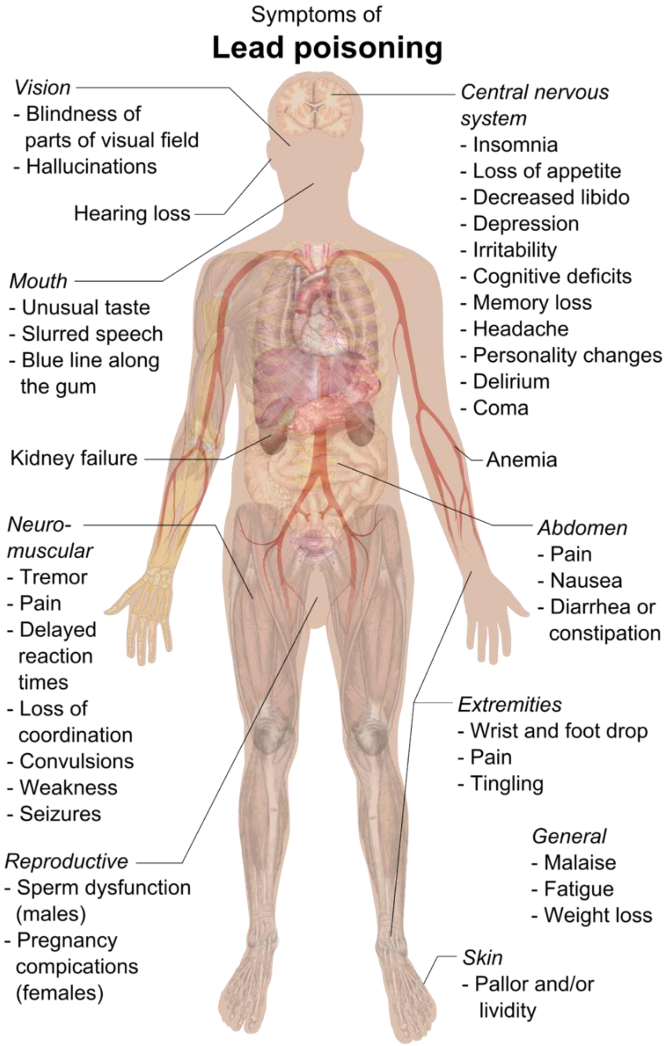


Figure: https://commons.wikimedia.org/wiki/File:Symptoms_of_lead_poisoning_(raster).png

- Remember: enzymes are proteins & all proteins must be folded into the correct structure to function
  - An unfolded protein = **denatured** protein = no longer functional
    - If our bodies get too hot, too acidic, too basic, too salty, etc., our enzymes will denature & we will die *(so we must maintain homeostasis)*

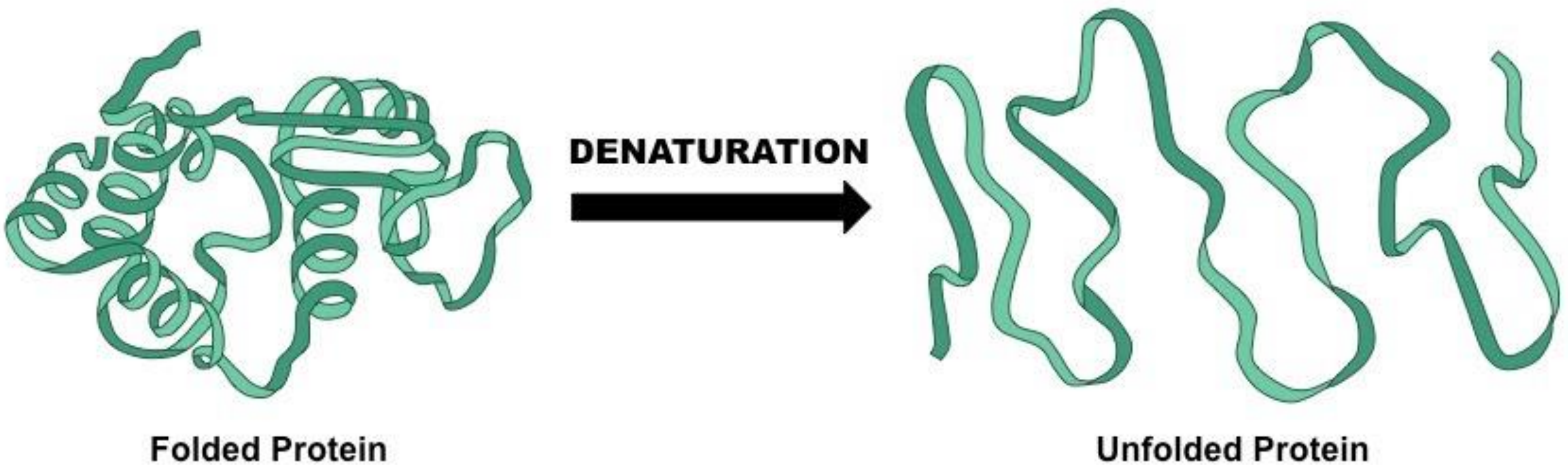


Figure: https://ib.bioninja.com.au/standard-level/topic-2-molecular-biology/24-proteins/denaturation.html

- <u>The surrounding environment, such as the pH & the temperature, affects enzymes</u>
  - Changing the pH to be more acidic or basic can cause enzyme denaturation
    - *must maintain constant pH of the blood (homeostasis)*

For most enzymes, max activity occurs at about pH 7.4 (close to neutral), though some work better at basic pH and some at acidic (such as stomach enzymes)

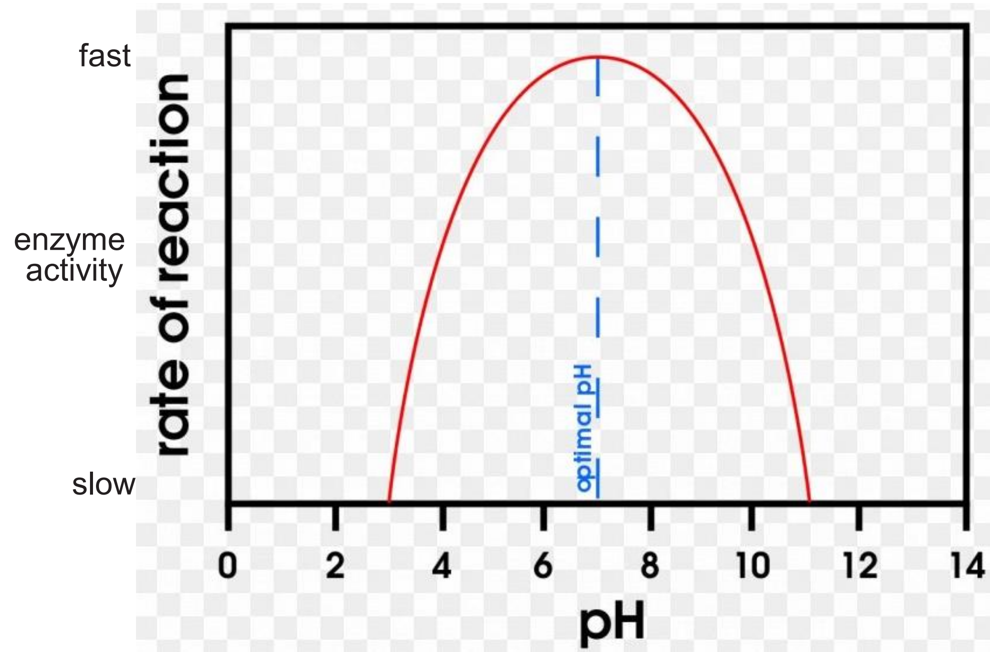


Figure: https://favpng.com/png_view/do-the-old-effect-ph-enzyme-denaturation-thermodynamic-activity-reaction-rate-png/DcheKRLW

– Changing temperatures to be cooler slows down enzymes

– Changing it to be hotter can cause denaturation

- *must maintain constant body temperatures (homeostasis)*

For most human enzymes, maximum activity occurs at about 98.6°F (37°C)

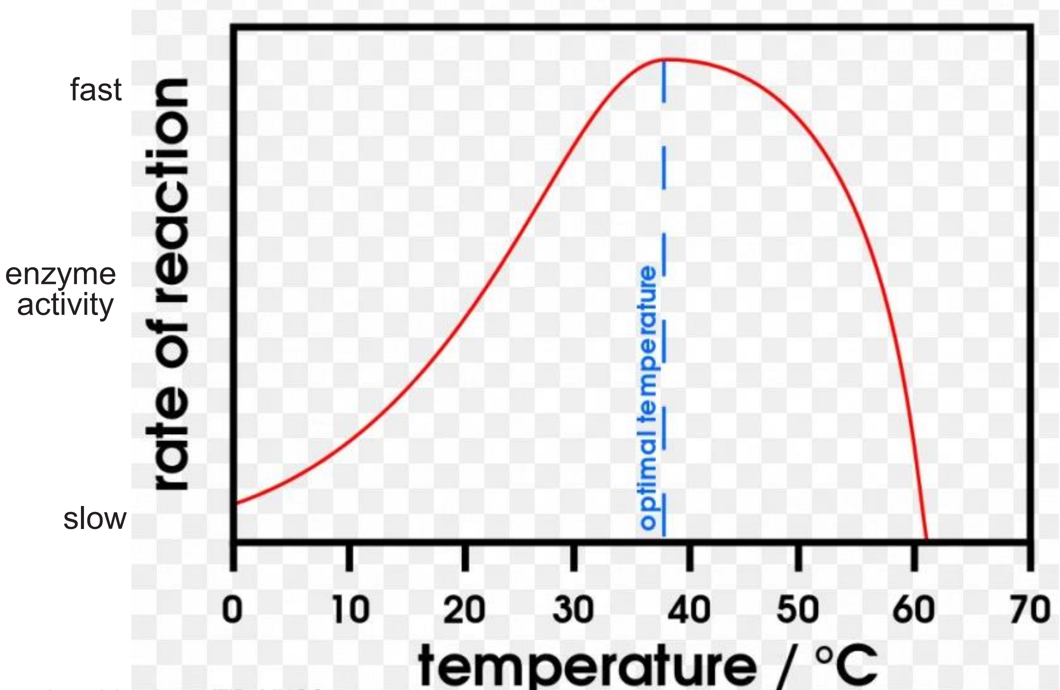


Figure: https://favpng.com/png_view/enzyme-substrate-chemical-reaction-thermodynamic-activity-ph-png/ZjBaMNGC

How do we get usable energy on the Earth?

- Chemical reactions store or release energy: so how do we get the energy on the Earth in the first place?
  - The most important endergonic reaction for life = **photosynthesis**
    - energy for living things on the Earth comes from the sun

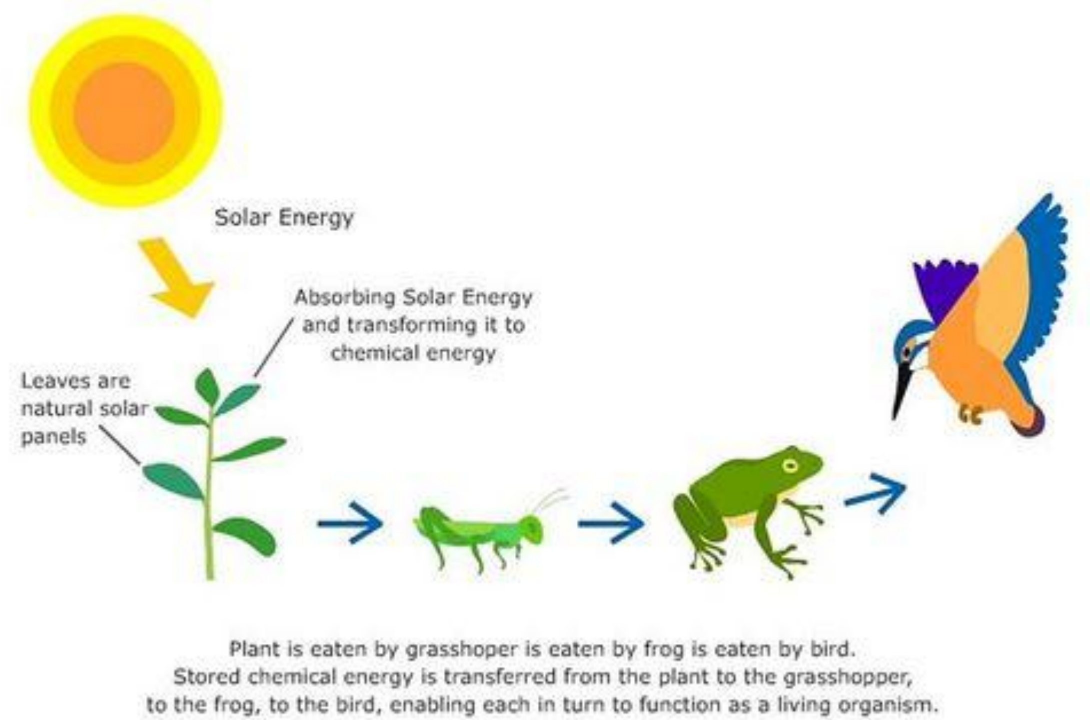


Figure: https://www.sciencelearn.org.nz/images/2174-a-food-energy-chain

- **Photosynthesis** = process by which some organisms capture sunlight & store it in the bonds of a sugar molecule
  - plants, protists (algae), & some bacteria perform photosynthesis
    - life on Earth depends on these organisms

Figure: https://commons.wikimedia.org/wiki/File:CSIRO_ScienceImage_4628_Bluegreen_algae_in_irrigation_drain.jpg

- Most organisms that undergo photosynthesis appear green
  - *Remember*: **chloroplasts** are the organelles inside cells where photosynthesis takes place
    - Chloroplasts contain light-capturing pigments (to trap sunlight)
    - Most common pigment = **chlorophyll**, which is green

The photosynthetic cells of a leaf are packed with chloroplasts, which contain green chlorophyll

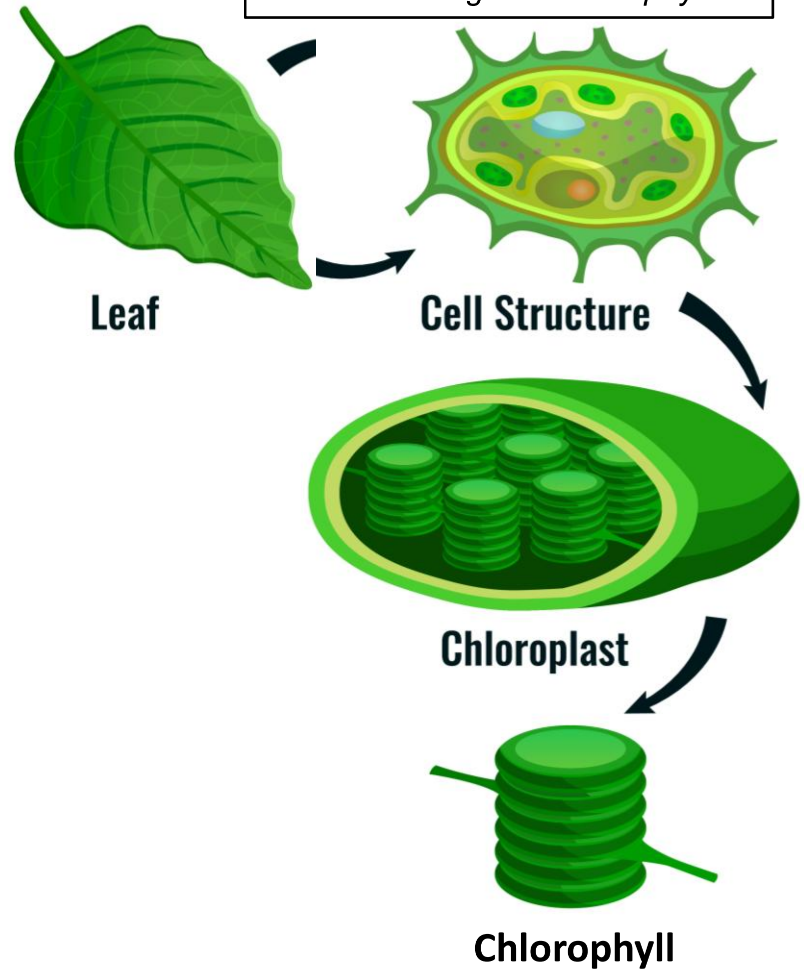
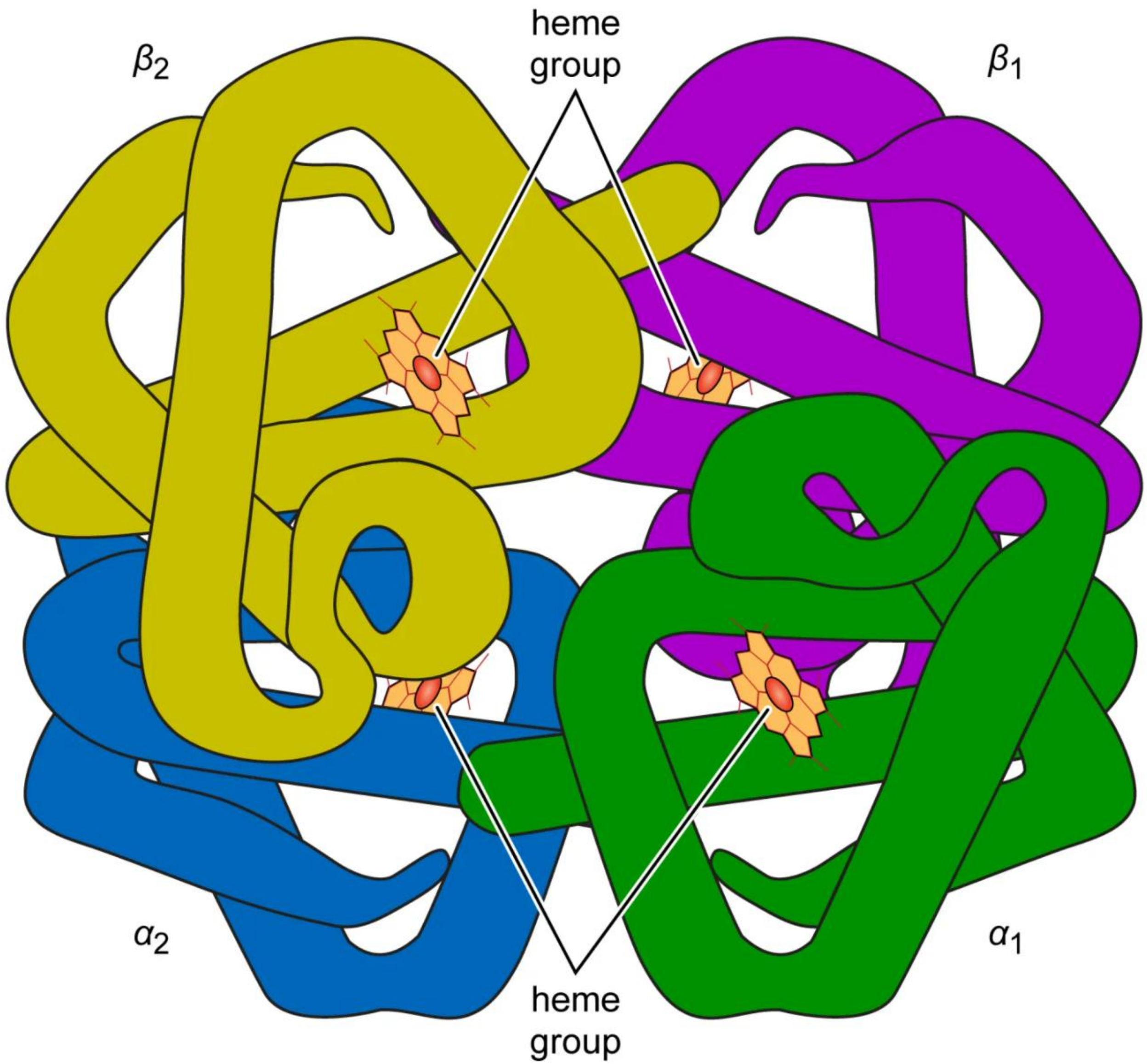
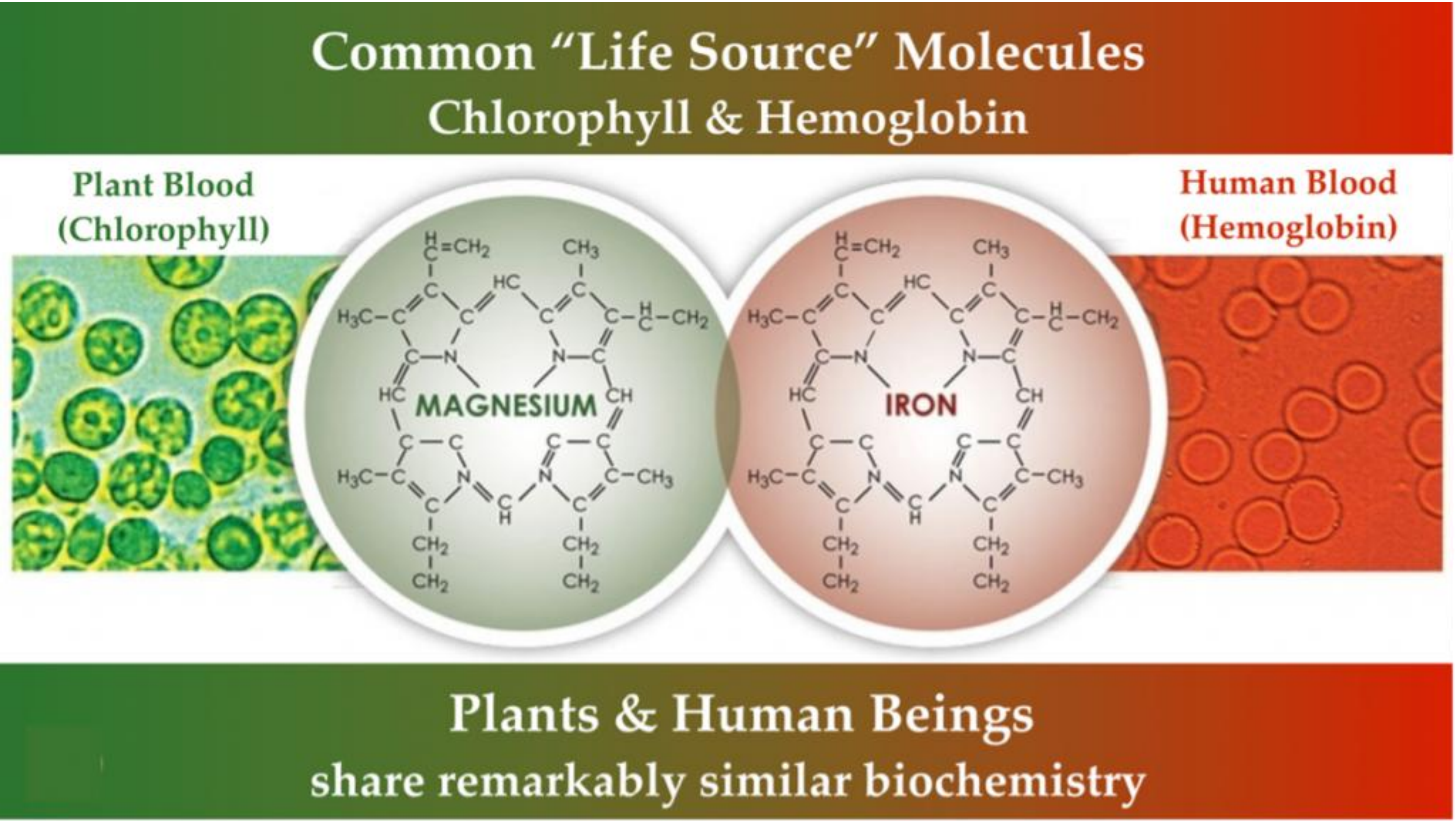


Figure: https://www.freepik.com/free-vector/chloroplast-converting-light-energy-into-sugar-green-plant-cells-food-photosynthesis-infographic-elements-schema_6847346.htm


heme
group
β_2
β_1
α_2
α_1
heme
group



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https://assets.bigcartel.com/product_images/127944483/porphyrinnecklace1b.jpg?auto=format&fit=max&h=1200&w=1200

This captures the charming side of scientists.

If you'd like to express a lifelong promise, why not gift him/her a lovely necklace or pendant like this?

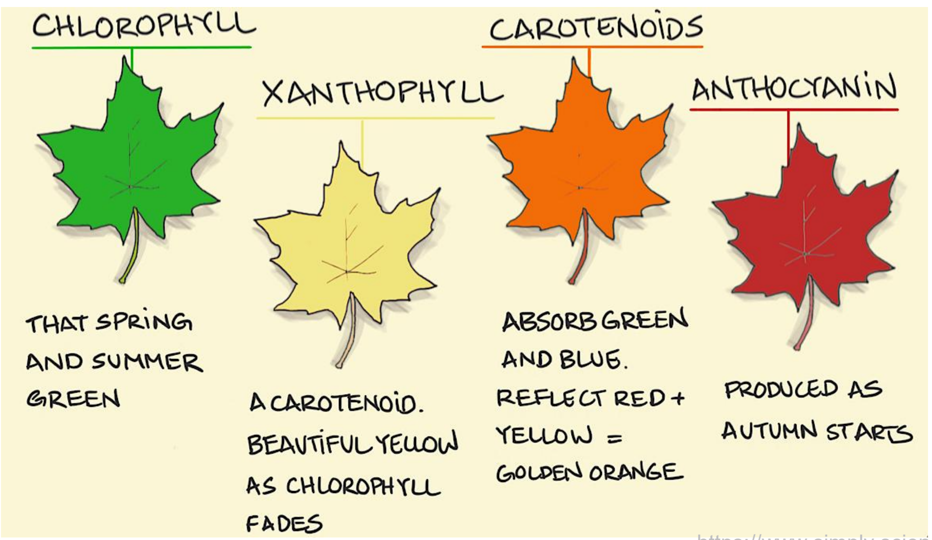
- If chlorophyll is green, why are some plants other colors?
  - Chlorophyll is the most common pigment, but plants have many other pigments
    - e.g. carotenoids (red, orange, & yellow)
    - e.g. anthocyanins (blue or purple)
      - Some plants have more carotenoids or anthocyanins, so they're purple or red, etc.

Figure: https://www.piqsels.com/en/public-domain-photo-fblzm

Figure: https://www.flickr.com/photos/mercadanteweb/8170759767

- Most plants have many types of pigments, but more of the chlorophyll in spring & summer – look green
  - When trees start to go dormant in the fall, chlorophyll is the 1st pigment to go, leaving other pigments to show through

Nature really knows how to play with colors



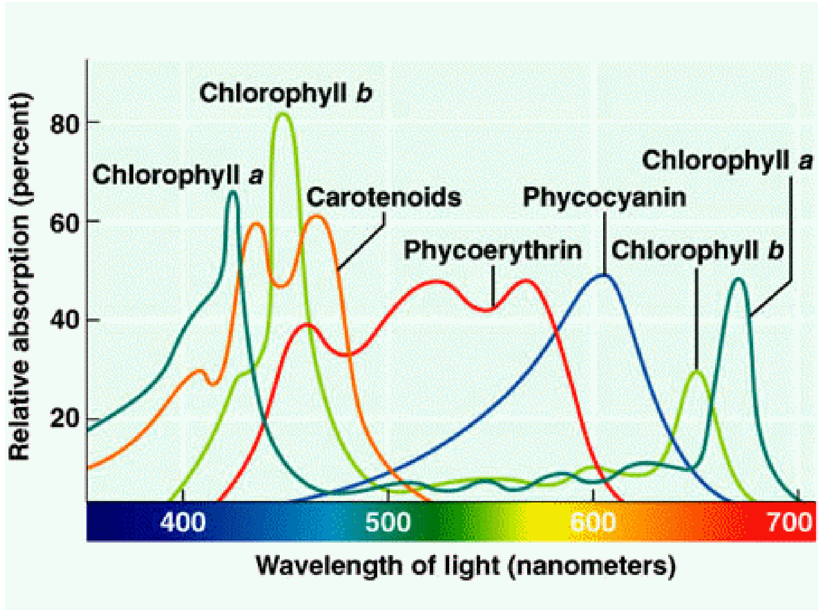
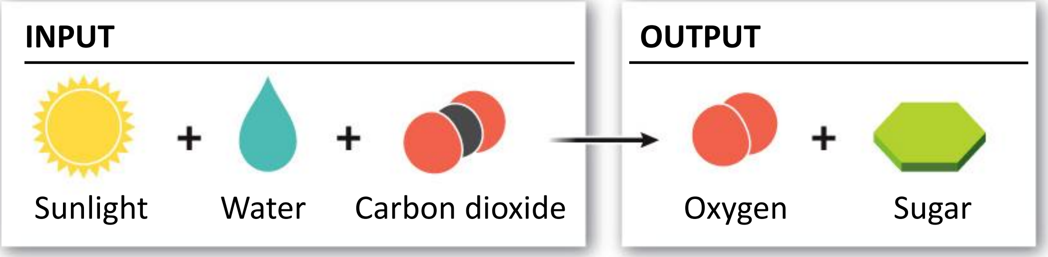
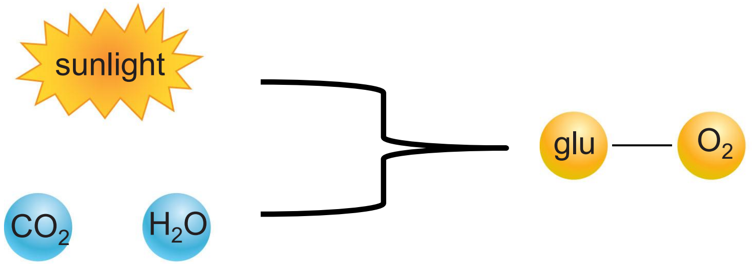


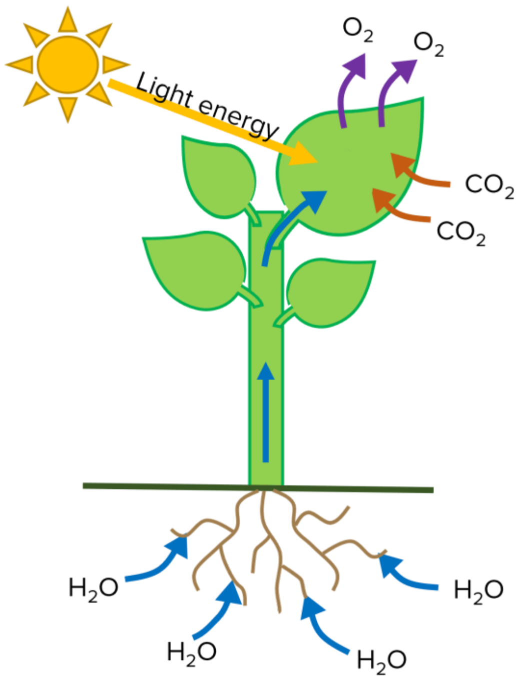
Figure: https://sketchplanations.com/autumn-leaves
https://www.simply.science/images/content/biology/cell_biology/photosynthesis/conceptmap/Photosynthetic_pigments2.gif

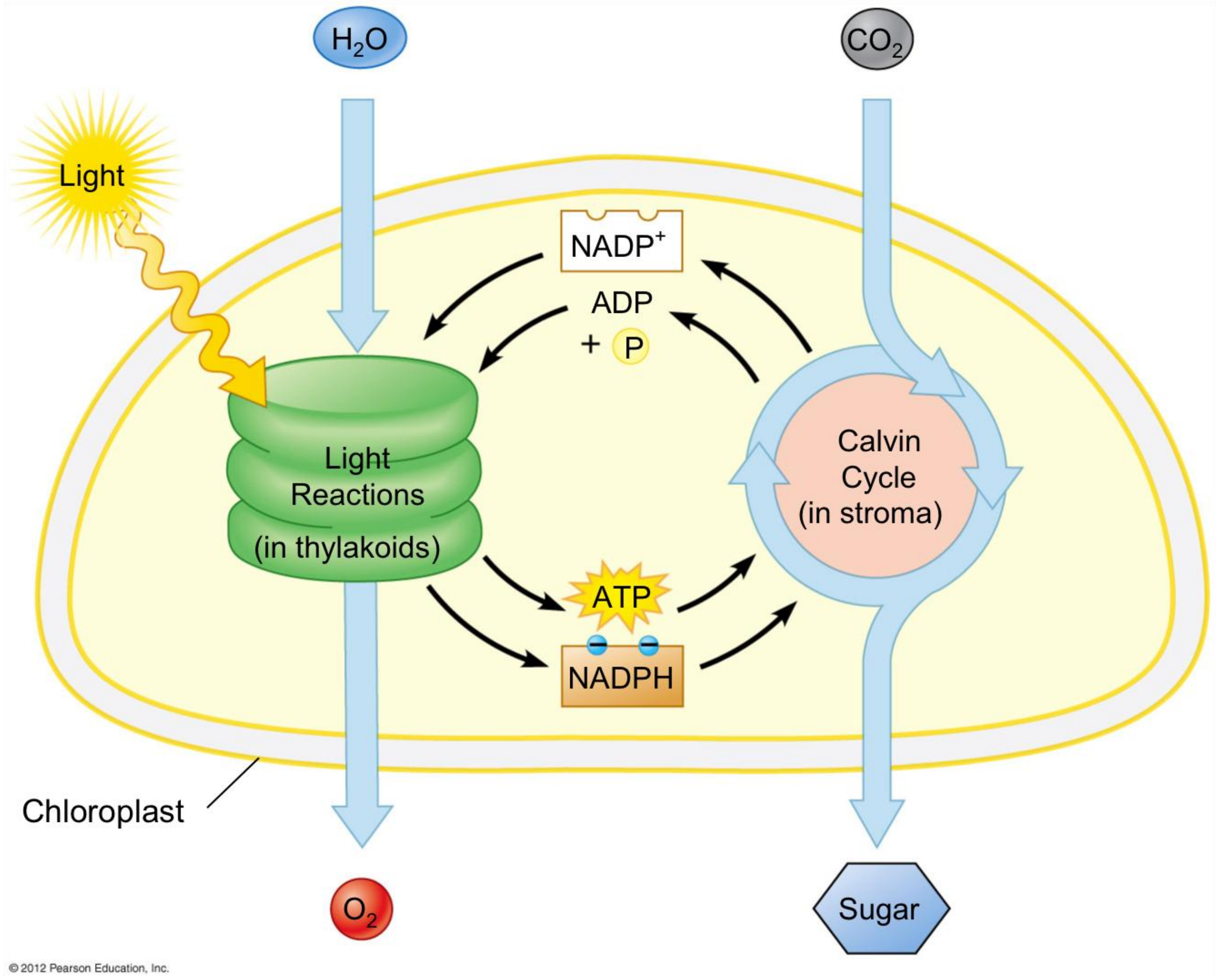
- How do plants capture sunlight & turn it into sugar/stored energy?
  - Sunlight is captured in pigments, then combined with water & CO_2 to produce a sugar molecule
  - O_2 is given off as waste



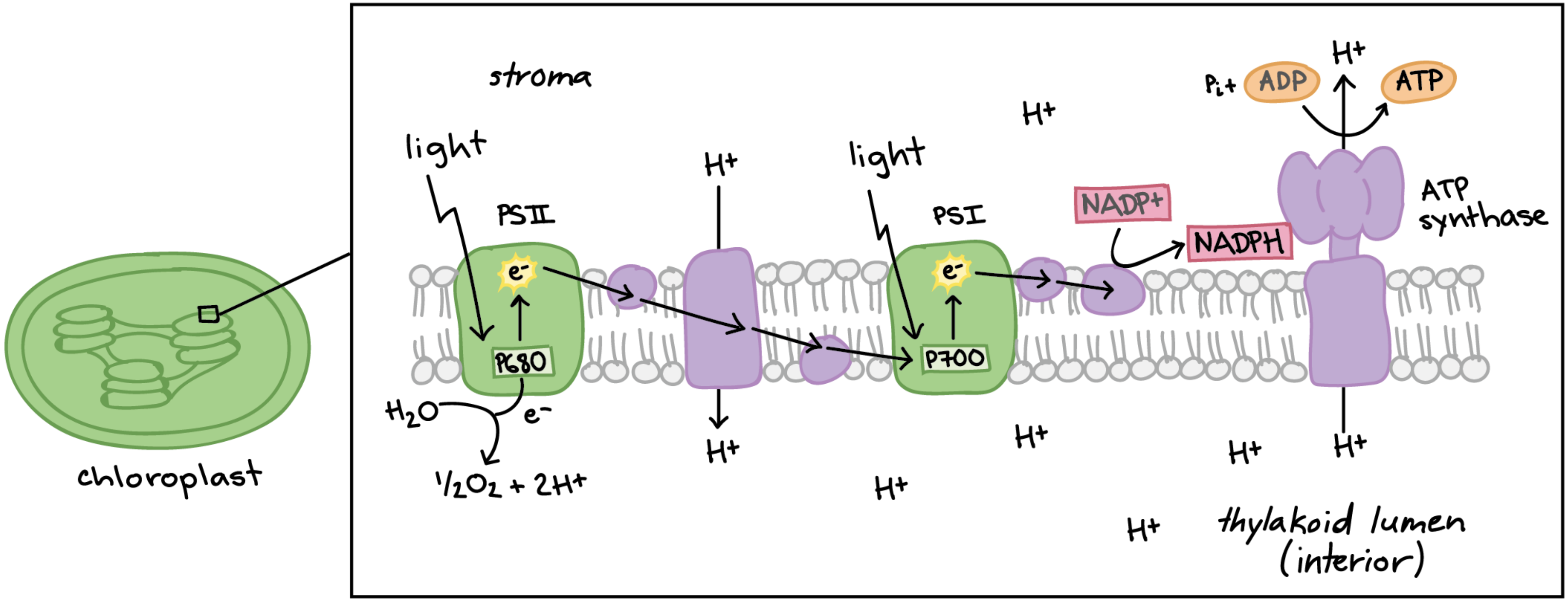
  - *Remember: photosynthesis stores energy: endergonic*







https://mmerevise.co.uk/wp-content/uploads/2022/07/Photosynthesis.png
https://alevelbiology.co.uk/wp-content/uploads/2019/04/Overview-of-photosynthesis_2.png



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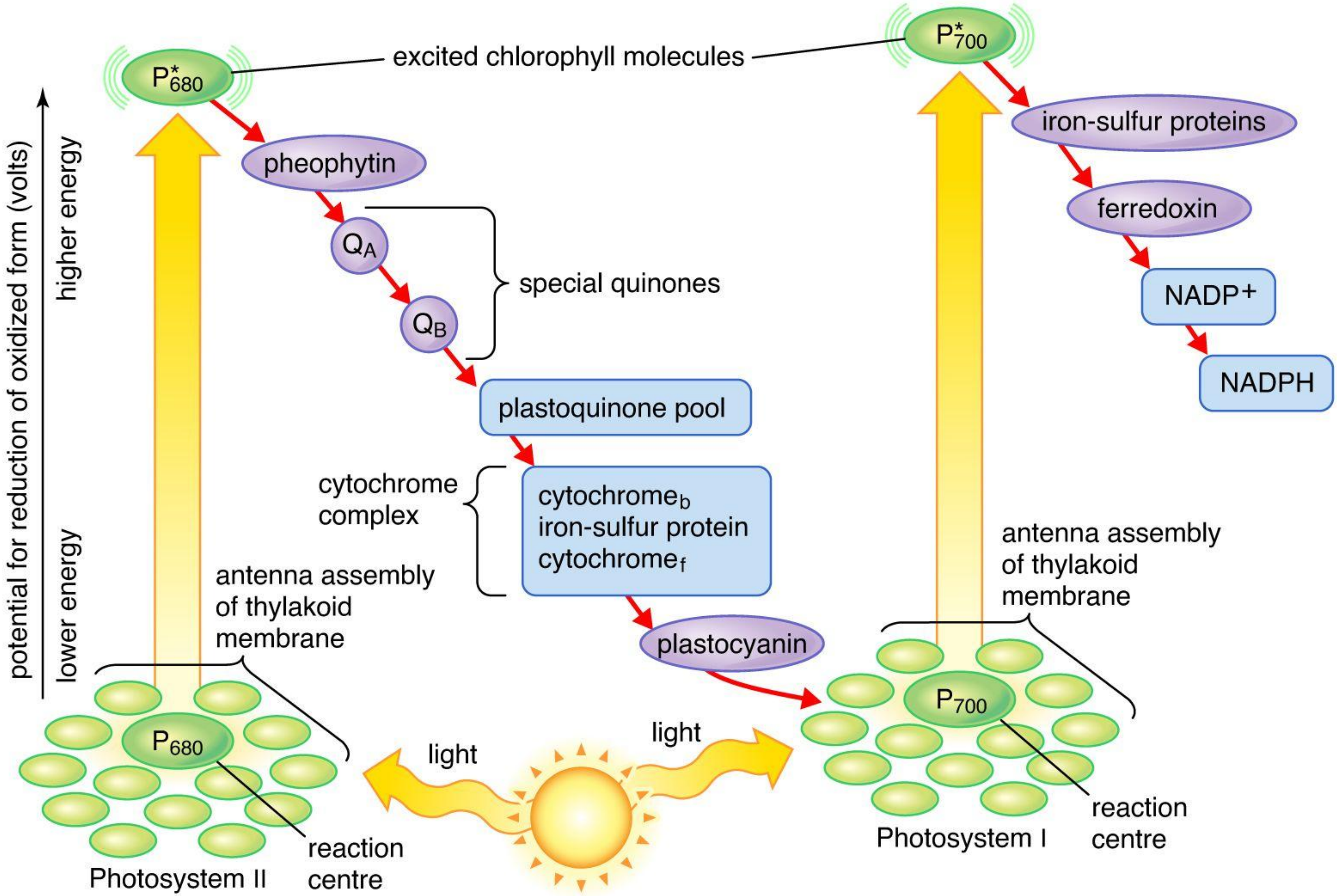
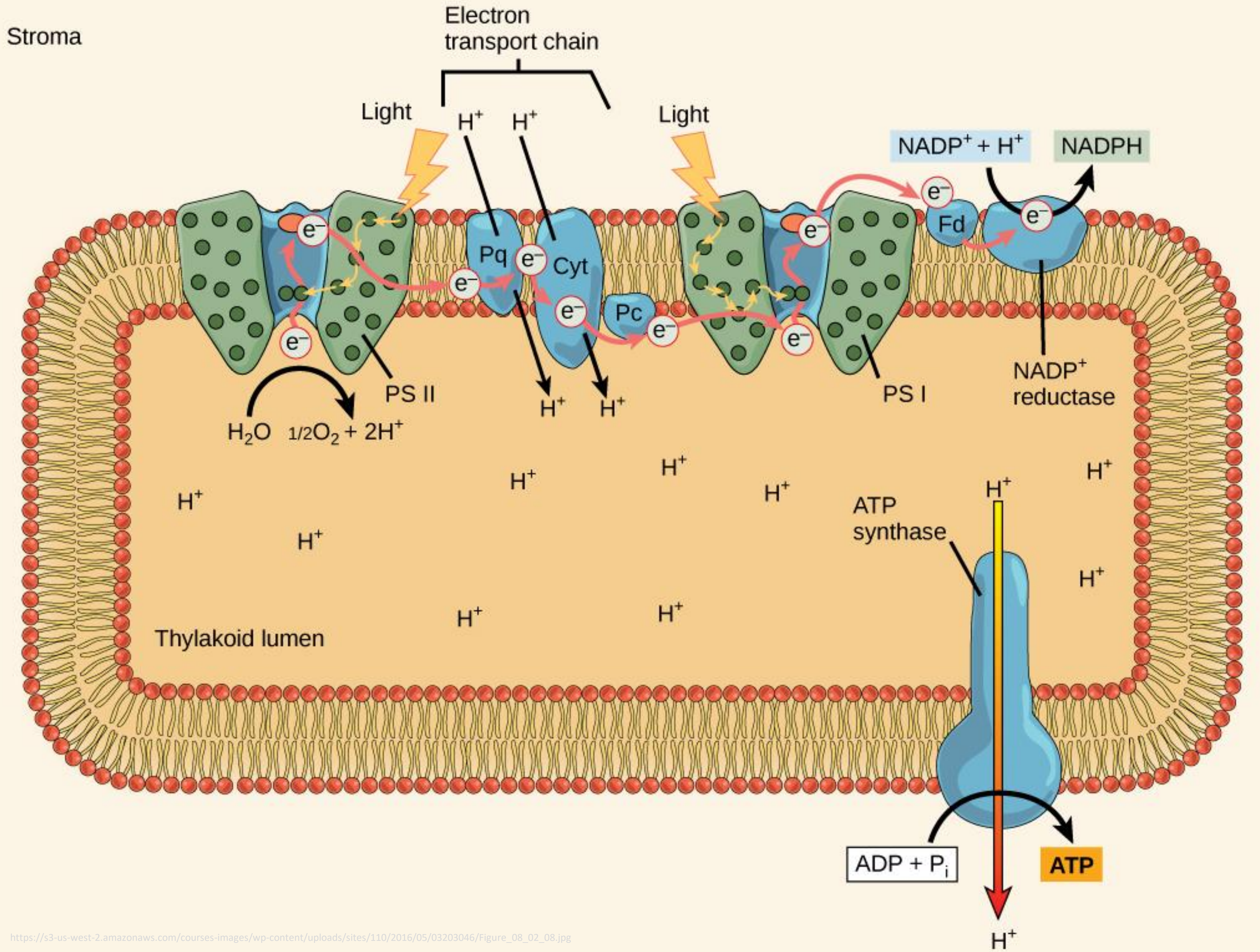


excited chlorophyll molecules
P^*_{680}
P^*_{700}
potential for reduction of oxidized form (volts)
higher energy
lower energy
pheophytin
Q_A
Q_B
special quinones
plastoquinone pool
cytochrome complex
cytochrome$_b$
iron-sulfur protein
cytochrome$_f$
plastocyanin
iron-sulfur proteins
ferredoxin
NADP+
NADPH
antenna assembly of thylakoid membrane
antenna assembly of thylakoid membrane
P_{680}
P_{700}
reaction centre
reaction centre
Photosystem II
Photosystem I
light
light



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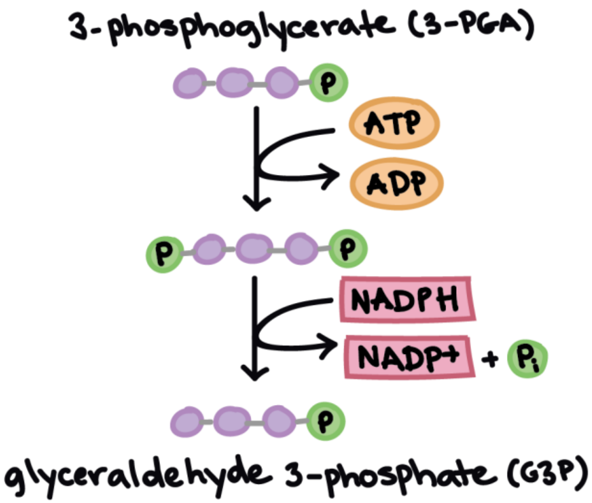

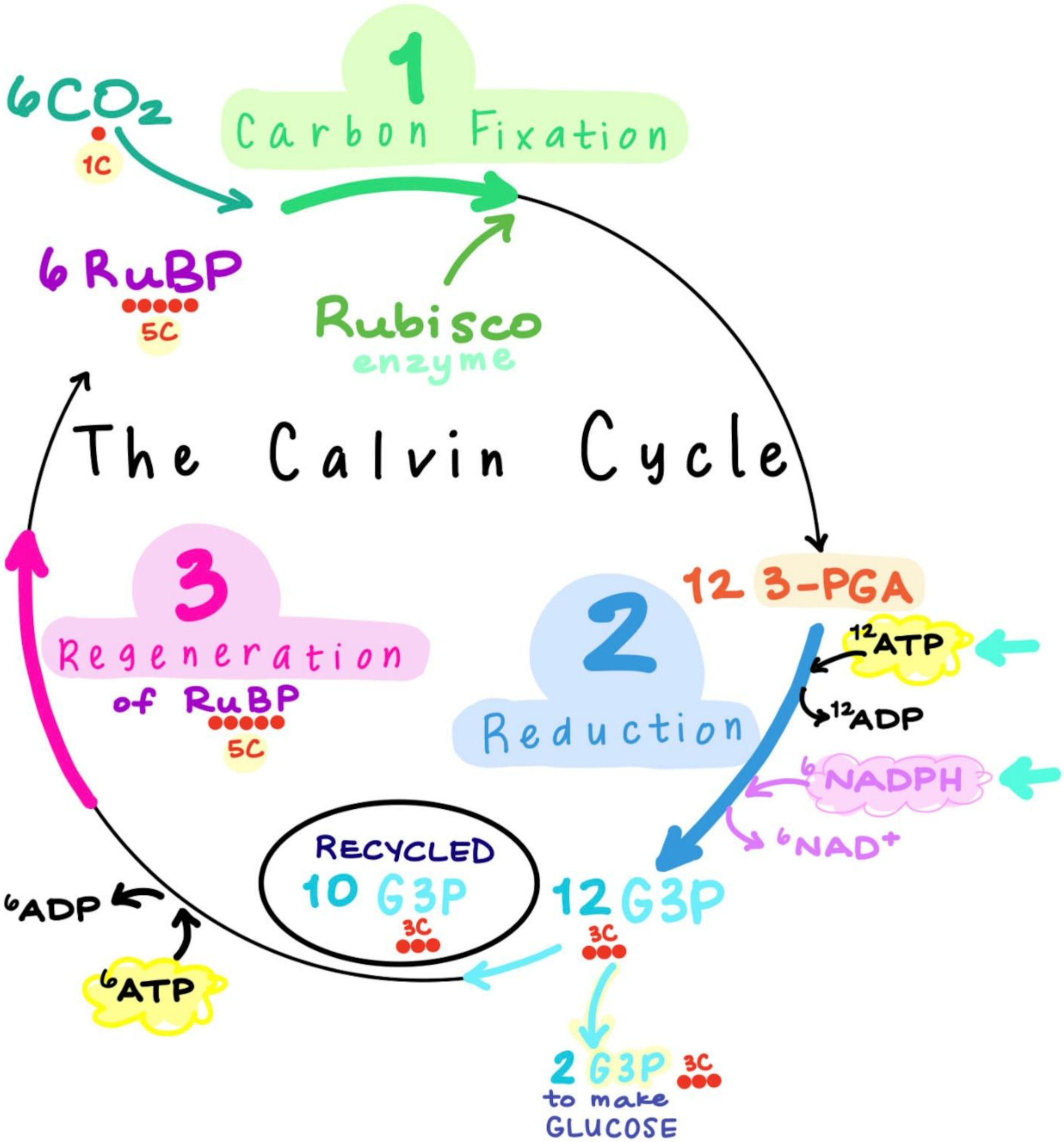

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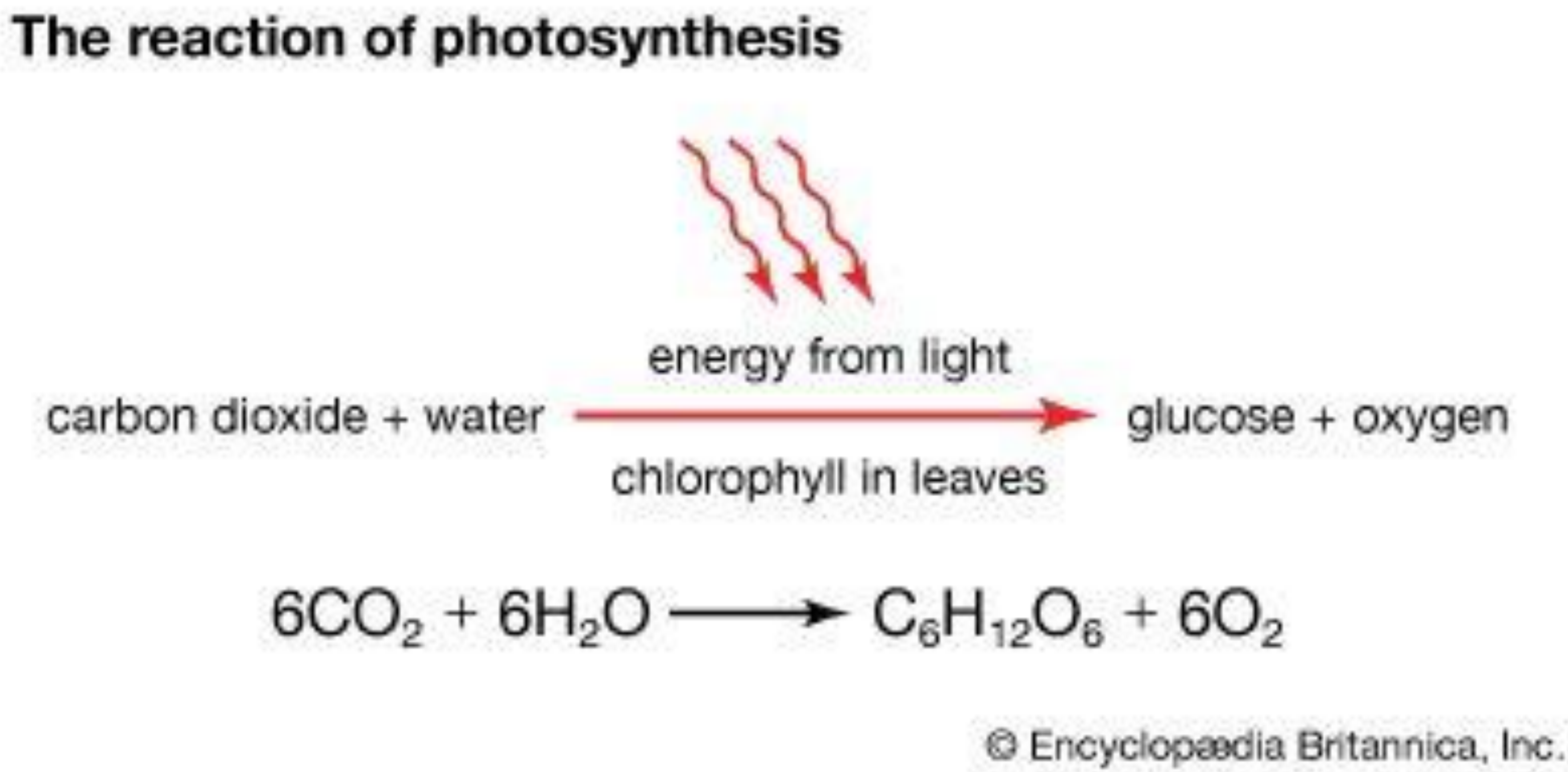
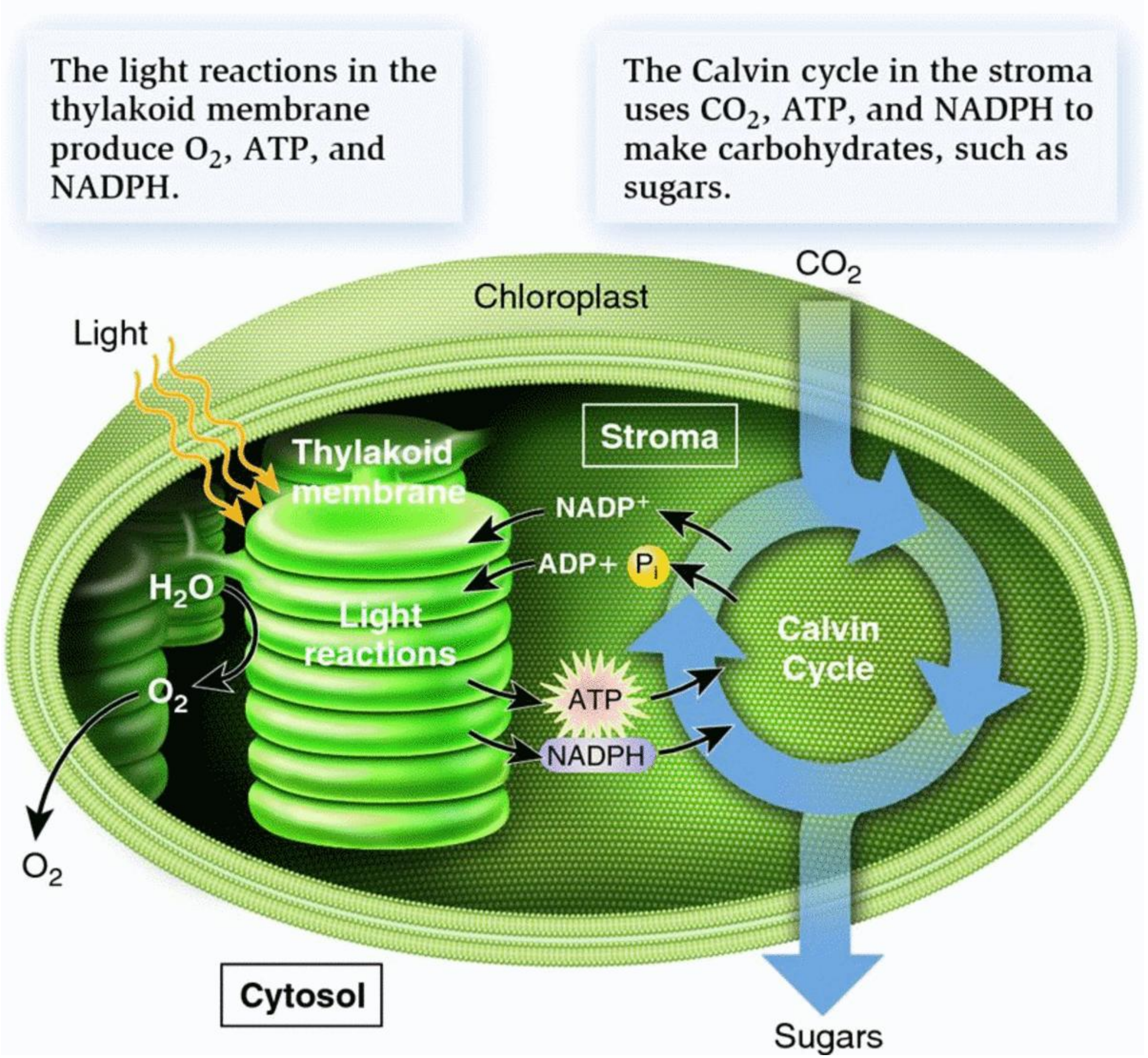
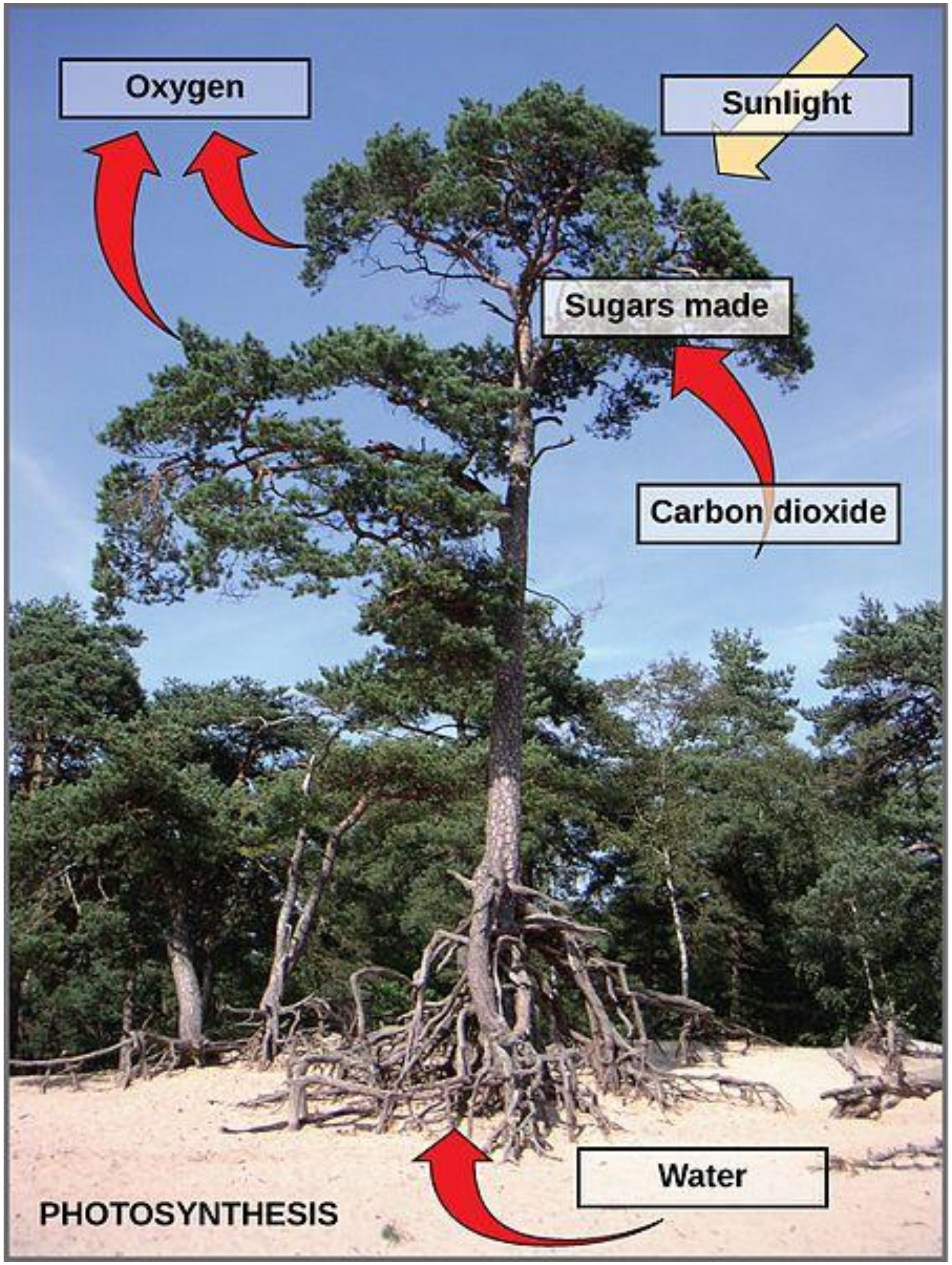

The reaction of photosynthesis
energy from light
carbon dioxide + water → glucose + oxygen
chlorophyll in leaves
$6CO_2 + 6H_2O \longrightarrow C_6H_{12}O_6 + 6O_2$
© Encyclopaedia Britannica, Inc.



https://discover.hubpages.com/education/What-are-the-Two-Stages-of-Photosynthesis-Applications-of-Photosynthesis-in-Modern-Technology

Oxygen added
to atmosphere



Energy from sun
captured and stored
in sugar molecules

Sugar = energy used to
grow plant & keep it alive

Carbon dioxide
absorbed from
atmosphere

Water absorbed from
ground through roots

Figure:
https://commons.wikimedia.org/wiki/File:Figure_08_01_03.jpg