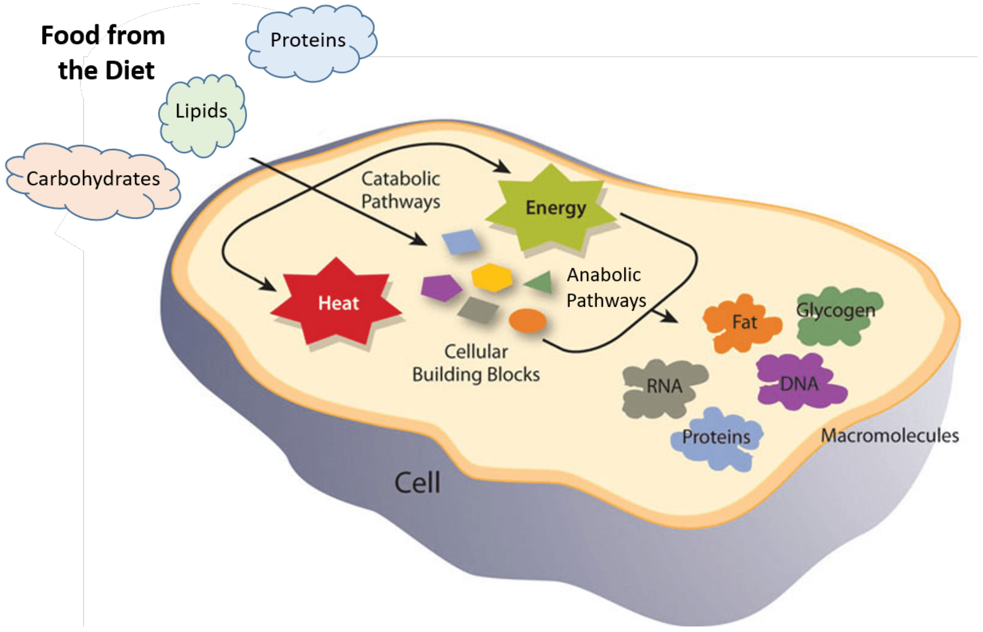
Lesson 5
Cellular Chemistry, Reaction Thermodynamics and Enzymes



Metabolism

- The cell is an ideal continuous chemical reactor
- The ensemble of cellular chemical reactions = **metabolism**
- **Anabolic reactions** = build up molecules (*e.g.*, condensation)

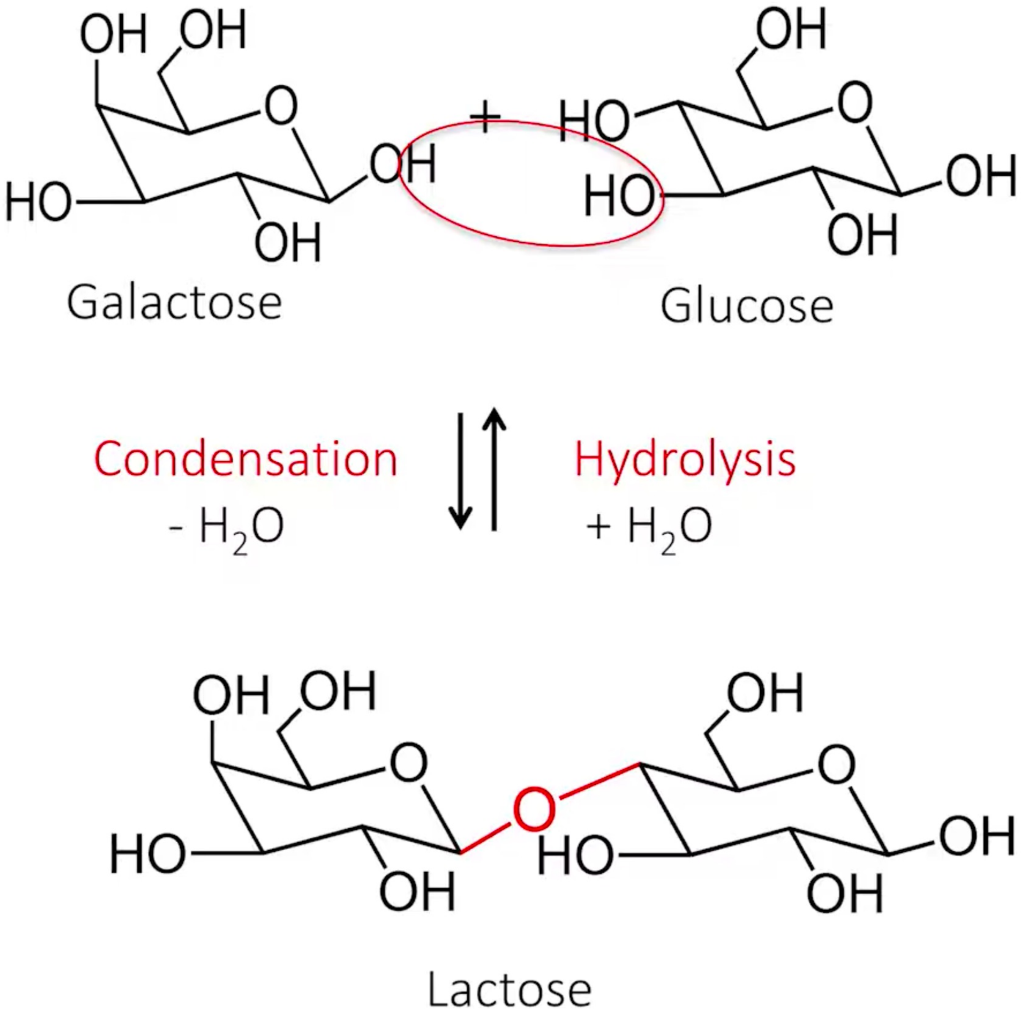
  M-OH + M-OH → M-O-M + H_2O

- **Catabolic reactions** = break down molecules (*e.g.*, hydrolysis)

  M-O-M + H_2O → 2 M-OH

Factory, Maurice Utrillo, 1923

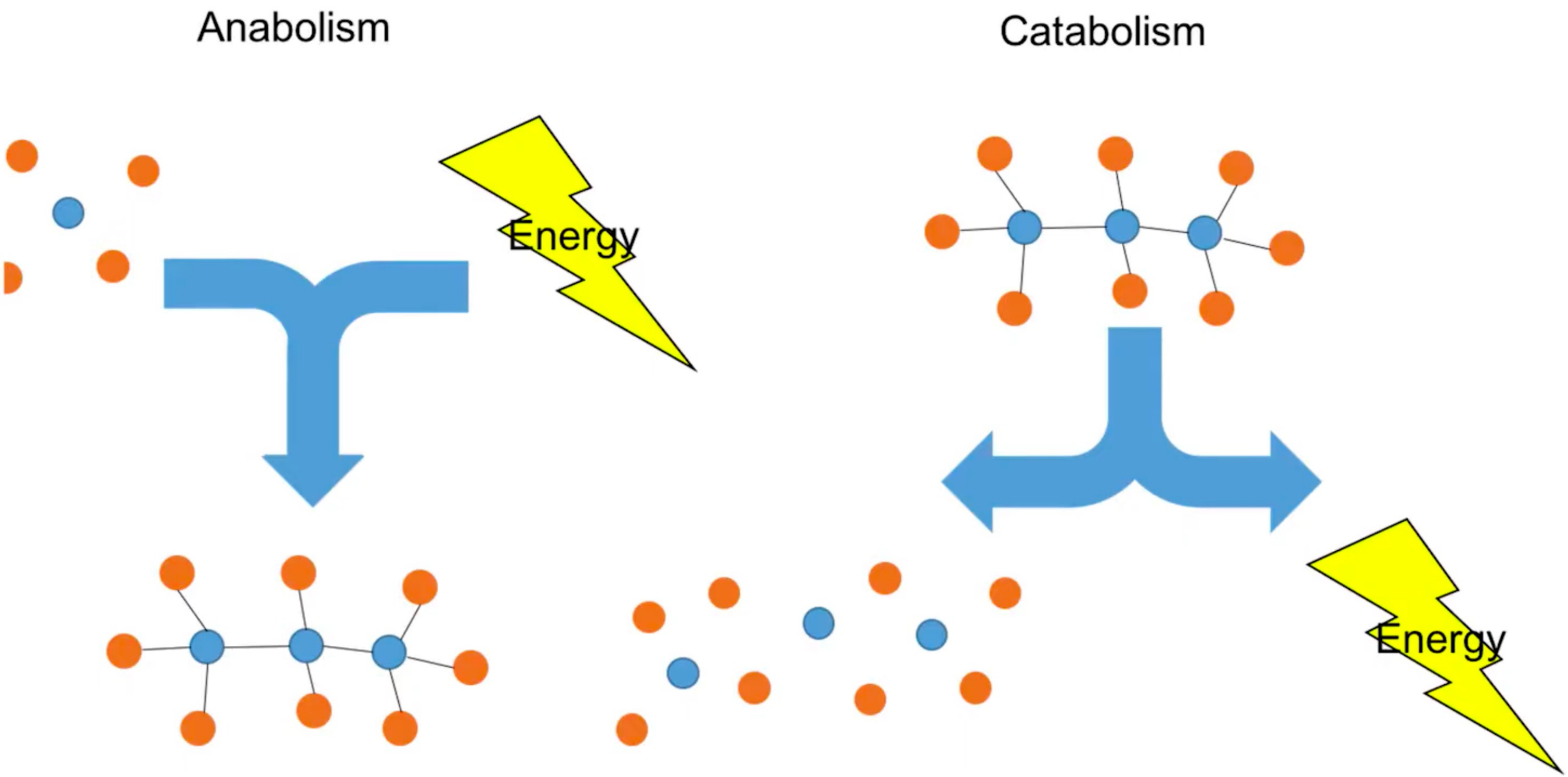
Condensation & hydrolysis



Condensation:
Covalent bonds form with loss of water
Build molecules
Anabolic

Hydrolysis:
Covalent bonds break with addition of water
Break down molecules
Catabolic

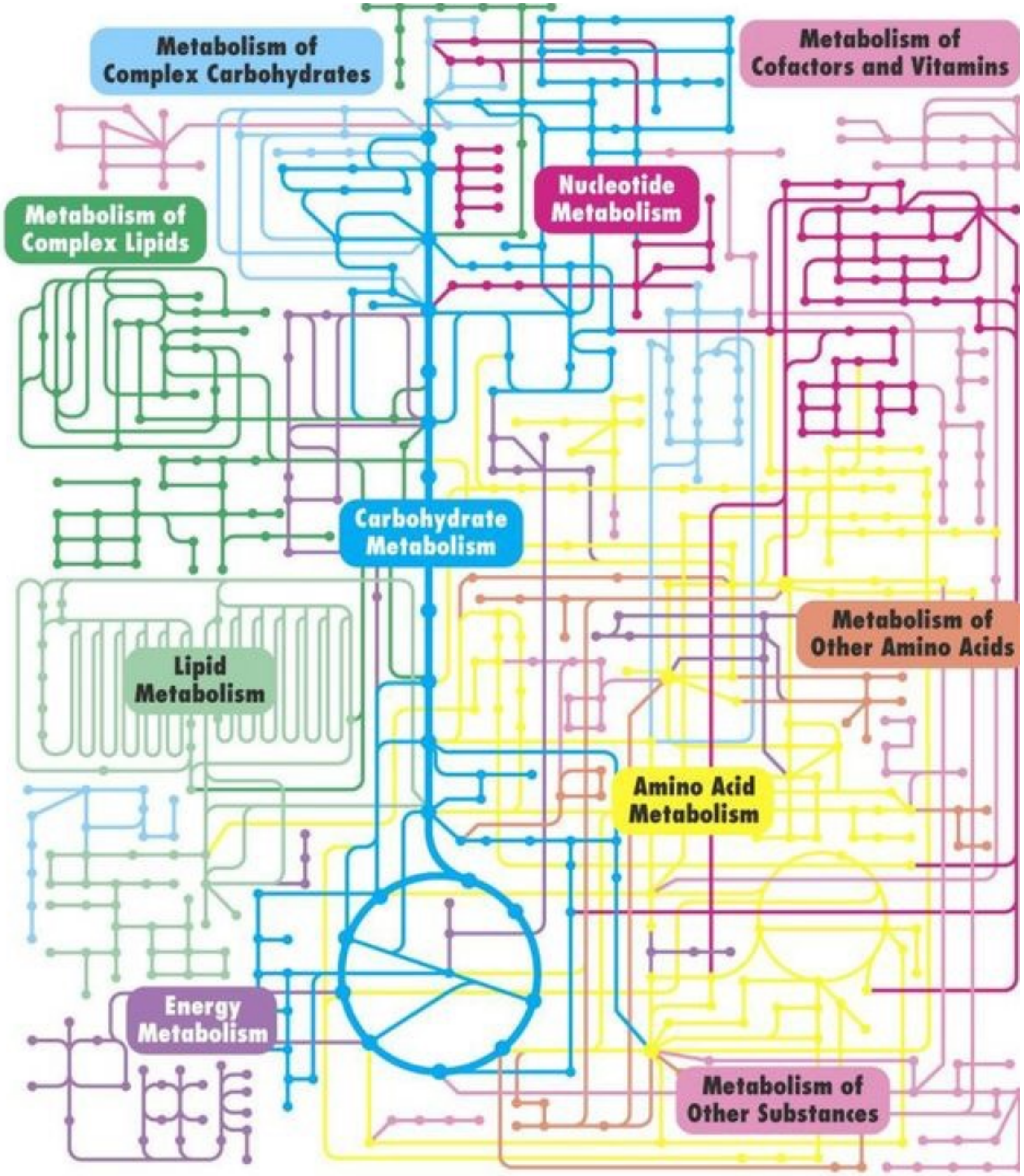
Metabolism & Energy



The metabolic map

Dots = molecules

Lines = chemical reactions making up the metabolism of the cell



Free energy difference

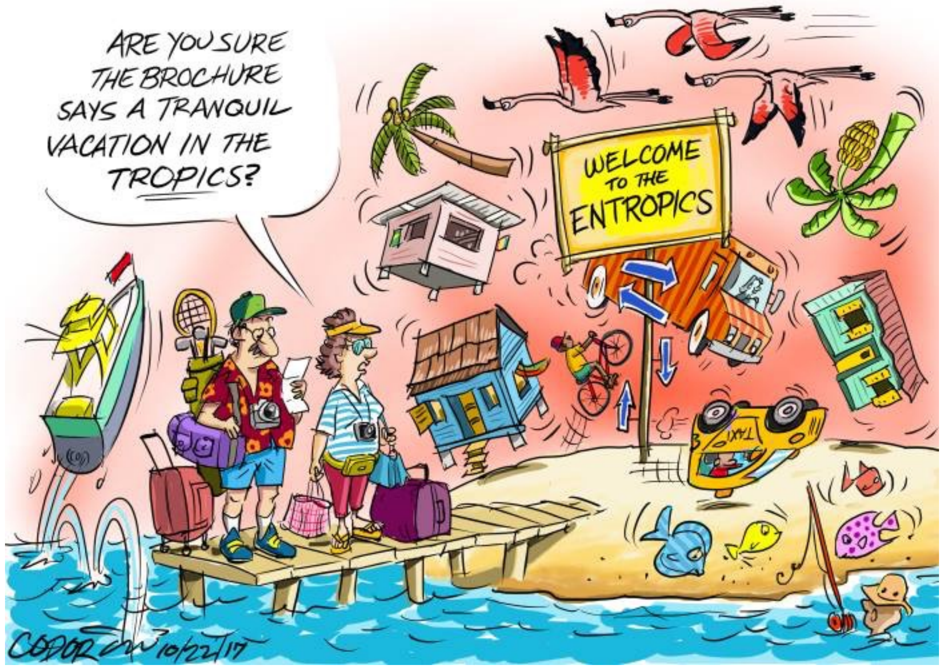
- Reactions are governed by **free energy** (*usable energy*) **G**

  Reagents ⇄ Products

- What really matters is the **free energy difference** $\Delta G = \Sigma G_P - \Sigma G_R$
- ΔG stems from a fundamental law of thermodynamics

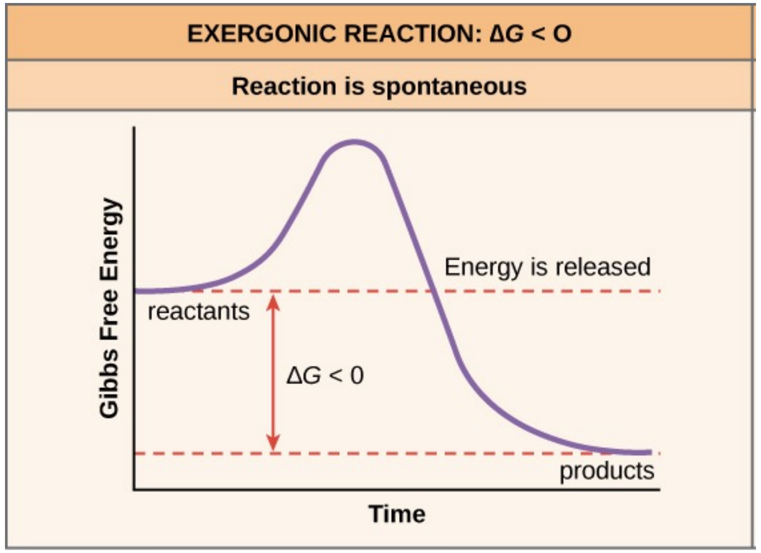
  $$\Delta G = \Delta H - T\Delta S$$

- **H** = **Enthalpy** = *total energy*
- **T** = **Temperature**
- **S** = **Entropy** = *useless energy*



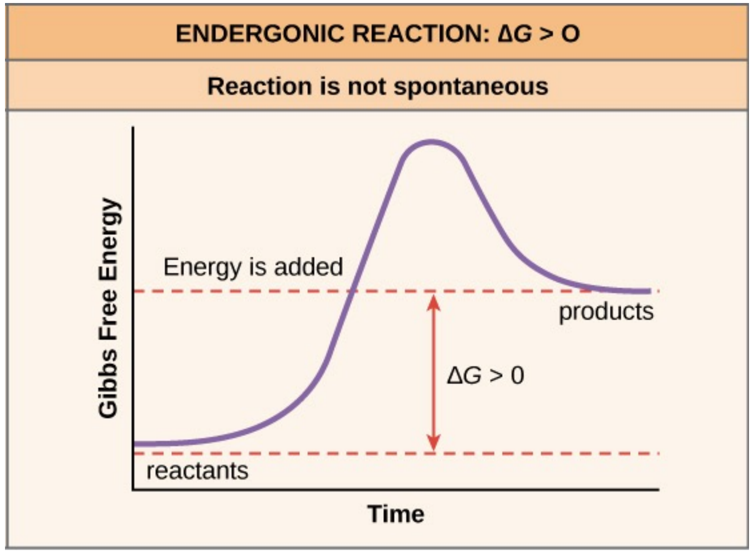
Free energy difference

- $\Delta G < 0$ ($G_P < G_R$) → Energy released, reaction proceeds (thermodynamically spontaneous, exergonic)



Free energy difference

- $\Delta G < 0$ ($G_P < G_R$) → Energy released, reaction proceeds (thermodynamically spontaneous, exergonic)
- $\Delta G > 0$ ($G_P > G_R$) → Reactions requires energy to proceed (thermodynamically non-spontaneous, endergonic)



Free energy difference

- $\Delta G < 0$ ($G_P < G_R$) → Energy released, reaction proceeds (thermodynamically spontaneous, exergonic)
- $\Delta G > 0$ ($G_P > G_R$) → Reactions requires energy to proceed (thermodynamically non-spontaneous, endergonic)
- $\Delta G = 0$ ($G_P = G_R$) → Chemical equilibrium (R→P = P→R)

$$A \leftrightarrow B$$

$$K_{eq} = [B]/[A]$$

$$\Delta G = -RT \ln [B]/[A]$$

⇩

$$\Delta G = -RT \ln K_{eq}$$

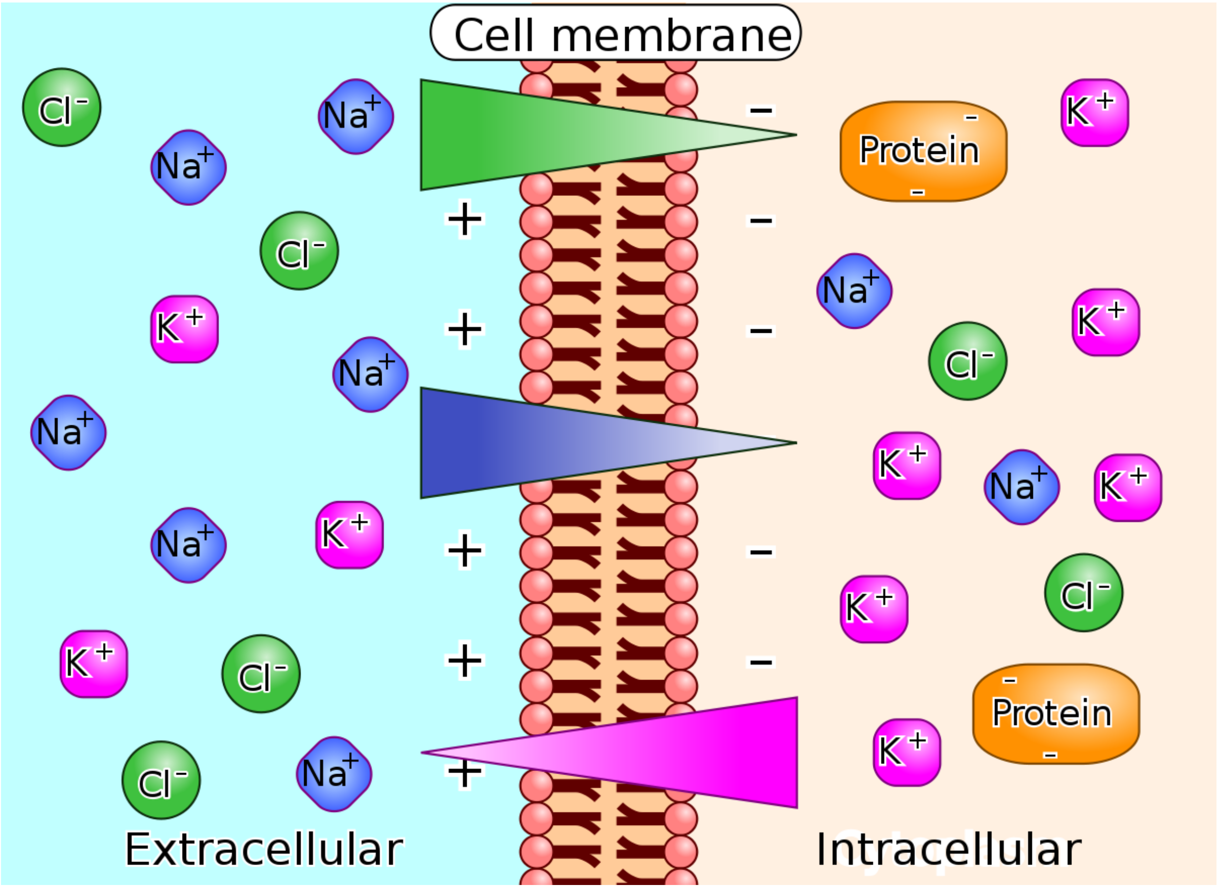
R= 8.314 J/(mol K) = 1.987 cal/(mol K)

Going to work in the cell factory

- Cells transfer energy from food molecules to run their processes
  - Synthesis
    - Complex molecules (DNA, proteins)
    - Organized structures (organelles)
  - Organization
    - Generation of specialized compartments to store and organize materials for specific tasks

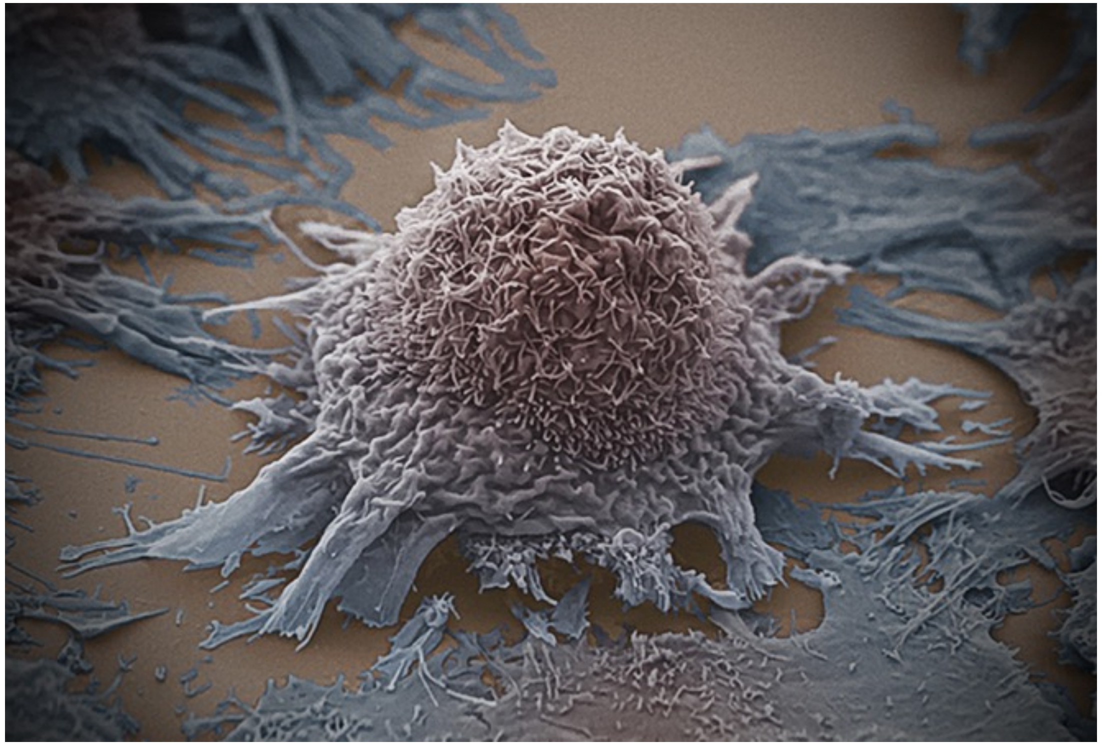
Going to work in the cell factory

- Cells transfer energy from food molecules to run their processes
    - Synthesis
        - Complex molecules (DNA, proteins)
        - Organized structures (organelles)
    - Organization
        - Generation of specialized compartments to store and organize materials for specific tasks
    - Creation of electrochemical gradients
        - Cells organize ions on either cell membrane sides to create electrochemical potentials
            - Mechanism that controls signaling and transfer of materials across the membranes



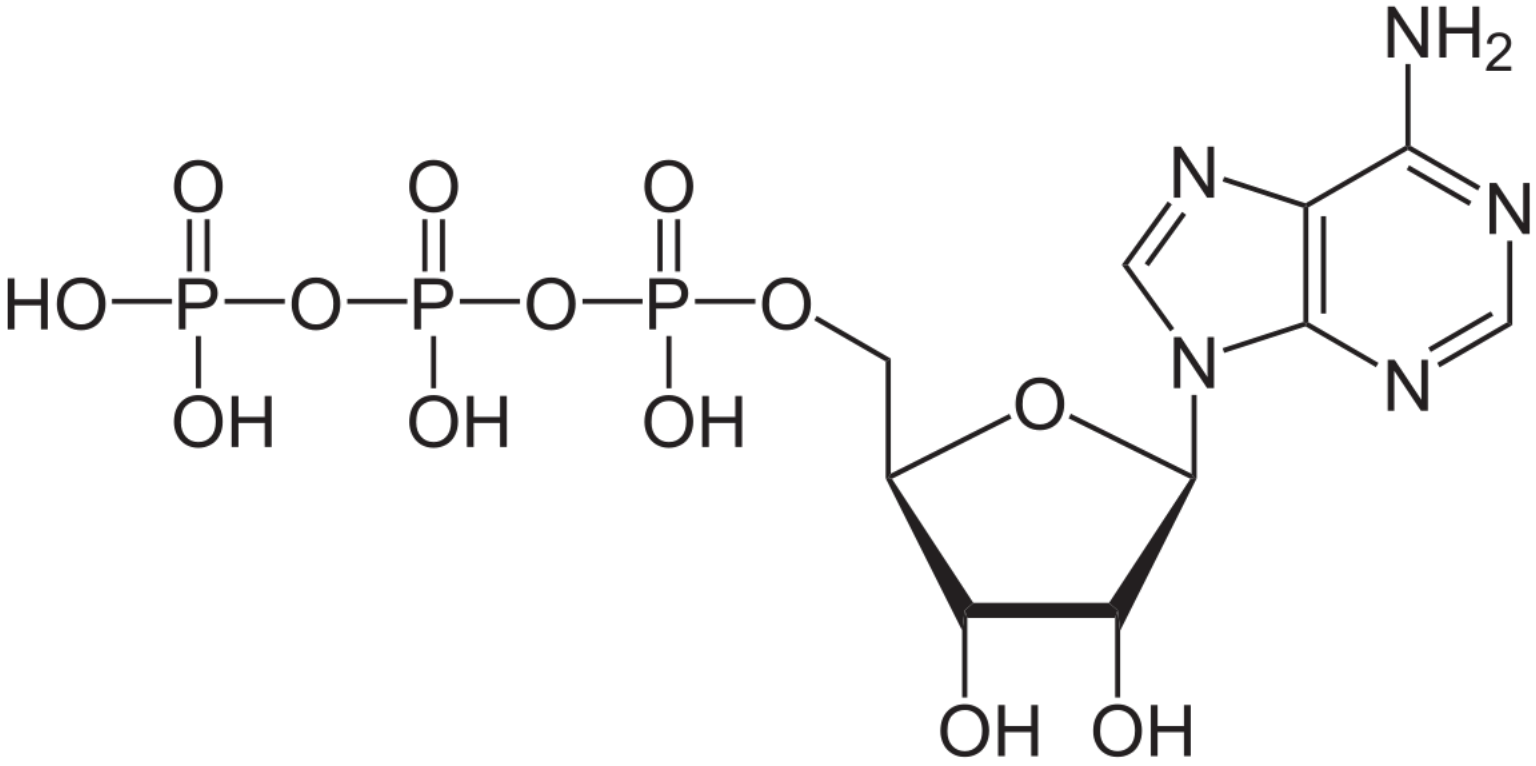
Going to work in the cell factory

- Cells transfer energy from food molecules to run their processes
  - Synthesis
    - Complex molecules (DNA, proteins)
    - Organized structures (organelles)
  - Organization
    - Generation of specialized compartments to store and organize materials for specific tasks
  - Creation of electrochemical gradients
    - Cells organize ions on either cell membrane sides to create electrochemical potentials
      - Mechanism that controls signaling and transfer of materials across the membranes
  - Transport and movement
    - Cells transport molecules from one side of the cell to another
    - Some cells swim or crawl using special motility proteins



Where does cell energy really come from?

- Cells do not use the energy from food directly
- Adenosine triphosphate, the energy middleman

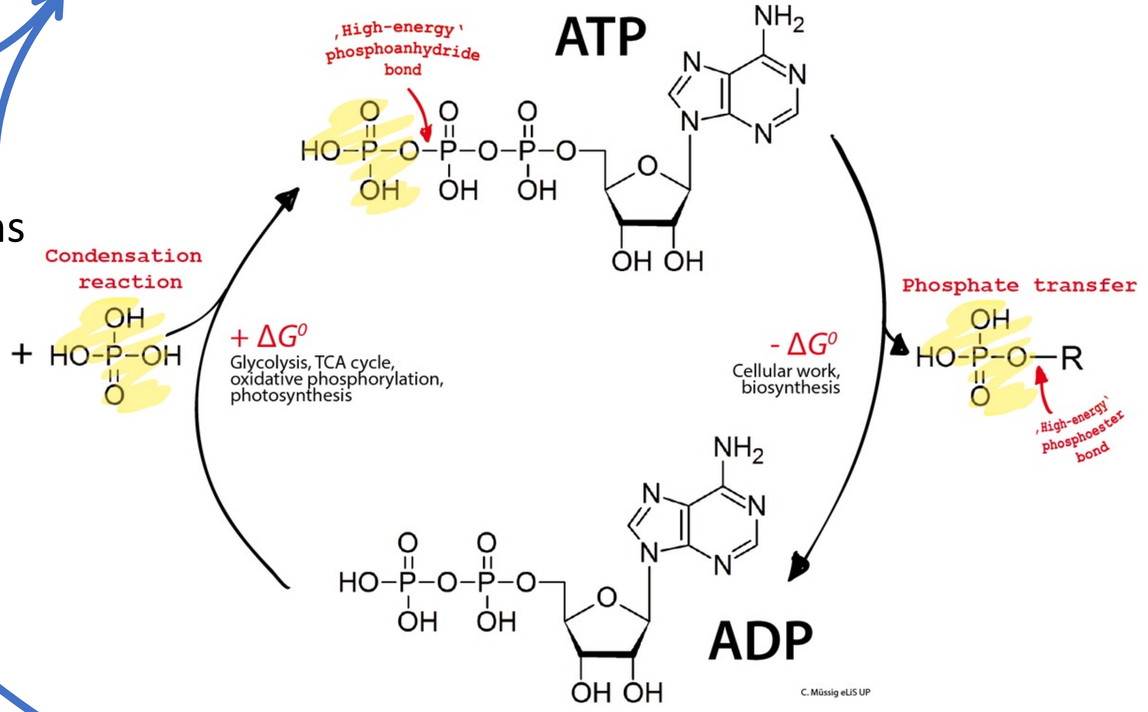


The ATP/ADP cycle

Simple molecules
glucose, amino acids, fatty acids

Energy absorbed

Catabolism – Exergonic reactions transfer energy from complex molecules to ATP



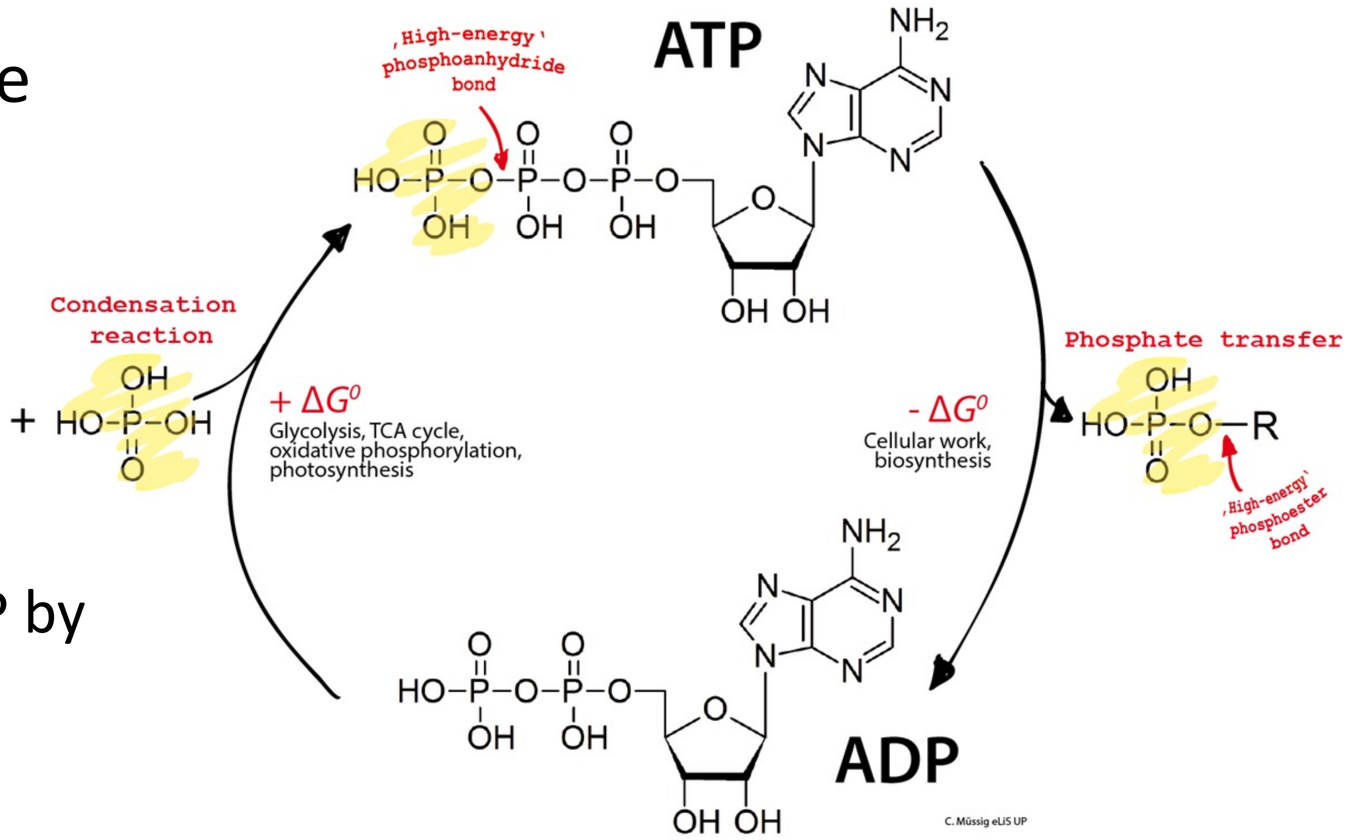
Anabolism – Endergonic reactions transfer energy from ATP to complex molecules

Energy released (for cell)

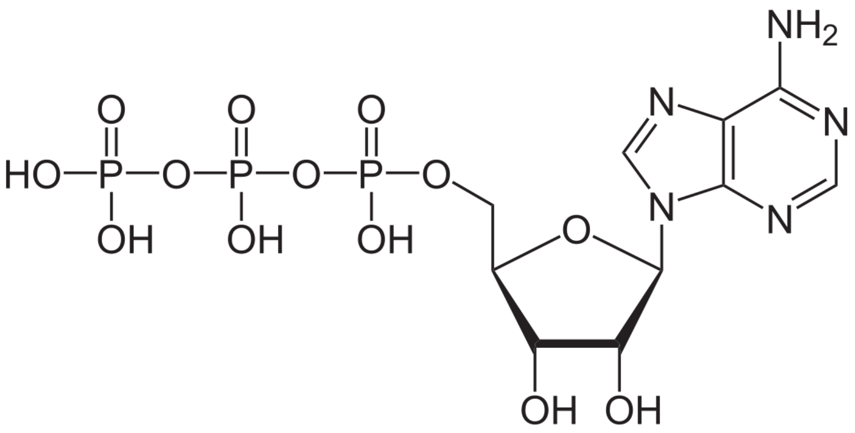
Complex molecules
polycarbs, proteins, lipids

The ATP/ADP cycle – energy coupling

- Cells make and break ATP all the time
- In endergonic reactions
  - Energy is provided by ATP hydrolysis to ADP and P_i
- In exergonic reactions
  - Energy is captured to restore ATP by ADP and P_i condensation



As easy as 1,2,3 – ATP, ADP and AMP

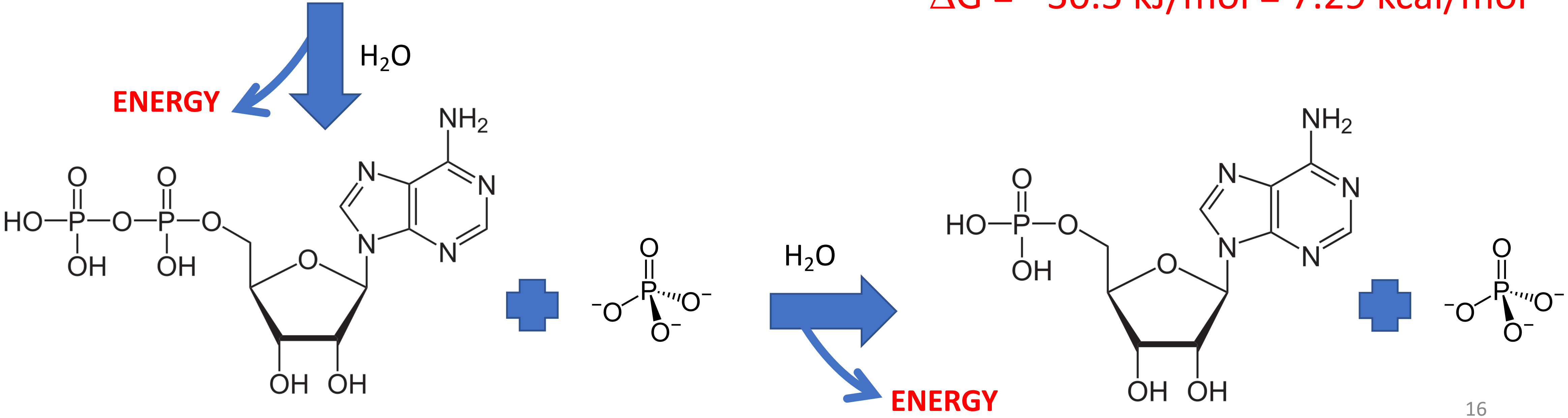


ATP → ADP + P_i

ΔG = - 30.5 kJ/mol = 7.29 kcal/mol

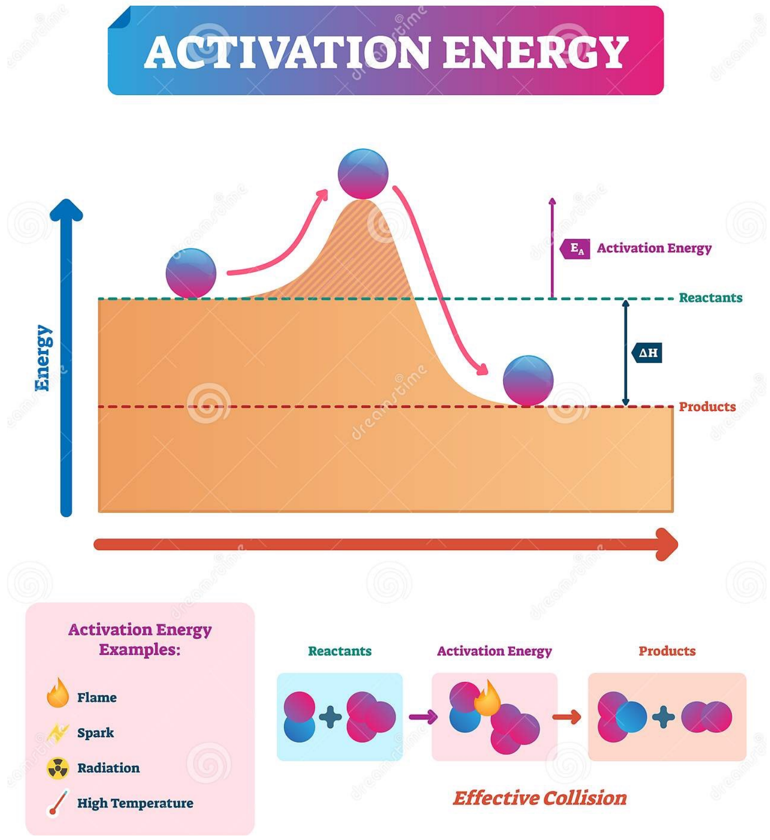
ADP → AMP + P_i

ΔG = - 30.5 kJ/mol = 7.29 kcal/mol



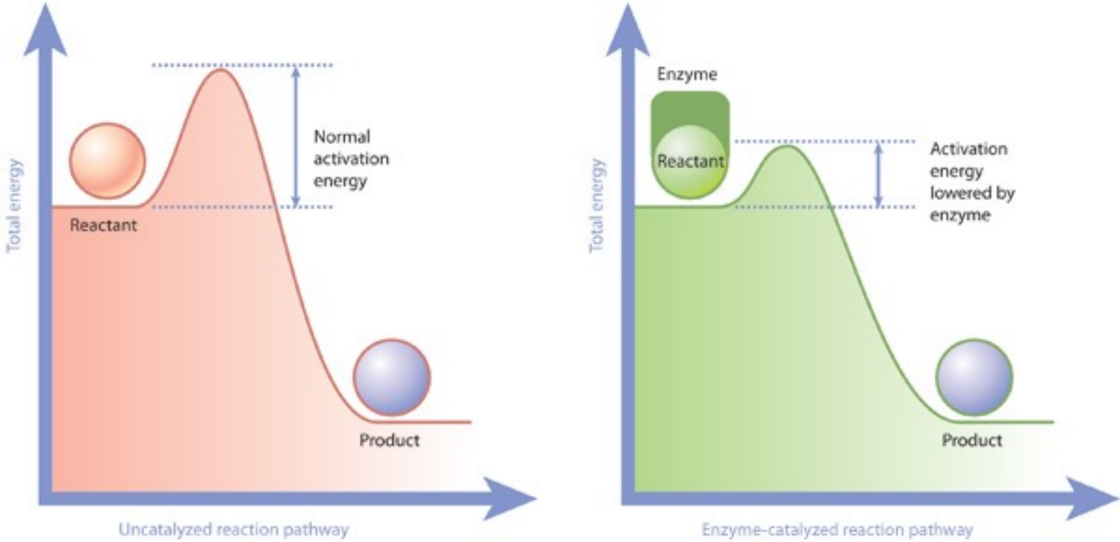
Free energy difference

- Even if a reaction is thermodynamically spontaneous ($\Delta G < 0$), it may not occur
  - It needs an "energetical push"
- **Activation energy E_a = energy barrier**



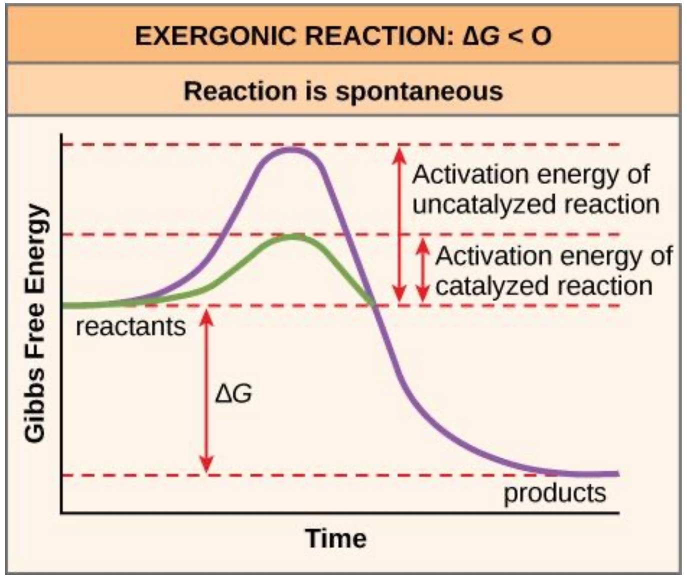
Enzymes

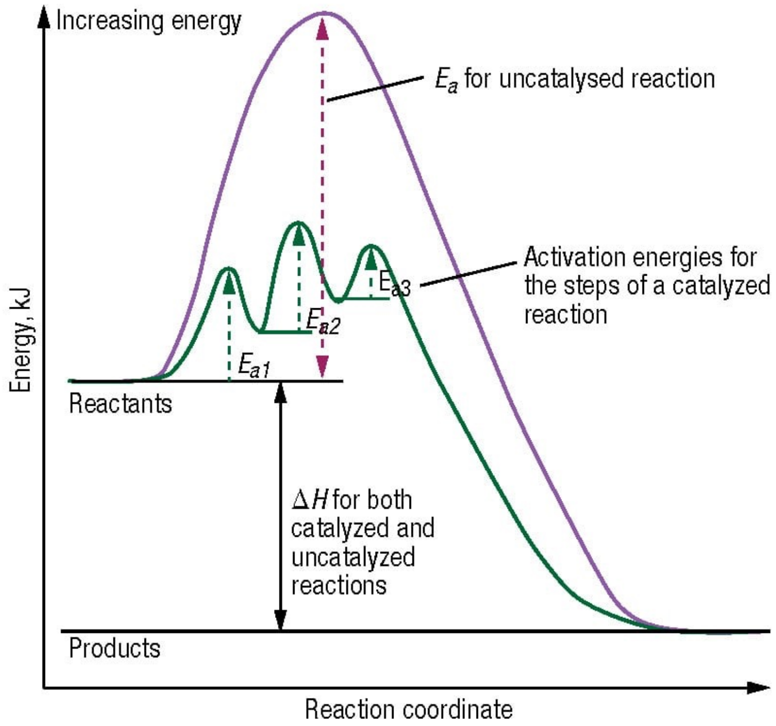
- Even if a reaction is thermodynamically spontaneous ($\Delta G < 0$), it may not occur
  - It needs an "energetical push"
- **Activation energy E_a = energy barrier**
- **Catalysts** = particular class of chemical substances that lower E_a and promote reactions
- **Enzymes** = biological catalysts (mostly proteins)



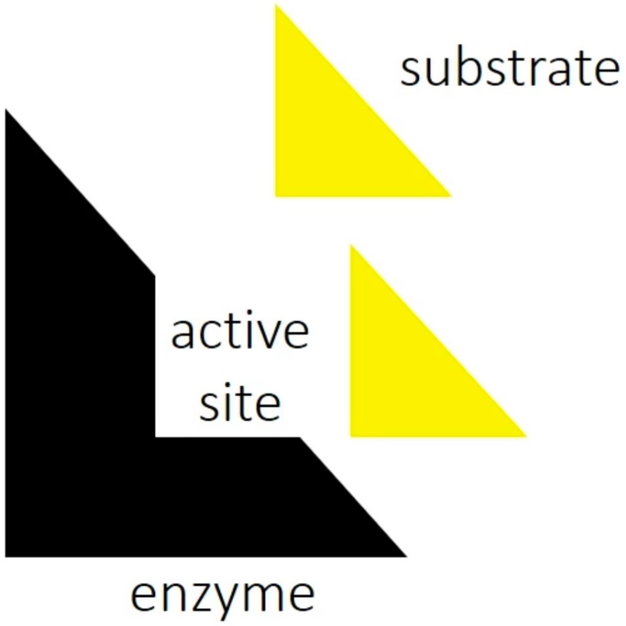
Enzymes

- There are approximately 1300 different enzymes found in the human cell
- Each enzyme catalyzes a specific chemical reaction
- **ENZYMES DO NOT CHANGE THE ΔG OF A REACTION BUT JUST SPEED UP THE REACTION RATE**
  - By breaking down the reaction into different steps, each of which has a low E_a



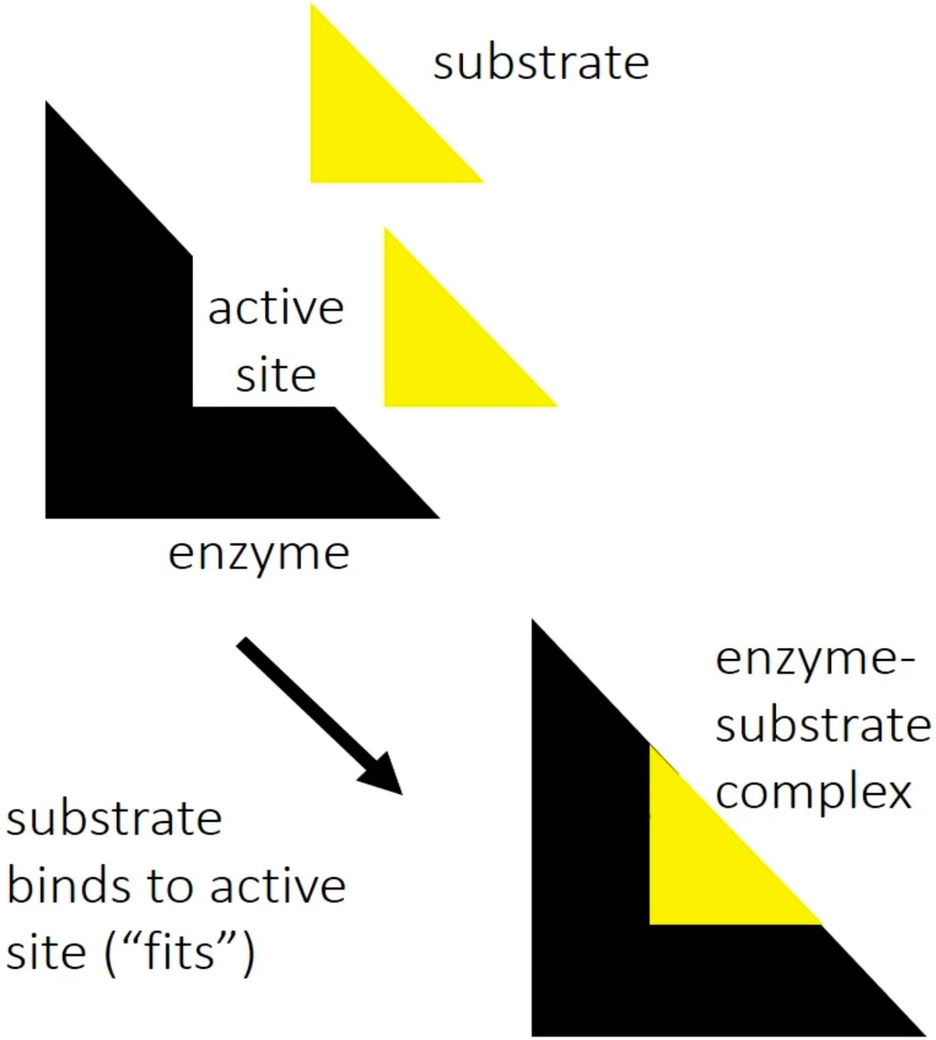


Enzymes



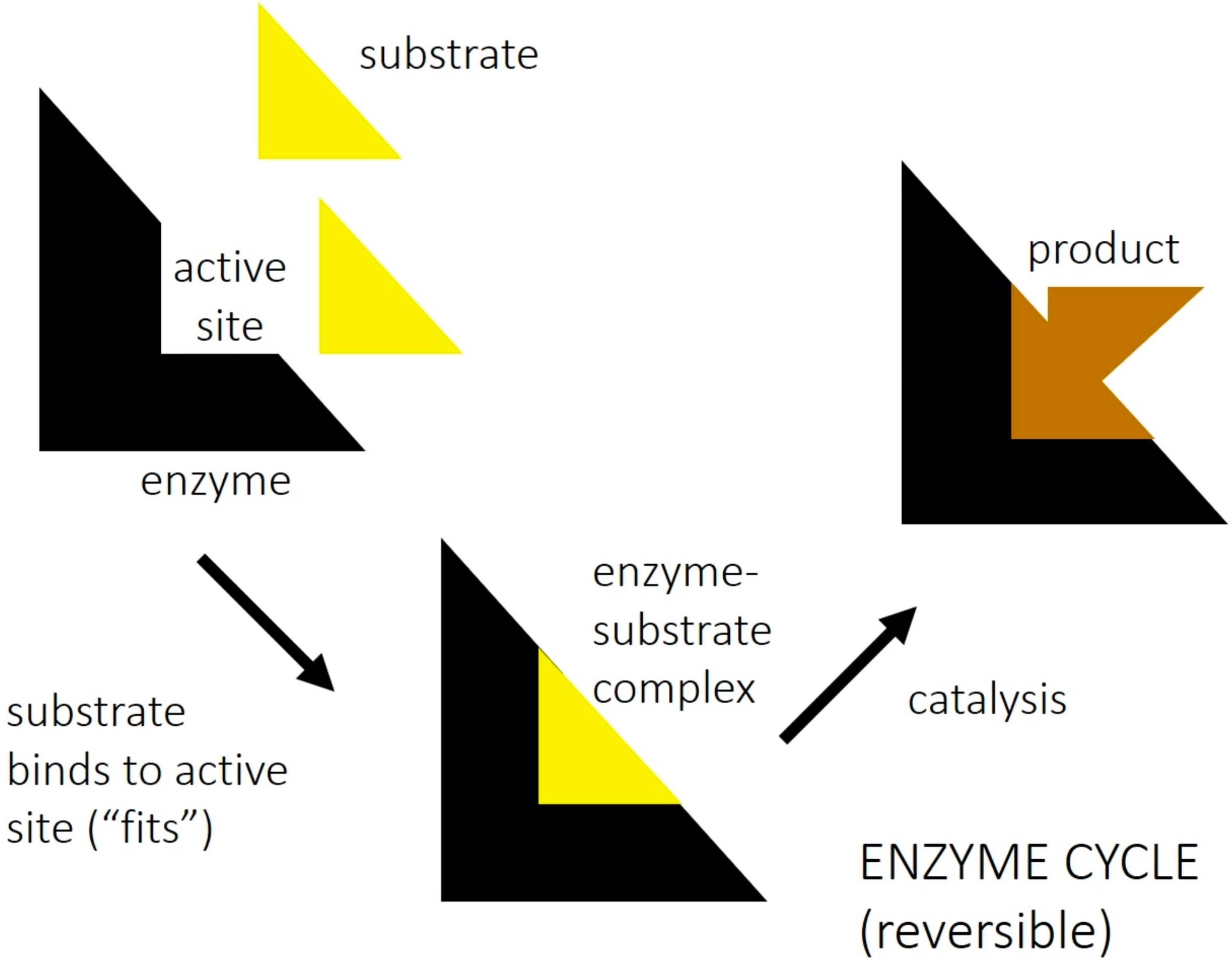
ENZYME CYCLE
(reversible)

Enzymes



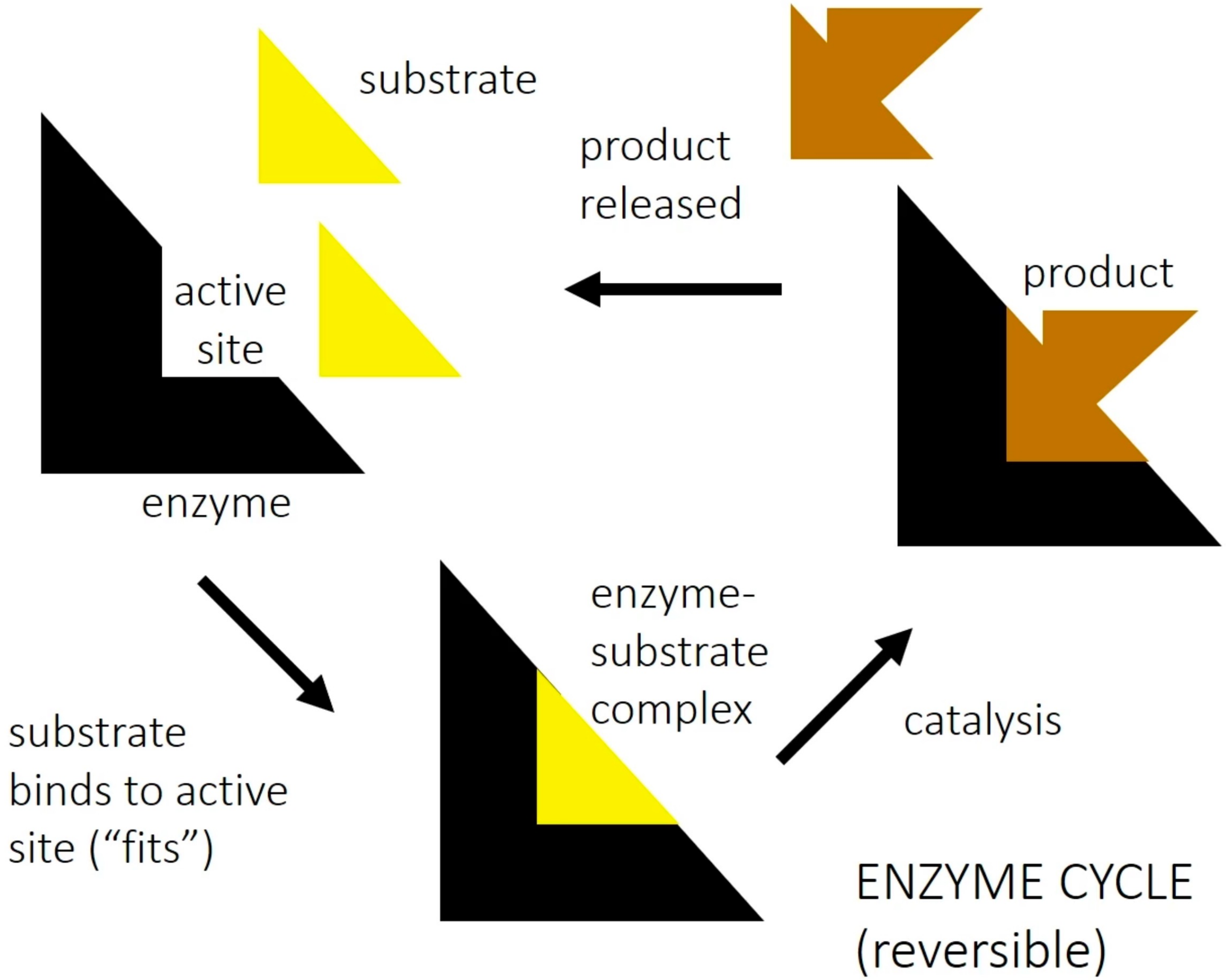
ENZYME CYCLE
(reversible)

Enzymes



substrate
active
site
enzyme
substrate
binds to active
site (“fits”)
enzyme-
substrate
complex
catalysis
product
ENZYME CYCLE
(reversible)

Enzymes

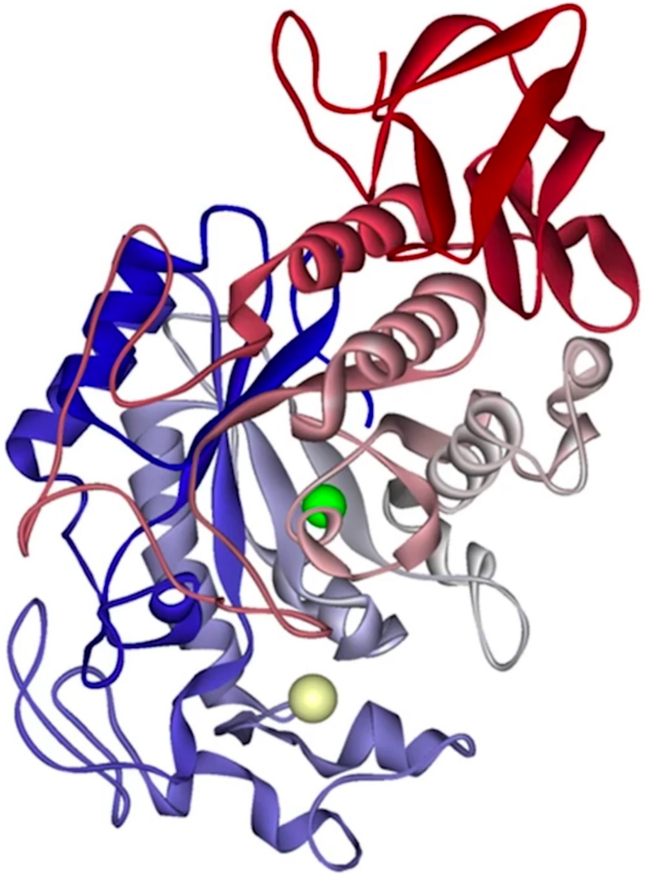

substrate
product
released
active
site
enzyme
product
enzyme-
substrate
complex
substrate
binds to active
site ("fits")
catalysis
ENZYME CYCLE
(reversible)

Enzyme specificity

Cellulose and starch
are both glucose polymers

Cellulase
breaks β-1,4 bonds in cellulose
People do not have this enzyme
so we cannot digest grass!

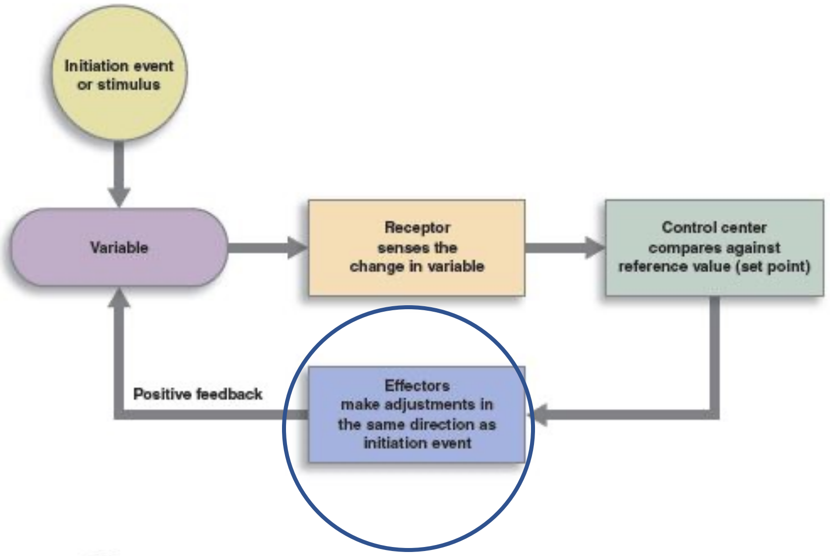
Amylase
breaks α-1,4 bonds in starch
People have this enzyme!

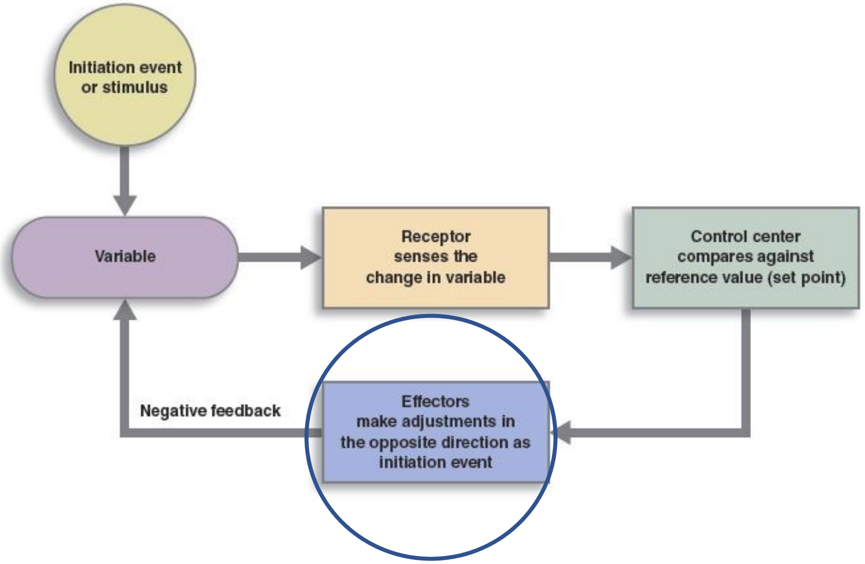


ENZYME SPECIFICITY

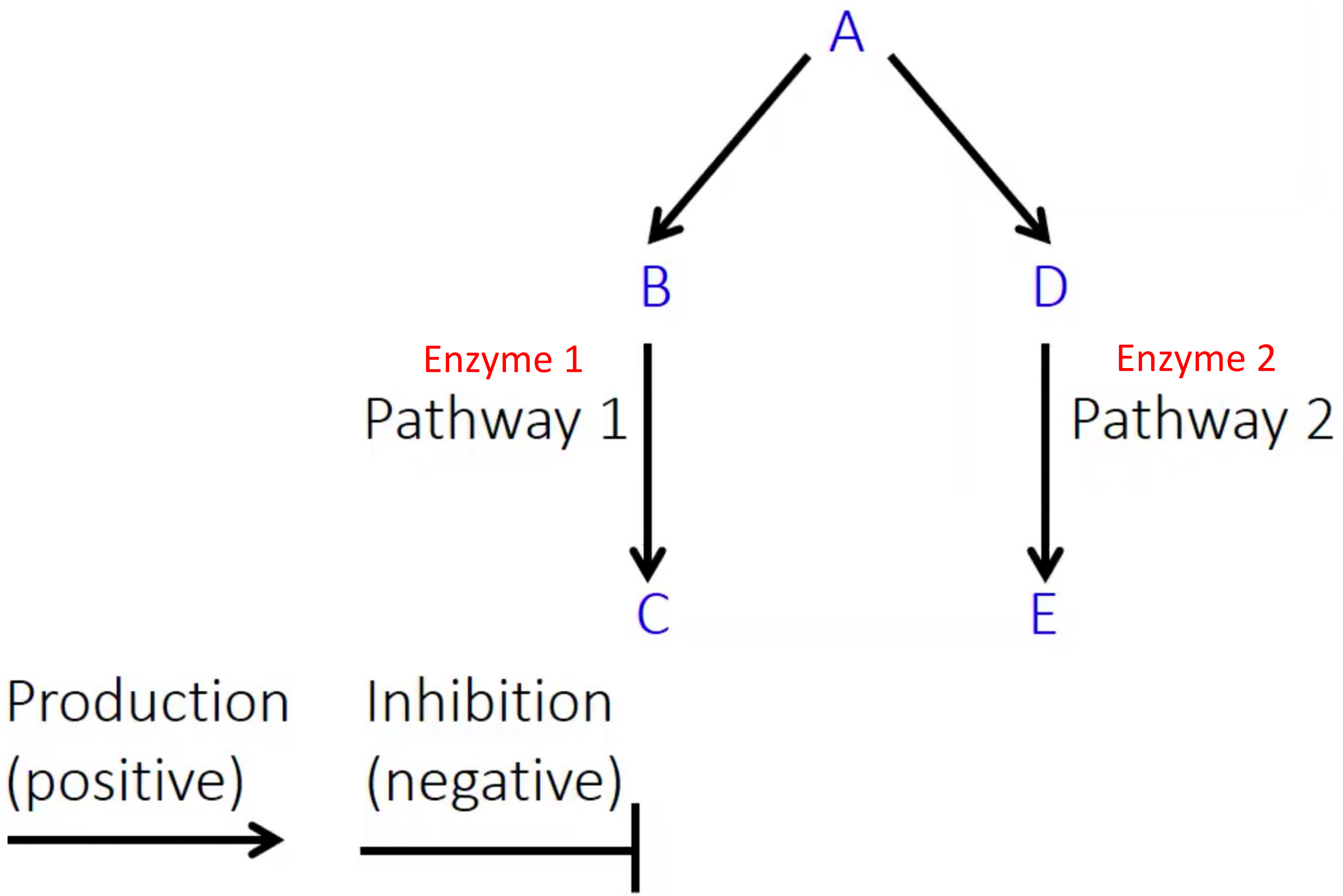
Metabolic pathways

- Cellular chemical reactions all catalyzed by enzymes
- Cellular chemical reactions are often linked into **pathways**
  - Ordered sequence of chemical reactions
- Pathways = the "cell production line"
  - Starting from point A → land up with a particular product that the cell really needs
- Reactions are organized into multistep pathways
- Cellular pathways are governed by internal feedback mechanisms
  - **Positive feedback** = make more product(s) along that particular pathway
  - **Negative feedback** = make less and/or stop producing product(s) along that particular pathways
- Cellular pathways can also be mastered by external control signals



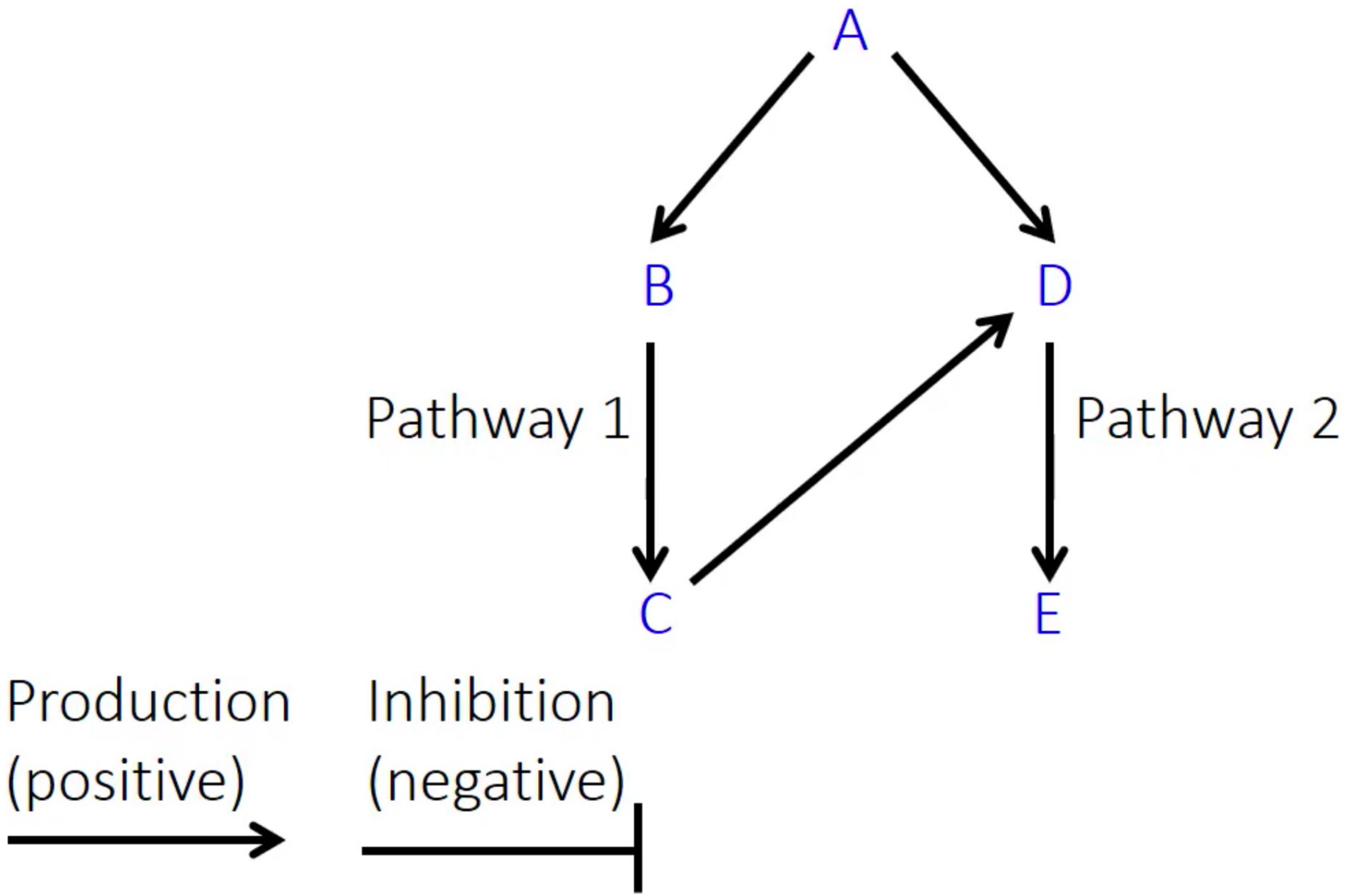


Pathways and feedback loops



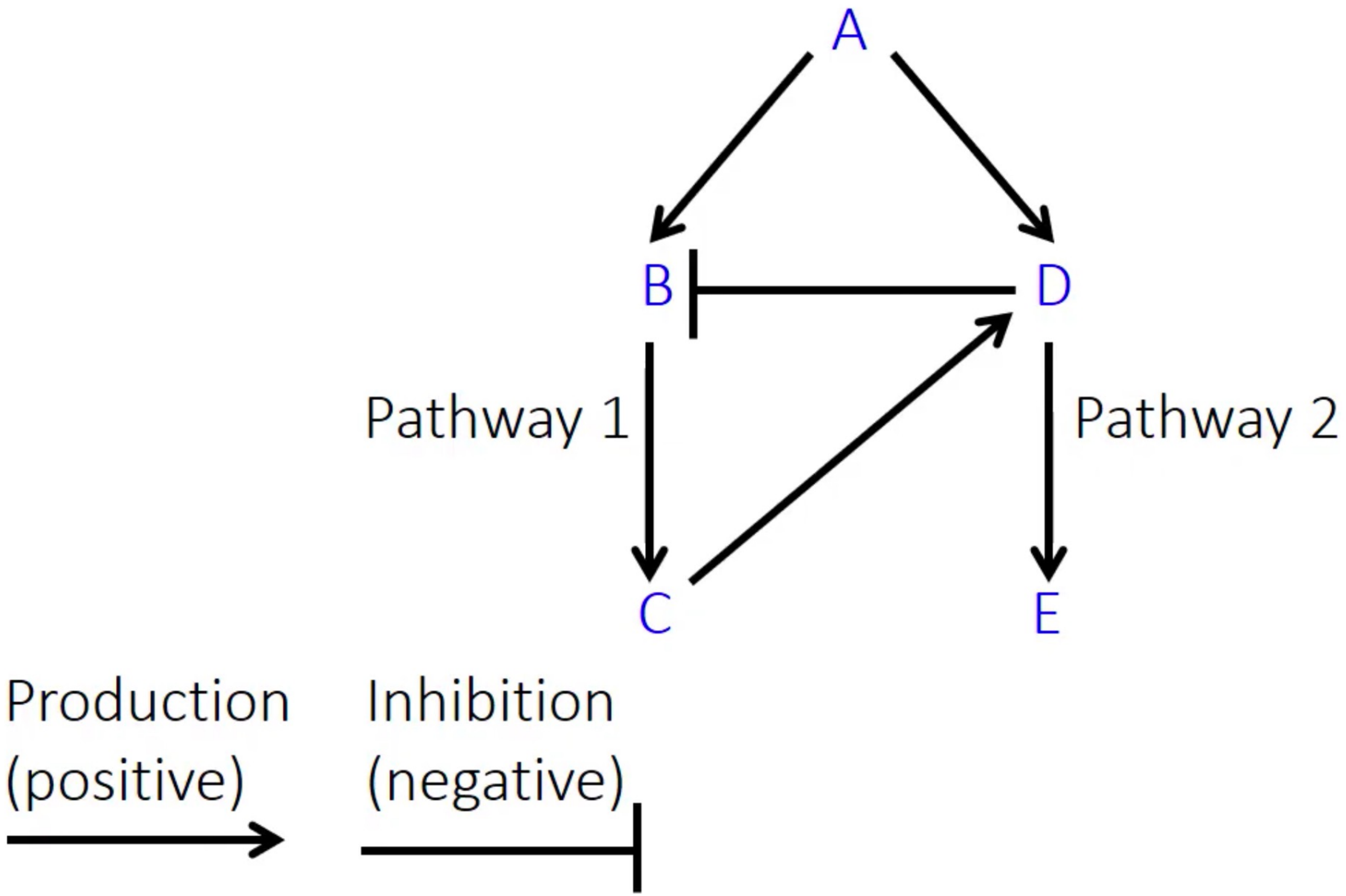
Positive feedback example

- Problem 1: when the cell gets a lot of product C it also needs a lot of product E
- Solution:
    - C (whatever the molecule is) speeds up the production of D
    - Increased D levels will increase the production of E



Negative feedback example

- Problem: the cell has enough D and now wants to produce E only by pathway 2
- Solution:
  - it turns off pathway 1
    - D inhibits production of B and hence of C
    - D is no longer produced via C
    - E is only produced via pathway 2



Real cellular pathway example

Phenylalanine metabolism and pathways
Every arrow = one or more enzymes!