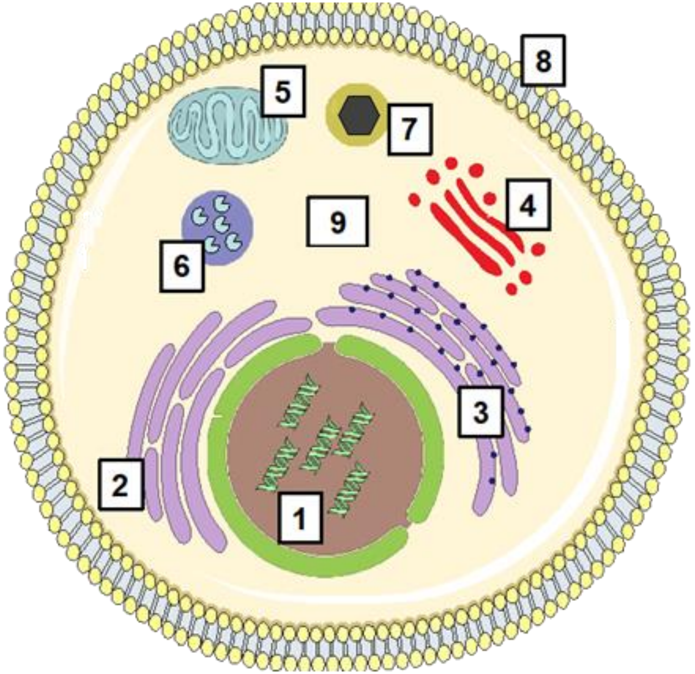
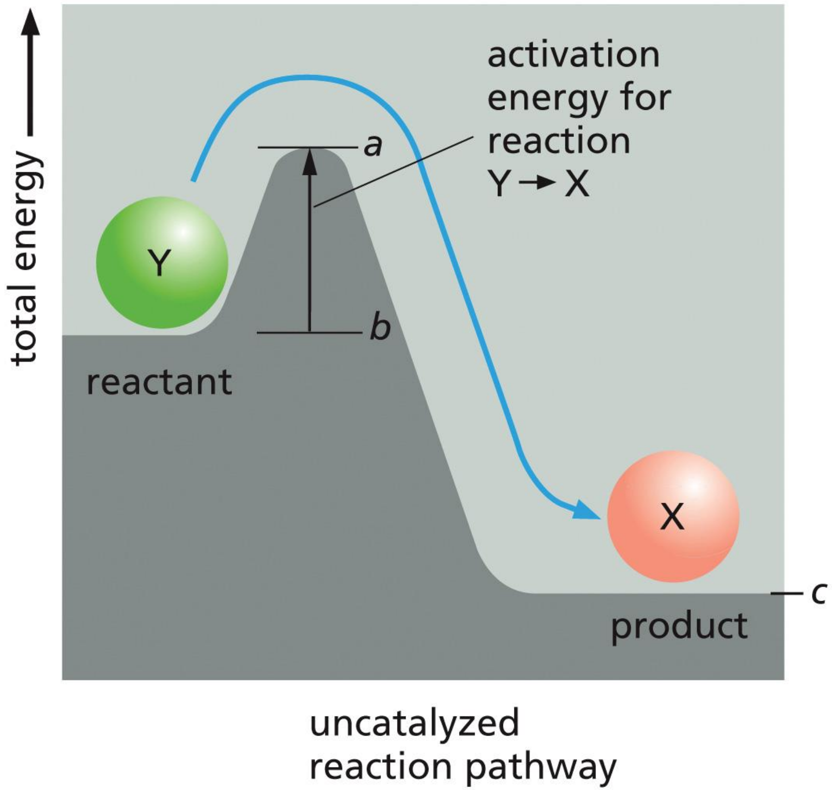
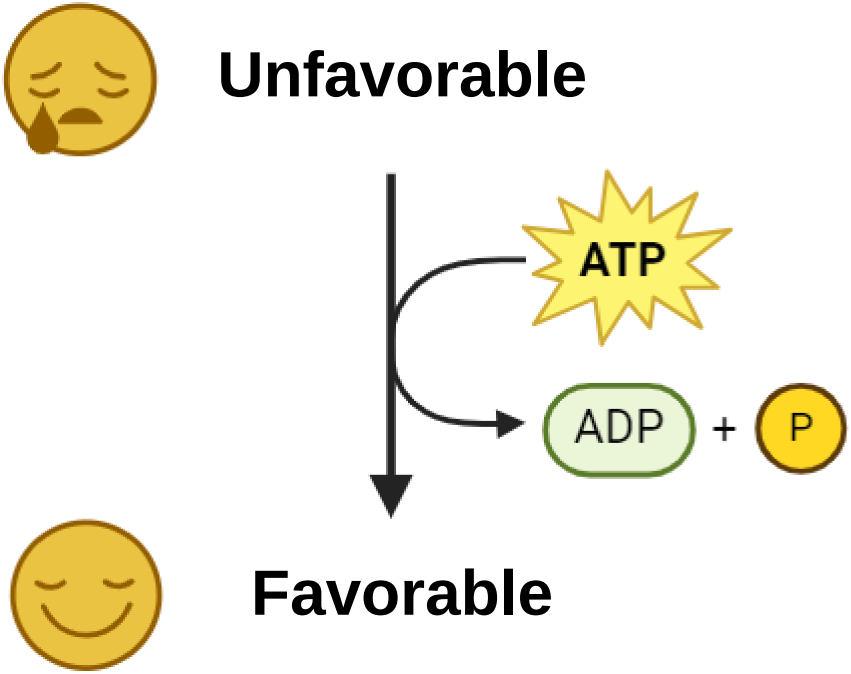
Test your knowledge of the Animal Cell

Organelle	Name	Function in the Cell
1		
2		
3		
4		
5		
6		
7		
8		
9		



Hints:
-6 has hydrolases
-7 has catalases





Chapter 3: Cell Energy, Catalysis, and Biosynthesis
Dr. Matthew Ellis

Learning Objectives for Chapter 3:

Upon completing this module, **you should be able to**:

1) Apply the 1st and 2nd laws of thermodynamics to biological systems.

2) Describe “free energy”, how free energy changes drive the direction of cellular reactions and the role of enzymes in this process.

3) Understand energy production in cells and the roles of key activated carriers in biosynthesis (e.g., ATP, NADPH).

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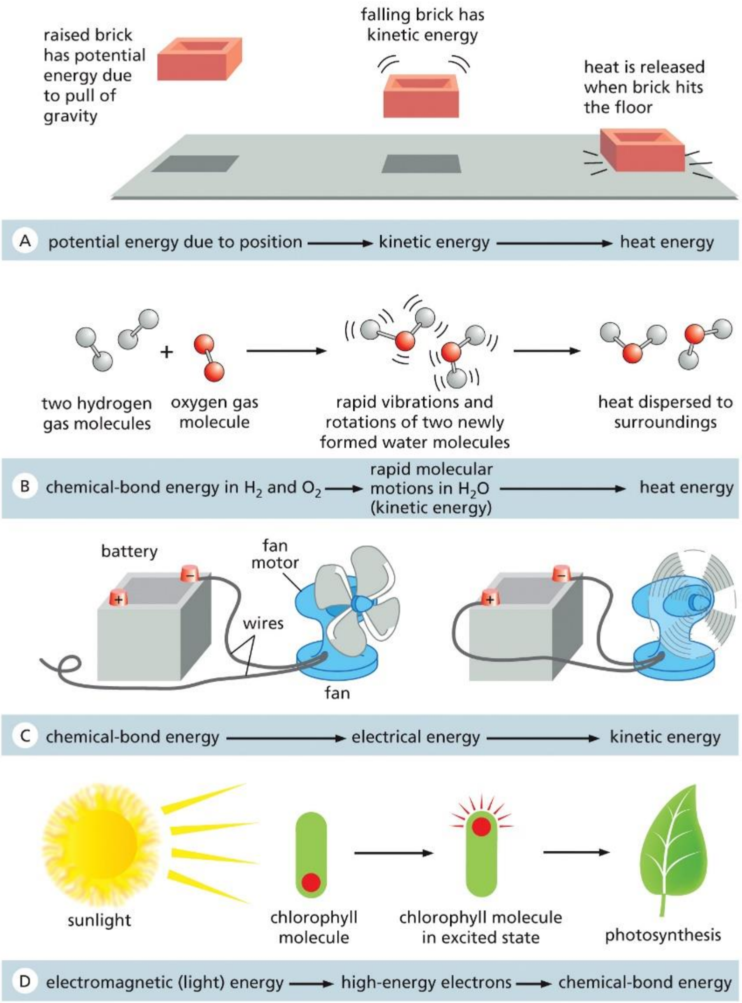
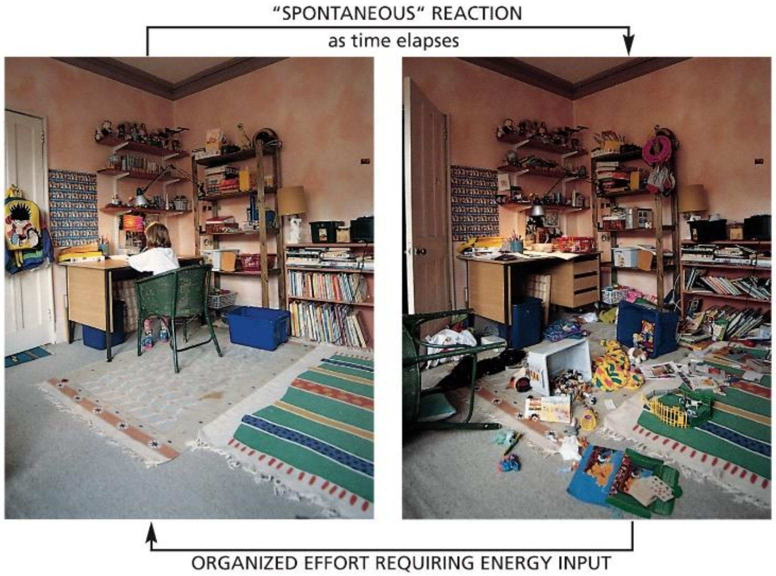
The 1st Law of Thermodynamics

- Energy cannot be created nor destroyed
  - Different forms of energy are interconvertible, but the **total amount of energy is conserved**



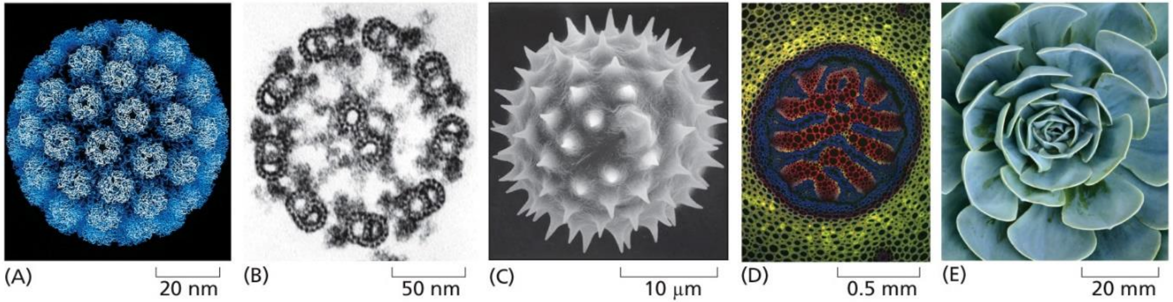
The 2nd Law of Thermodynamics

- The energy in the universe (or in any closed system) is always moving towards **more disorder** (*entropy*)



Biological systems are very ordered, not what the universe strives for….

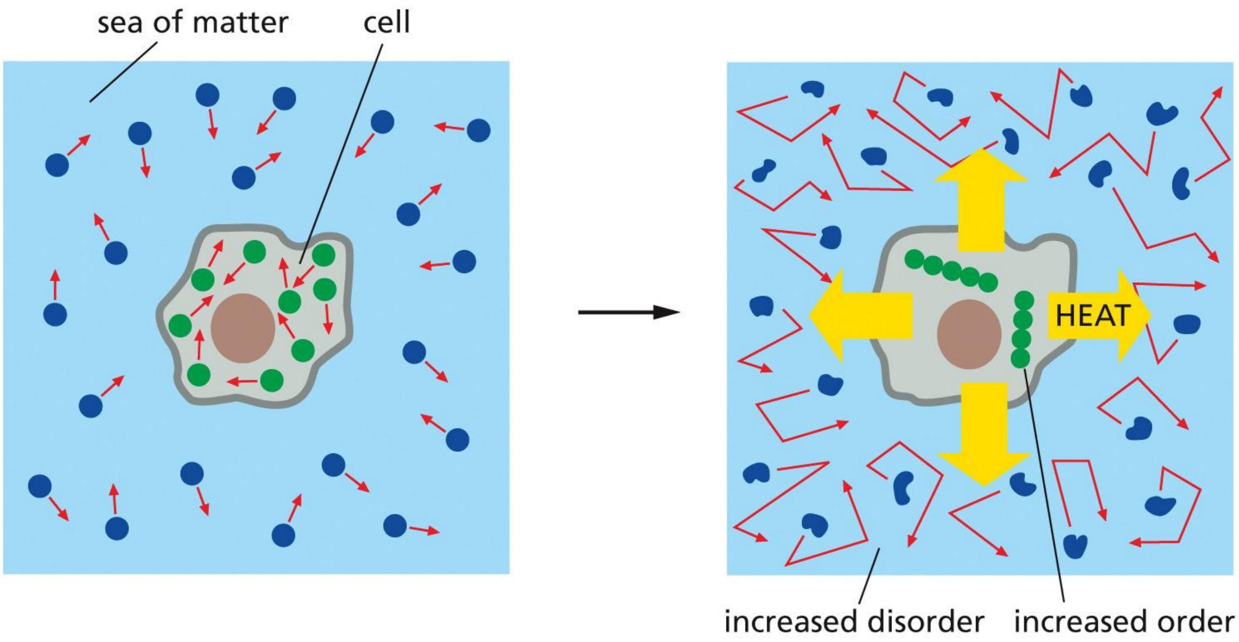
A, courtesy of Robert Grant, Stéphane Crainic, and James M. Hogle; B, courtesy of Lewis Tilney; C, courtesy of Colin MacFarlane and Chris Jeffree; D, courtesy of Jim Haseloff.



- Cells do not defy this law by maintaining order, instead they maintain order by displacing *heat energy back into the universe* (thus the energy is converted and the total energy maintained)

- In other words, *generating order is always coupled with an increase in the universe's disorder*

Formation of a bond releases energy (heat) as atoms become more stable when they form bonds (they complete their outermost electron shell!)



- This heat is released into the external system, increasing the energy and disorder

Energy is a System

Total Energy = Usable Energy + Unusable Energy

T: Temperature (degrees Kelvin)

S: Entropy, a measure of disorder

Energy is a System

Total Energy	=	Usable Energy	+	Unusable Energy
<u>Enthalpy (H)</u> Total energy in the system		**<u>Gibbs Free Energy (G)</u>** Energy is a system available to do work		**<u>Entropy Term (TS)</u>** Energy lost to disorder and therefore *not* available to do work
H	**=**	**G**	**+**	**TS**

T: Temperature (degrees Kelvin)

S: Entropy, a measure of disorder

$$\boxed{G = H - TS}$$

This is the **Gibbs Free Energy Equation**

Measuring changes (Δ; final value – initial value) in energy can explain how biological reactions occur *spontaneously*

$$\Delta G = \Delta H - T\Delta S$$

- For any process to occur spontaneously, both the 1st and 2nd laws of thermodynamics must be obeyed:
  - By the 1st law:
    - ΔH (change in the total energy of the system) = 0
  - By the 2nd law:
    - Δ S (entropy, disorder) = positive value, so T Δ S = positive
- Together this makes **ΔG a negative value for <u>all spontaneous reactions</u>**

Spontaneous? What does it really mean?

- In terms of biology, spontaneous means a reaction is **energetically favorable**, and *given sufficient time* **will occur** without external input

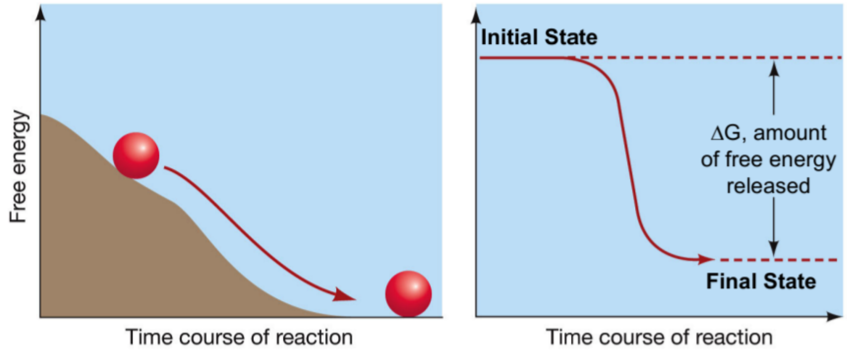
- It does not necessarily mean:
  - The reaction will happen quickly or suddenly

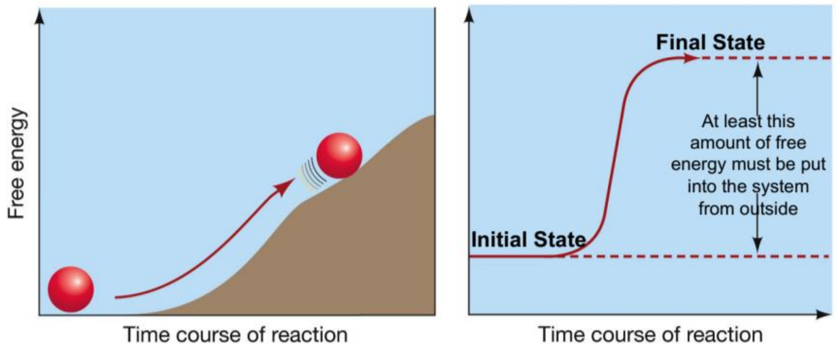
  - The reaction is quirky, impulsive, or whimsical

https://www.pinterest.com/pin/12807180175318804/

SQUARECAP Q#1-2

Think of a ball rolling down a hill on its own versus a ball being pushed up a hill





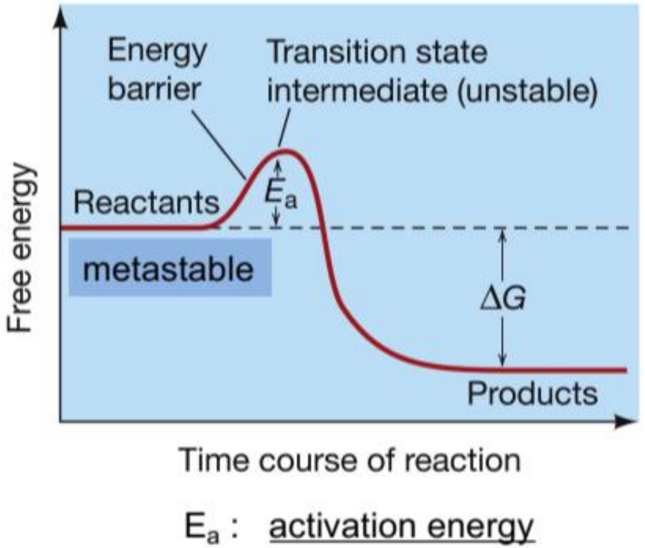
This process will happen by itself due to gravity

<u>Spontaneous</u>

This process is unlikely to happen by itself as it is working against gravity

<u>Not Spontaneous</u>

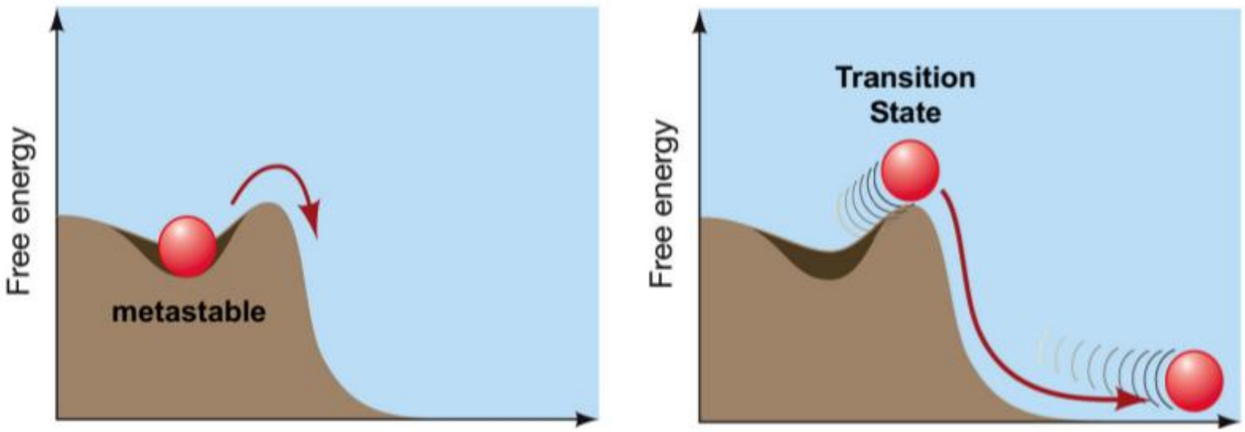
Metastability and Transition States



- While overall products are more stable than reactants in spontaneous reactions ($\Delta G < 0$), most chemical reactants are semi-stable (*metastable*) meaning that they are not yet at the desired equilibrium lowest energy state (product) that would be achieved given infinite time and must first push through a less stable, higher energy *transition state* before they can reach equilibrium

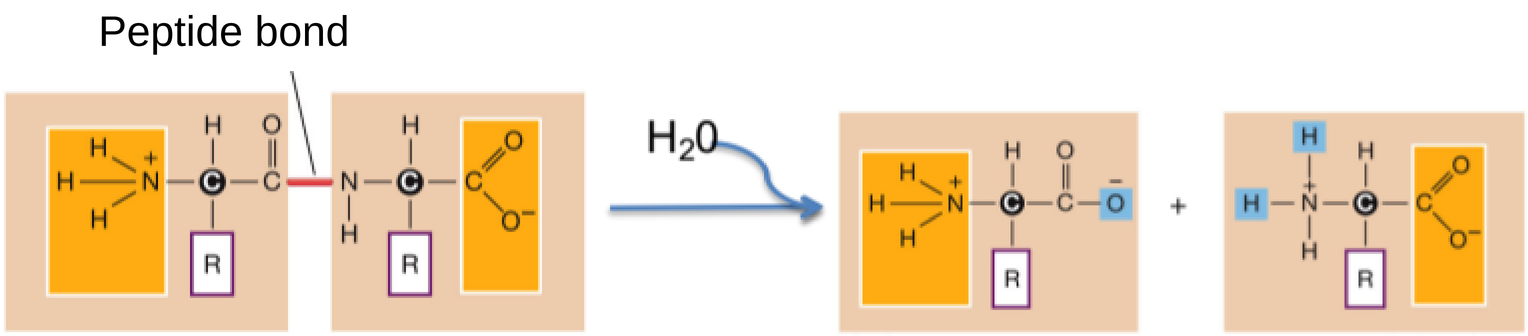
- This energy barrier is what causes many spontaneous reactions to take a very long time to occur naturally

Consider our ball analogy:



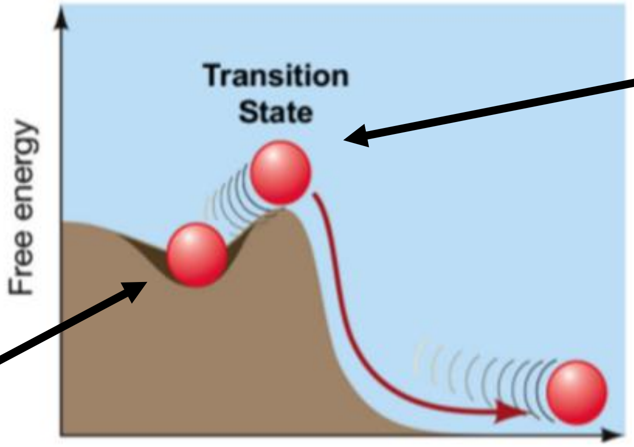
- With the ball in a divot, it is now metastable compared to the transition state
- It will remain in this non-equilibrium state until sufficiently perturbed to move out of it

Consider the breaking of a peptide bond:



- ΔG = -5 kcal/mol for this reaction
- Half-time for this reaction (i.e., how long it would take for half of the starting material to fully convert into the ending material) **is 7 years!**

Wait a second…why would these reactions ever occur if formation of the transition state is non-spontaneous?

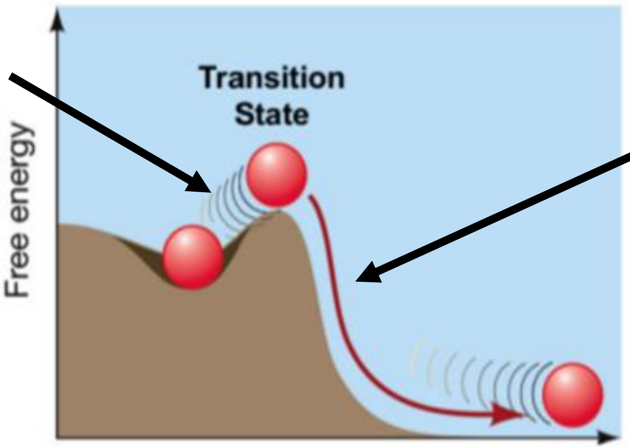


Higher energy, less stable state

Lower energy, more stable state

Brownian motion (*randomness*) and reaction kinetics (*speed*)!

Random chance confirmational change (*<u>very unlikely and slow</u>*)



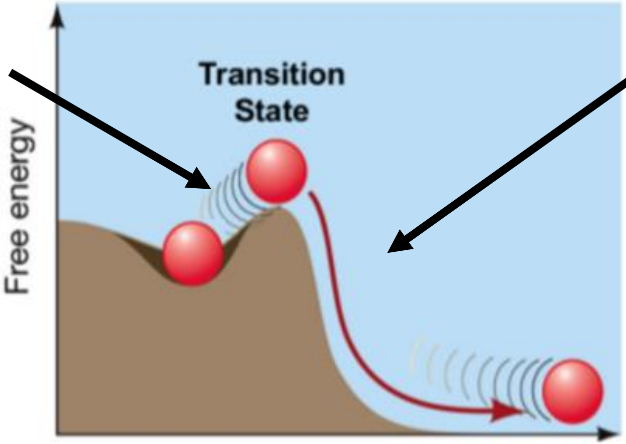
Highly favorable reaction progression to reach equilibrium (*<u>very likely and fast</u>*)

- Remember that molecules don't have agendas, they are just moving around in space and short-lived noncovalent interactions govern reactivity
- From the transition state the molecule *<u>can go in either direction</u>*, back towards the reactant (unproductive, but constantly happening) or towards the product (productive, also constantly happening)

Consider a roulette wheel:

Random chance confirmational change (*<u>very unlikely and slow</u>*)

Highly favorable reaction progression to reach equilibrium (*<u>very likely and fast</u>*)



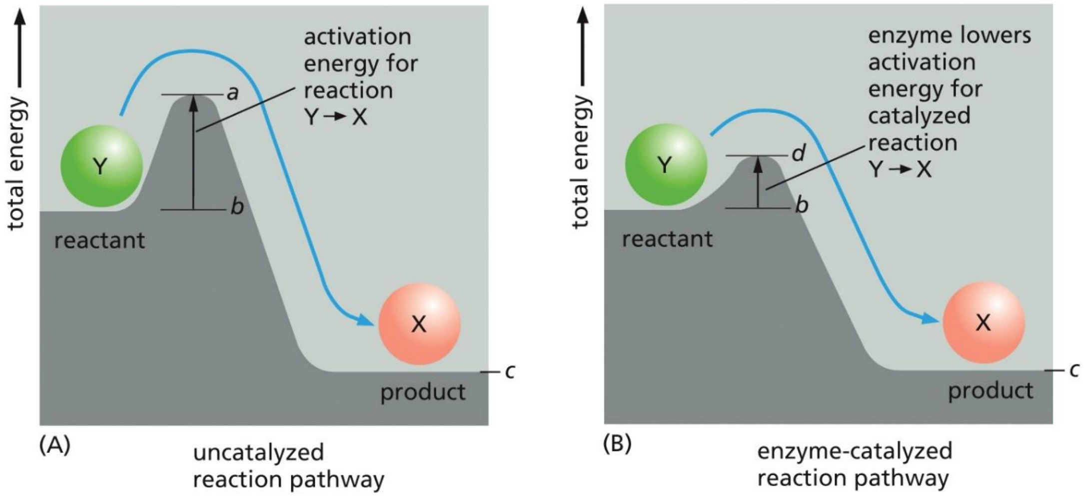
- A roulette wheel has 18 red numbers, 18 black numbers, and 1 green number (zero)
  - Moving naturally from the reactant to the transition state is like trying to hit zero in roulette, definitely possible, but highly unlikely
  - Moving naturally from the transition state to the products is more like trying to hit zero on a modified roulette wheel where every outcome is now green

https://www.northernquest.com/casino/table-games/roulette; https://cookjack248.medium.com/beating-roulette-testing-the-reverse-labouch%C3%A8re-betting-system-b59a17e0d453

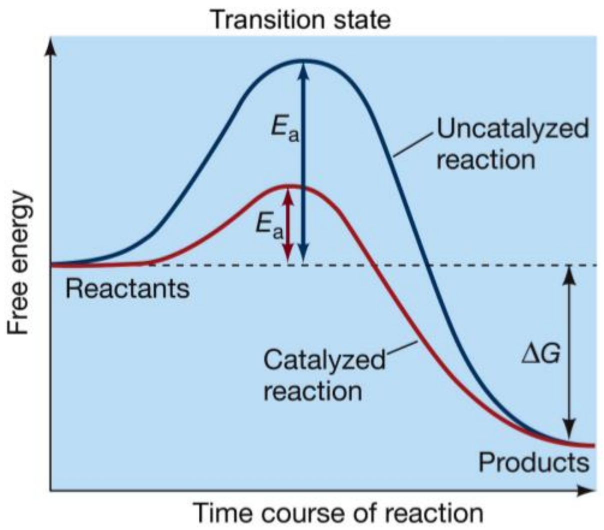
Catalysts increase the likelihood a favorable reaction will occur

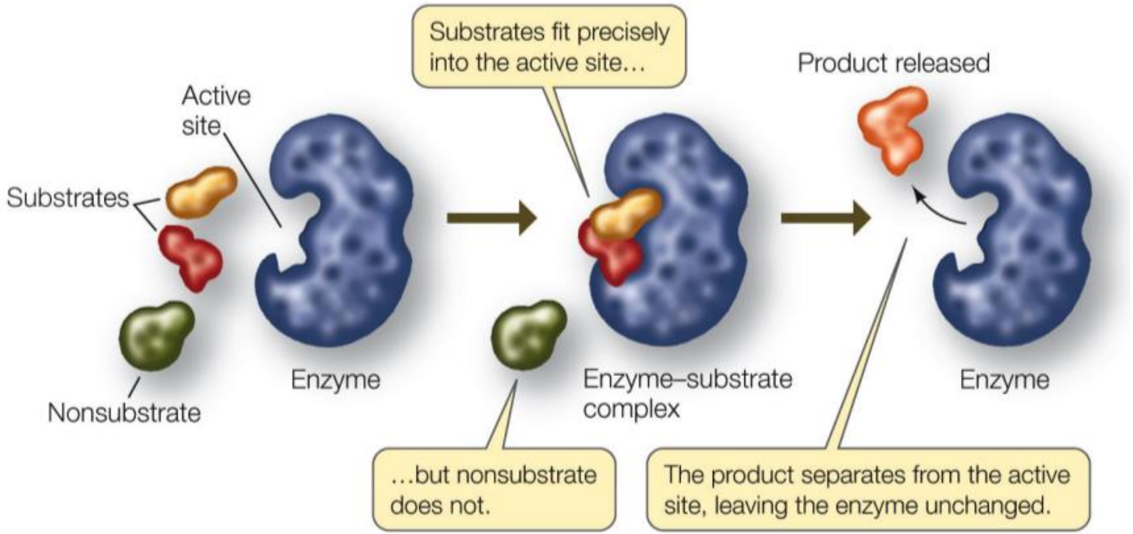
- Chemical reactions proceed in the direction that causes a net loss of free energy (*spontaneous reactions; negative ΔG*)
  - **Activation energy** (a-b) is energy required to convert molecule Y to X
  - **ΔG** (c-b) is the total energy change for conversion of Y to X

- **Catalysts** *reduce the activation energy* needed to initiate spontaneous reactions
  - **Enzymes** is the term for protein catalysts in biological reactions
  - Catalysts are cyclic by definition, meaning they are not consumed during the reaction and can be used again



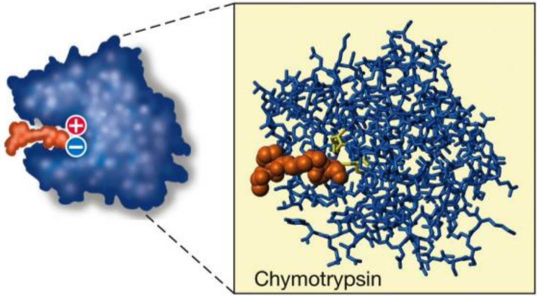
Enzymes bind substrates (reactants) and catalyze reactions to produce products



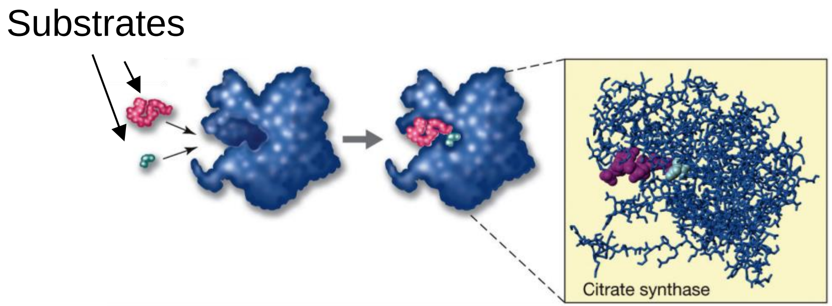


Enzyme Mechanisms:

- **Stabilize the transition state**
  - Non-covalent interactions between the enzyme <u>*active site*</u> and the transition state help to partially stabilize the unstable conformation, lowering its Gibbs Free Energy and reducing the activation energy



- **Orient the substrates**
  - Enzymes can also hold the freely rotating substrates in fixed conformations that are highly conducive to reaching the transition state, thereby increasing the reaction speed
    - As if someone placed a magnet under the sole green zero of a roulette wheel



SQUARECAP Q#3-4

Learning Objectives for Chapter 3:

Upon completing this module, **you should be able to**:

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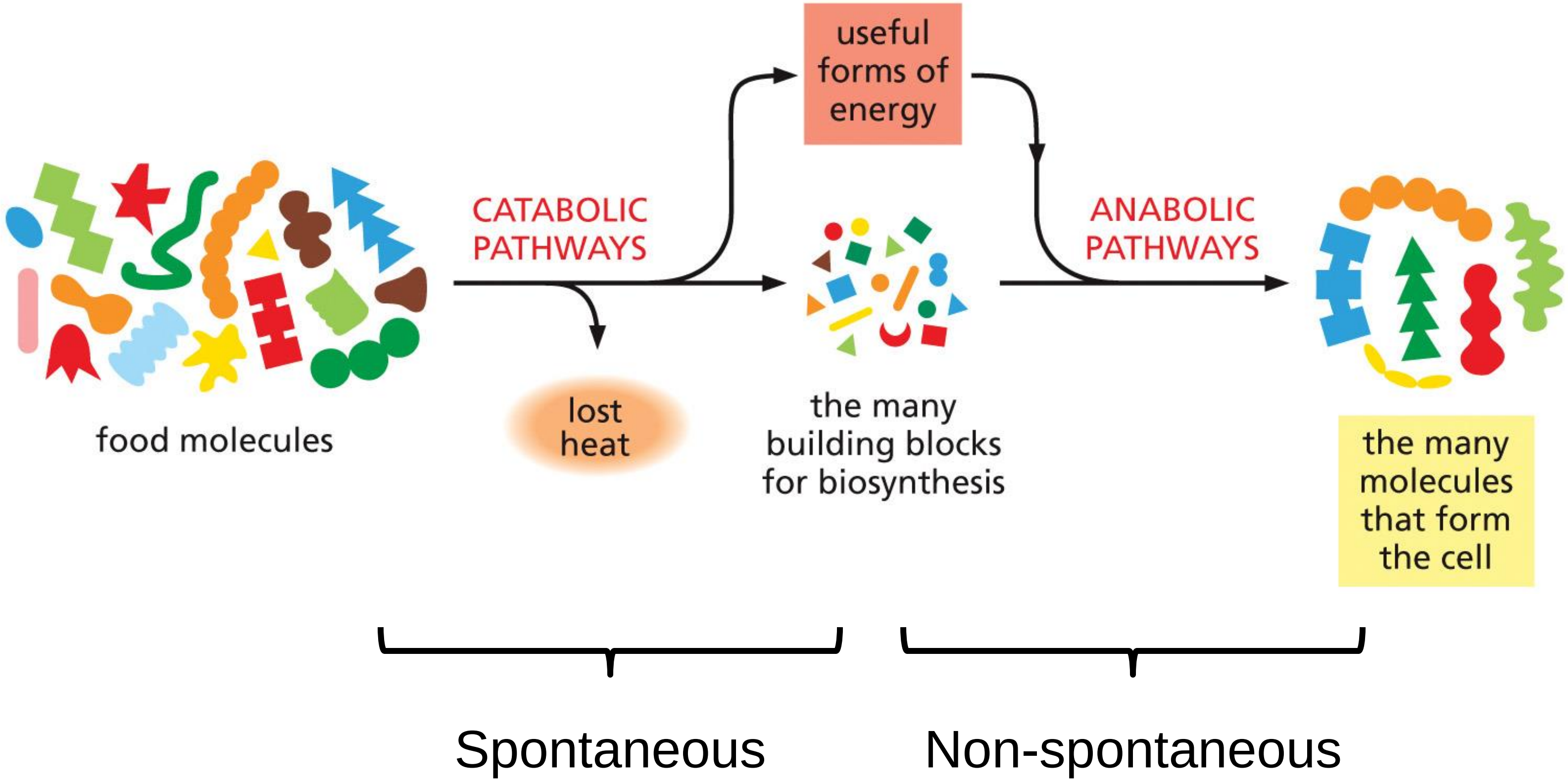
3) Understand energy production in cells and the roles of key activated carriers in biosynthesis (e.g., ATP, NADPH).

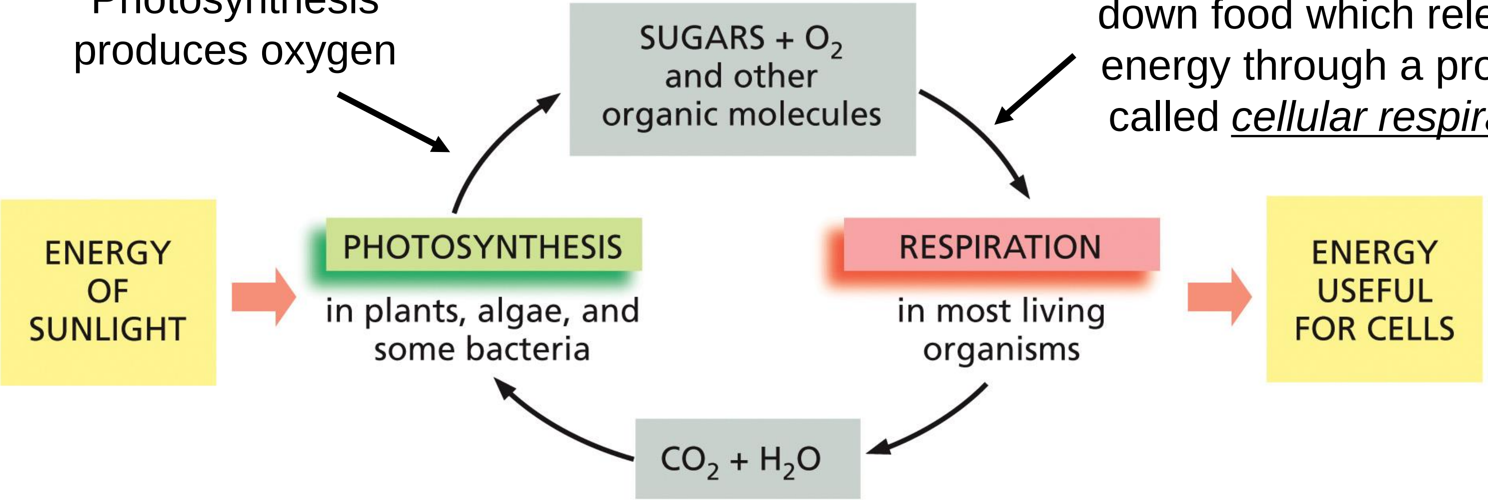
Metabolism (the breakdown and formation of different macromolecules) governs energy usage in our body



Cells obtain energy by the *oxidation* of organic molecules

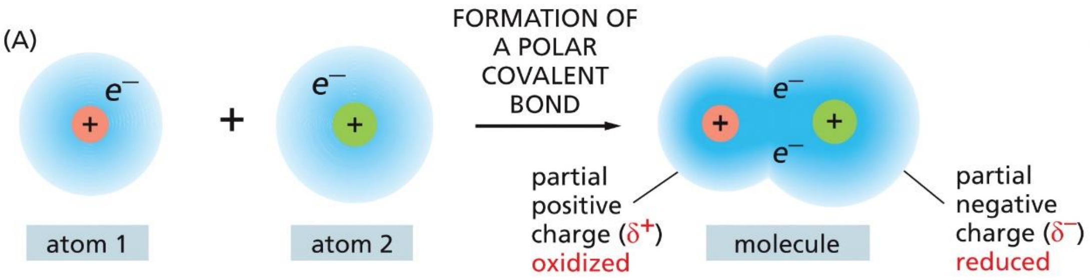
Photosynthesis produces oxygen

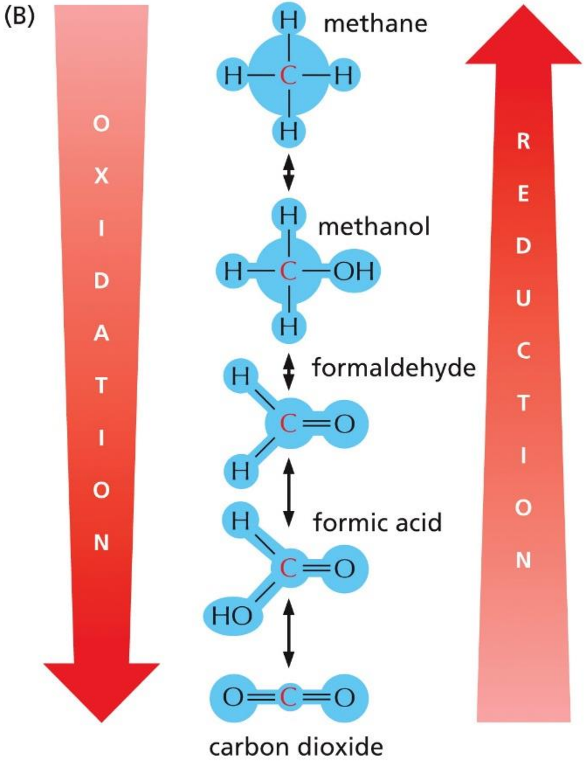
We use this oxygen to break down food which releases energy through a process called *cellular respiration*



Cell respiration and photosynthesis are complementary processes

Oxidation and reduction reactions





- Oxidation = gain of oxygen (loss of electrons)
- Reduction = loss of oxygen (gain of electrons)

- **O**xidation **I**s **L**oss; **R**eduction **I**s **G**ain

https://ib.bioninja.com.au/higher-level/topic-8-metabolism-cell/untitled/energy-conversions.html

Activated carriers are essential for cellular processes

- Activated carriers shuttle energy from energetically favorable reactions to energetically unfavorable reactions, *coupling them* together and allowing them to occur spontaneously
    - Formation of activated carriers is coupled to energetically favorable reactions

- This energy is stored as readily transferable chemical groups (e.g., phosphate) or high energy electrons

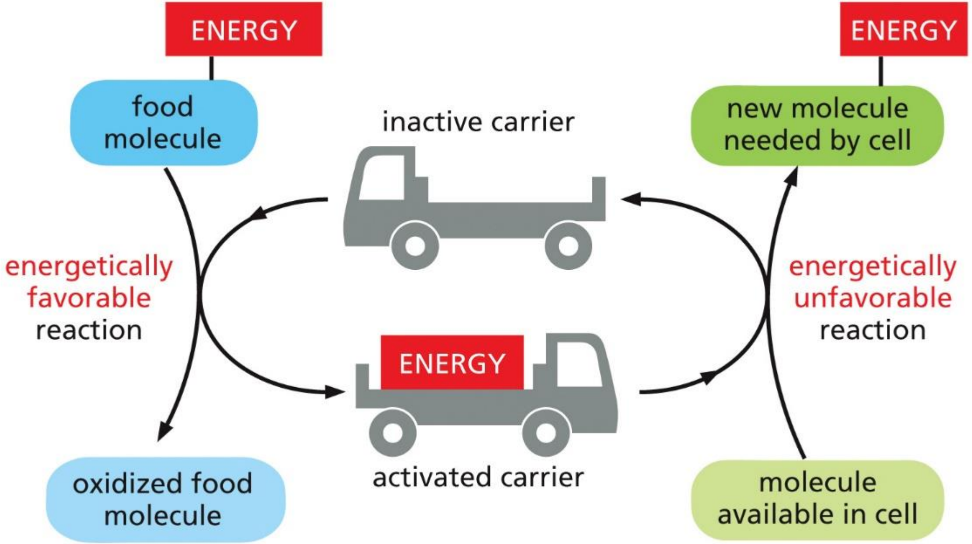
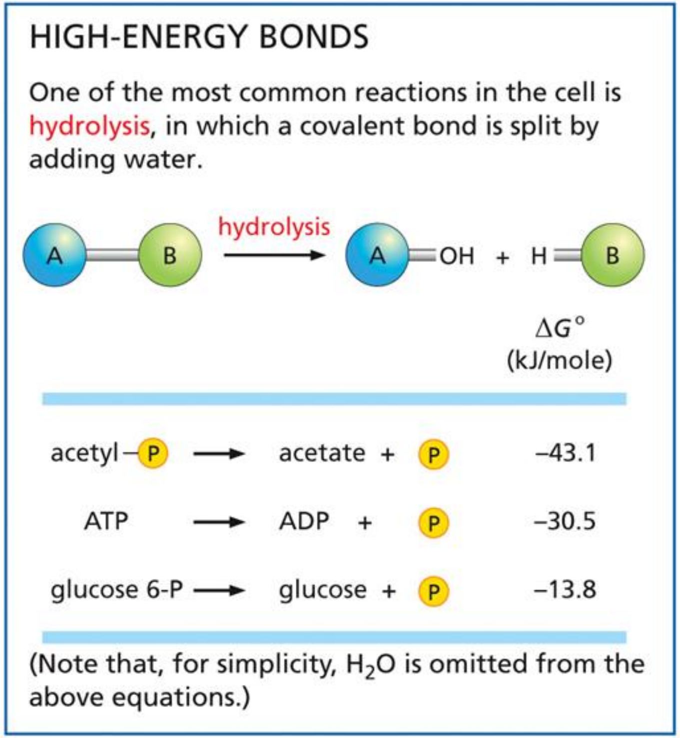


TABLE 3–2 SOME ACTIVATED CARRIERS WIDELY USED IN METABOLISM	
Activated Carrier	Group Carried in High-Energy Linkage
ATP	phosphate
NADH, NADPH, $FADH_2$	electrons and hydrogens
Acetyl CoA	acetyl group
Carboxylated biotin	carboxyl group
S-adenosylmethionine	methyl group
Uridine diphosphate glucose	glucose

Hydrolysis is a common reaction in the cell



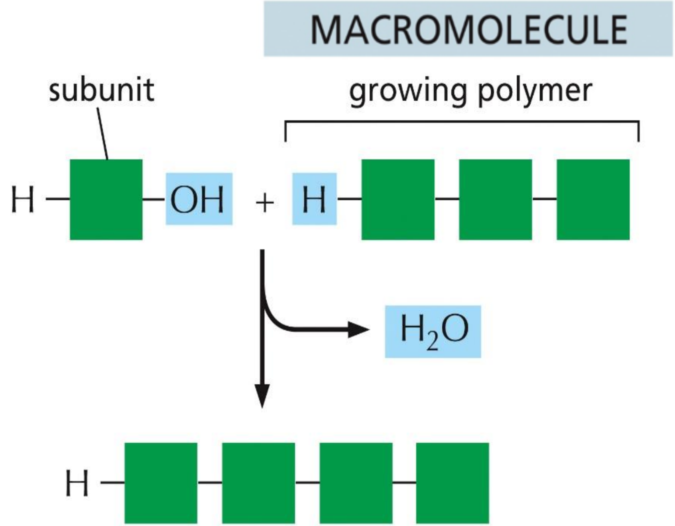
HIGH-ENERGY BONDS

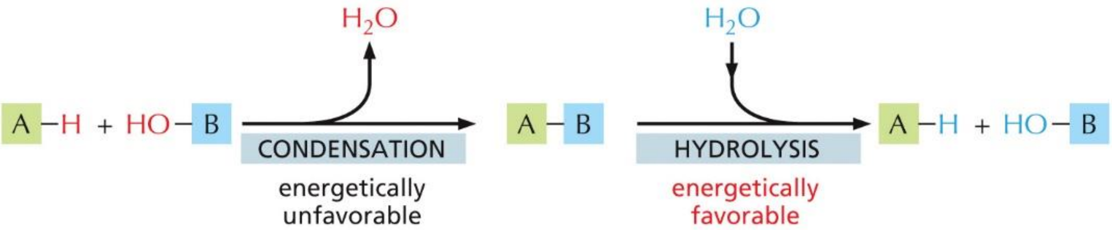
One of the most common reactions in the cell is hydrolysis, in which a covalent bond is split by adding water.

				$\Delta G°$ (kJ/mole)
acetyl–P	→	acetate +	P	–43.1
ATP	→	ADP +	P	–30.5
glucose 6-P	→	glucose +	P	–13.8

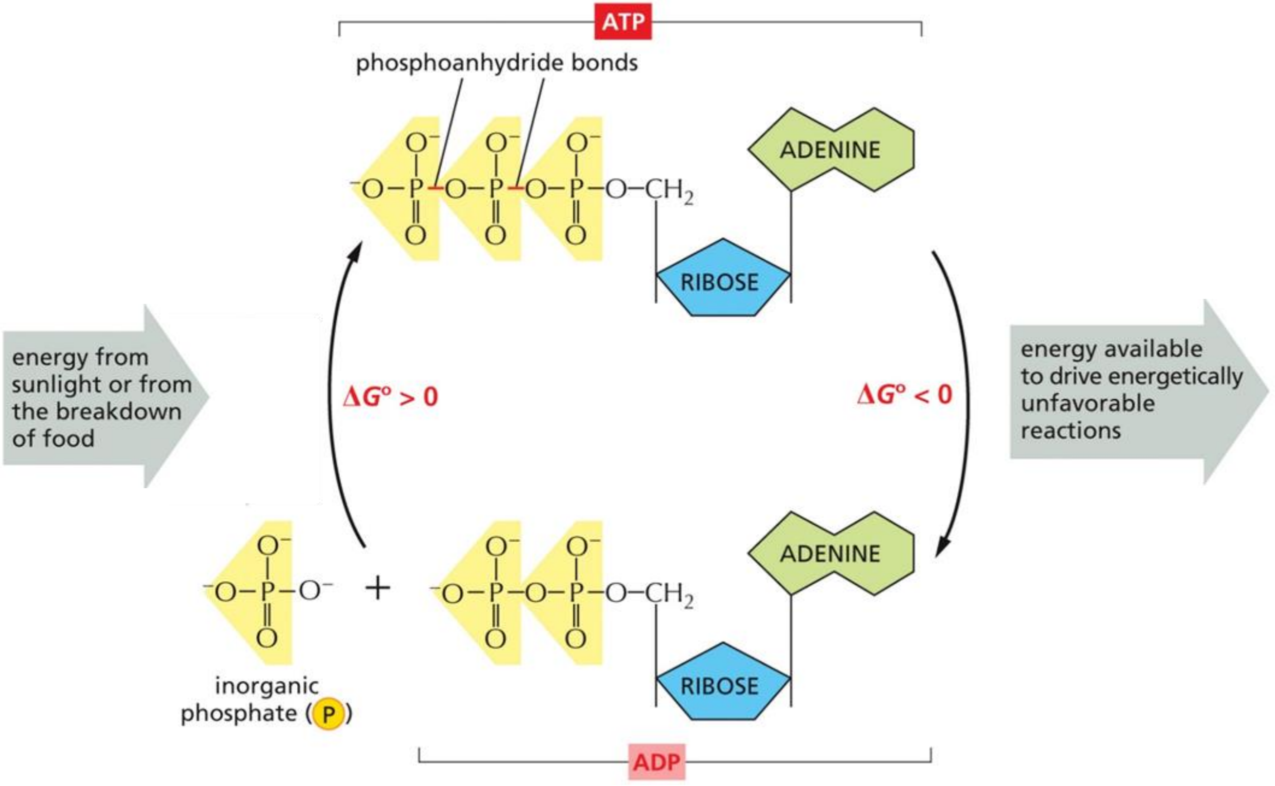
(Note that, for simplicity, H_2O is omitted from the above equations.)

Recall:

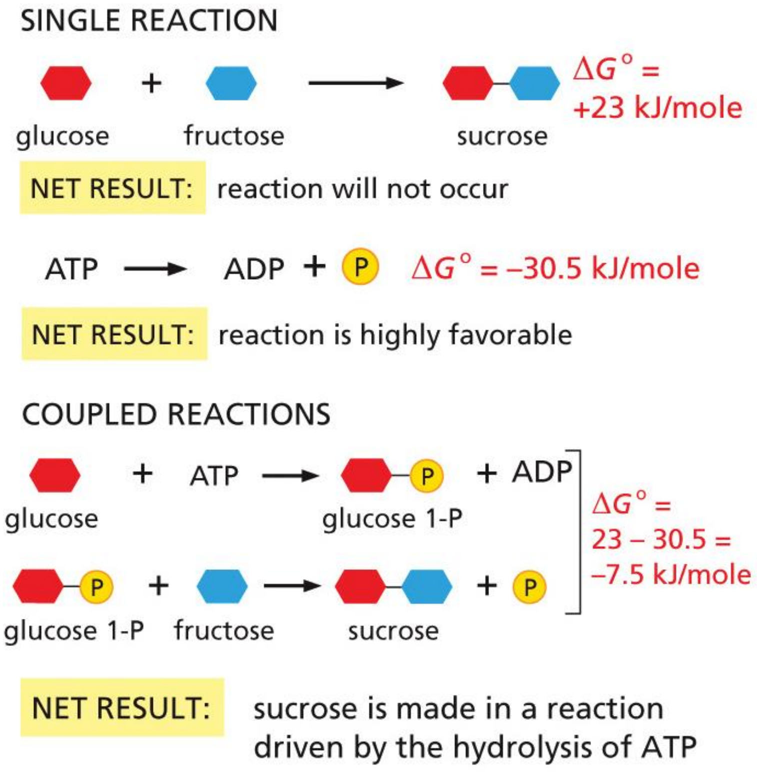




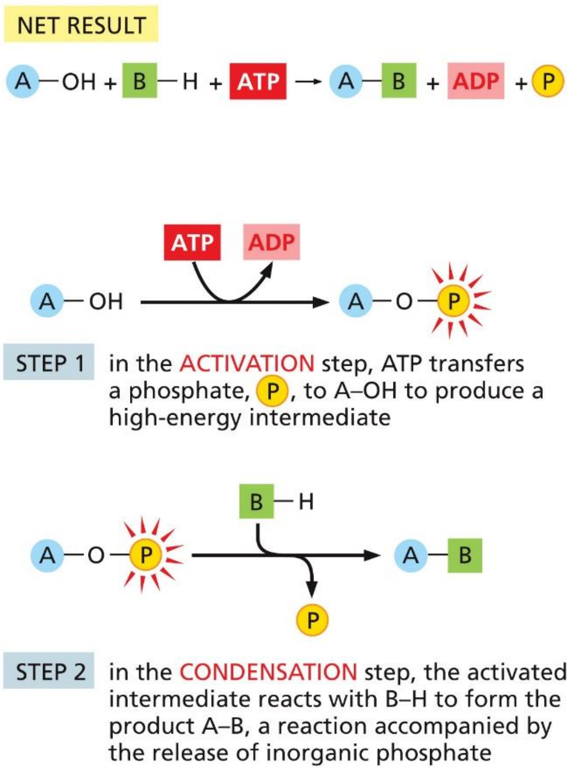
Adenosine triphosphate (ATP) is the most widely used activated carrier

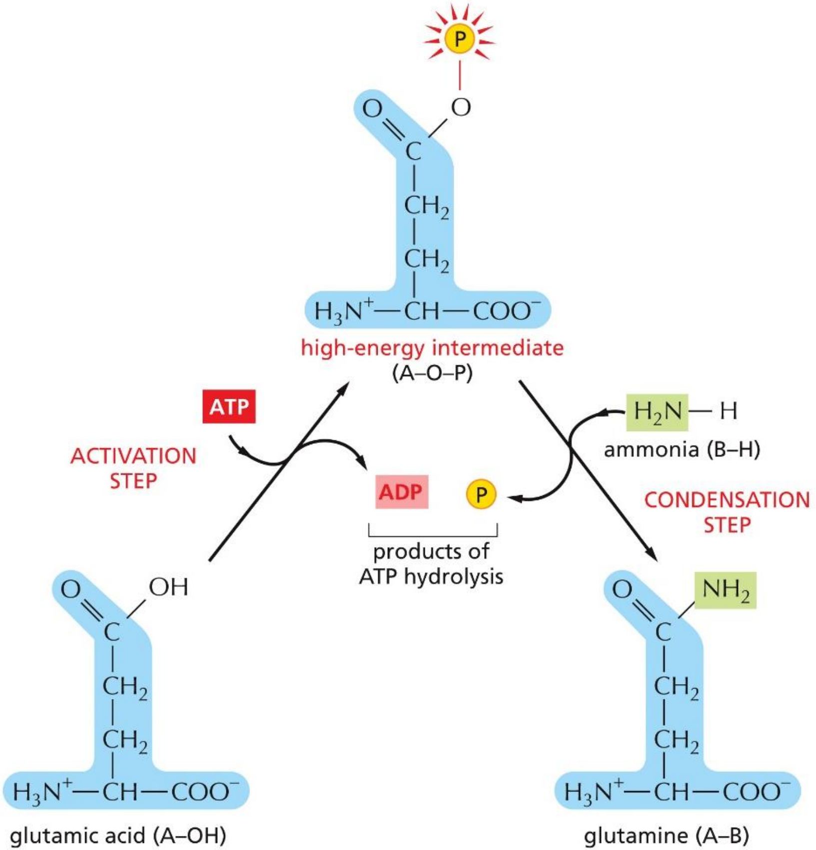


Coupling an energetically favorable reaction can help drive an energetically unfavorable reaction to occur: just combine the respective ΔG's!



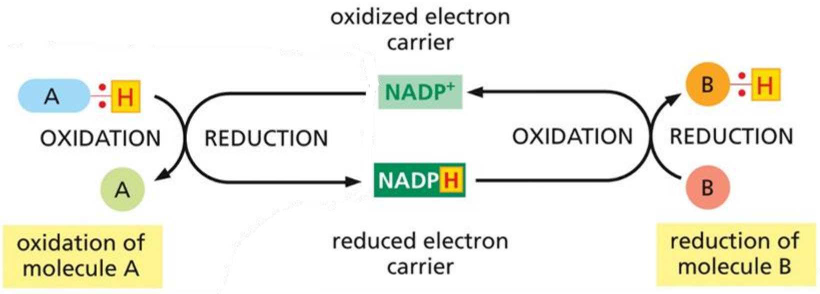
Energy stored in ATP is often harnessed to join two molecules (A and B) together

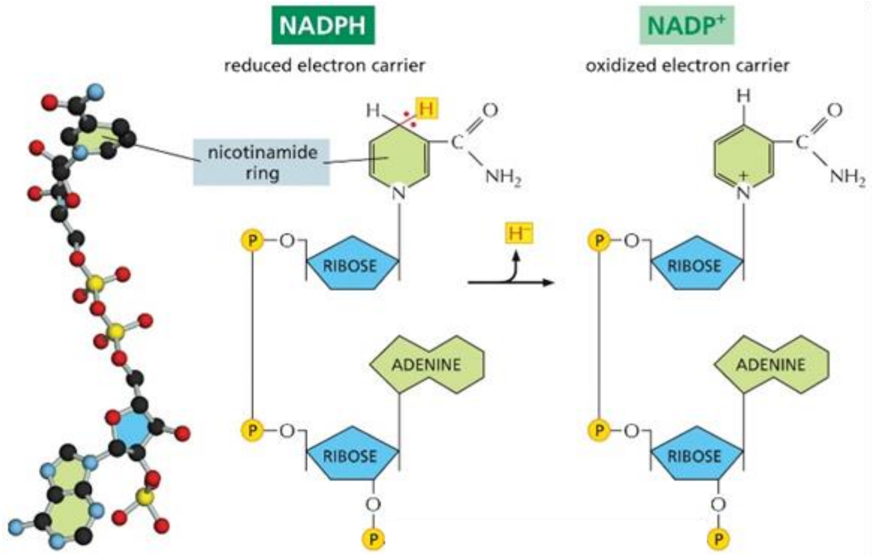




NADPH: an activated carriers of electrons

Recall: OIL RIG





- NADPH donates its high-energy electrons together with a proton (H). *NADP+ is more stable* so this is favorable reaction resulting in *large negative free energy change*
  - Therefore, this can be coupled to unfavorable reactions leading to product formation similarly to ATP

- The utilization of electrons for energy production will be covered in more detail when we learn about cellular respiration and the electron transport chain

SQUARECAP Q#5-6

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Feedback/Reflection

Reminder:
Syllabus Quiz due tonight! Worth 2% of overall grade!

https://forms.gle/vbdZXee89Dh9diY78