Big Idea 2: Biological systems utilize free energy and molecular building blocks to grow, to reproduce and to maintain dynamic homeostasis.

Enduring understanding 2.A: Growth, reproduction and maintenance of the organization of living systems require free energy and matter.

Essential knowledge 2.A.1: All living systems require constant input of free energy.

a. Life requires a highly ordered system.

Evidence of student learning is a demonstrated understanding of each of the following:

1. Order is maintained by constant free energy input into the system.
2. Loss of order or free energy flow results in death.
3. Increased disorder and entropy are offset by biological processes that maintain or increase order.

* Order

Cells are the smallest collection of matter that are alive.

- Subatomic particles
  ↓
- Atoms
  ↓
- Molecules
  ↓
- Organelles
  ↓
- CELLS

NOT ALIVE

LIVING

LIFE ITSELF IS AN EMERGENT PROPERTY, WHERE THE SUM IS GREATER THAN ITS PARTS

Biological Order and Disorder

- **Cells** create ordered structures from less organized starting materials.
- **Organisms** are complex ordered structures from less organized starting material
  - Fibonacci Numbers
- **Complex organisms evolved from simpler organisms.** This does in any way violate the second law of thermodynamics. The entropy of a system can decrease as long as the entropy of its surroundings increase.

Organisms are islands of low entropy
in an sea of increasing entropy.

- Organs
  ↓
- Organ Systems
  ↓
- Organisms
  ↓
- Populations
  ↓
- Communities
  ↓
- Ecosystems
  ↓
- Biosphere }

APPROX. A 12 MILE "BUBBLE" AROUND EARTH WHERE LIFE CAN BE FOUND

Essential knowledge 2.A.1: All living systems require constant input of free energy.

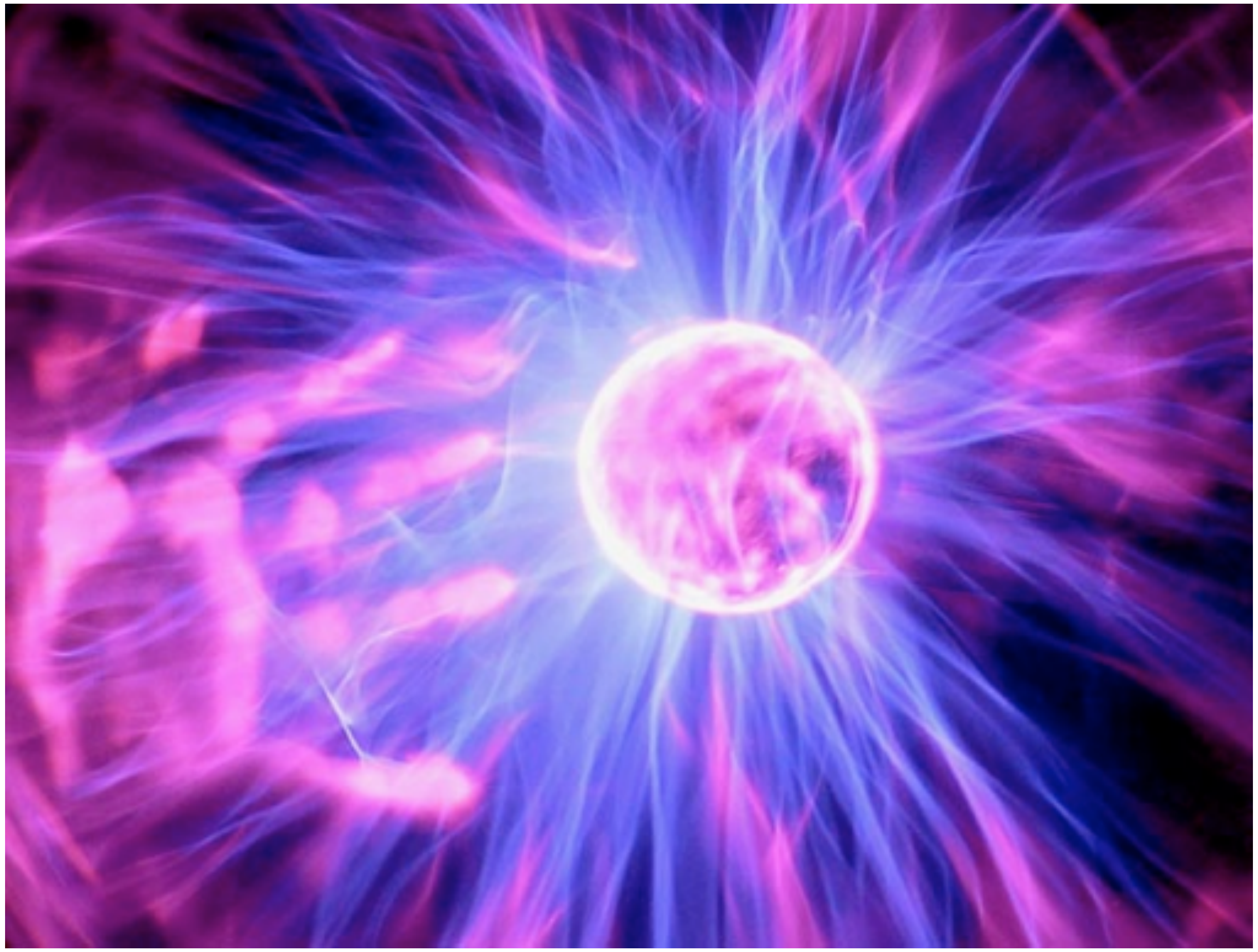
b. Living systems do not violate the second law of thermodynamics, which states that entropy increases over time.

Evidence of student learning is a demonstrated understanding of each of the following:

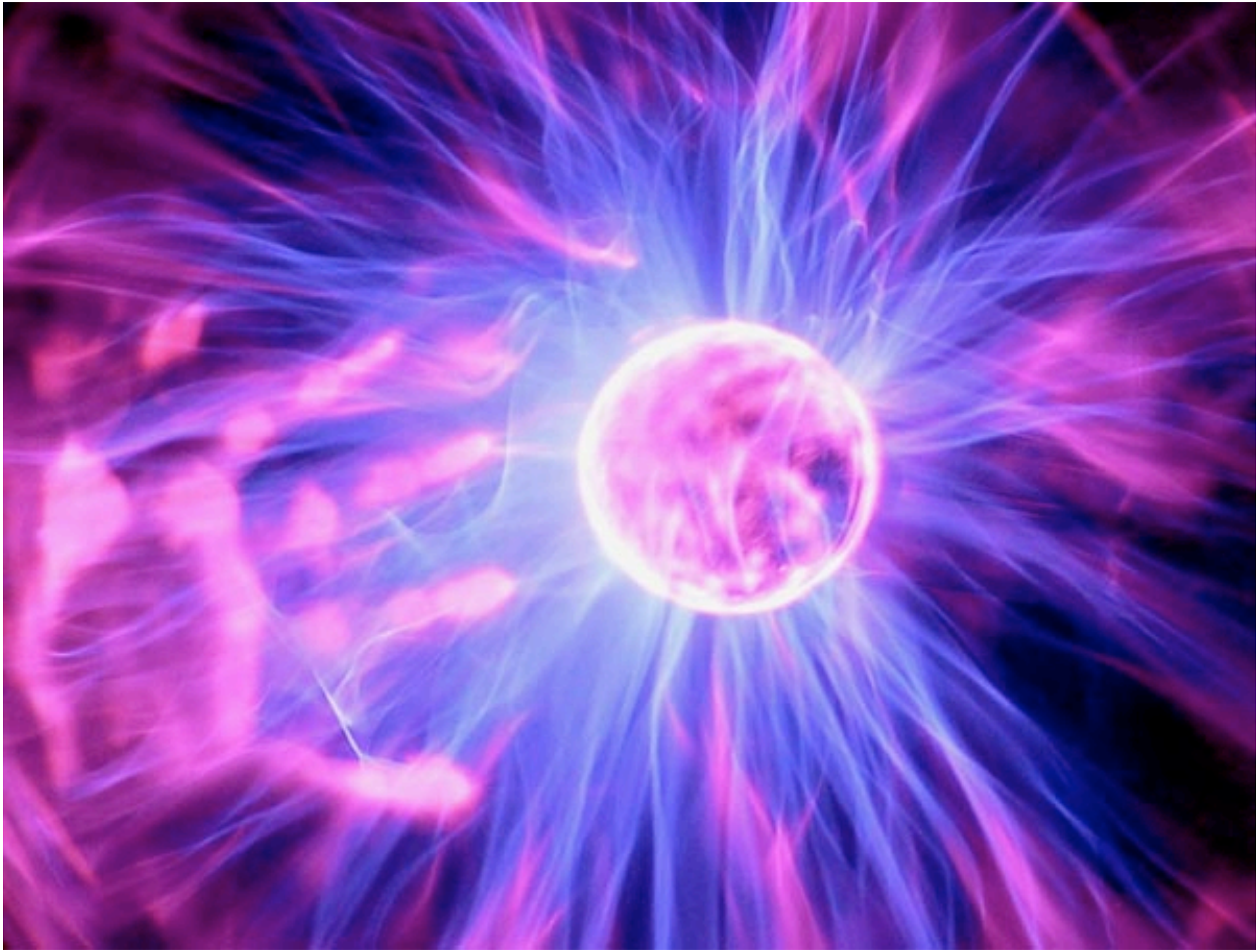
1. Order is maintained by coupling cellular processes that increase entropy (and so have negative changes in free energy) with those that decrease entropy (and so have positive changes in free energy).
2. Energy input must exceed free energy lost to entropy to maintain order and power cellular processes.
3. Energetically favorable exergonic reactions, such as, that have a negative change in free energy can be used to maintain or increase order in a system by being coupled with reactions that have a positive free energy change.

Intro to Metabolism

Main Idea: Metabolism, the collection of all cellular reactions, transforms matter and energy.



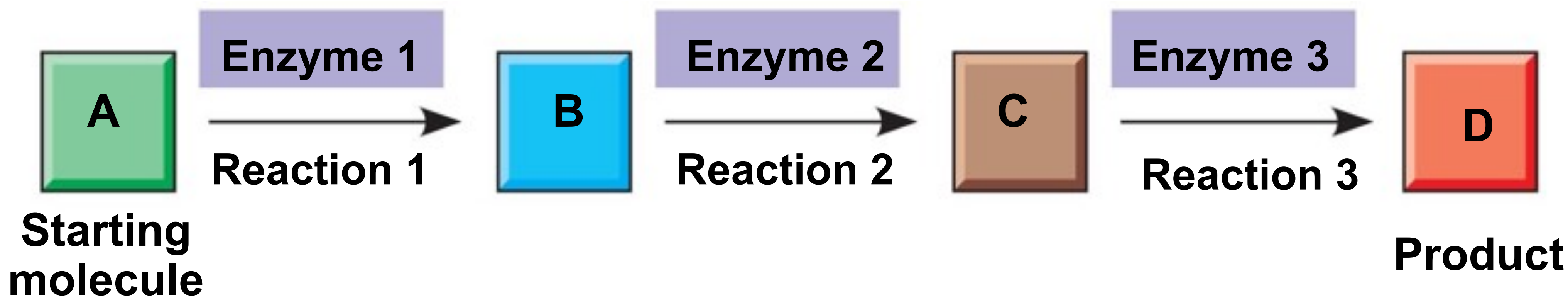
Some Background INFO



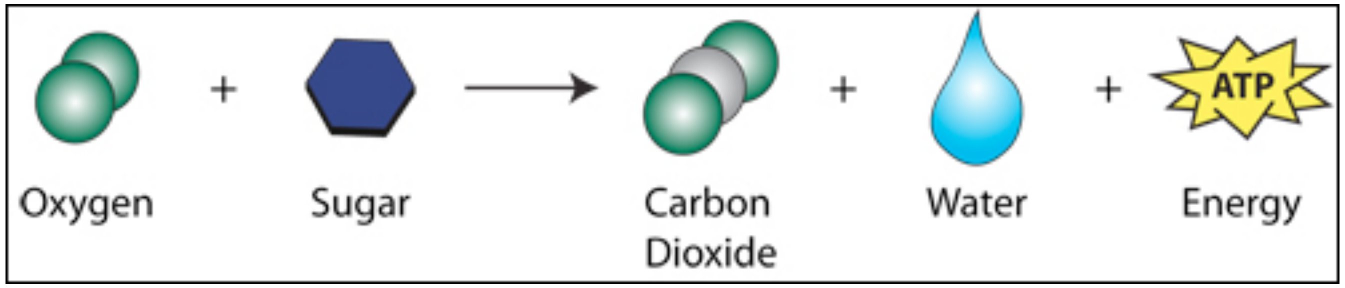
AN ORGANISM'S METABOLISM TRANSFORMS MATTER AND ENERGY, SUBJECT TO THE LAWS OF THERMODYNAMICS

Organization of the Chemistry of Life into Metabolic pathways

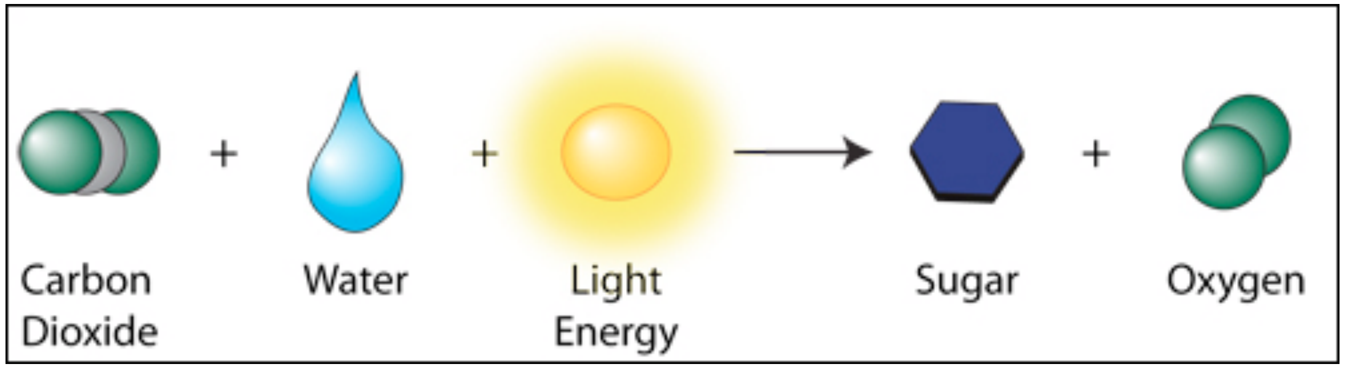
- Metabolic pathways begin with a specific molecule, which is then altered in a series steps, resulting in a certain product.



- **Catabolic Pathways:** release energy by breaking down complex molecules into simpler molecules
  - Ex. Cell Respiration



- **Anabolic Pathways:** consume energy to build complex molecules from simpler molecules
  - Ex. Photosynthesis



Notice the location of "energy" relative to the arrow in the chemical equation.

Forms of Energy

- **Energy is**...the capacity to do work, the ability to cause change, the ability to rearrange matter, the ability to move matter against opposing forces.
- **Kinetic Energy** is associated with the motion of objects
    - Moving objects can perform work, by imparting motion onto other objects
- **Heat or Thermal Energy** is kinetic energy associated with the random movement of atoms and molecules

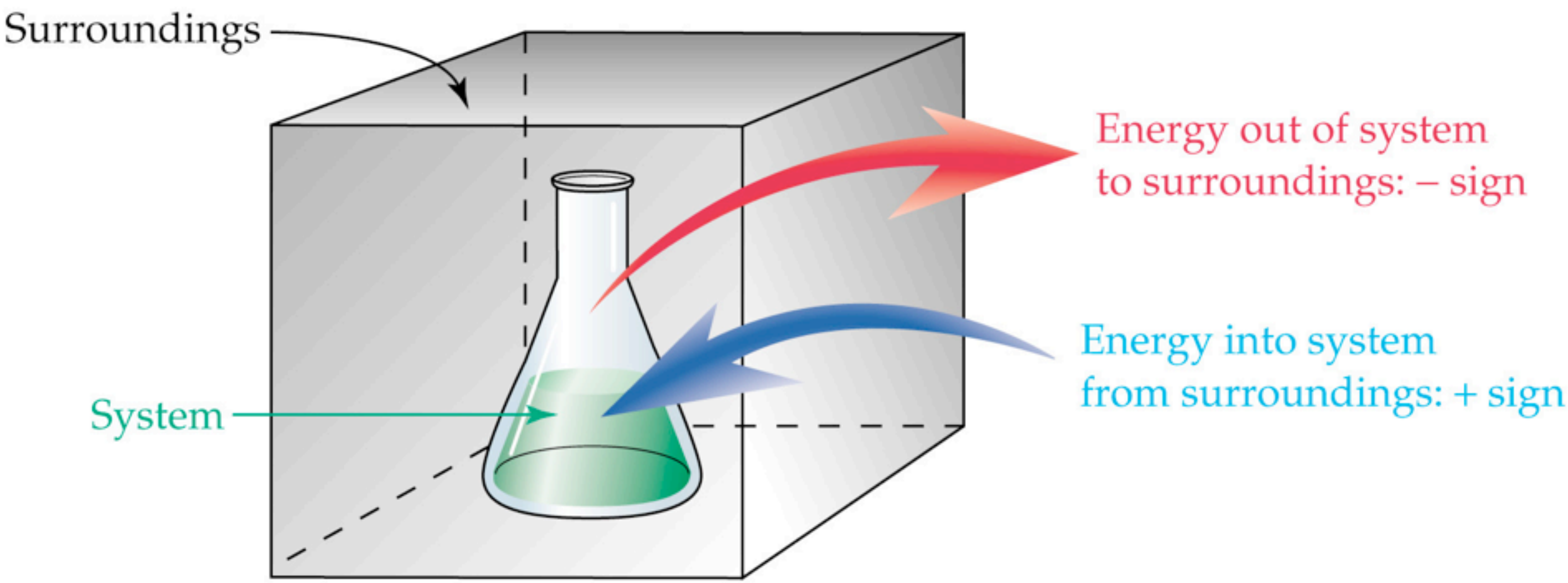
Forms of Energy (continued)

- **Potential Energy** is the energy that matter possesses as a result of its location or structure
- **Chemical Energy** is refers to the potential energy available for release in a chemical reaction.
    - This chemical energy was derived from light during photosynthesis...Organisms are energy transformers.

The Laws of Energy Transformation

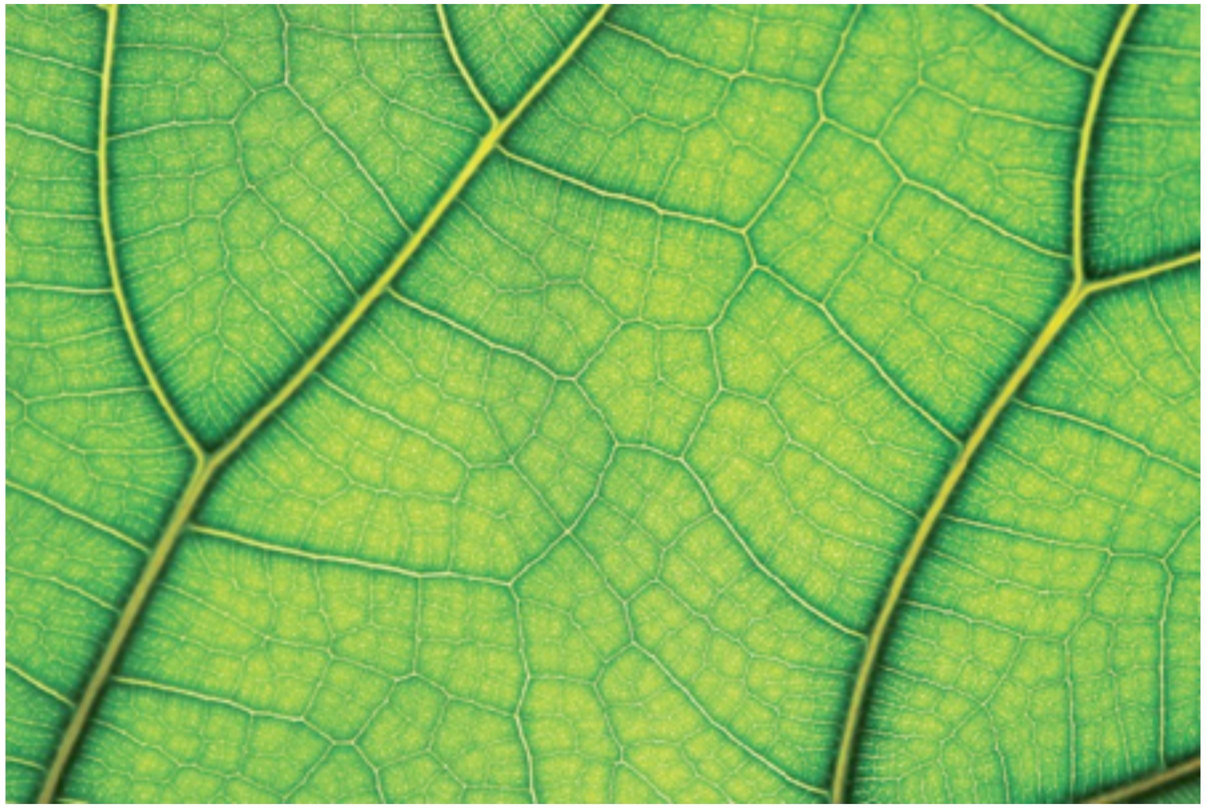
- **Thermodynamics** is the study of energy transformations that occur in a collection of matter.
  - **System**- denotes the matter under study
  - **Surroundings**- everything outside the system
  - **Isolated systems**- where energy and matter are not transferred between the system and surroundings
  - **Open systems**- where energy and matter are transferred between the system and surroundings
- Two laws of thermodynamics govern energy transformations.

$$\Delta E = E_{\text{final}} - E_{\text{initial}}$$



First Law of Thermodynamics

- **First Law of Thermodynamics:** Energy can be transferred and transformed, but it can not be created or destroyed.
  - This is the principle of energy conservation
  - *The electric company and plants are energy transformers*

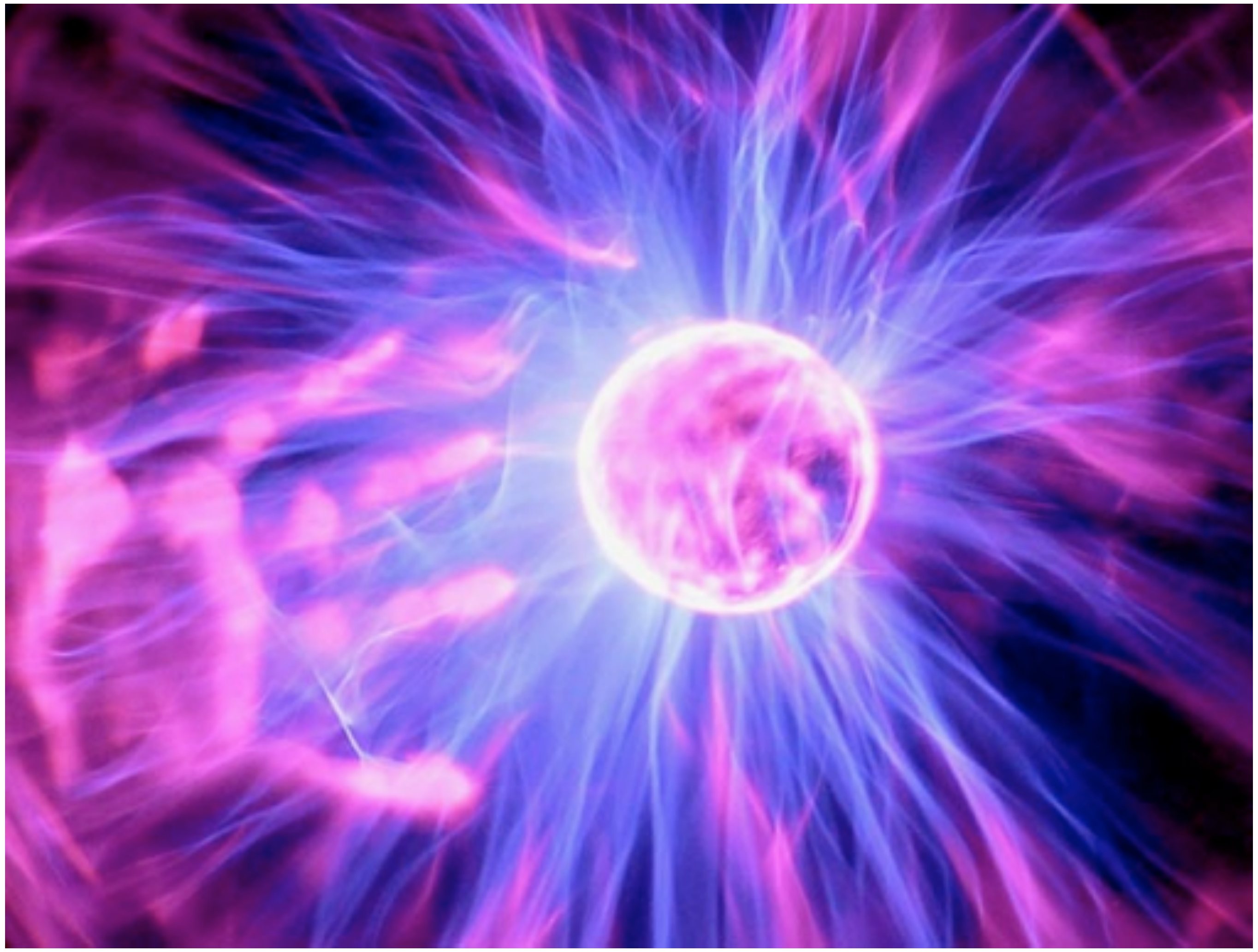


Second Law of Thermodynamics

- **Second Law of Thermodynamics:** Every energy transfer or transformation increases the entropy (disorder) of the universe
  - With energy transfer or transformation some energy is becomes unavailable to do work
  - Most of the is lost to the surroundings as heat.
- **Spontaneous processes** occur without an input of energy, in order for this to take place the process increase the disorder of the universe
  - Spontaneous does not imply speed but rather a process that is energetically favorable.
    - Ex. rusting nail

Intro to Metabolism

Main Idea: Biologists want to know which reactions occur spontaneously and which require an input of energy.



THE FREE-ENERGY CHANGE OF A REACTION TELLS US WHETHER OR NOT THE REACTION OCCURS SPONTANEOUSLY

Free-Energy Change, G△

- **Free Energy:** is the portion of a system's energy that can perform work
- Change in Free Energy = (change in total energy) - (temperature)(change in entropy)

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

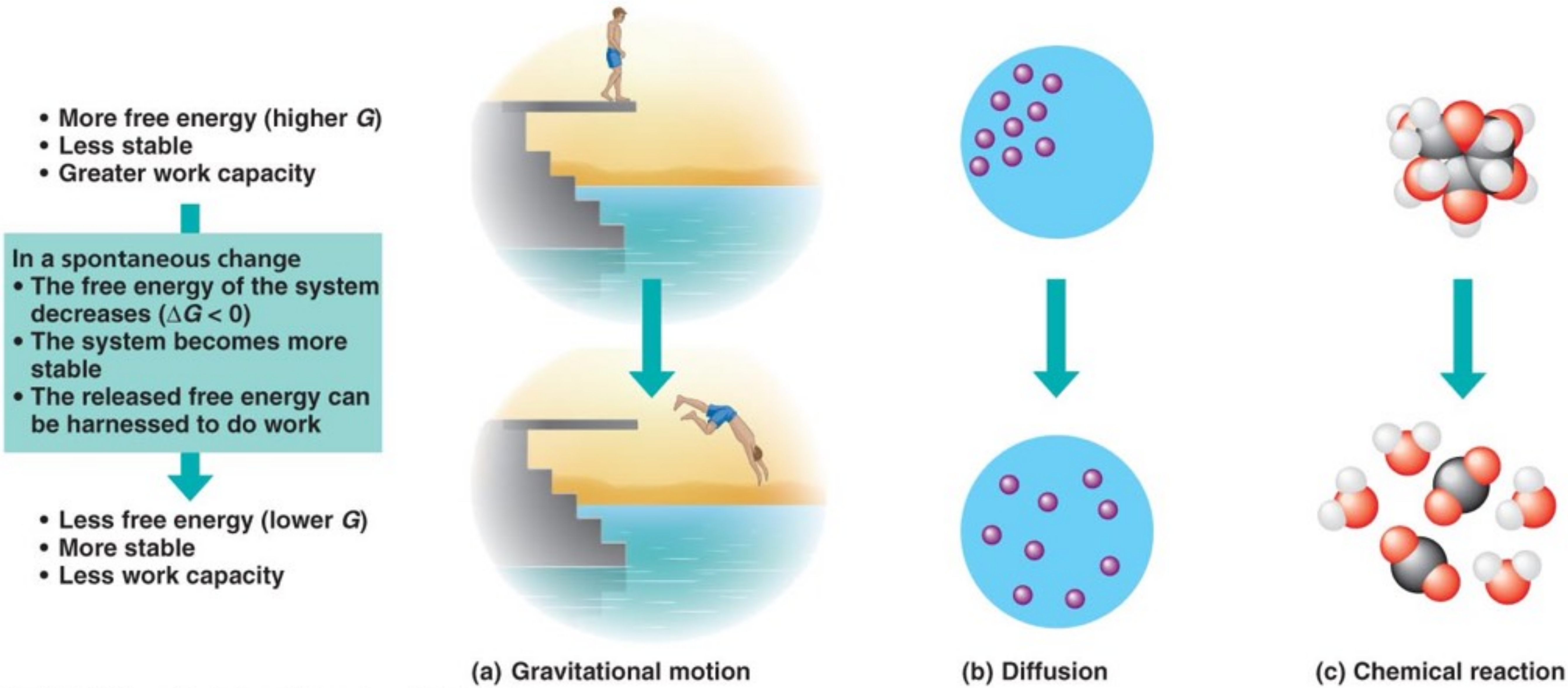
Free Energy, Stability & Equilibrium

- Once we know ΔG we can predict if a reaction is spontaneous.

$\Delta G<0$ reaction is spontaneous

$\Delta G>0$ reaction is nonspontaneous

- We can think of free energy as a measure of a system's instability-its tendency to change to a more stable state
- Unless something prevents it systems will move towards greater stability


• More free energy (higher G)
• Less stable
• Greater work capacity
In a spontaneous change
• The free energy of the system decreases (∆G < 0)
• The system becomes more stable
• The released free energy can be harnessed to do work
• Less free energy (lower G)
• More stable
• Less work capacity
(a) Gravitational motion
(b) Diffusion
(c) Chemical reaction

Essential knowledge 2.A.1: All living systems require constant input of free energy.

b. Living systems do not violate the second law of thermodynamics, which states that entropy increases over time.

2. Energy input must exceed free energy lost to entropy to maintain order and power cellular processes.

Free Energy, Stability & Equilibrium

Free Energy, Stability & Equilibrium

- Maximum stability is described by the term *equilibrium*.

Free Energy, Stability & Equilibrium

- Maximum stability is described by the term *equilibrium*.
- Systems naturally move towards equilibrium but never spontaneously move away from equilibrium.

Free Energy, Stability & Equilibrium

- Maximum stability is described by the term *equilibrium*.
- Systems naturally move towards equilibrium but never spontaneously move away from equilibrium.
- Free energy decreases as reactions move towards equilibrium

Free Energy, Stability & Equilibrium

- Maximum stability is described by the term *equilibrium.*
- Systems naturally move towards equilibrium but never spontaneously move away from equilibrium.
- Free energy decreases as reactions move towards equilibrium
- Most chemical reactions are reversible and will naturally eventually reach equilibrium

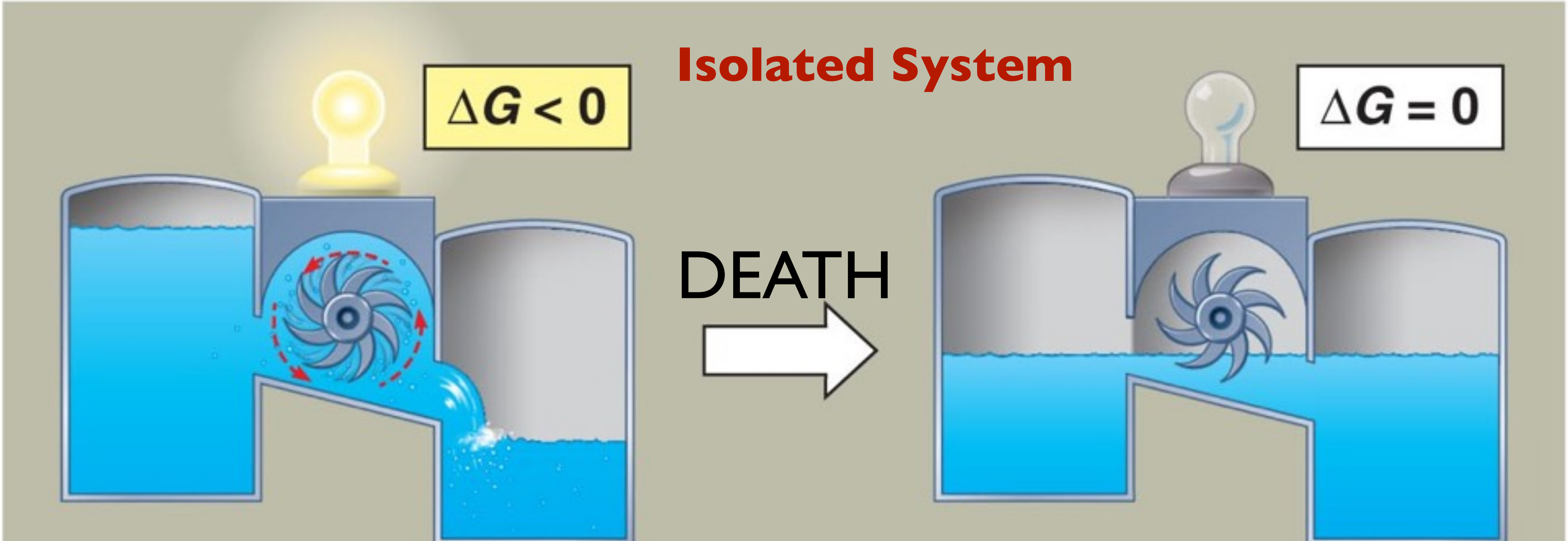
Free Energy, Stability & Equilibrium

- Maximum stability is described by the term *equilibrium.*
- Systems naturally move towards equilibrium but never spontaneously move away from equilibrium.
- Free energy decreases as reactions move towards equilibrium
- Most chemical reactions are reversible and will naturally eventually reach equilibrium
- However...A process is spontaneous and can do work only when it is moving away from equilibrium

Free Energy, Stability & Equilibrium

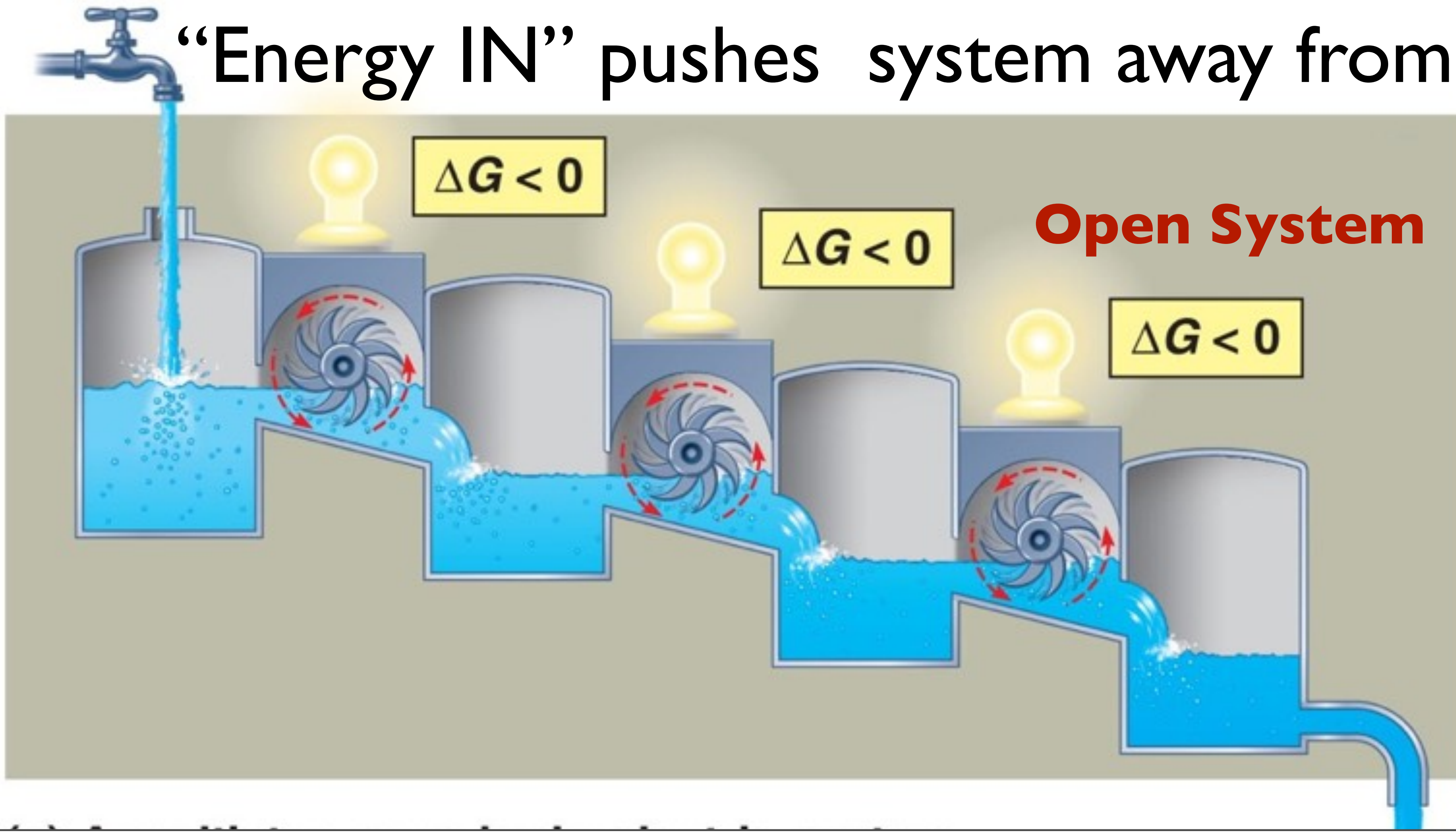
- Maximum stability is described by the term *equilibrium.*
- Systems naturally move towards equilibrium but never spontaneously move away from equilibrium.
- Free energy decreases as reactions move towards equilibrium
- Most chemical reactions are reversible and will naturally eventually reach equilibrium
- However...A process is spontaneous and can do work only when it is moving away from equilibrium
- **As a result cells must constantly "push" reactions away from equilibrium, otherwise free energy decreases, work can not get done and the cell dies**

Isolated System



DEATH

"Energy IN" pushes system away from equilibrium



Open System

REMEMBER LAST SLIDE

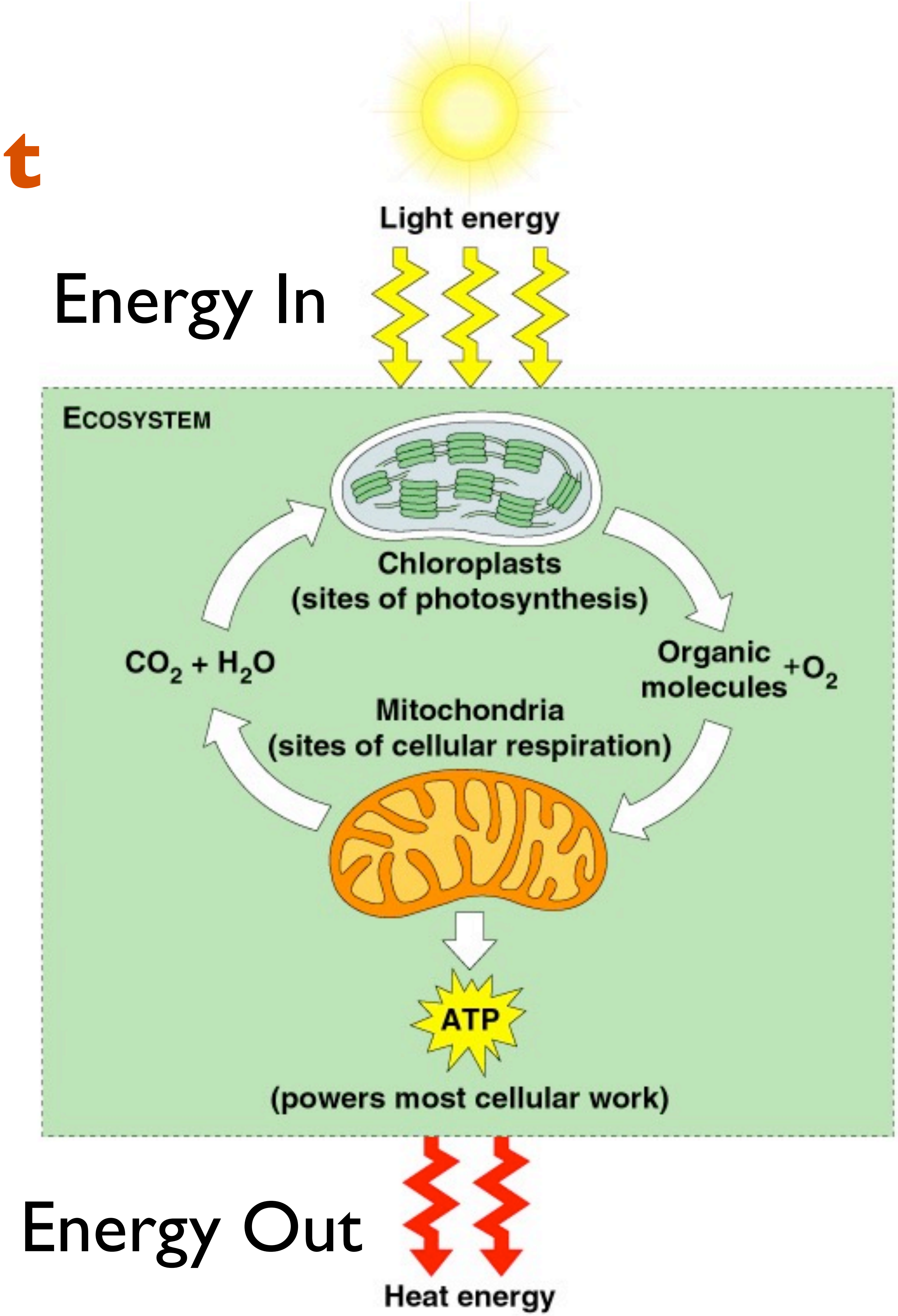
As a result cells must constantly "push" reactions away from equilibrium, otherwise free energy decreases, work can not get done and the cell dies

Ecological Viewpoint

REMEMBER LAST SLIDE

As a result cells must constantly "push" reactions away from equilibrium, otherwise free energy decreases, work can not get done and the cell dies,

Now apply this idea to ecosystems...there has to be a constant energy input and energy output to maintain order at the level ecosystems



2. Equilibrium & Metabolism

2. Equilibrium & Metabolism

- Recall that isolated systems eventually reach equilibrium and can do no work

2. Equilibrium & Metabolism

- Recall that isolated systems eventually reach equilibrium and can do no work
- Recall if a cell has reached equilibrium it is dead

2. Equilibrium & Metabolism

- Recall that isolated systems eventually reach equilibrium and can do no work
- Recall if a cell has reached equilibrium it is dead
- **The fact that metabolism as a whole is never at equilibrium is one of the defining features of life.**

2. Equilibrium & Metabolism

- Recall that isolated systems eventually reach equilibrium and can do no work
- Recall if a cell has reached equilibrium it is dead
- **The fact that metabolism as a whole is never at equilibrium is one of the defining features of life.**
- The constant flow of materials in and out of the cell keeps the metabolic pathways from ever reaching equilibrium

Free Energy & Metabolism

1. Exergonic & Endergonic Reactions

$\triangle$

$\triangle$

$\triangle$

$$C_6H_{12}O_6 \;+\; 6\;O_2 \longrightarrow 6\;CO_2 \;+\; 6\,H_2O$$

$$\triangle G = -686\ \text{kcal/mol}$$

Free Energy & Metabolism

1. Exergonic & Endergonic Reactions

- Based upon free energy reactions are classified as either...

$\triangle$

$\triangle$

$\triangle$

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

$$\triangle G = -686 \text{ kcal/mol}$$

Free Energy & Metabolism

I. Exergonic & Endergonic Reactions

- Based upon free energy reactions are classified as either...
- **Exergonic Reactions:** proceed with a net *release* of free energy

  $\triangle$

  $\triangle$

  $\triangle$

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

$$\triangle G = -686 \text{ kcal/mol}$$

Free Energy & Metabolism

I. Exergonic & Endergonic Reactions

- Based upon free energy reactions are classified as either...
- **Exergonic Reactions:** proceed with a net *release* of free energy
  - $\triangle$G decreases
  - $\triangle$
  - $\triangle$

$$C_6H_{12}O_6 \; + \; 6\ O_2 \longrightarrow 6\ CO_2 \; + \; 6\ H_2O$$

$$\triangle G = -686 \text{ kcal/mol}$$

Free Energy & Metabolism

I. Exergonic & Endergonic Reactions

- Based upon free energy reactions are classified as either...
- **Exergonic Reactions:** proceed with a net *release* of free energy
  - $\triangle$G decreases
  - $\triangle$G is negative

$\triangle$

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

$$\triangle G = -686\ \text{kcal/mol}$$

Free Energy & Metabolism

I. Exergonic & Endergonic Reactions

- Based upon free energy reactions are classified as either...
- **Exergonic Reactions:** proceed with a net *release* of free energy
  - $\triangle$G decreases
  - $\triangle$G is negative
  - $\triangle$G's magnitude represents max amount of work

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

$$\triangle G = -686 \text{ kcal/mol}$$

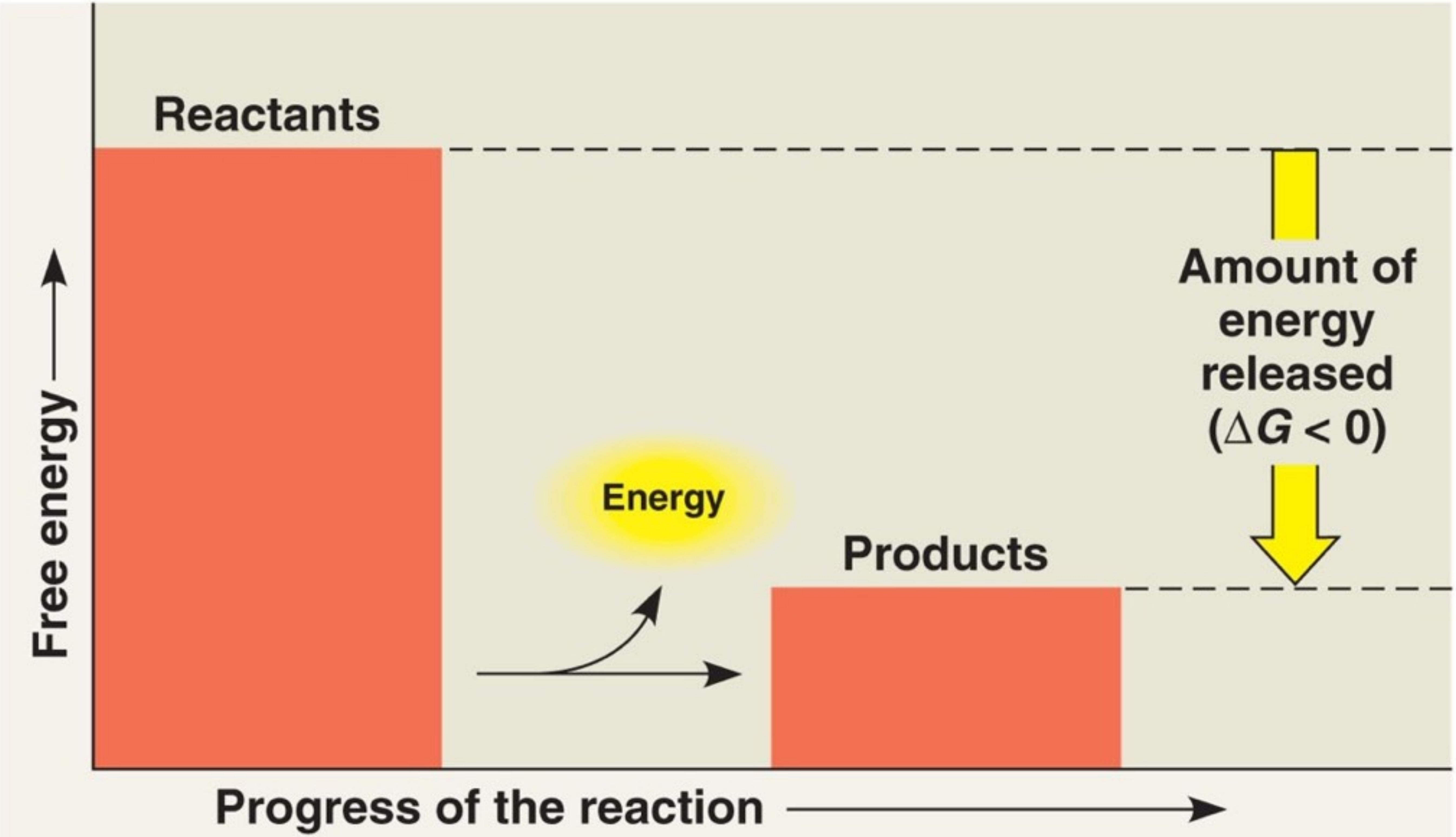
Free Energy & Metabolism

I. Exergonic & Endergonic Reactions

- Based upon free energy reactions are classified as either...
- **Exergonic Reactions:** proceed with a net *release* of free energy
  - $\triangle$G decreases
  - $\triangle$G is negative
  - $\triangle$G's magnitude represents max amount of work
  - Reaction is spontaneous

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

$$\triangle G = -686 \text{ kcal/mol}$$



(a) Exergonic reaction: energy released

Exergonic & Endergonic Reactions continued

Δ

Δ

Δ

Exergonic & Endergonic Reactions continued

- Based upon free energy reactions are classified as either...
    - Δ
    - Δ
    - Δ

Exergonic & Endergonic Reactions continued

- Based upon free energy reactions are classified as either...
- **Endergonic Reactions:** absorb free energy from its surroundings
  - $\triangle$
  - $\triangle$
  - $\triangle$

Exergonic & Endergonic Reactions continued

- Based upon free energy reactions are classified as either...
- **Endergonic Reactions:** absorb free energy from its surroundings
  - $\triangle$G increases

  $\triangle$

  $\triangle$

Exergonic & Endergonic Reactions continued

- Based upon free energy reactions are classified as either...
- **Endergonic Reactions:** absorb free energy from its surroundings
  - △G increases
  - △G is positive

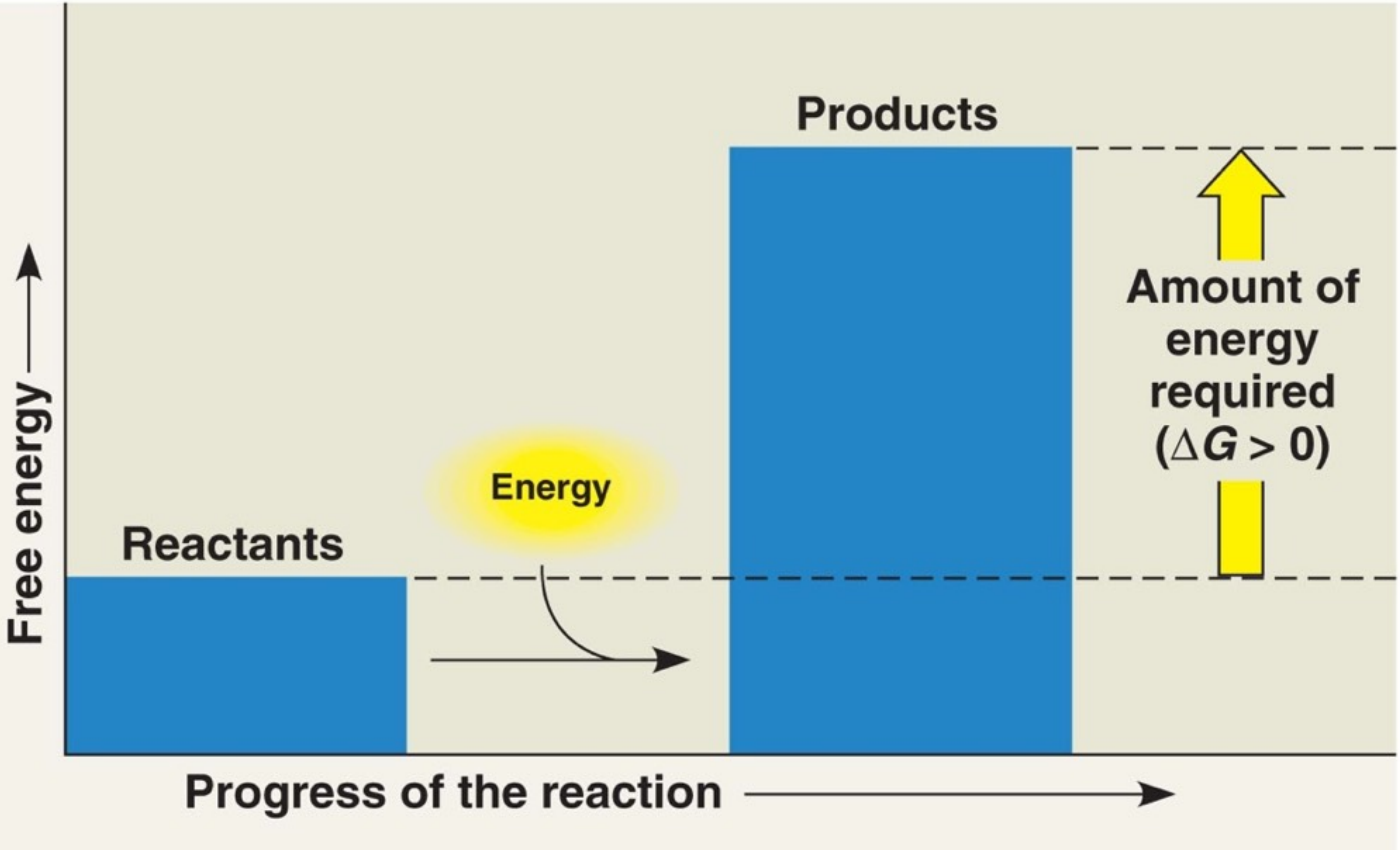
△

Exergonic & Endergonic Reactions continued

- Based upon free energy reactions are classified as either...
- **Endergonic Reactions:** absorb free energy from its surroundings
  - $\triangle$G increases
  - $\triangle$G is positive
  - $\triangle$G's magnitude represents amount of work needed

Exergonic & Endergonic Reactions continued

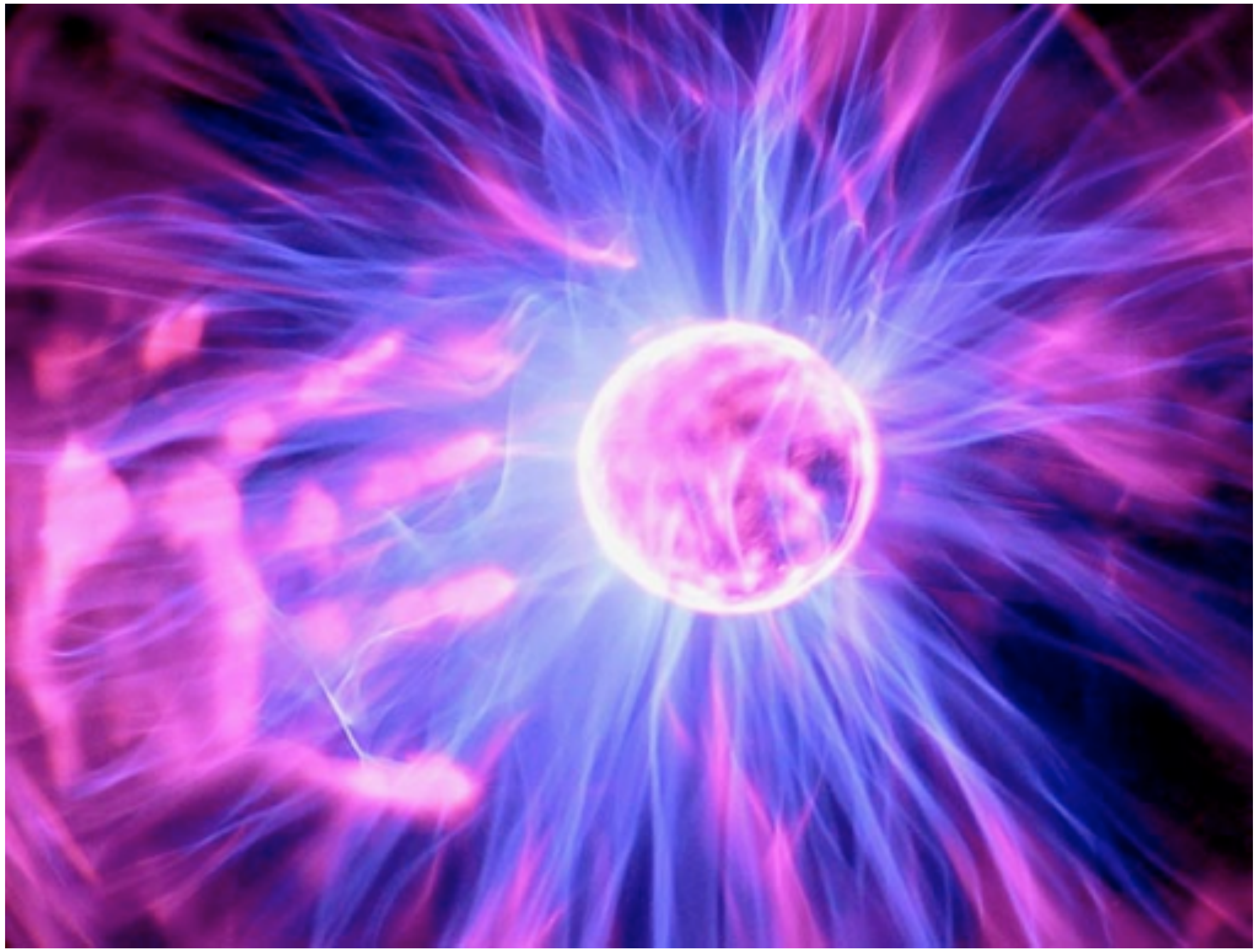
- Based upon free energy reactions are classified as either...
- **Endergonic Reactions:** absorb free energy from its surroundings
  - $\triangle$G increases
  - $\triangle$G is positive
  - $\triangle$G's magnitude represents amount of work needed
  - Reaction is nonspontaneous



(b) Endergonic reaction: energy required

Intro to Metabolism

Main Idea: The cell uses the energy released from exergonic reactions to power the endergonic reactions.



Essential knowledge 2.A.1: All living systems require constant input of free energy.

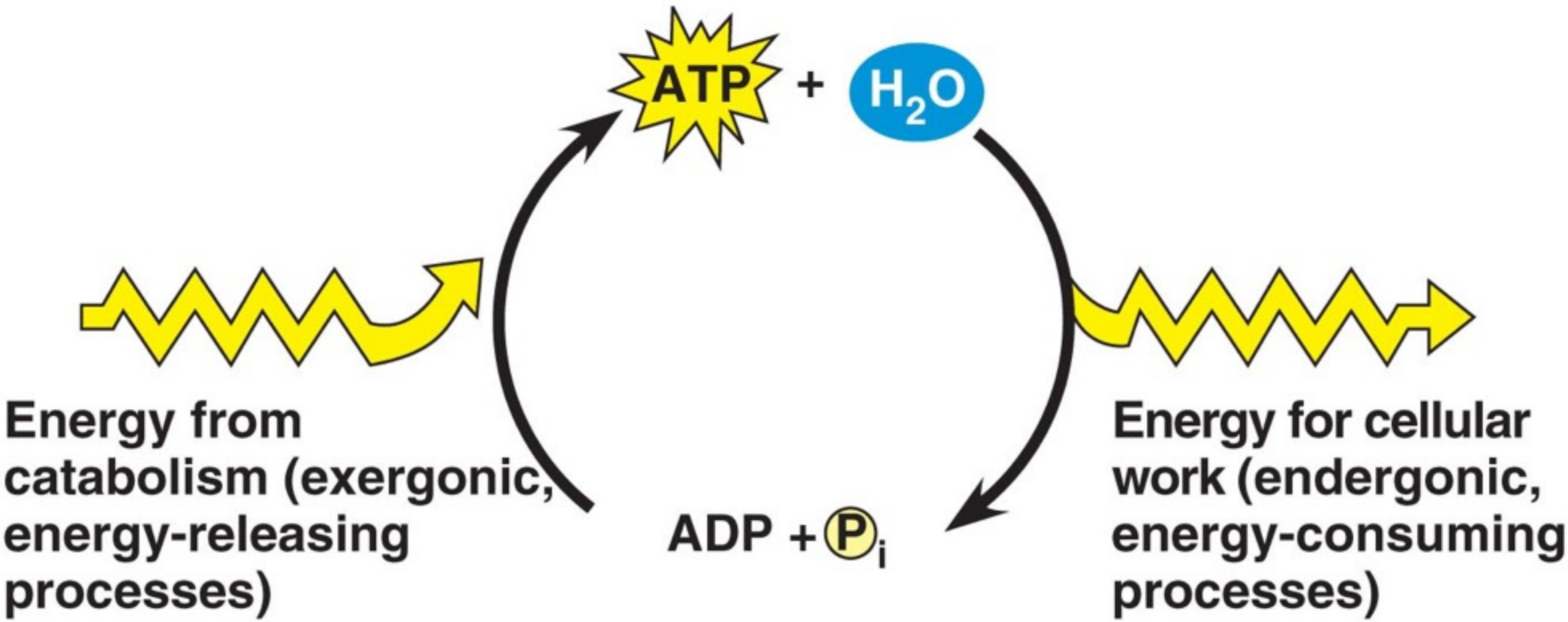
b. Living systems do not violate the second law of thermodynamics, which states that entropy increases over time.

1. Order is maintained by coupling cellular processes that increase entropy (and so have negative changes in free energy) with those that decrease entropy (and so have positive changes in free energy).

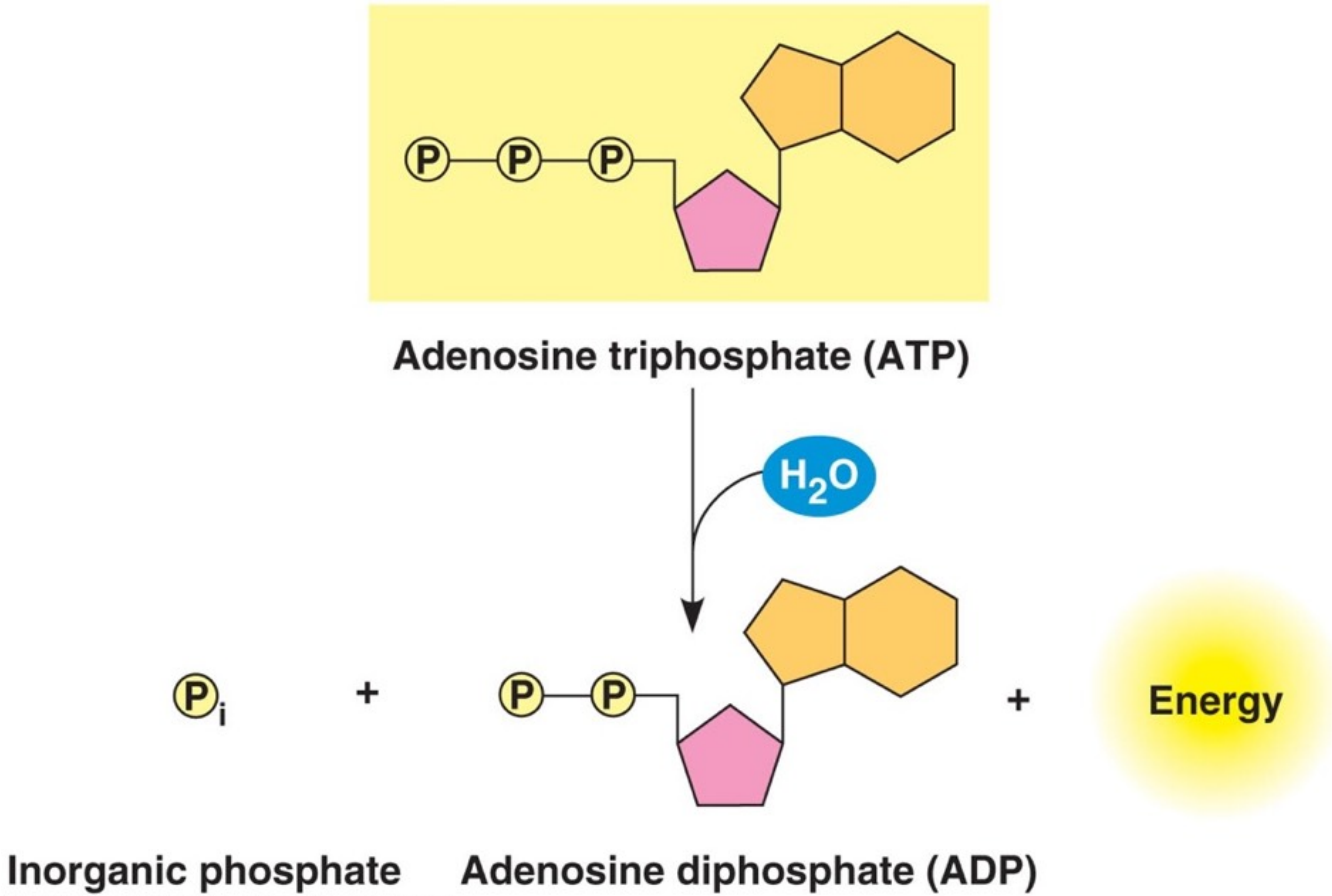
3. Energetically favorable exergonic reactions, such as, that have a negative change in free energy can be used to maintain or increase order in a system by being coupled with reactions that have a positive free energy change.

The Regeneration of ATP

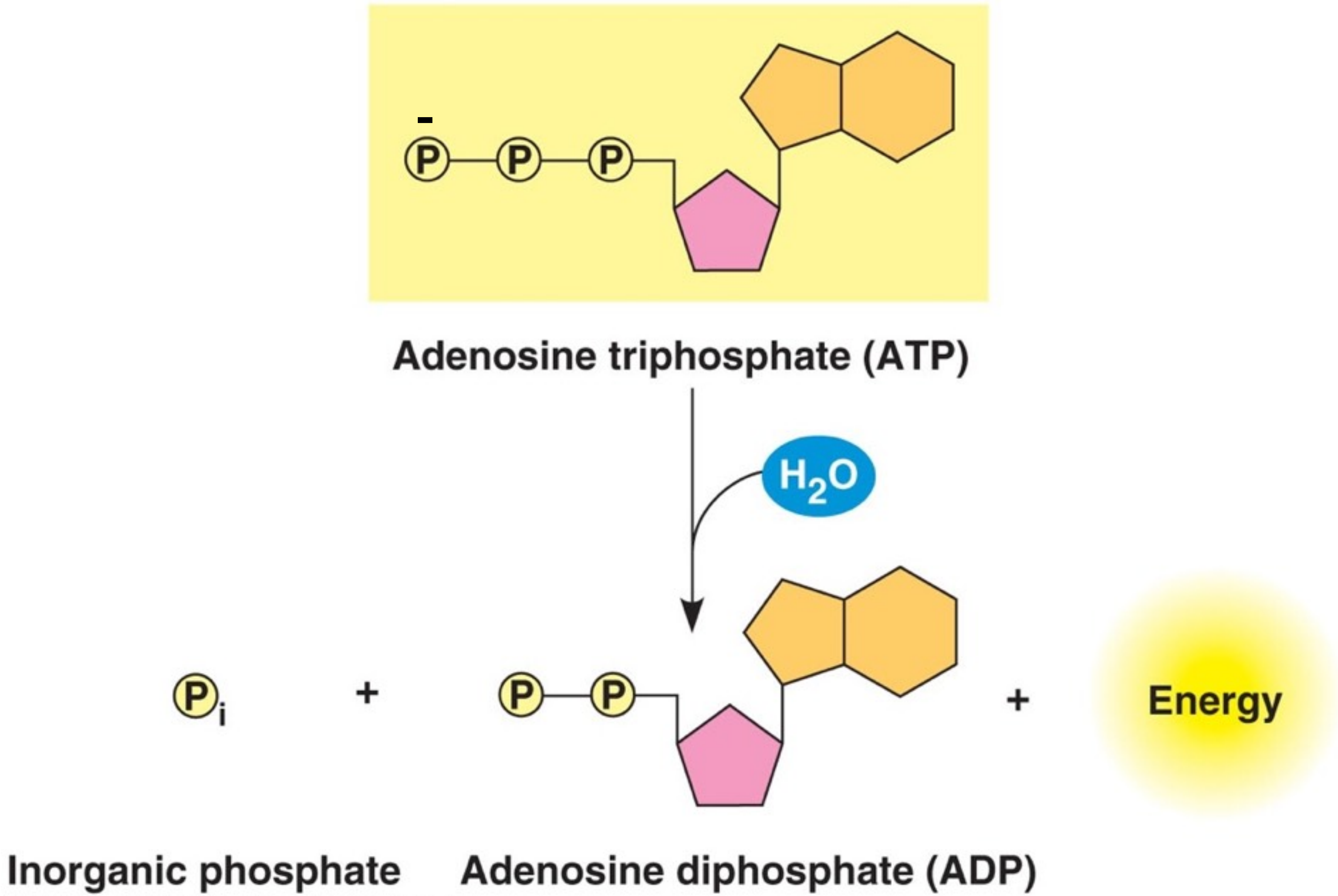
- ATP is hydrolyzed continuously.
- ATP is renewable and can be regenerated
- The ATP cycle below can consume and regenerate 10 million per second



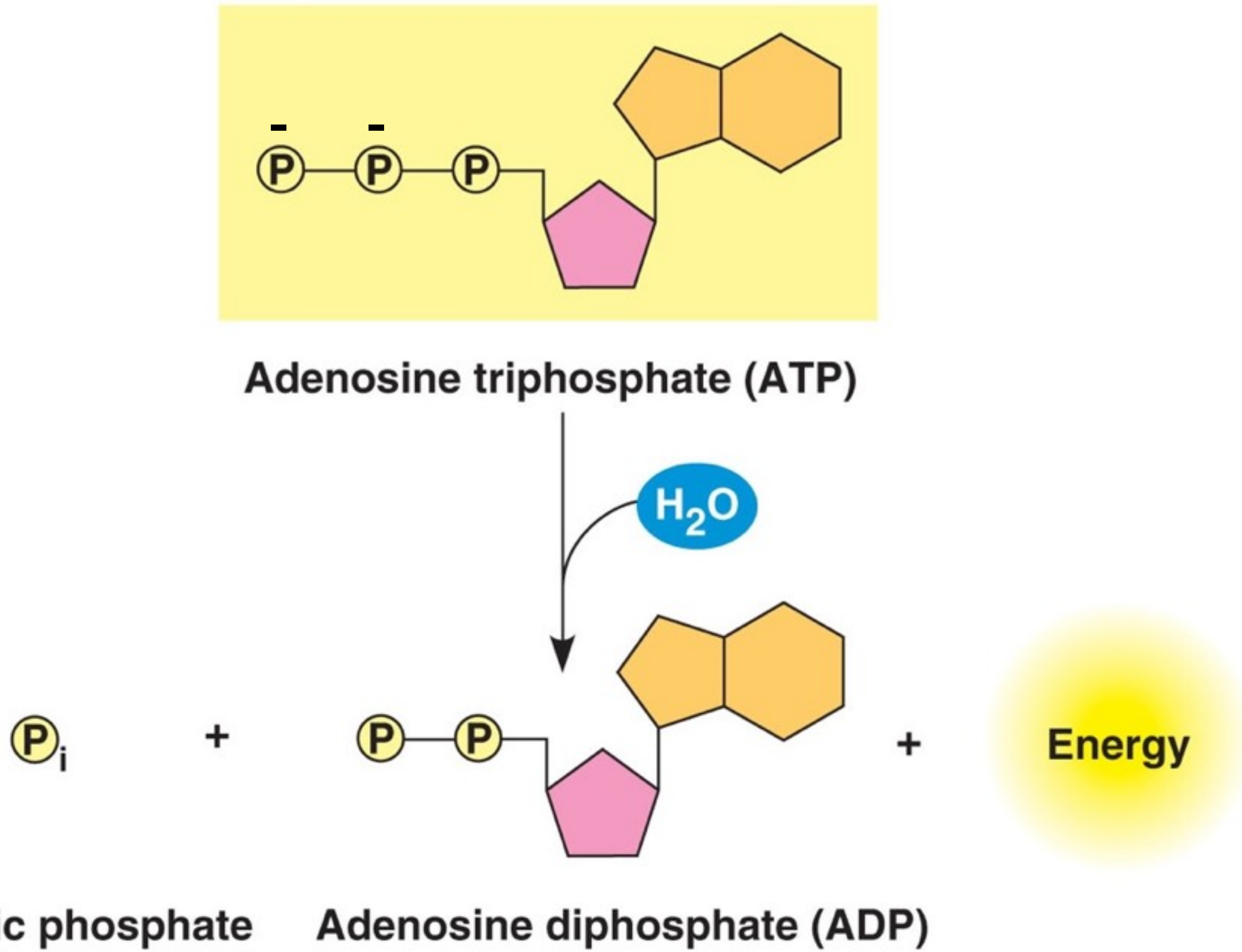
The Structure & Hydrolysis of ATP



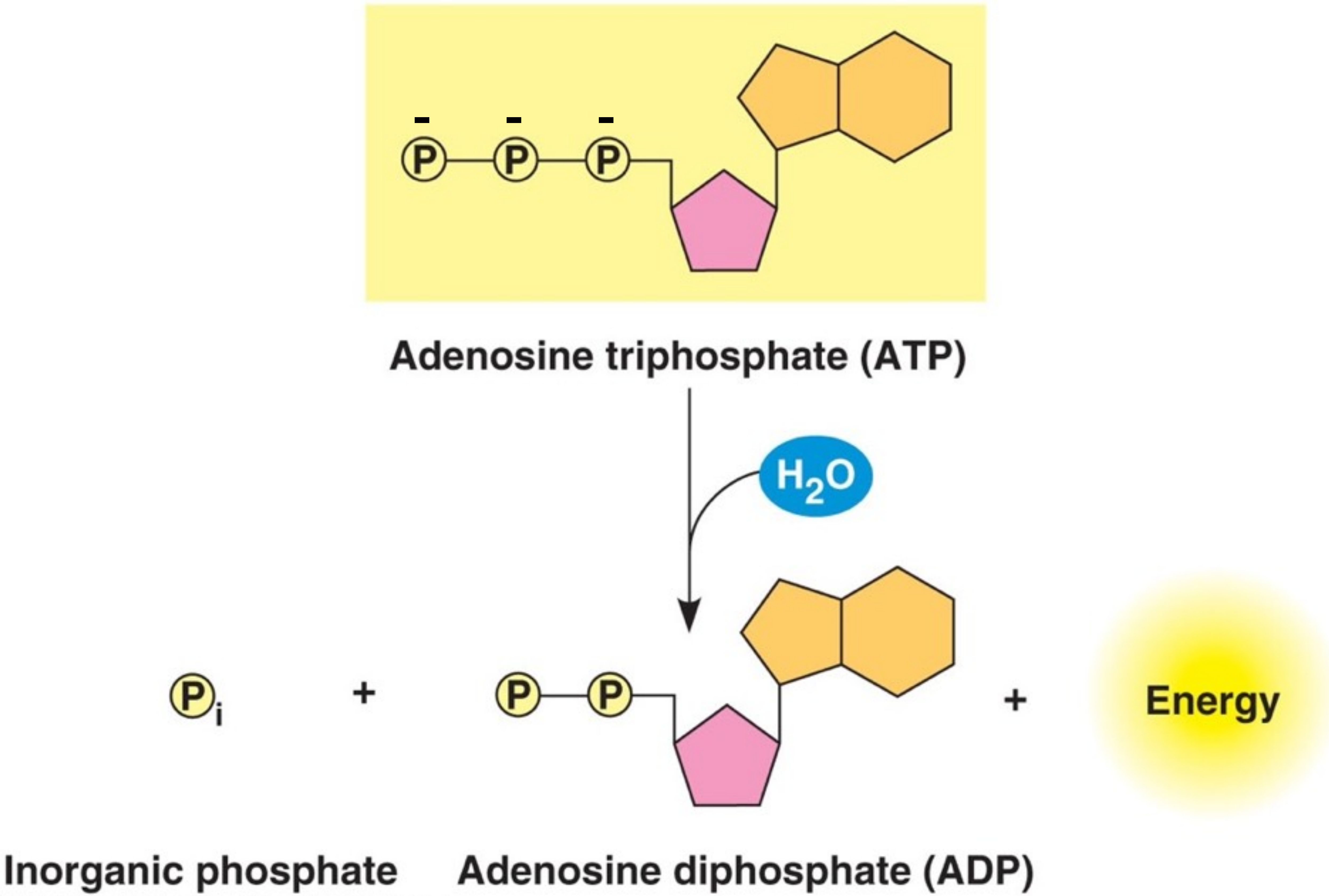
The Structure & Hydrolysis of ATP



The Structure & Hydrolysis of ATP

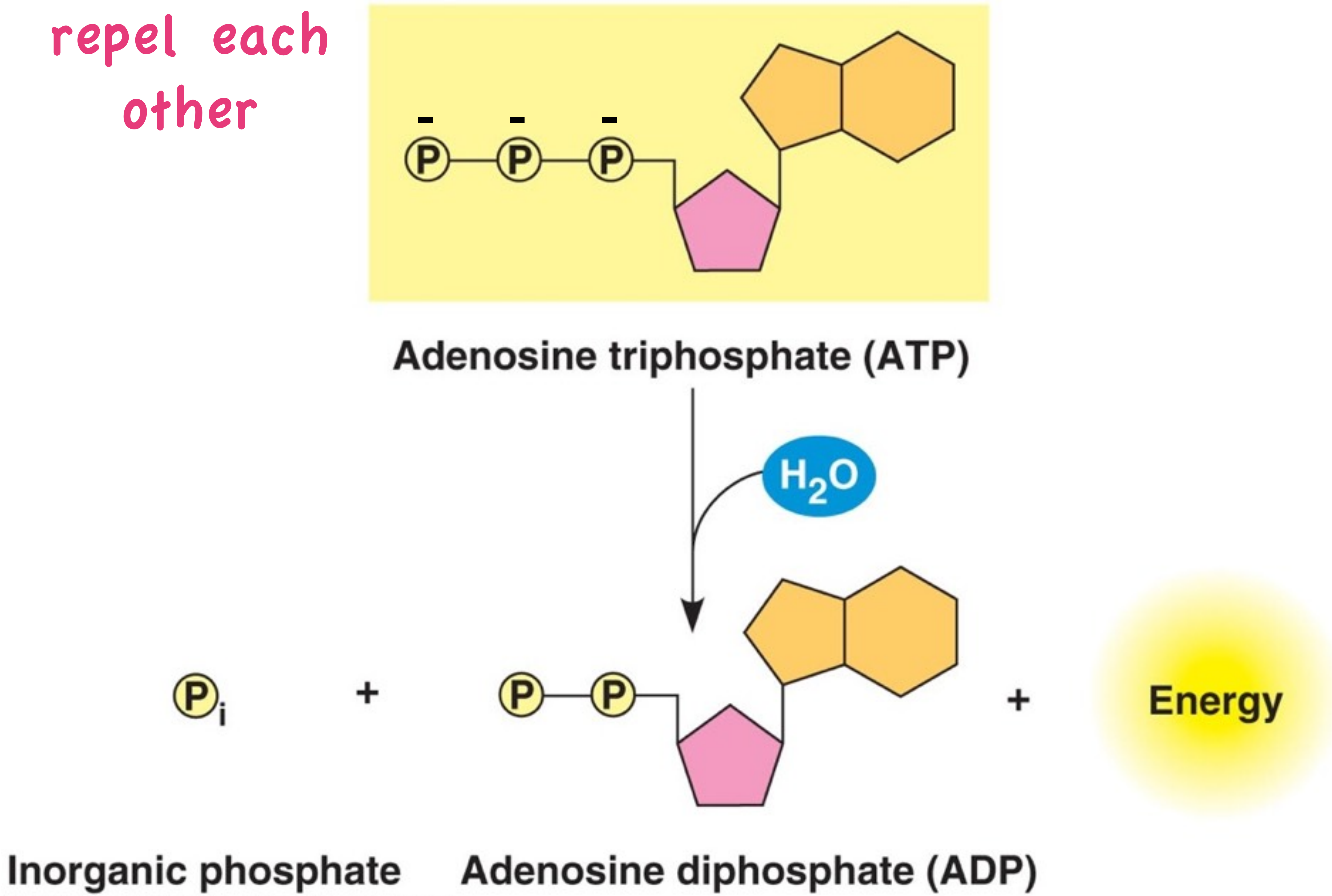


The Structure & Hydrolysis of ATP



The Structure & Hydrolysis of ATP

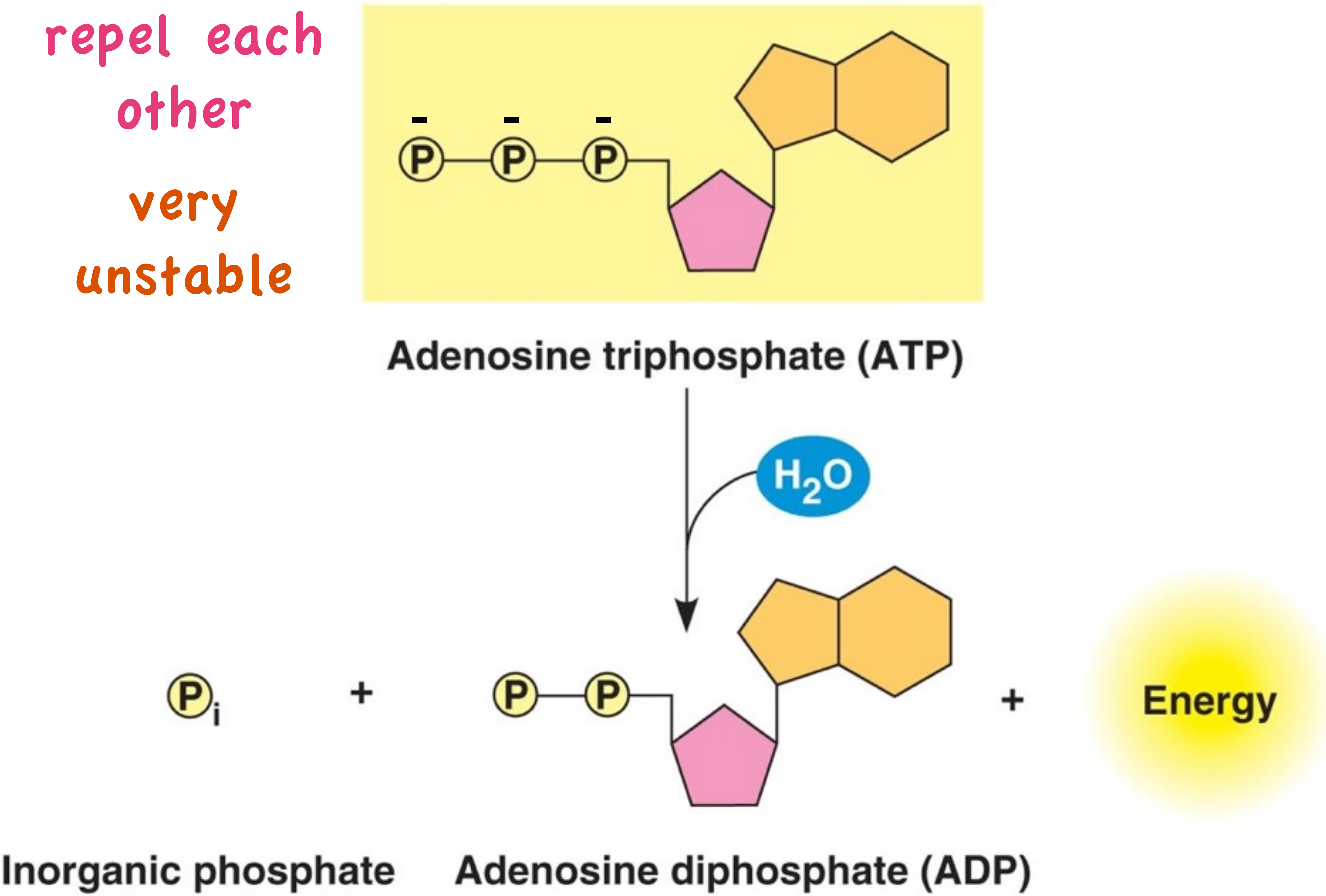
repel each other



The Structure & Hydrolysis of ATP

repel each other

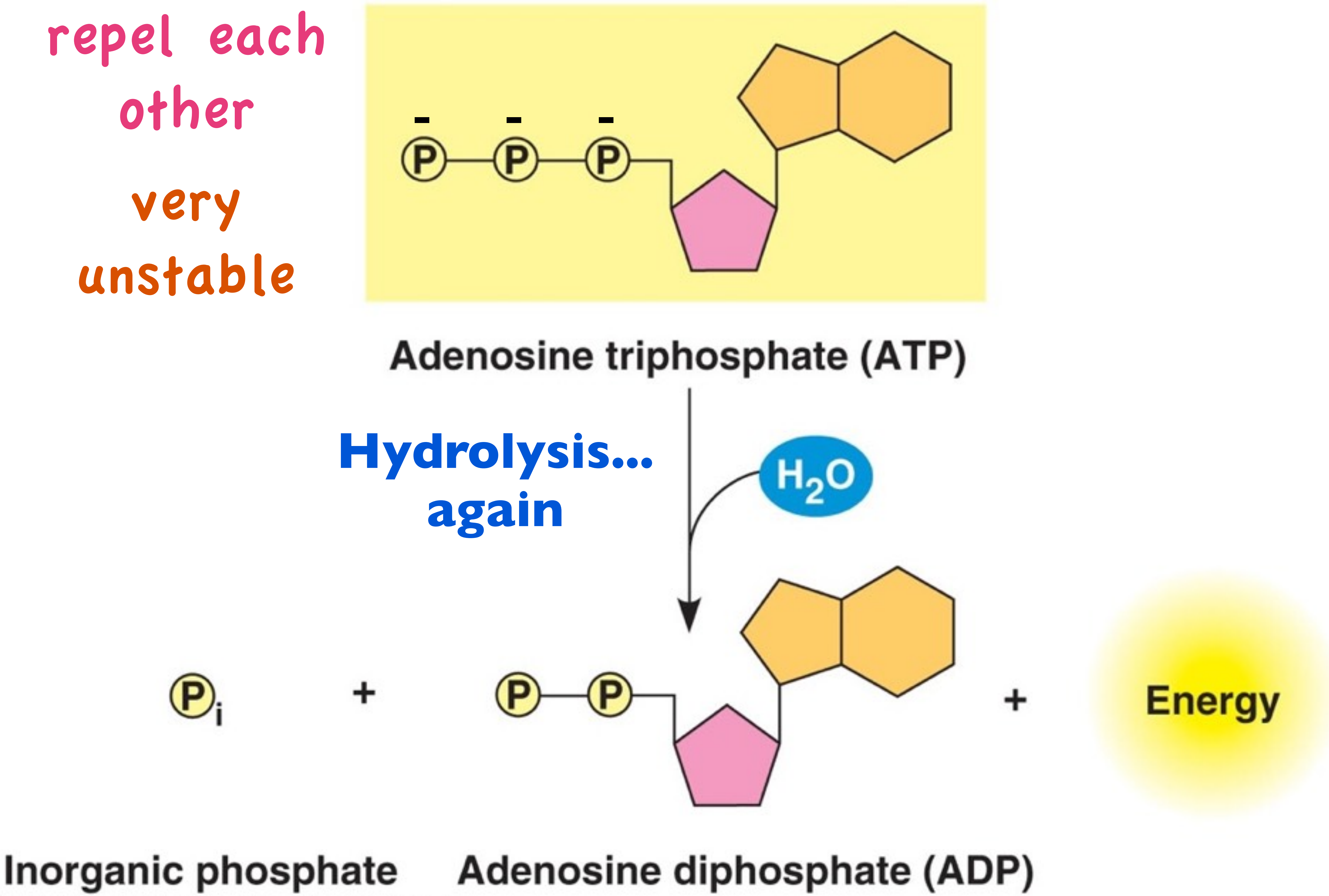
very unstable



The Structure & Hydrolysis of ATP

repel each other

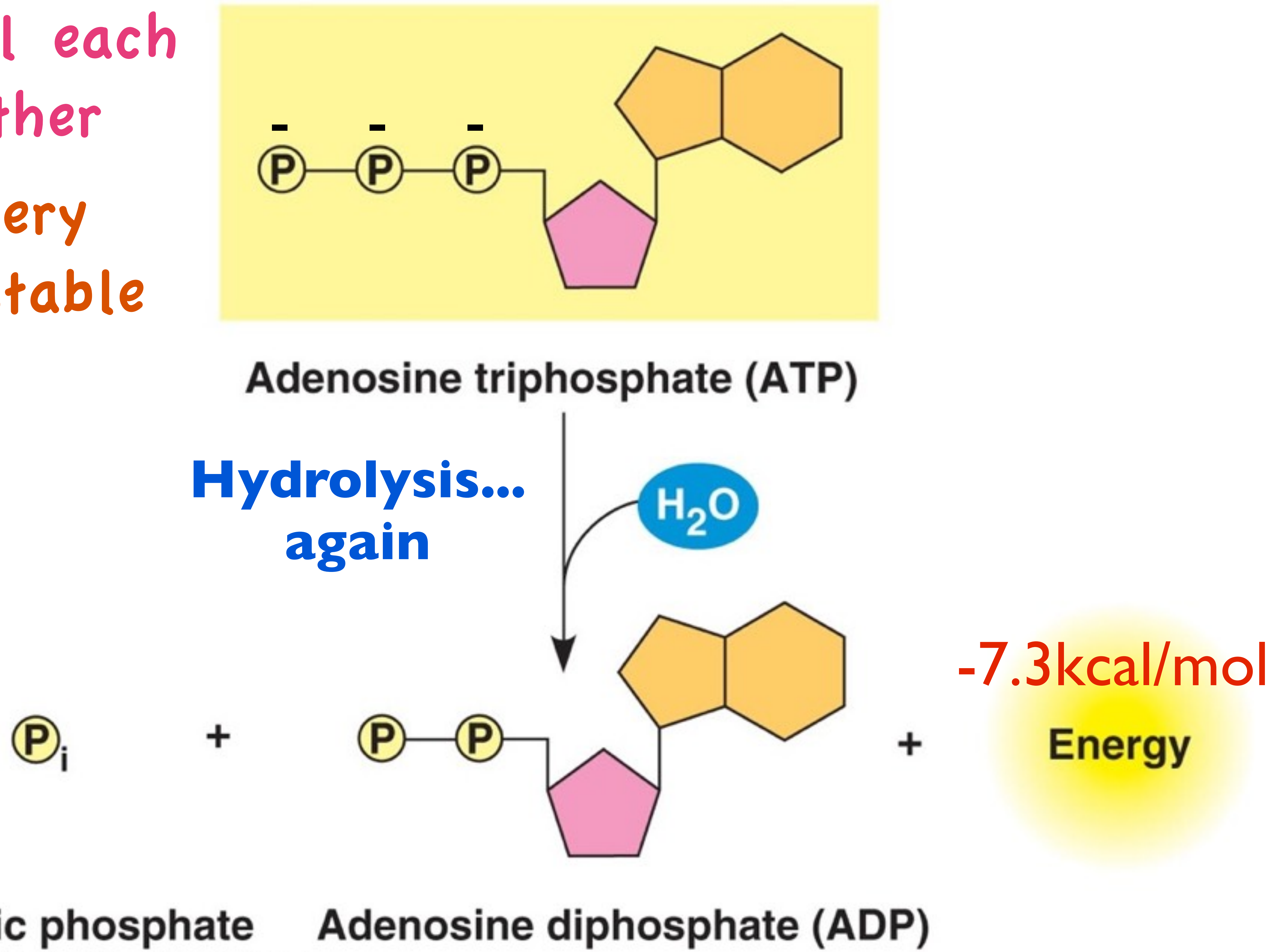
very unstable



The Structure & Hydrolysis of ATP

repel each other

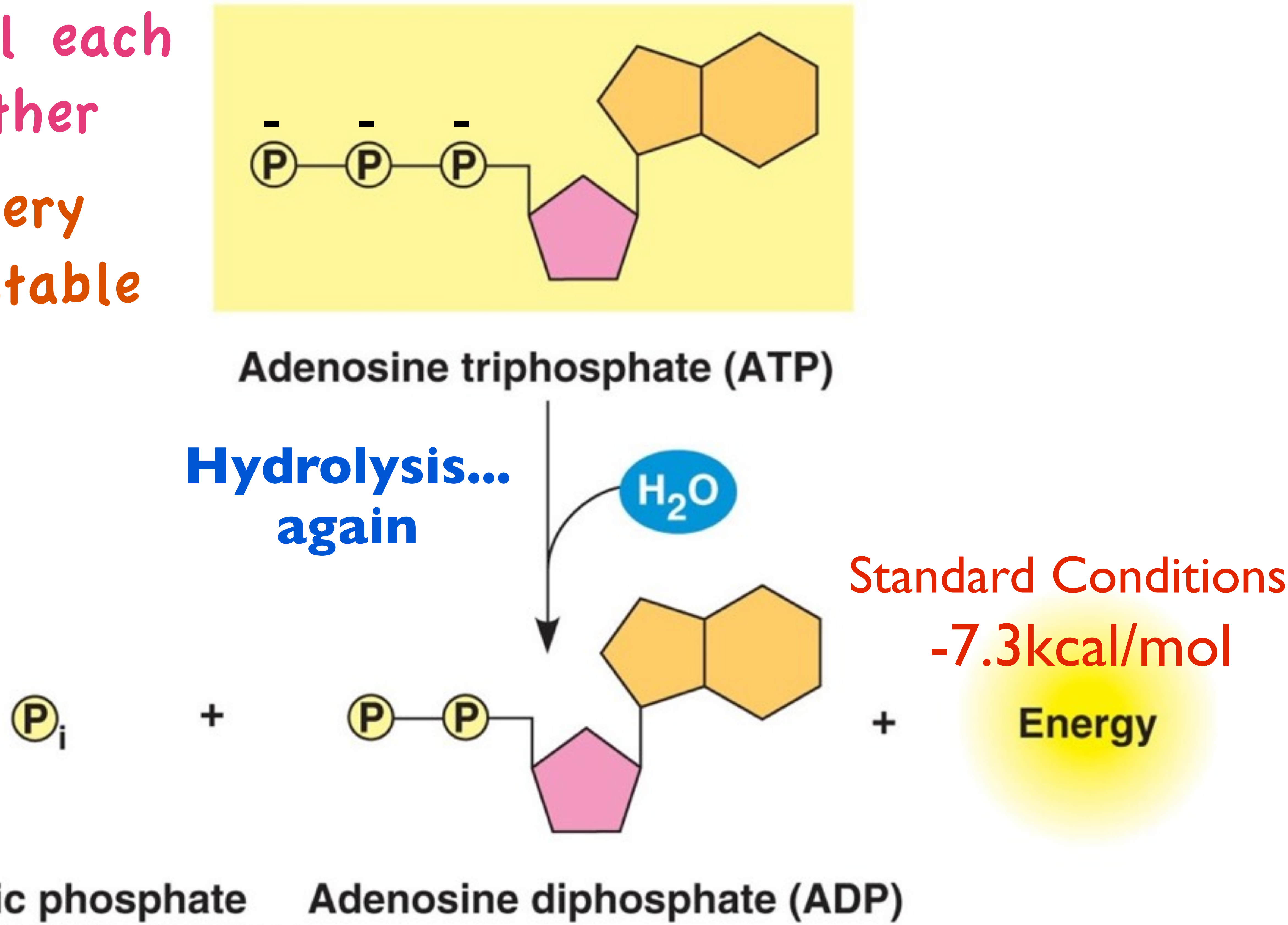
very unstable



The Structure & Hydrolysis of ATP

repel each other

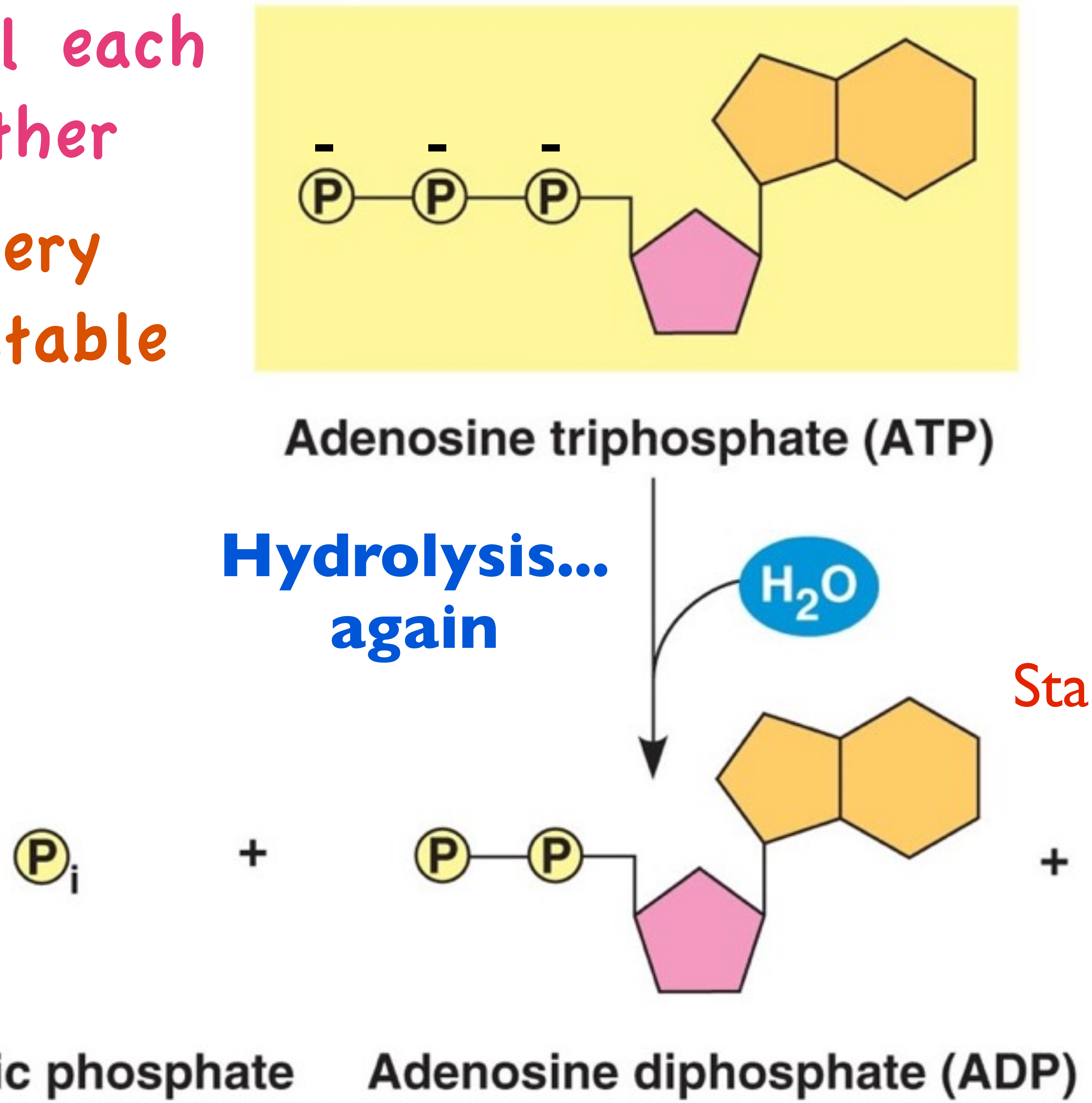
very unstable



The Structure & Hydrolysis of ATP

repel each other

very unstable



Hydrolysis... again

Standard Conditions

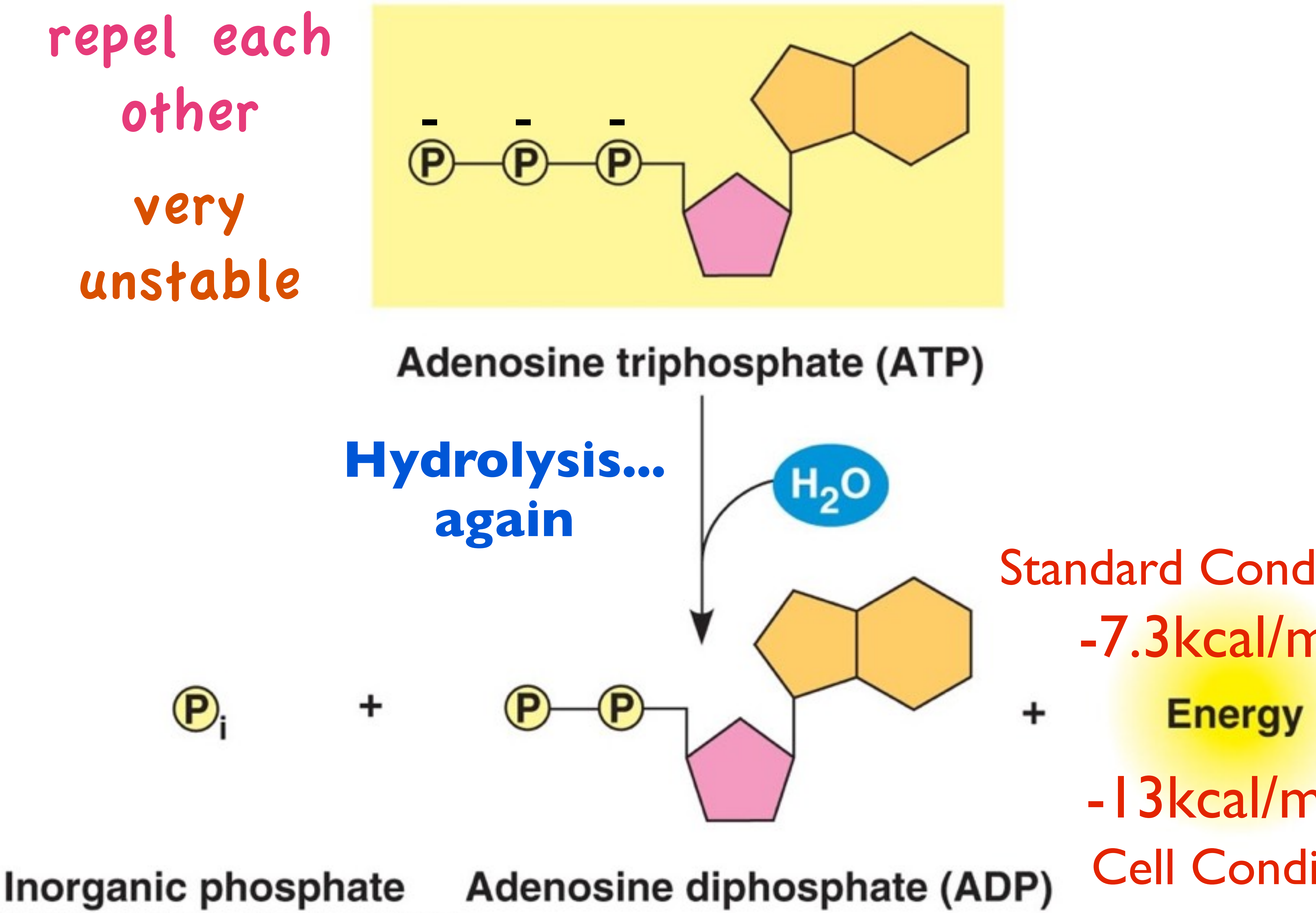
-7.3kcal/mol

-13kcal/mol

The Structure & Hydrolysis of ATP

repel each other

very unstable



Hydrolysis... again

Standard Conditions

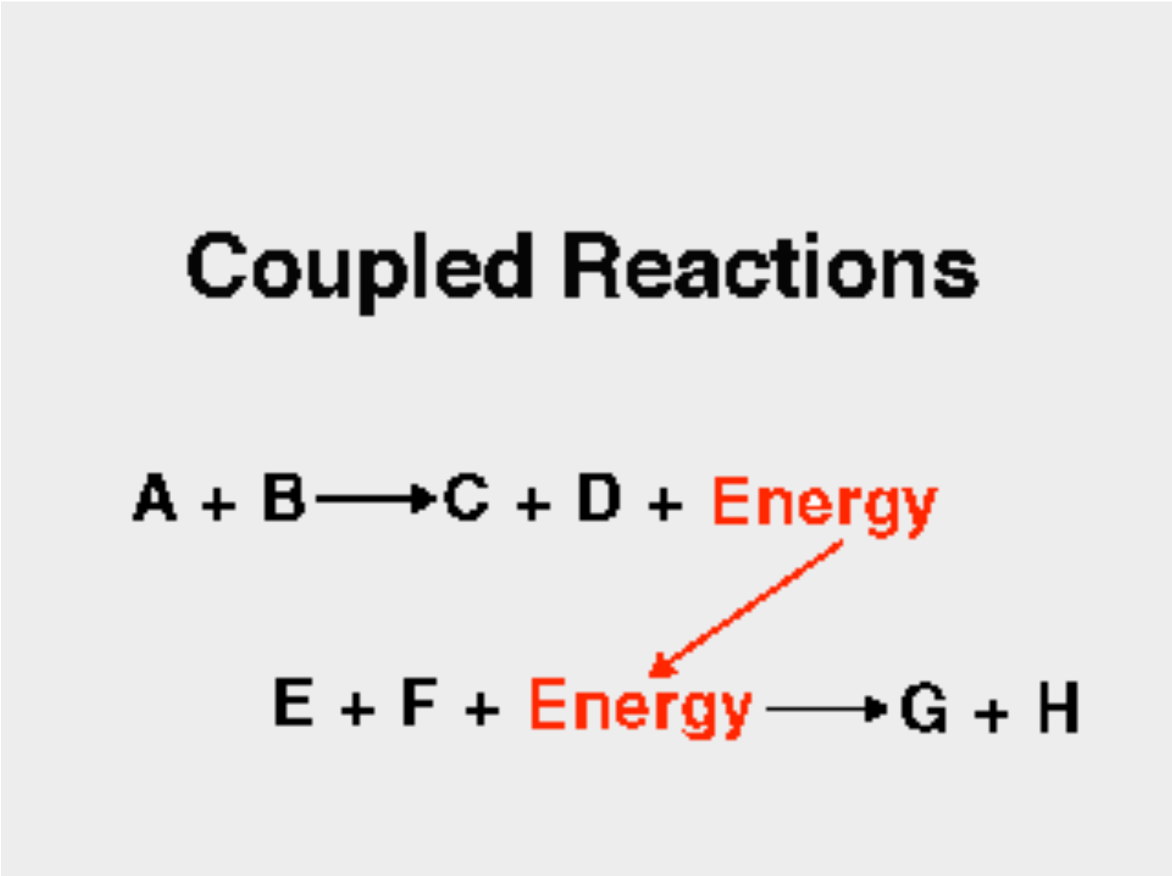
-7.3kcal/mol

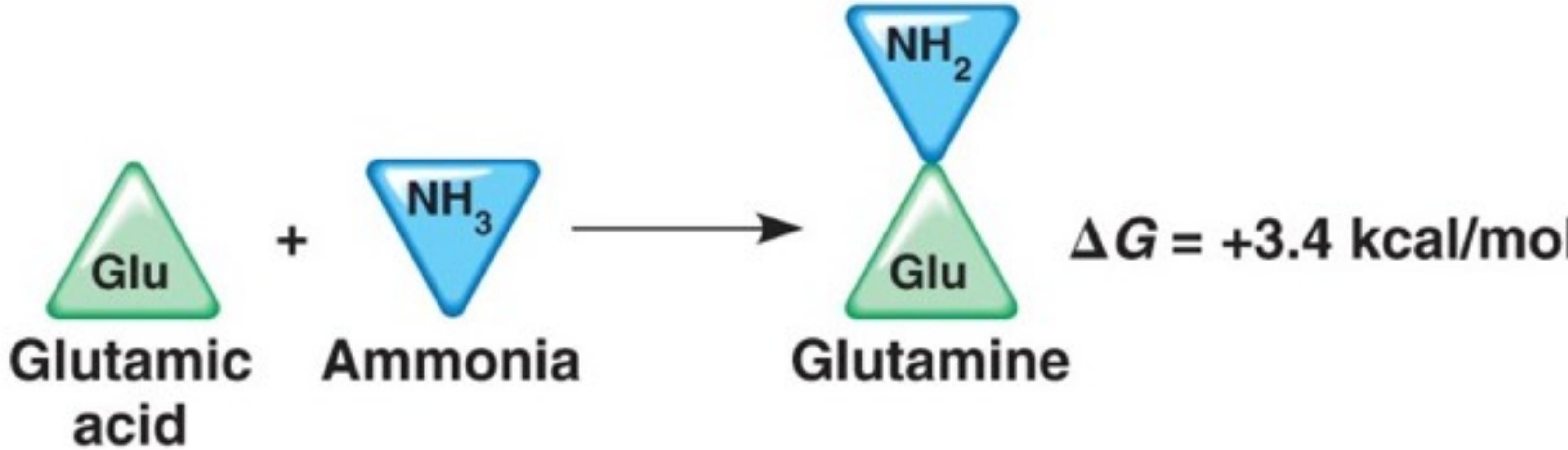
-13kcal/mol

Cell Conditions

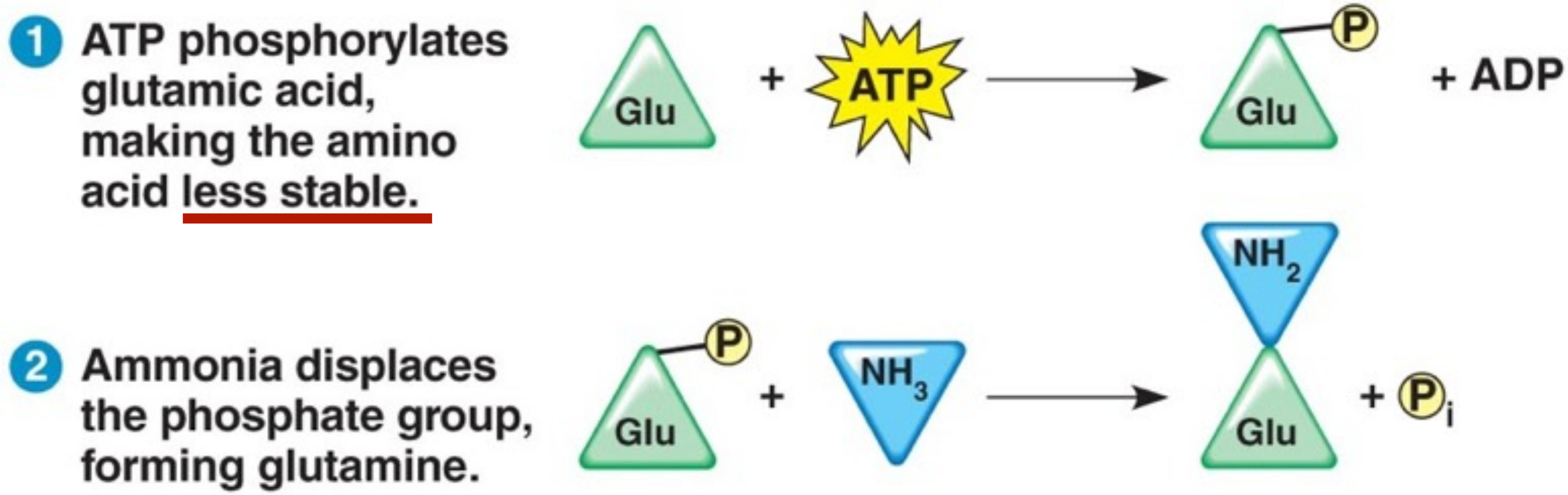
How the Hydrolysis of ATP Performs Work

- When ATP is hydrolyzed in a test tube, the release of free energy merely heats up the surroundings.
- At times this may be useful for an organism to warm itself
- However at other times this heat could be dangerous
- *Instead cells prefer to harness the energy released from ATP hydrolysis and use it power endergonic reactions and cellular work.*





(a) Endergonic reaction



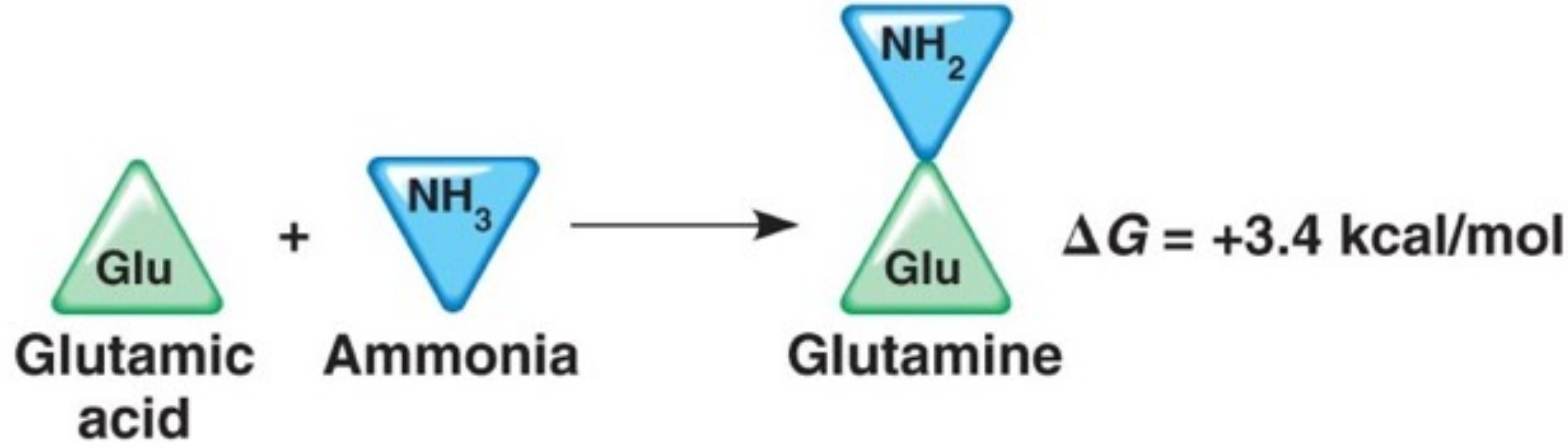
(b) Coupled with ATP hydrolysis, an exergonic reaction

$$Glu + NH_3 \longrightarrow Glu\text{—}NH_2 \qquad \Delta G = +3.4 \text{ kcal/mol}$$

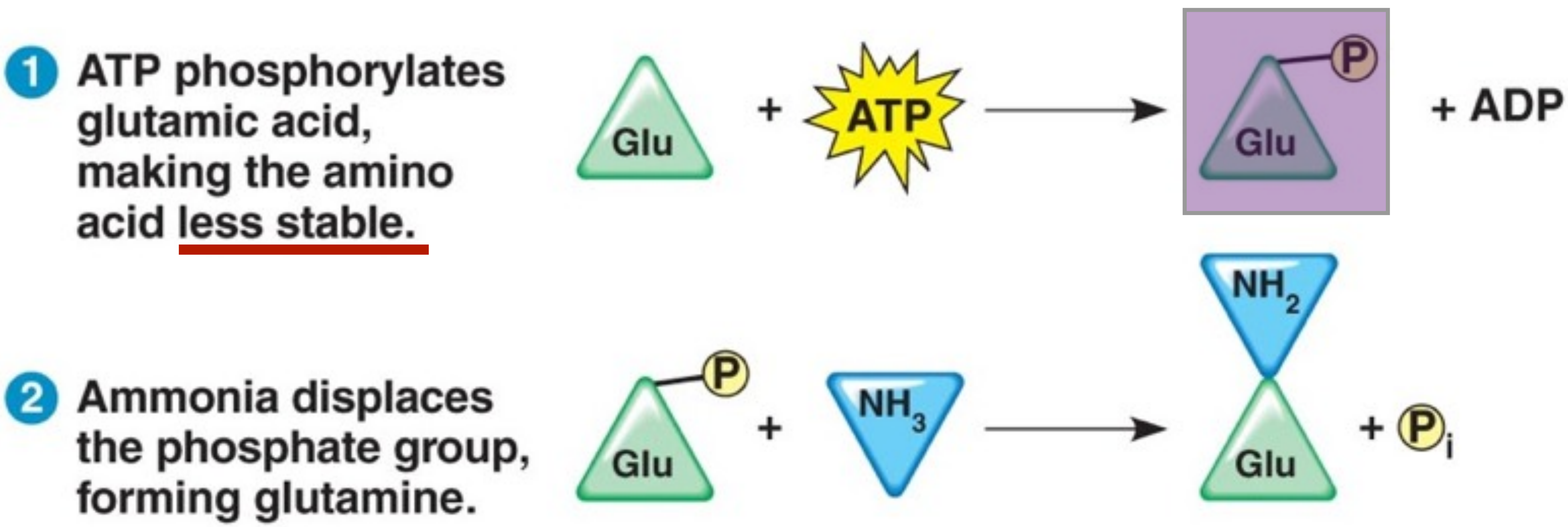
$$ATP \longrightarrow ADP + P_i \qquad \underline{\Delta G = -7.3 \text{ kcal/mol}}$$

$$\text{Net } \Delta G = -3.9 \text{ kcal/mol}$$

(c) Overall free-energy change



(a) Endergonic reaction



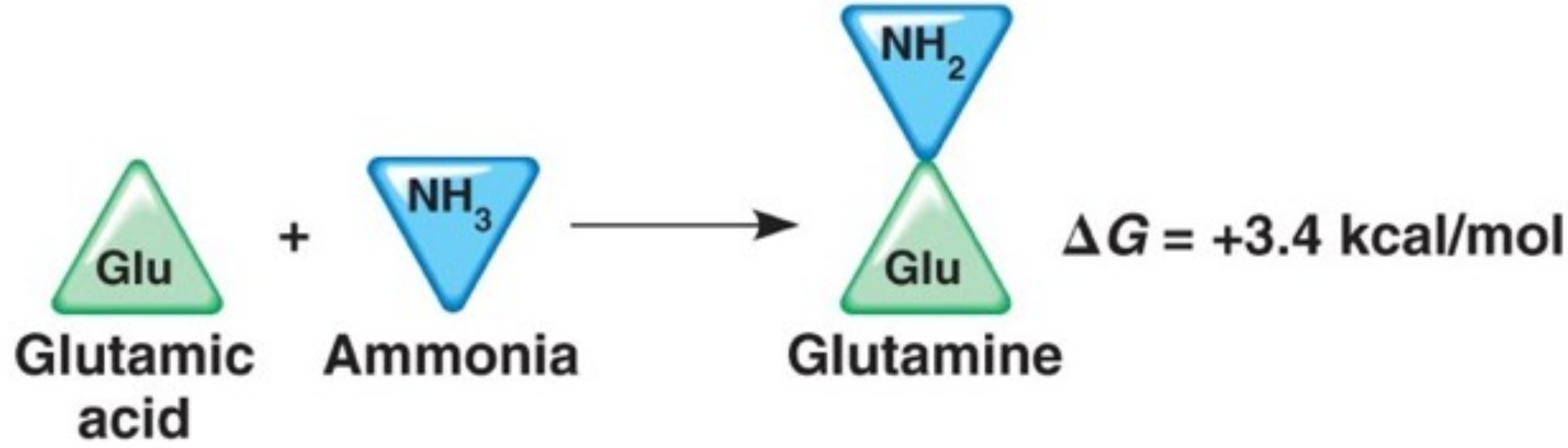
(b) Coupled with ATP hydrolysis, an exergonic reaction

$$\text{Glu} + NH_3 \longrightarrow \text{Glu—}NH_2 \qquad \Delta G = +3.4 \text{ kcal/mol}$$

$$\text{ATP} \longrightarrow \text{ADP} + P_i \qquad \Delta G = -7.3 \text{ kcal/mol}$$

$$\text{Net } \Delta G = -3.9 \text{ kcal/mol}$$

(c) Overall free-energy change

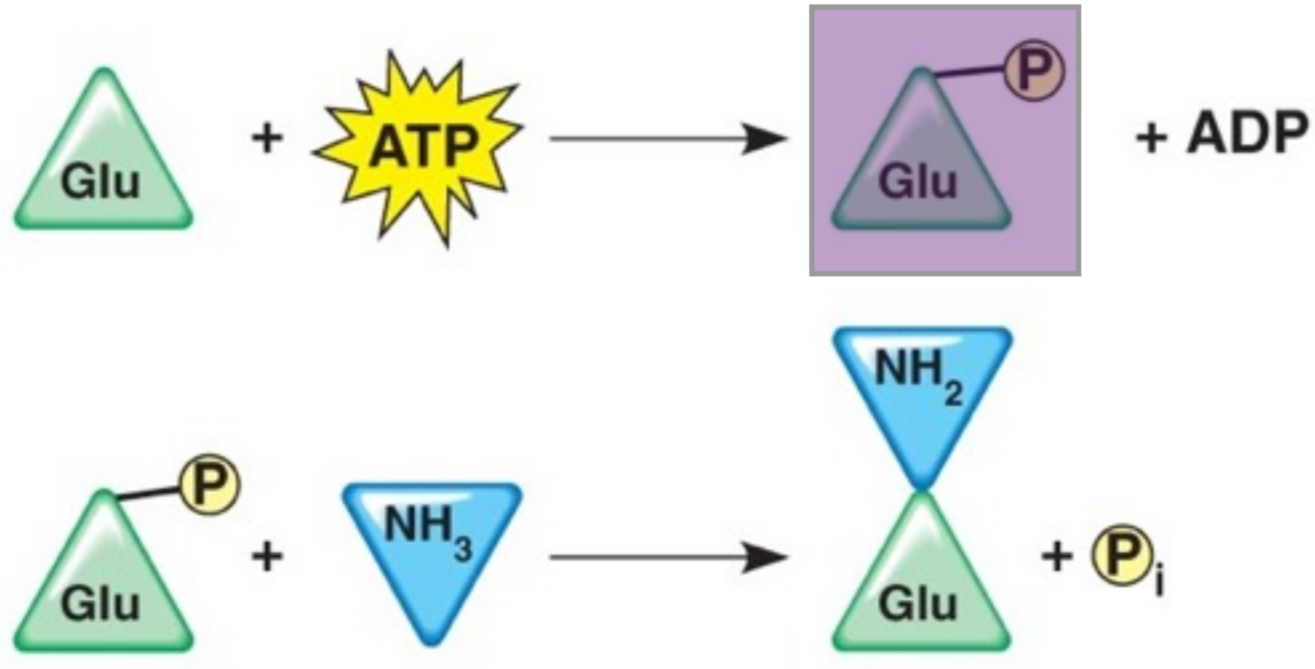


(a) Endergonic reaction

less stable

1 ATP phosphorylates glutamic acid, making the amino acid less stable.

2 Ammonia displaces the phosphate group, forming glutamine.



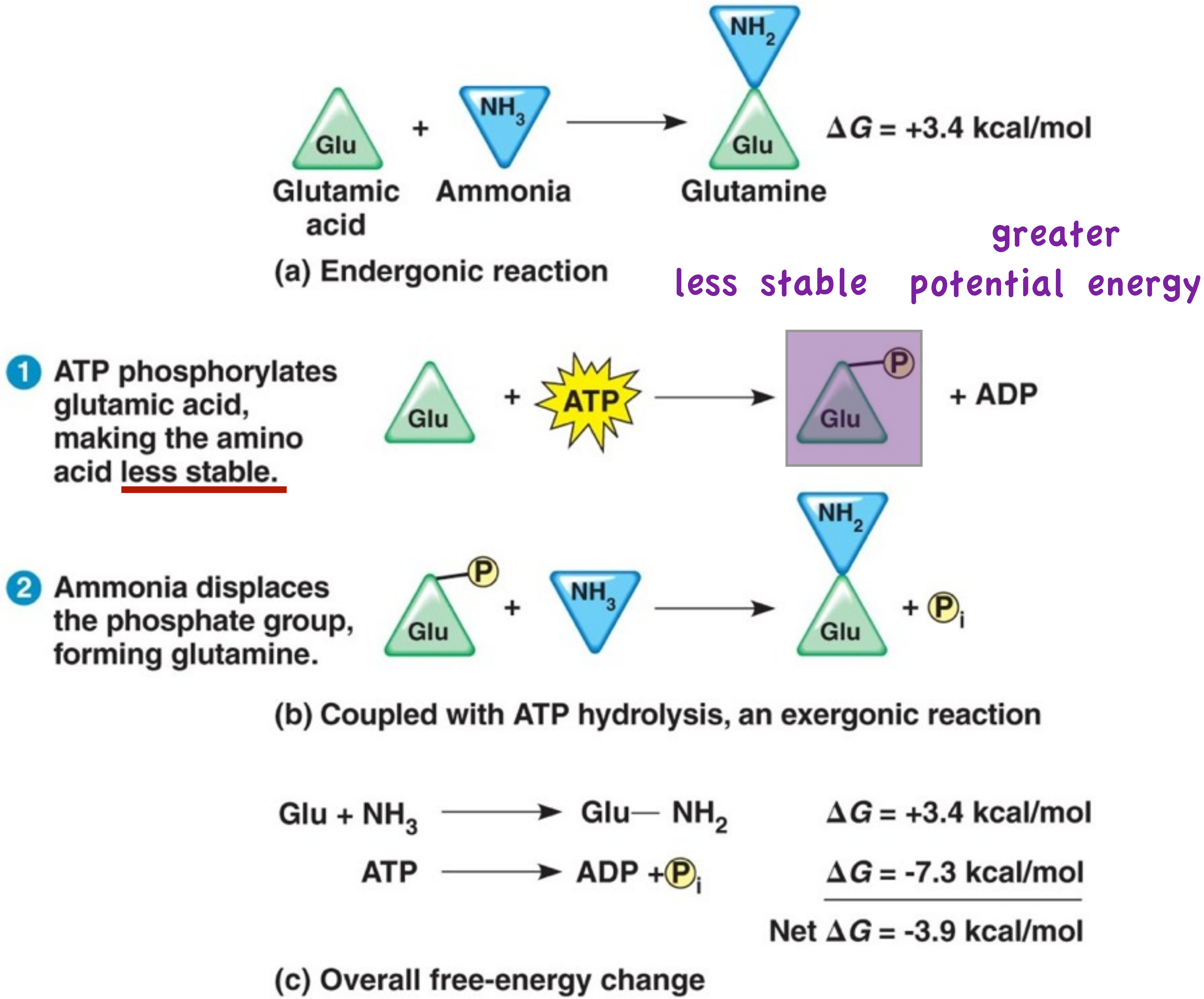
(b) Coupled with ATP hydrolysis, an exergonic reaction

$$\text{Glu} + NH_3 \longrightarrow \text{Glu—}NH_2 \qquad \Delta G = +3.4\ \text{kcal/mol}$$

$$\text{ATP} \longrightarrow \text{ADP} + P_i \qquad \Delta G = -7.3\ \text{kcal/mol}$$

$$\text{Net } \Delta G = -3.9\ \text{kcal/mol}$$

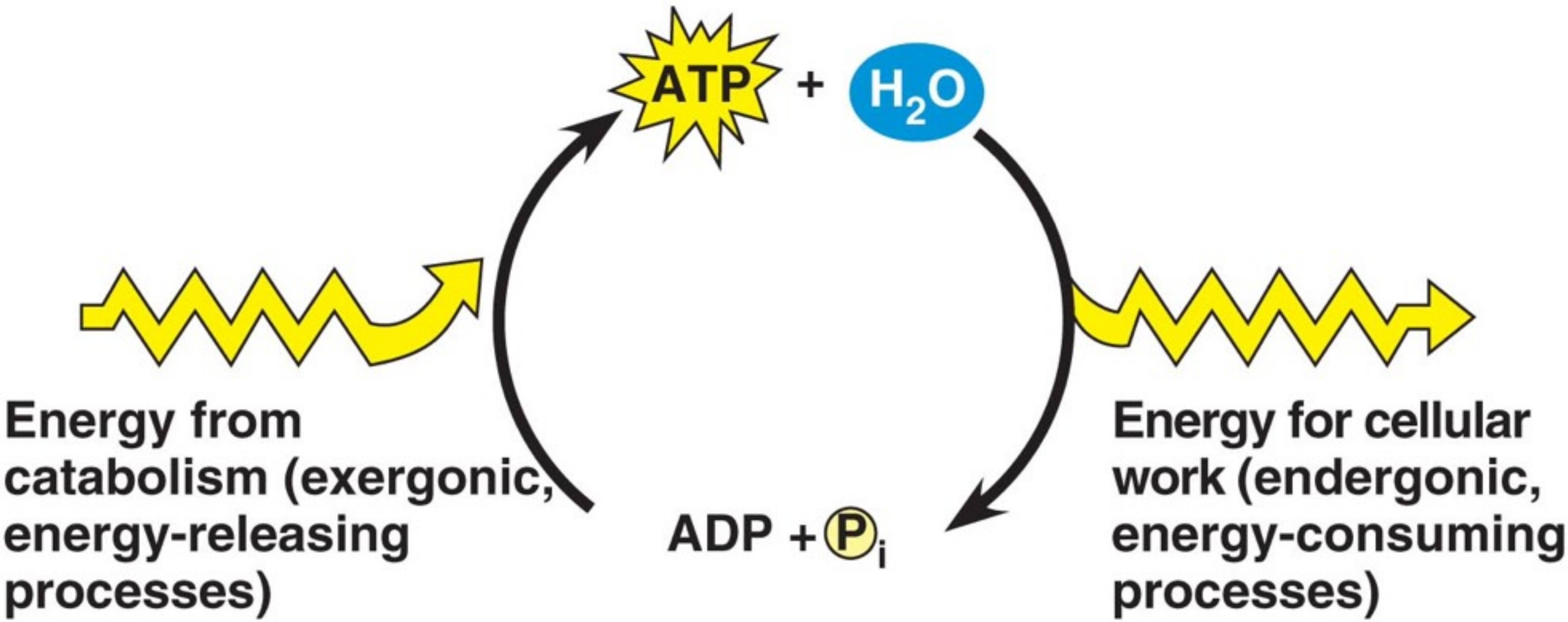
(c) Overall free-energy change



Glu
+
NH3
NH2
Glu
ΔG = +3.4 kcal/mol
Glutamic acid
Ammonia
Glutamine
(a) Endergonic reaction
greater
less stable
potential energy
1 ATP phosphorylates glutamic acid, making the amino acid less stable.
Glu
+
ATP
P
Glu
+ ADP
2 Ammonia displaces the phosphate group, forming glutamine.
P
Glu
+
NH3
NH2
Glu
+ Pi
(b) Coupled with ATP hydrolysis, an exergonic reaction
Glu + NH3
Glu— NH2
ΔG = +3.4 kcal/mol
ATP
ADP + Pi
ΔG = -7.3 kcal/mol
Net ΔG = -3.9 kcal/mol
(c) Overall free-energy change

The Regeneration of ATP

- ATP is hydrolyzed continuously.
- ATP is renewable and can be regenerated
- The ATP cycle below can consume and regenerate 10 million per second



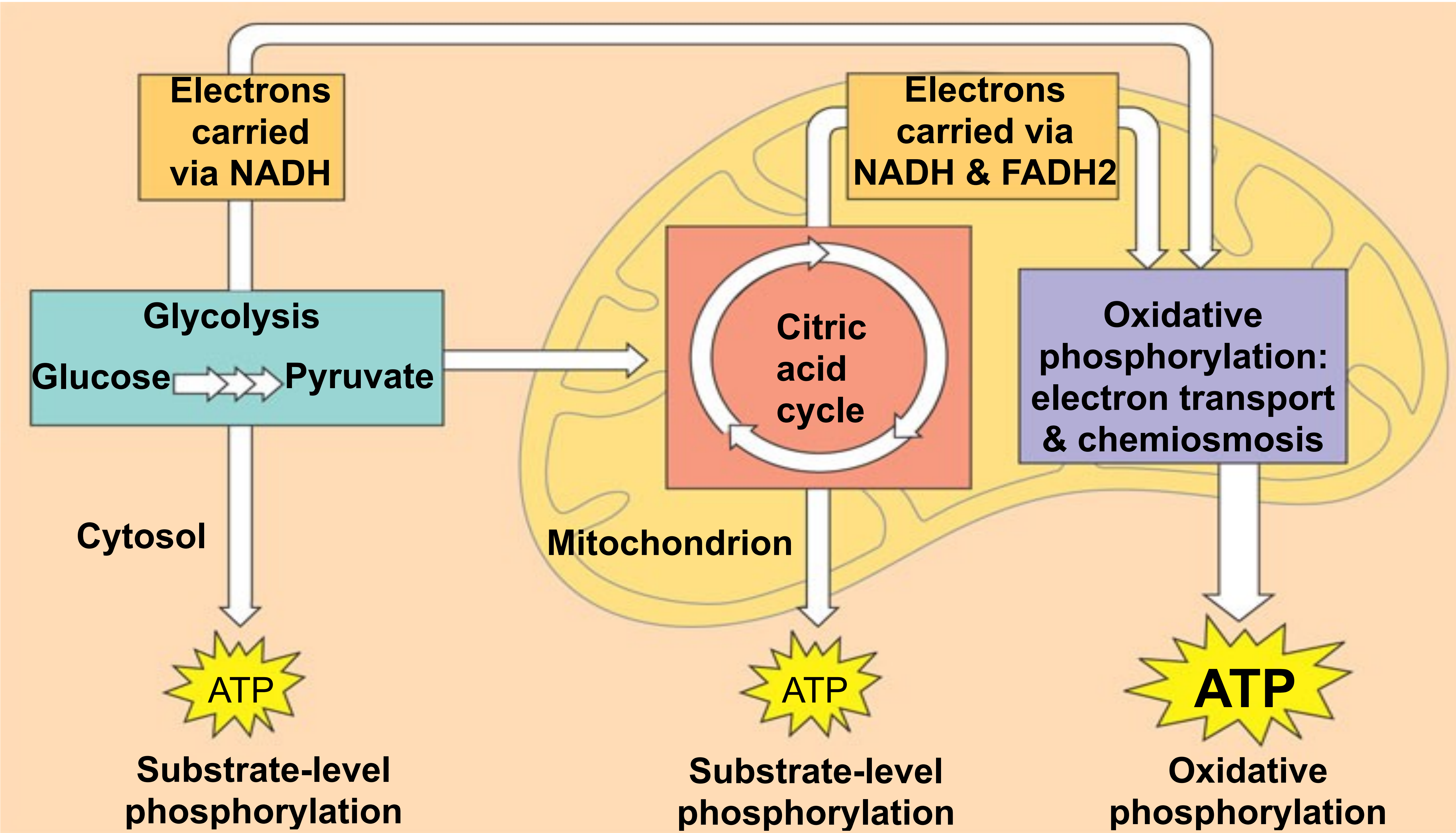
Essential knowledge 2.A.1: All living systems require constant input of free energy.

c. Energy-related pathways in biological systems are sequential and may be entered at multiple points in the pathway. [See also 2.A.2]

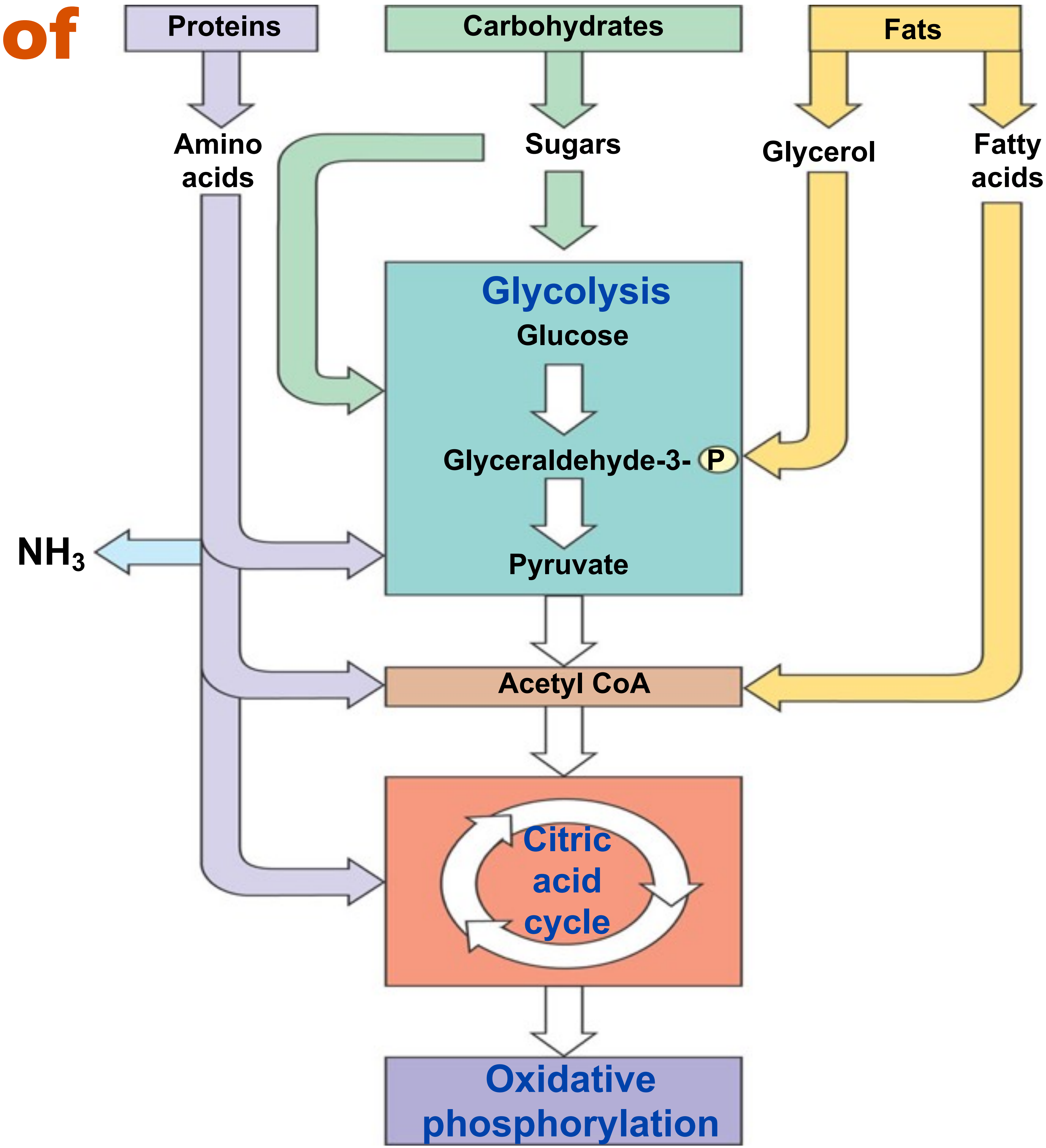
To foster student understanding of this concept, instructors can choose an illustrative example such as:

1. Krebs cycle
2. Glycolysis
3. Calvin cycle
4. Fermentation

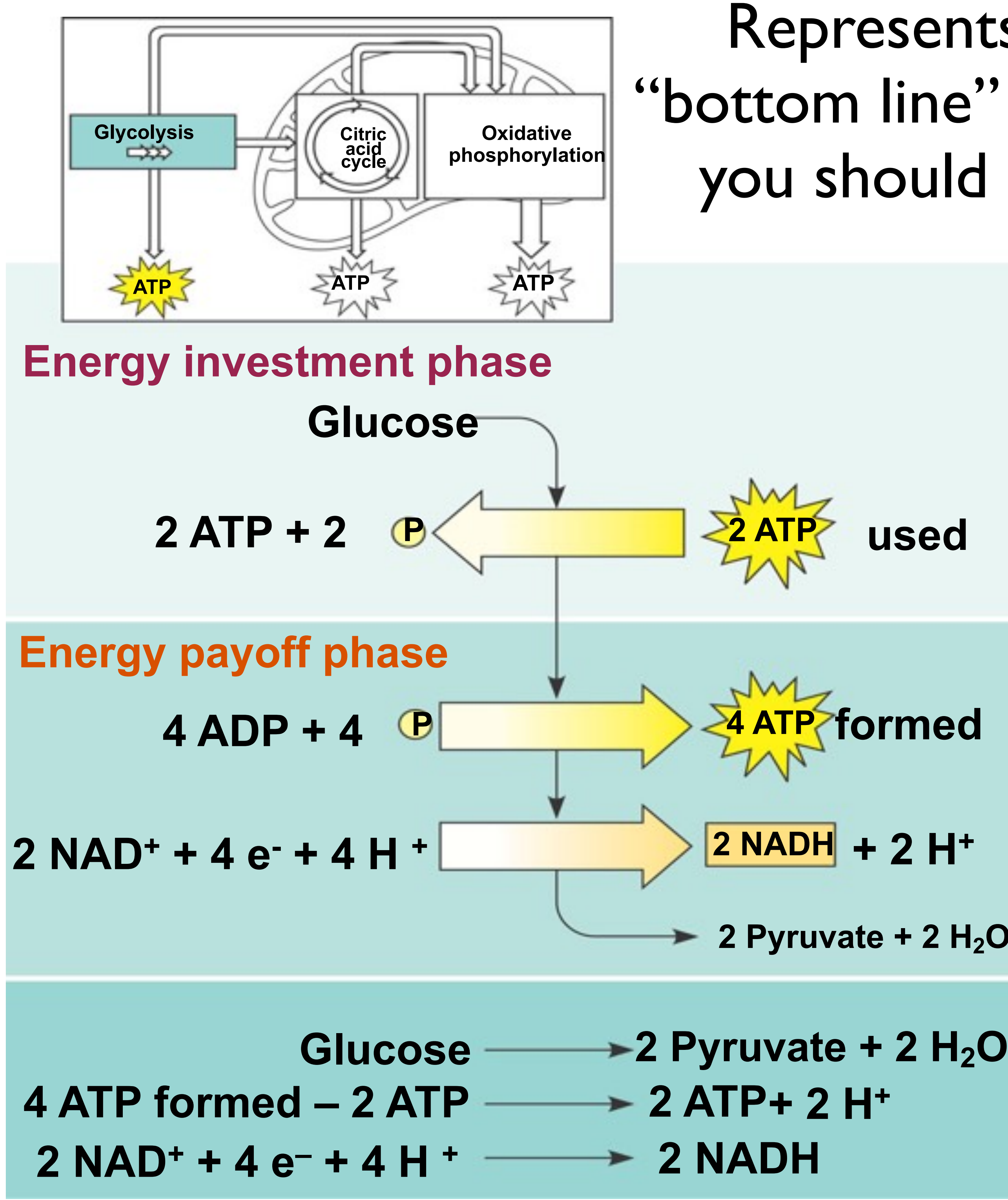
An Overview of Cellular Respiration



Versatility of Catabolic Pathways



An Overview of Glycolysis



Represents the "bottom line" of what you should know

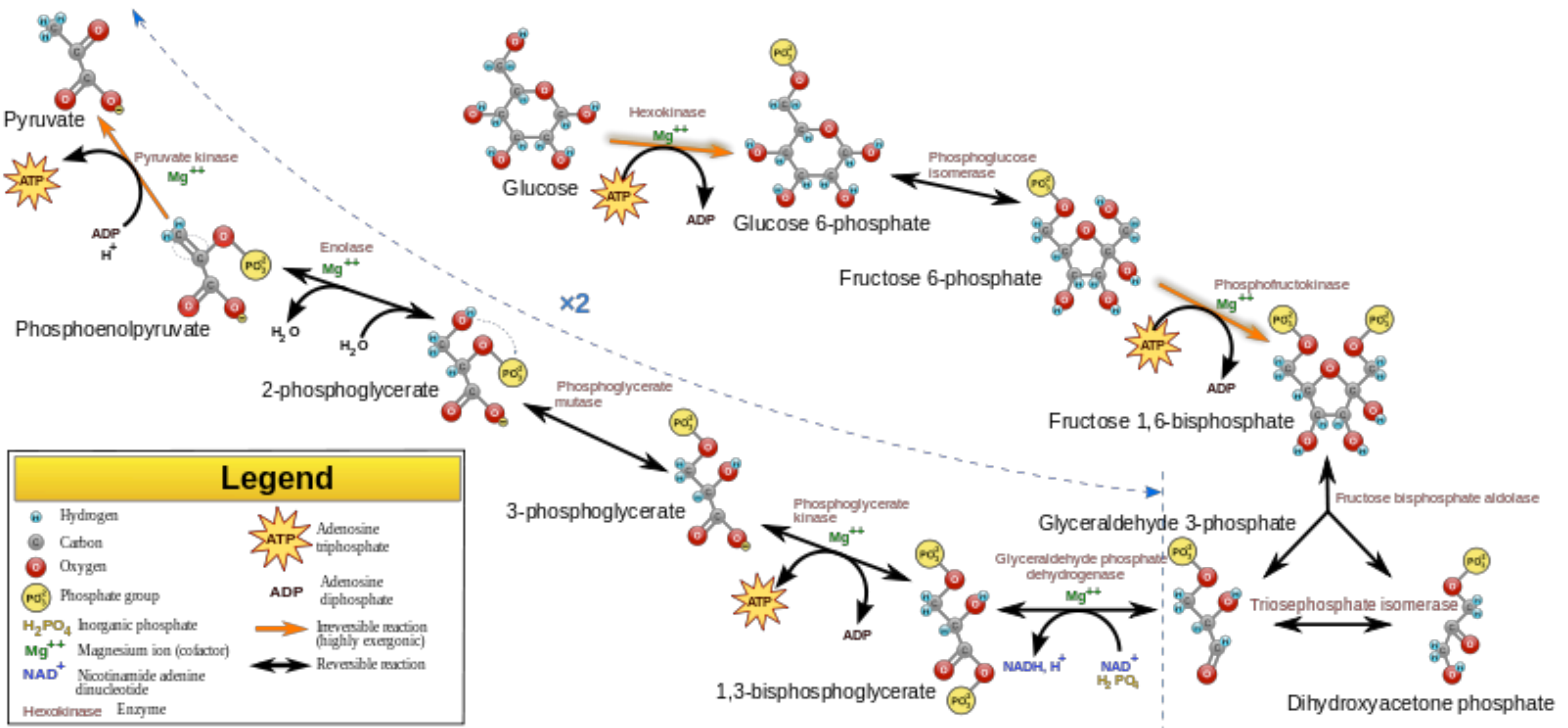
Glycolysis only extracts 25% of the potential energy, the rest still resides in pyruvate

A Closer Look at Glycolysis

You are not responsible for these details.

Instead let's use to do the following:

1. Notice the sequential nature of the metabolic pathway
2. Imagine how a cell could incorporate molecules into this pathway at various points
3. Look for exergonic reactions powering endergonic reactions



Essential knowledge 2.A.1: All living systems require constant input of free energy.

d. Organisms use free energy to maintain organization, grow and reproduce.

Evidence of student learning is a demonstrated understanding of each of the following:

1. Organisms use various strategies to regulate body temperature and metabolism.

To foster student understanding of this concept, instructors can choose an illustrative example such as:

1. Endothermy (the use of thermal energy generated by metabolism to maintain homeostatic body temperatures)
2. Ectothermy (the use of external thermal energy to help regulate and maintain body temperature)
3. Elevated floral temperatures in some plant species

Endothermy & Ectothermy

“source of heat”

- ***Endothermic*** organisms are warmed (from within) mostly by their metabolism
  - ex. birds, mammals
- ***Ectothermic*** organisms gain (from outside) most of their heat from external sources
  - ex. amphibians, lizards, snakes, fish

Note: These modes are not mutually exclusive!

Remember life's adaptations are all about "trade offs"

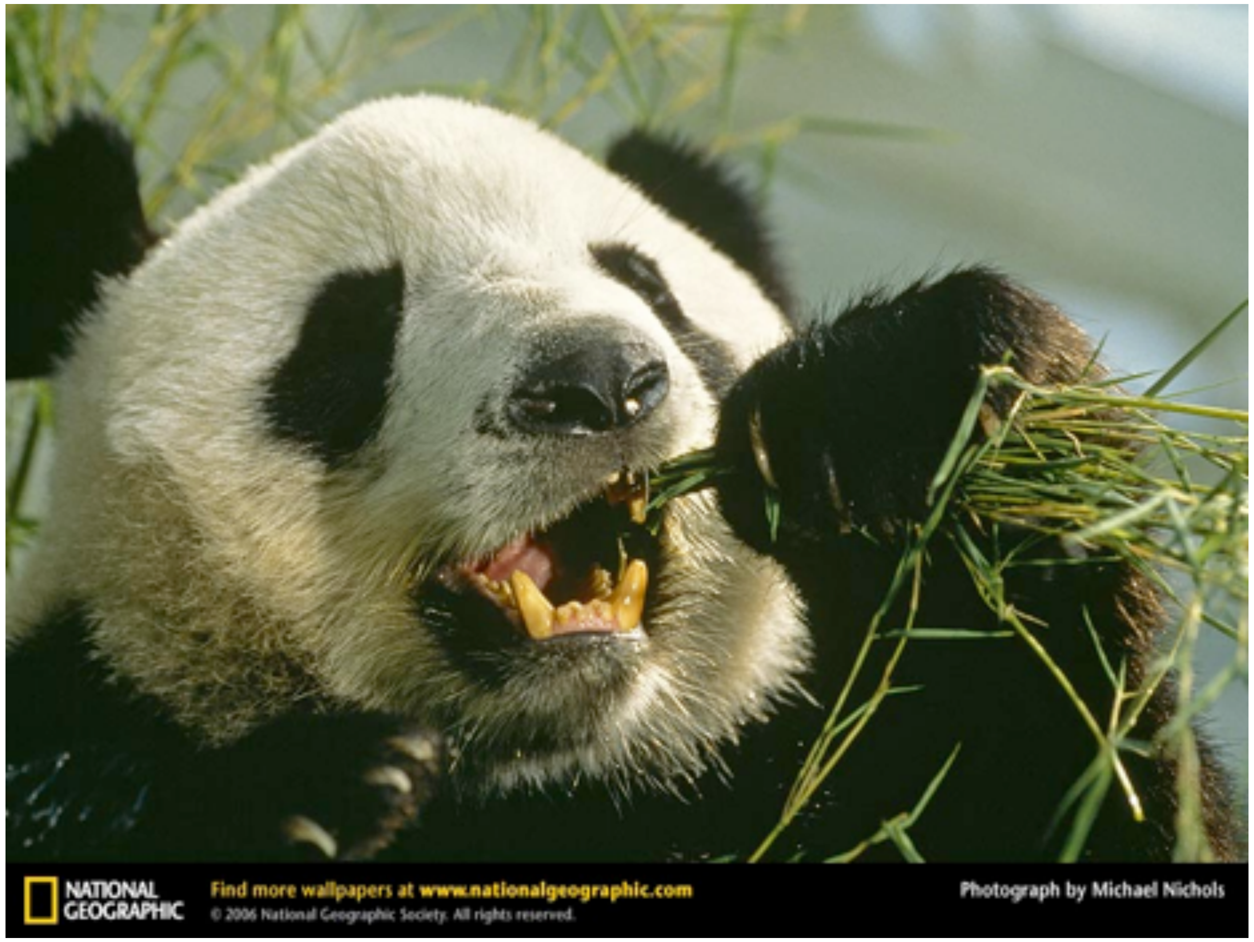
Endotherms...Pros!

- ***Endotherms*** can maintain stable body temps even with large fluctuations in environmental temps
- ***Endotherms*** function well in cold climates (not so for ectotherms)
- ***Endotherms*** function well in hot climates (they have cooling mechanisms)

Remember life's adaptations are all about "trade offs"

Endotherms...Cons!

- ***Endotherms*** do not tolerate large changes in their internal temps, inside temps are tightly regulated.
- ***Endotherms*** must consume large amounts of food to fuel their metabolisms



Remember life's adaptations are all about "trade offs"

Ectotherms...Pros!

- ***Ectotherms*** can tolerate a larger range of internal temps
- ***Endotherms*** do not require large amounts of food

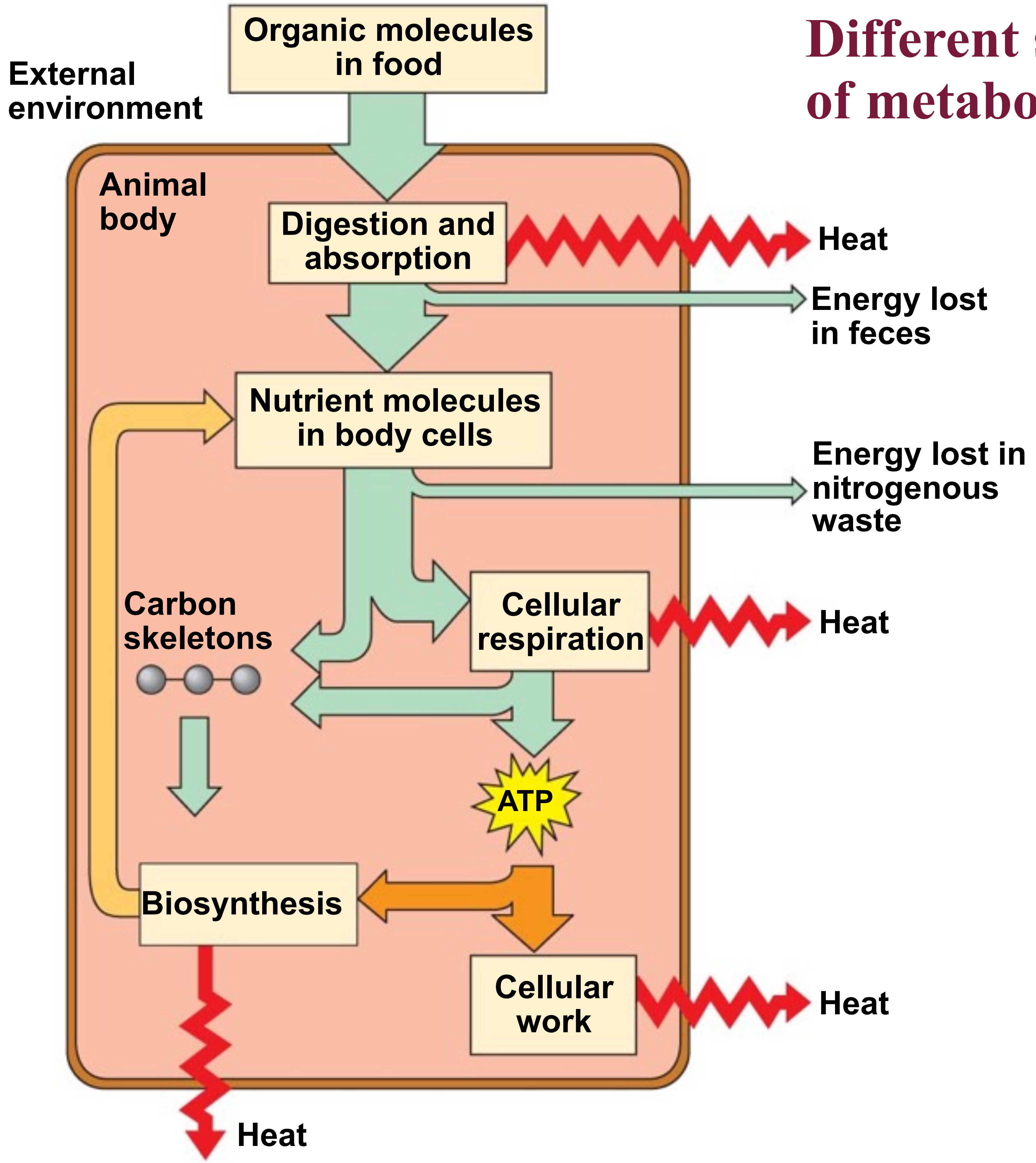
Remember life's adaptations are all about "trade offs"

Ectotherms...Cons!

- ***Ectotherms*** do not tolerate sudden and or large fluctuations in environmental temperatures
- ***Ectotherms*** are rarely active in cold climates

In spite of this ectothermy is a successful strategy for thermoregulation supported by the abundance and diversity of ectothermic organisms

Different sources of metabolic heat



Adjusting Metabolic Heat Production

- Endotherms can vary heat production-***thermogenesis***-to match changing rates of heat loss.
  - ex. increase muscle activity through moving or shivering.
  - Check this out...chickadees can maintain a body temp of 40℃ (104 °F) in temps as low as -40 ℃ (-40 °F)
- Some mammals can generate heat at the cellular level through increase ATP production- *nonshivering thermogenesis*.
- *Brown fat* located in the neck and shoulder region is specialized for rapid heat production
  - brown fat accounts for 5% of total body weight in human infants

Essential knowledge 2.A.1: All living systems require constant input of free energy.

d. Organisms use free energy to maintain organization, grow and reproduce.

Evidence of student learning is a demonstrated understanding of each of the following:

2. Reproduction and rearing of offspring require free energy beyond that used for maintenance and growth. Different organisms use various reproductive strategies in response to energy availability.

To foster student understanding of this concept, instructors can choose an illustrative example such as:

1 Seasonal reproduction in animals and plants

2 Life-history strategy (biennial plants, reproductive diapause)

Animal Reproduction (Sexual)

Reproductive Cycles

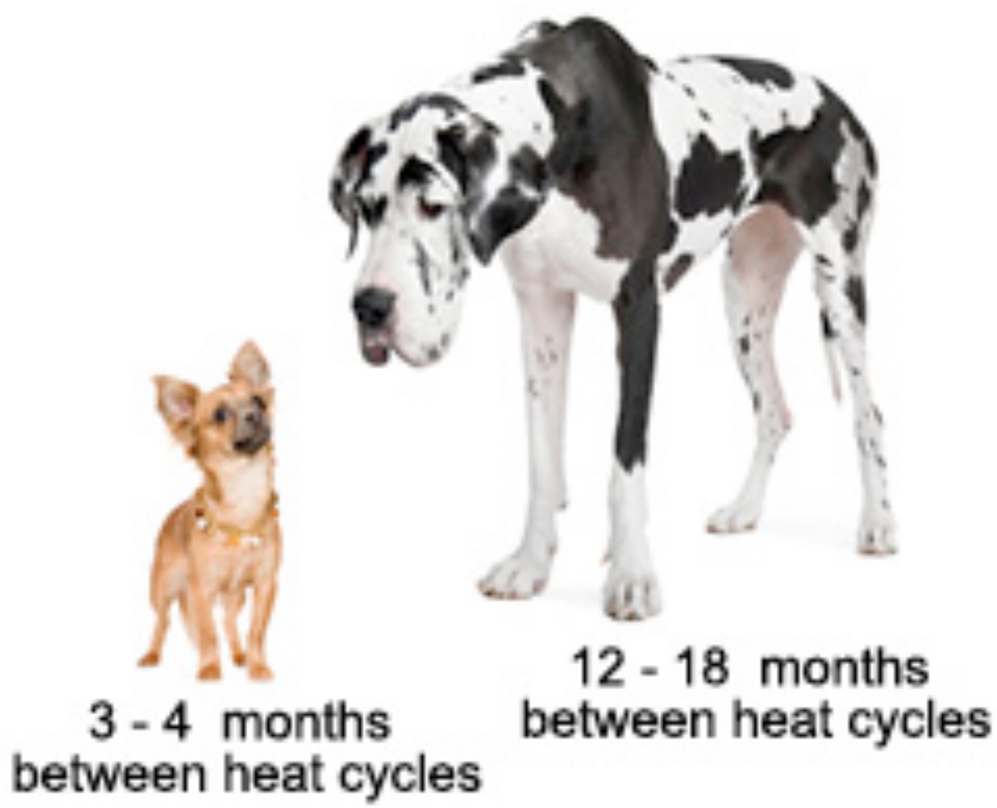
- Most animals exhibit cycles in reproductive activity
- Cycles are often seasonal
  - reproduction takes place when resources are most available and environmental conditions most favorable
  - Ex. Sheep
    - Ewes (females) are fertile for two weeks in the fall
    - sheep gestation period is 5 months
    - lambs are born in the spring
  - Cycles are controlled by hormones
  - Regulated by environmental cues: light, temp, rainfall, etc

Reproductive Cycles & Climate Change

- Because reproductive cycles are often seasonal, climate change can decrease reproductive success
- Danish scientists have shown a 75% decline in Caribou reproduction compared 1993
  - Caribou migrate to calving grounds using daylight length as their cue
  - Since 1993 the average spring temps have rise by 4 degrees C.
  - As a result tundra thaws earlier, plants sprout earlier and the timing has resulted in less nutrition for nursing females and a higher mortality rate among calfs

Estrous Cycles

- Season /climate has strong effect on these cycles
- Only time when vaginal changes permit mating
- Rat cycle is 5 days, some like bears and dogs have only one cycle per year (others a few)



Population Ecology

Main Idea: The "purpose of life" is pass genes into the future.

Main Idea: In order to do this successfully life must first *survive* and then *reproduce*.

Main Idea: *Natural selection* has favored certain *life histories* over others. Think of these *life histories* as strategies for reproductive success.

Do you think that the perfect life history exists today? If not will it exist in the future? Why or Why not?

LIFE HISTORY TRAITS

- traits that influence an organisms survival and reproduction
- entails 4 main variables
  - *WHEN* reproduction begins
    - (age of 1st reproductive attempt or age of maturity)
  - *HOW OFTEN* they reproduce
    - (once in their life or multiple times throughout)
  - *HOW MANY* offspring they produce
    - (per reproductive attempt or cycle)
  - *PARENTAL CARE* they provide
    - (can range from no care at all to years of extensive care)

Evolution of Life History Diversity

- Nature has selected the most successful reproductive strategies over time
  - Like all adaptations there are "Trade Offs"
    - limited resources, competition and a multitude other important life functions will not allow for the perfect adaptation(s)
  - Like all adaptations there is No Conscious Choice reflected in an organisms development, behavior, physiology or structure

How is a peacocks tail an example of a "trade off"?

What famous biologist formulated ideas about evolution that involved aspects of choice in an organisms acquisition of adaptations?

Evolution of Life History Diversity

- Many life histories exist but looking at Two opposing extremes helps us to better understand all of the different life histories
- Semelparity and Iteroparity represent the two ideal and opposing life strategies
  - Semelparity: "big bang" reproduction, a one time effort that results in the production of hundreds to millions of gametes, seeds or offspring
  - This is the "Quantity Strategy"!
  - It is commonly favored/found in species who live in 1.)harsh and unpredictable environments, 2.)species with high infant mortality and 3.)species who are preyed upon
    - Ex. salmon, agave, annuals, squid, arachnids, grain crops, most vegetables, butterflies

Evolution of Life History Diversity

- Semelparity and Iteroparity represent the two ideal and opposing life strategies
  - Iteroparity: "repeated" reproductive efforts, each resulting in the production of a few, large gametes, seeds or offspring
  - This is the "Quality Strategy"!
  - It is commonly favored/found in species who live in 1.) dependable environments with plenty of resources, 2.)species who live near their carrying capacity 3.)species who are involved in intense competition for resources
    - Ex. perennial plants, cockroaches, mosquitoes, all birds, most mammals, reptiles, fish

In reality most life histories are intermediate and specific to each species situation

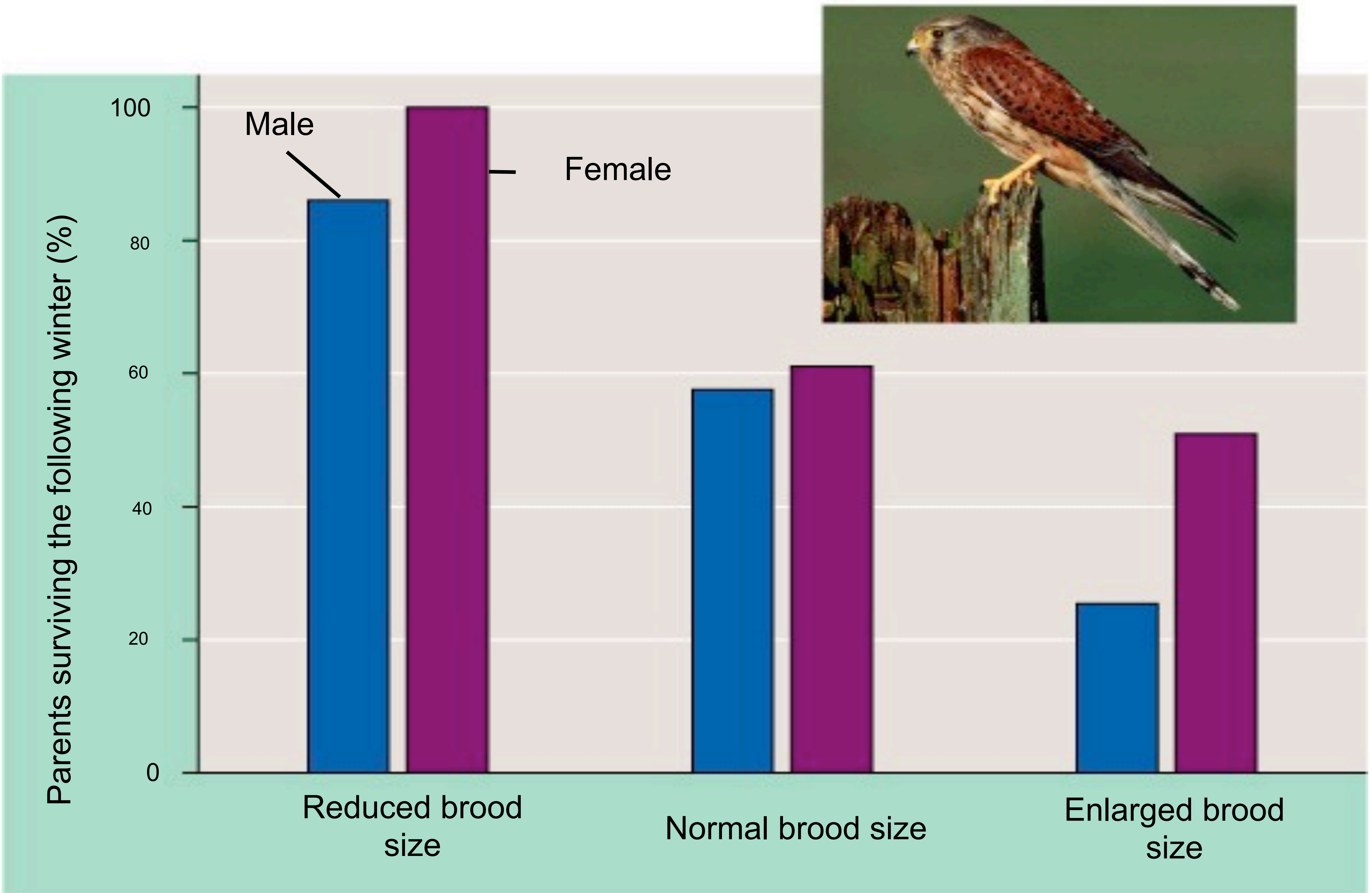
Trade Offs (Cost/Benefit Analysis)

- There is an indirect relationship between the number of offspring and parental care.
  - producing more offspring puts more genes into the future but the provisions will have to go down as time and resources are limited thus quality is sacrificed
  - producing less allows for better provision but less offspring means less genes going into the future thus quantity is sacrificed

Bottom Line...Selective Pressures influence the number and size of offspring along with the extent of care given.

EXPERIMENT

Researchers in the Netherlands studied the effects of parental caregiving in European kestrels over 5 years. The researchers transferred chicks among nests to produce reduced broods (three or four chicks), normal broods (five or six), and enlarged broods (seven or eight). They then measured the percentage of male and female parent birds that survived the following winter. (Both males and females provide care for chicks.)



CONCLUSION The lower survival rates of kestrels with larger broods indicate that caring for more offspring

Essential knowledge 2.A.1: All living systems require constant input of free energy.

d. Organisms use free energy to maintain organization, grow and reproduce.

Evidence of student learning is a demonstrated understanding of each of the following:

3. There is a relationship between metabolic rate per unit body mass and the size of multicellular organisms — generally, the smaller the organism, the higher the metabolic rate.

- Concept 40.3: Animals use the chemical energy in food to sustain form and function
- All organisms require chemical energy for
  - Growth, repair, physiological processes, regulation, and reproduction

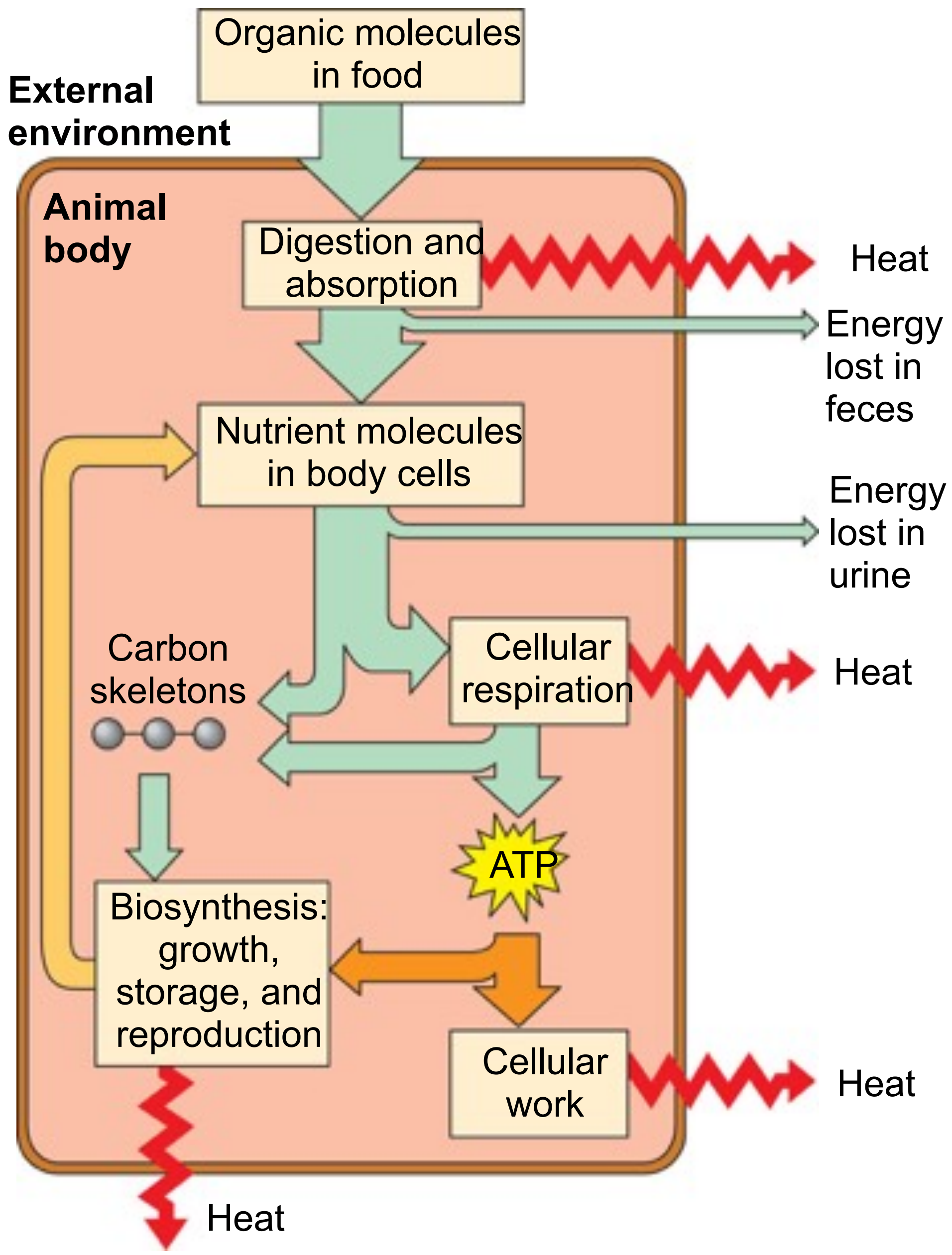
Bioenergetics

- The flow of energy through an animal, its bioenergetics
  – Ultimately limits the animal's behavior, growth, and reproduction
  – Determines how much food it needs
- Studying an animal's bioenergetics
  – Tells us a great deal about the animal's adaptations

Energy Sources and Allocation

- Animals harvest chemical energy
  - From the food they eat
- Once food has been digested, the energy-containing molecules
  - Are usually used to make ATP, which powers cellular work

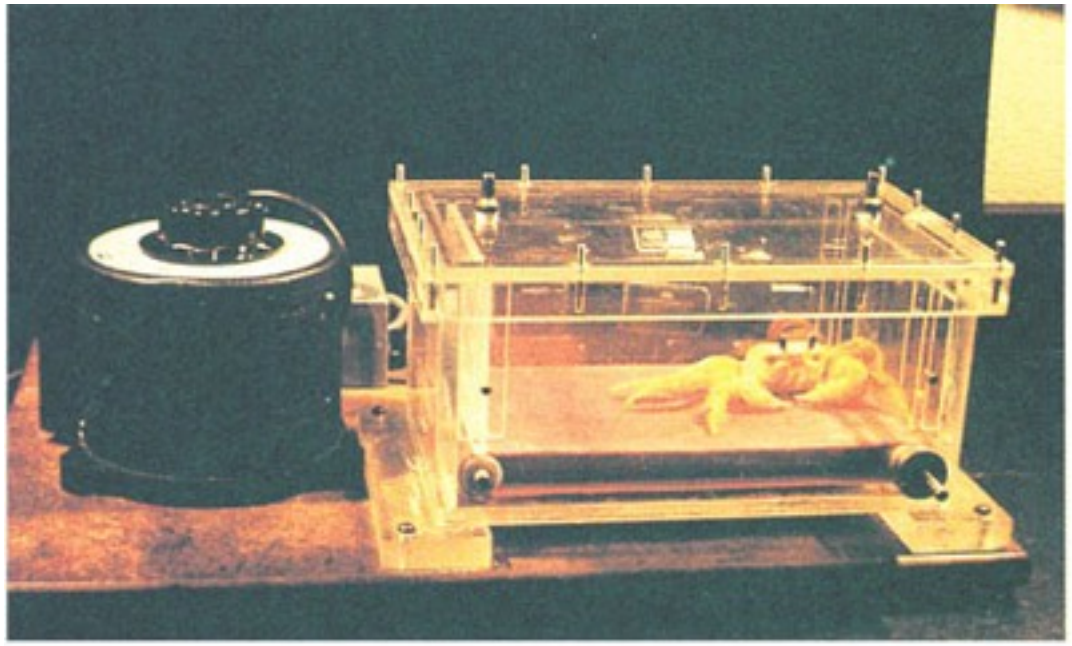
- After the energetic needs of staying alive are met
  - Any remaining molecules from food can be used in biosynthesis



Quantifying Energy Use

- An animal's metabolic rate
  - Is the amount of energy an animal uses in a unit of time
  - Can be measured in a variety of ways

- One way to measure metabolic rate
  - Is to determine the amount of oxygen consumed or carbon dioxide produced by an organism



(a) This photograph shows a ghost crab in a respirometer. Temperature is held constant in the chamber, with air of known O_2 concentration flowing through. The crab's metabolic rate is calculated from the difference between the amount of O_2 entering and the amount of O_2 leaving the respirometer. This crab is on a treadmill, running at a constant speed as measurements are made.

(b) Similarly, the metabolic rate of a man fitted with a breathing apparatus is being monitored while he works out on a stationary bike.

Bioenergetic Strategies

- An animal's metabolic rate
  - Is closely related to its bioenergetic strategy

- Birds and mammals are mainly endothermic, meaning that
  - Their bodies are warmed mostly by heat generated by metabolism
  - They typically have higher metabolic rates

- Amphibians and reptiles other than birds are ectothermic, meaning that
  - They gain their heat mostly from external sources
  - They have lower metabolic rates

Influences on Metabolic Rate

- The metabolic rates of animals
  - Are affected by many factors

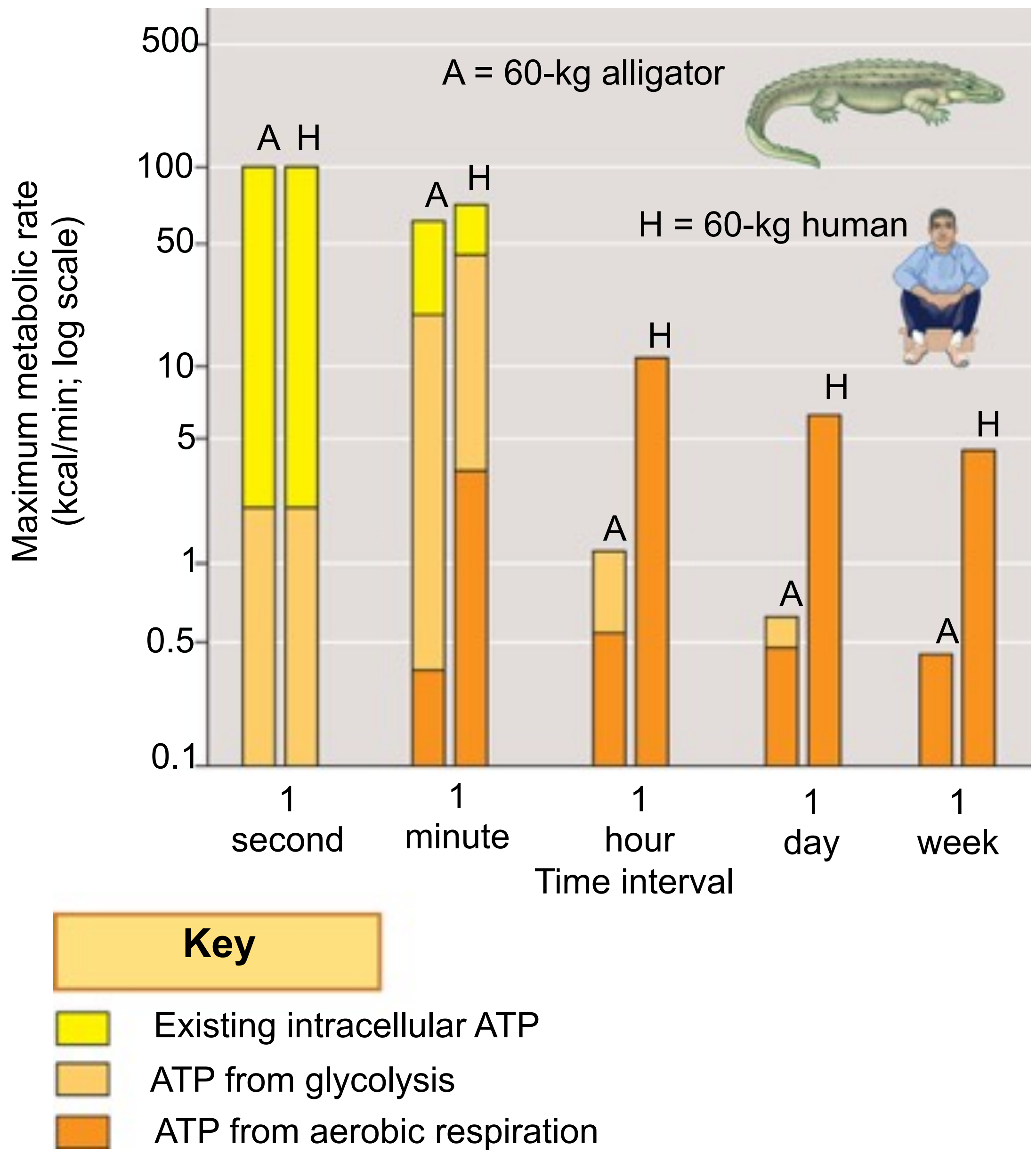
Size and Metabolic Rate

- Metabolic rate per gram
- Is inversely related to body size among similar animals

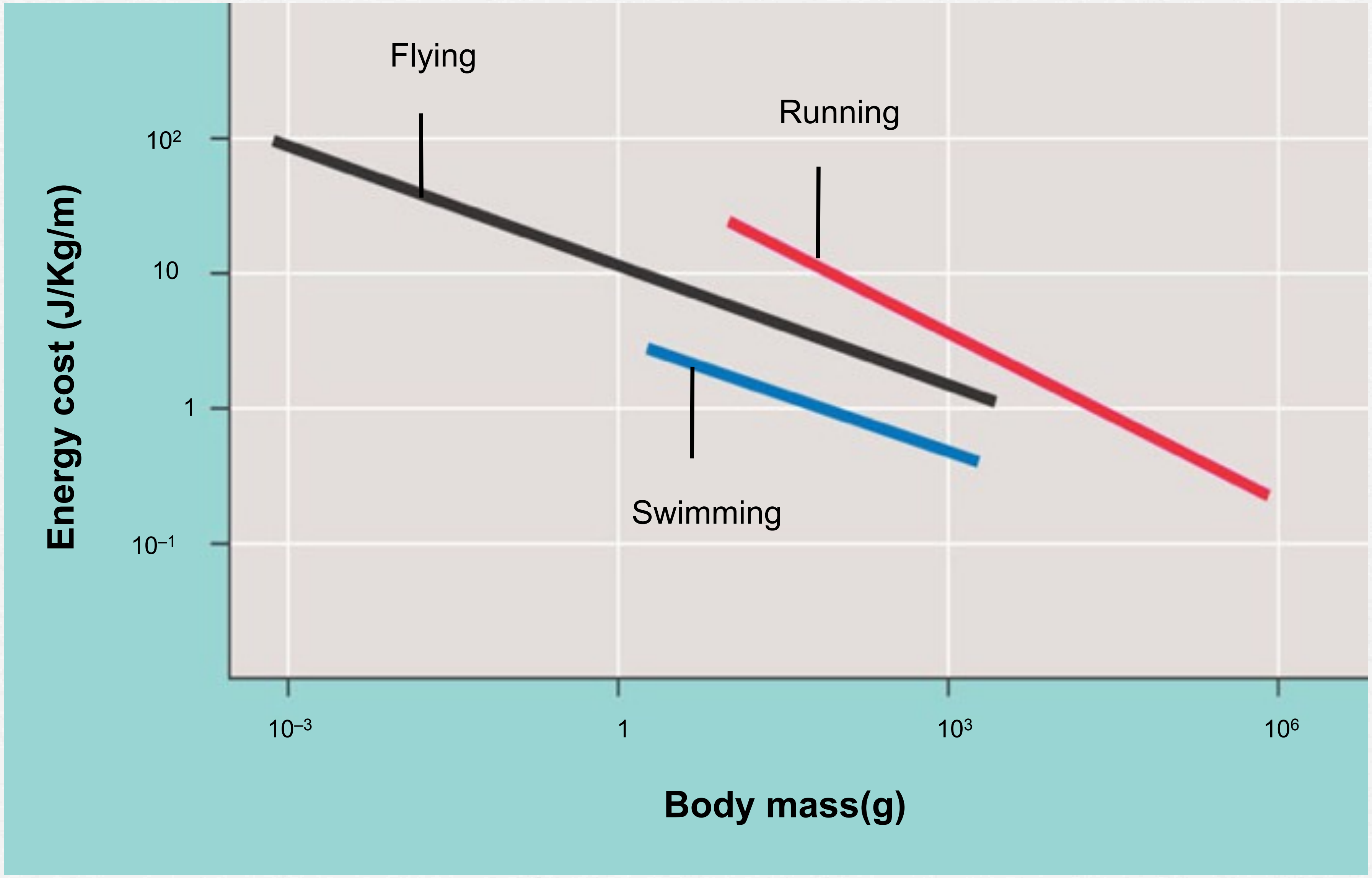
Activity and Metabolic Rate

- The basal metabolic rate (BMR)
  - Is the metabolic rate of an endotherm at rest
- The standard metabolic rate (SMR)
  - Is the metabolic rate of an ectotherm at rest
- For both endotherms and ectotherms
  - Activity has a large effect on metabolic rate

- In general, an animal's maximum possible metabolic rate
  - Is inversely related to the duration of the activity



Energy Costs of Locomotion



For animals of a given body mass, swimming is the most energy-efficient and running the least energy-efficient mode of locomotion.

In any mode, a small animal expends more energy per kilogram of body mass than a large animal.

*When we look at energy cost per minute (instead of per meter) flying is the least energy-efficient mode of locomotion.

Essential knowledge 2.A.1: All living systems require constant input of free energy.

d. Organisms use free energy to maintain organization, grow and reproduce.

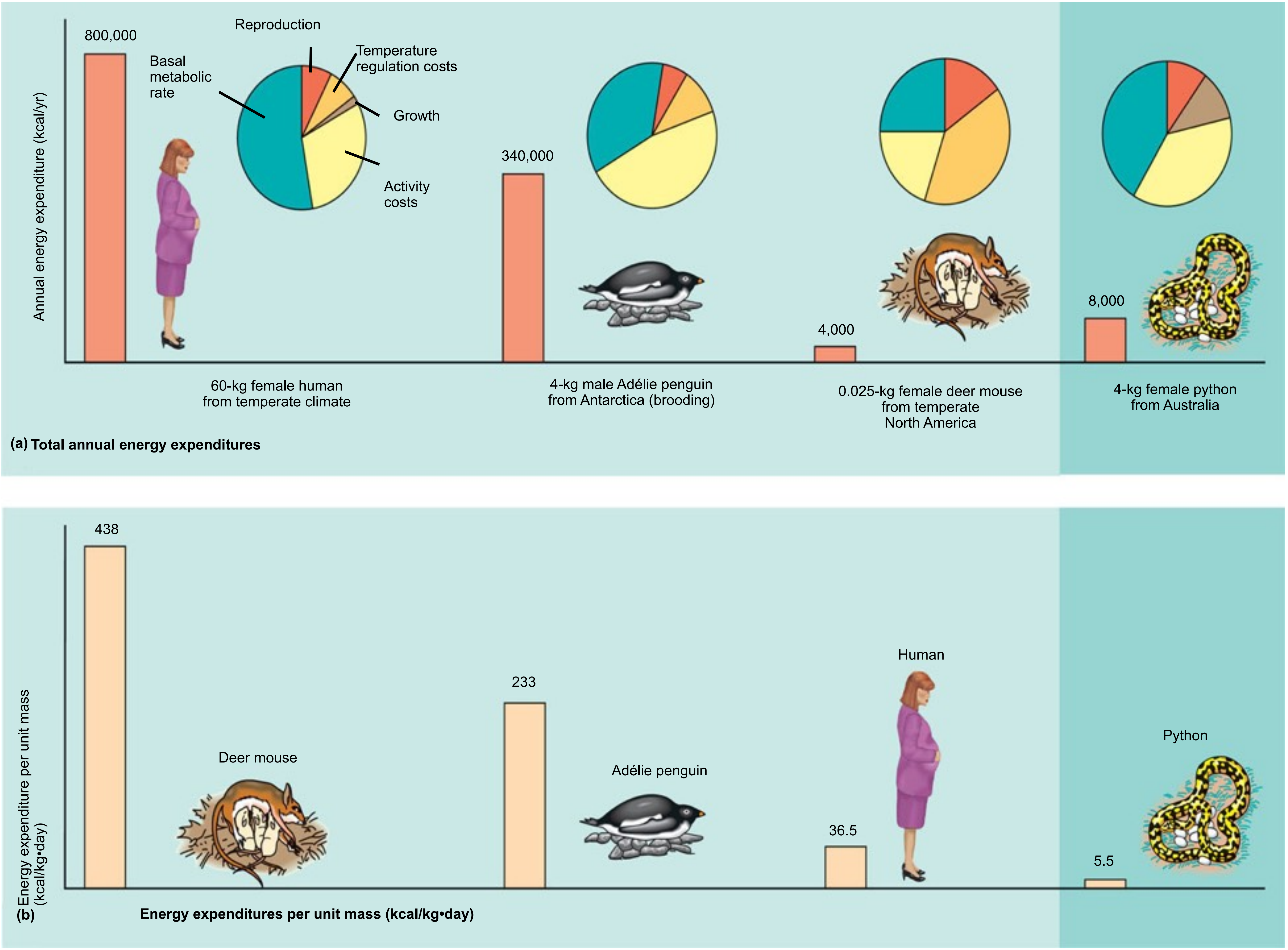
Evidence of student learning is a demonstrated understanding of each of the following:

4. Excess acquired free energy versus required free energy expenditure results in energy storage or growth.

Energy Budgets

- Different species of animals
  - Use the energy and materials in food in different ways, depending on their environment

- An animal's use of energy
  - Is partitioned to BMR (or SMR), activity, homeostasis, growth, and reproduction



Annual energy expenditure (kcal/yr)
800,000
Reproduction
Basal metabolic rate
Temperature regulation costs
Growth
Activity costs
340,000
4,000
8,000
60-kg female human from temperate climate
4-kg male Adélie penguin from Antarctica (brooding)
0.025-kg female deer mouse from temperate North America
4-kg female python from Australia
(a) Total annual energy expenditures
Energy expenditure per unit mass (kcal/kg•day)
438
Deer mouse
233
Adélie penguin
Human
36.5
Python
5.5
(b) Energy expenditures per unit mass (kcal/kg•day)

Essential knowledge 2.A.1: All living systems require constant input of free energy.

d. Organisms use free energy to maintain organization, grow and reproduce.

Evidence of student learning is a demonstrated understanding of each of the following:

5. Insufficient acquired free energy versus required free energy expenditure results in loss of mass and, ultimately, the death of an organism.

Essential knowledge 2.A.1: All living systems require constant input of free energy.

e. Changes in free energy availability can result in changes in population size.

Population Ecology

Main Idea: Conditions are rarely ideal and as such the environment can support a limited number of individuals

Main Idea: The maximum number of individuals that the environment can sustain is its carrying capacity.

Main Idea: Population growth rate decreases as a population approaches its carrying capacity.

"REAL" POPULATION GROWTH

- Start with exponential growth and add an expression that reduces the per capita rate of increase as N increases.
    - *K = carrying capacity*
    - *so (K-N)/K is the fraction of K that is still available for population growth*
        - *population growth decreases dramatically as N approaches K, furthermore K (carrying capacity) is certainly determined in part by the available energy*

A. Logistic Growth Model

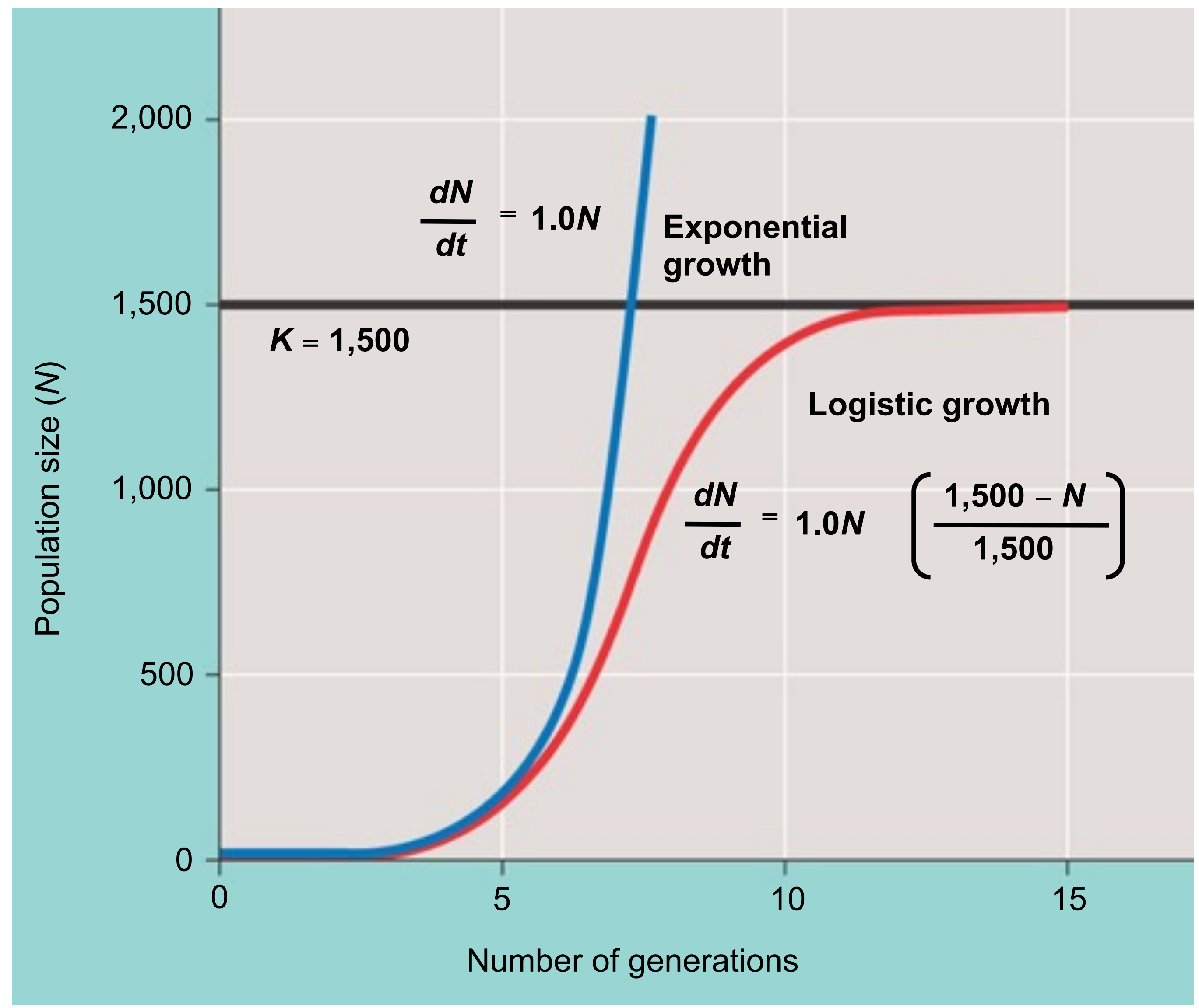
- "graphed" **logistic growth** takes on a "**S**" shaped curve
- the equation for logistic growth is seen below

$$\frac{dN}{dt} = r_{max}N\frac{(K - N)}{K}$$

Table 52.3 **A Hypothetical Example of Logistic Population Growth, Where $K = 1{,}000$ and $r_{max} = 0.05$ per Individual per Year**

Population Size: N	Intrinsic Rate of Increase: r_{max}	$\left(\frac{K-N}{K}\right)$	Per Capita Growth Rate: $r_{max}\left(\frac{K-N}{K}\right)$	Population Growth Rate:* $r_{max}N\left(\frac{K-N}{K}\right)$
20	0.05	0.98	0.049	+1
100	0.05	0.90	0.045	+5
250	0.05	0.75	0.038	+9
500	0.05	0.50	0.025	+13
750	0.05	0.25	0.013	+9
1,000	0.05	0.00	0.000	0

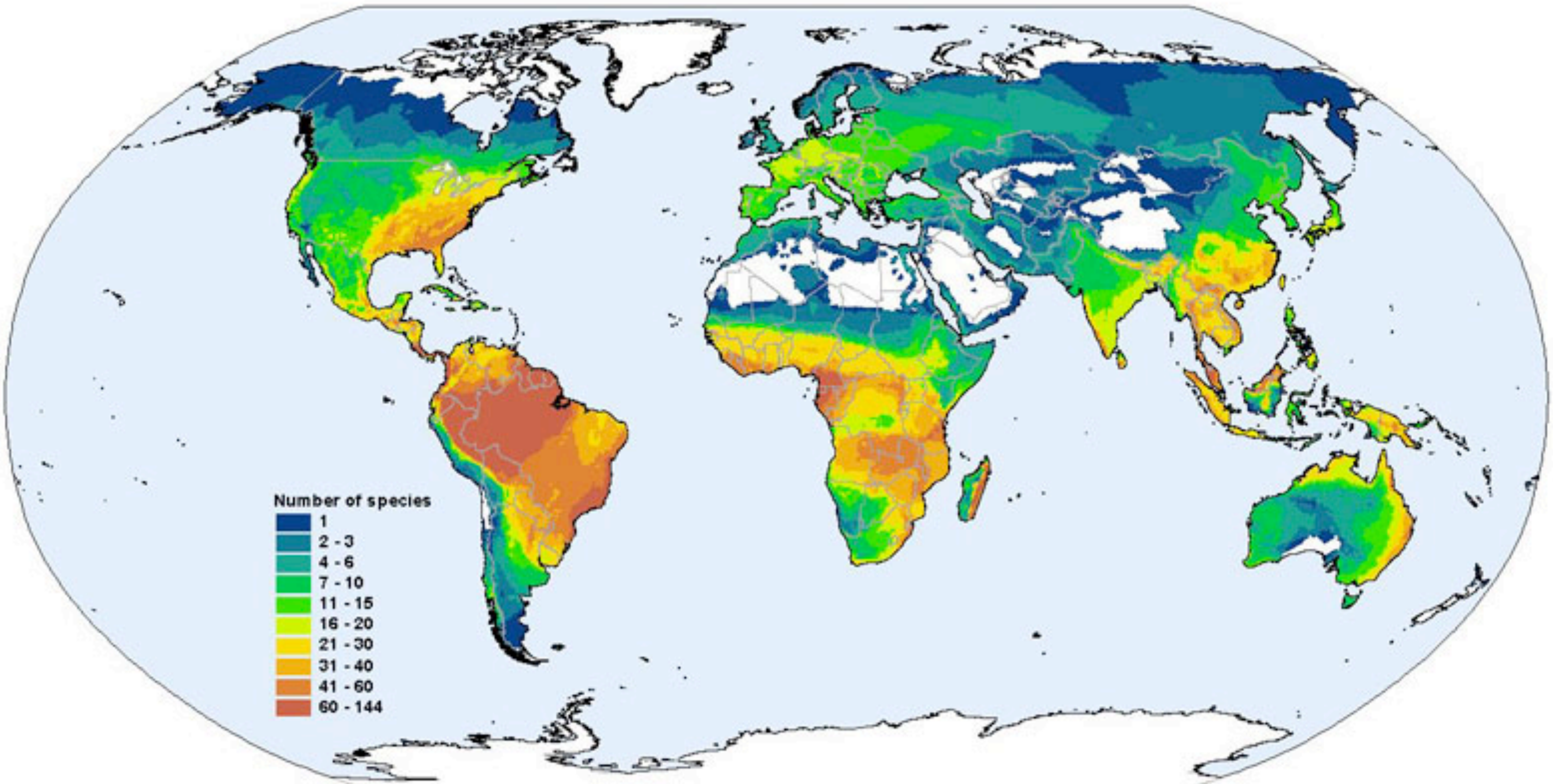
*Rounded to the nearest whole number.



Logistic Growth in Real Populations

- Logistic Model Assumptions
  - 1. that populations adjust instantly and smoothly as it approaches the carrying capacity (K)
    - However there is often a delay involved causing the population to overshoot the carrying capacity
  - 2. that each individual added has the same negative effect on growth rate
  - This model is a starting point for more complex ones!

Notice species richness increases as you move toward the equator due in part to more available energy



Essential knowledge 2.A.1: All living systems require constant input of free energy.

f. Changes in free energy availability can result in disruptions to an ecosystem.

To foster student understanding of this concept, instructors can choose an illustrative example such as:

1. Change in the producer level can affect the number and size of other trophic levels.

2. Change in energy resources levels such as sunlight can affect the number and size of the trophic levels.

PHYSICAL LAWS GOVERN ENERGY FLOW & CHEMICAL CYCLING IN ECOSYSTEMS

Conservation of Energy

- **First Law of Thermodynamics**: energy can not be created nor destroyed...only transferred and transformed.
  - **The sun is the ultimate source of energy for most ecosystems and life itself on our planet.**
  - Energy enters ecosystems as solar radiation.
  - Autotrophs *transform* solar radiation into chemical energy.
  - Heterotrophs consume autotrophs and *transfer* this chemical energy through food chains.

Energy, Mass & Trophic Levels

- **Primary Producers** *consists of autotrophs and their trophic level supports all others*. Think of it this way...autotrophs link heterotrophs to the ultimate source of energy for most life...the sun!
  - Producers (autotrophs) are *photosynthetic organisms* that use solar energy to synthesize organic compounds (sugars) which they use to fuel cellular respiration and as building blocks for growth.
    - As producers begin to synthesize compounds chemical bonds must be formed. It is the energy in these bonds that provide the energy for life processes and growth.
      - An exception to this scenario is found in chemosynthetic bacteria that serve as producers in a few less common ecosystems.

Does the 2nd Law of Thermodynamics contradict the theory of evolution? Explain

Ecosystems

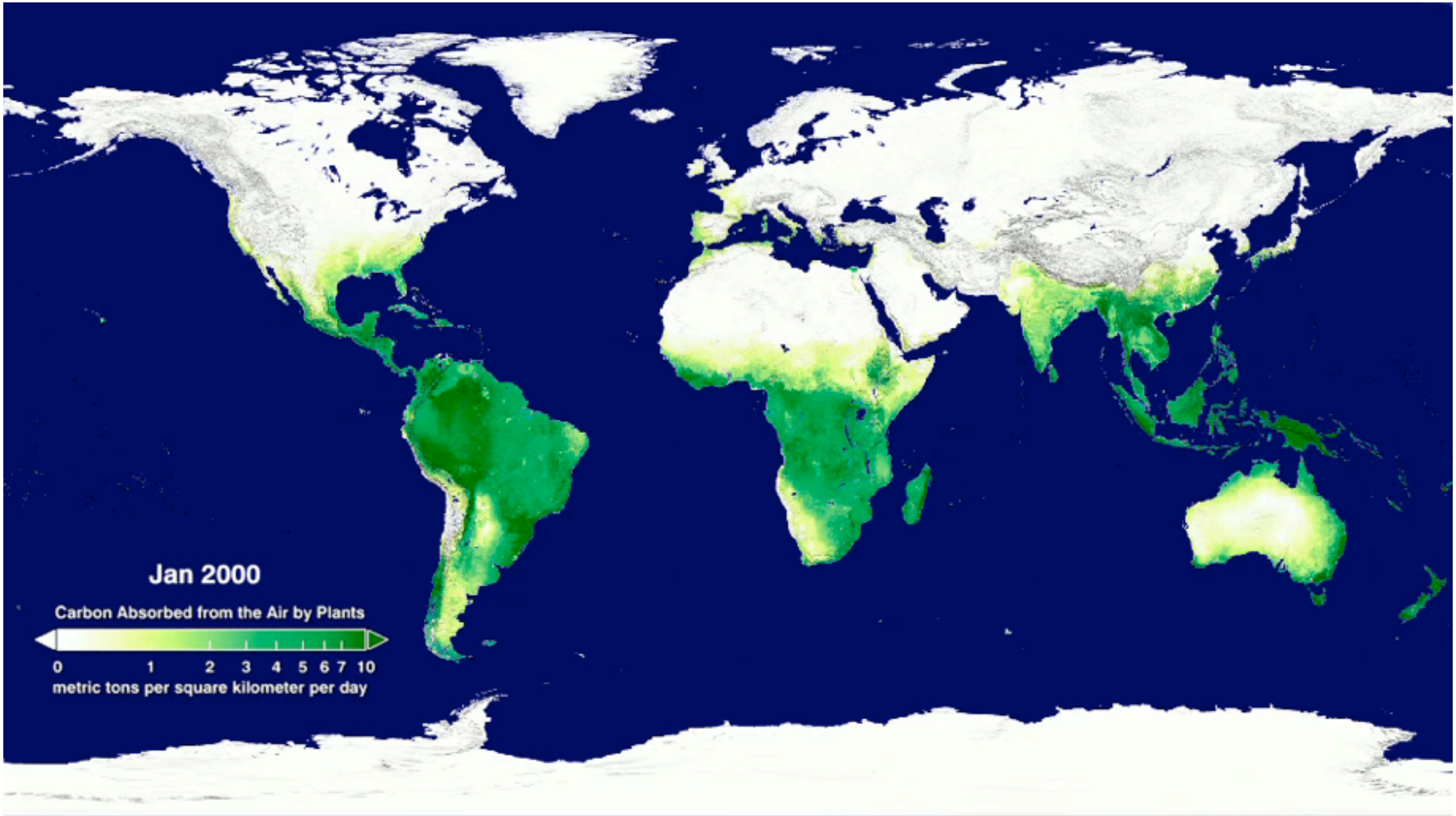
Main Idea: Energy and other limiting factors control primary production.

Main Idea: Primary production dictates the energy budget for the entire ecosystem.

ENERGY AND OTHER LIMITING FACTORS CONTROL PRIMARY PRODUCTION IN ECOSYSTEMS

- **Primary production** is the amount of light energy converted to chemical energy in a given period of time
- The amount of light energy converted to chemical energy by autotrophs effects the amount of heterotrophs it can support in higher trophic levels.
- **Energy transfer is a major theme in biology, energy transfer underlies all biological interactions.**

- **Gross Primary Production (GPP)** is the total amount of solar energy converted to chemical energy per unit time.

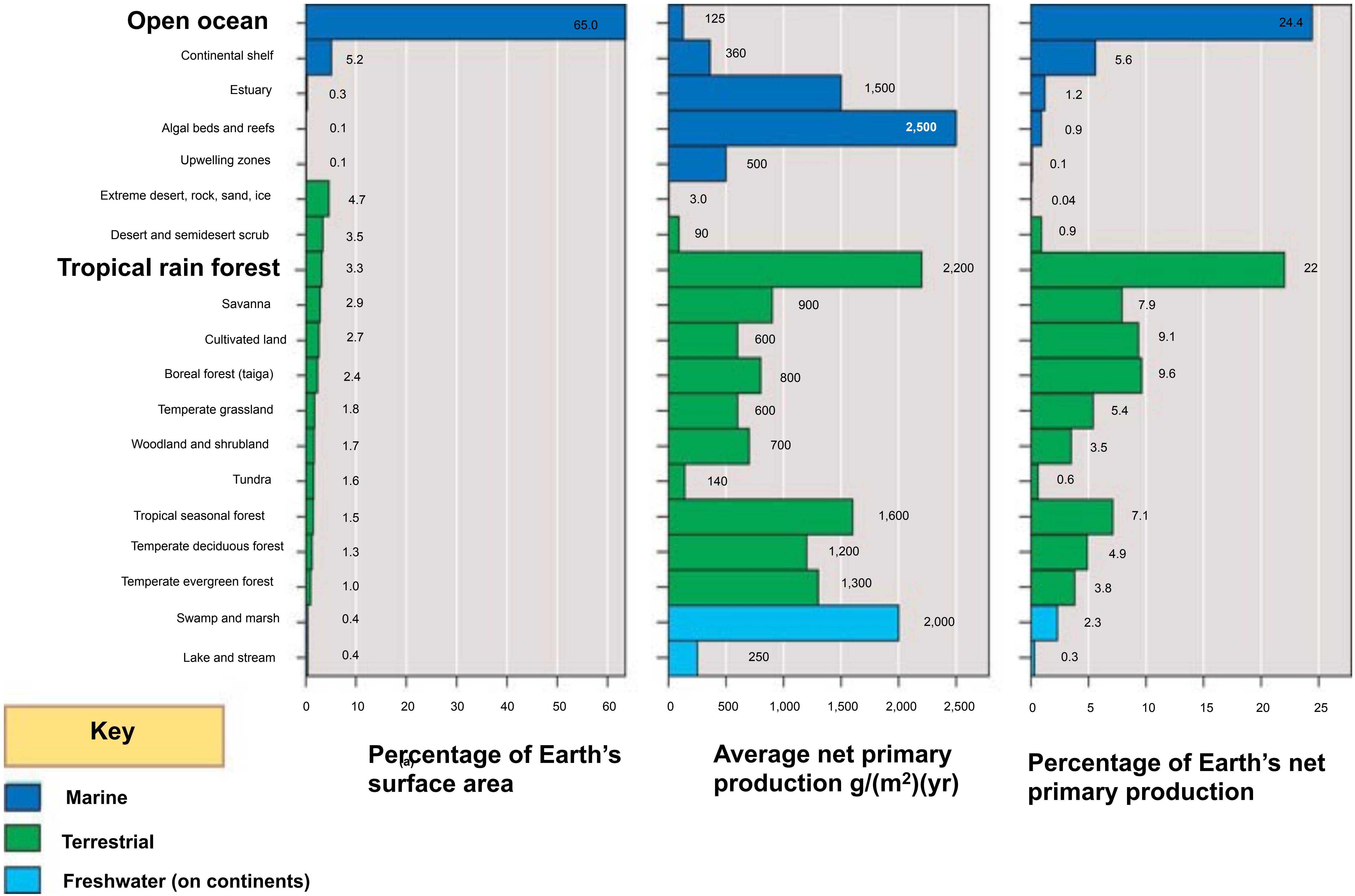


The gross primary productivity of the world's land areas for the period 2000-2009 as calculated from Terra's MODIS instrument. The original 8-day average GPP data has been smoothed to a 24-day average to make the animation less noisy.

2. Gross and Net Production

- **Gross Primary Production (GPP)** is the total amount of solar energy converted to chemical energy per unit time.
- **Net Primary Production (NPP)** is the difference between GPP and autotrophic respiration R_a.
  - $NPP = GPP - R_a$ (on average NPP is about half of GPP)
  - NPP can be expressed in two ways:
    - { $J/(m^2)(year)$ } or { $g/(m^2)(year)$ }

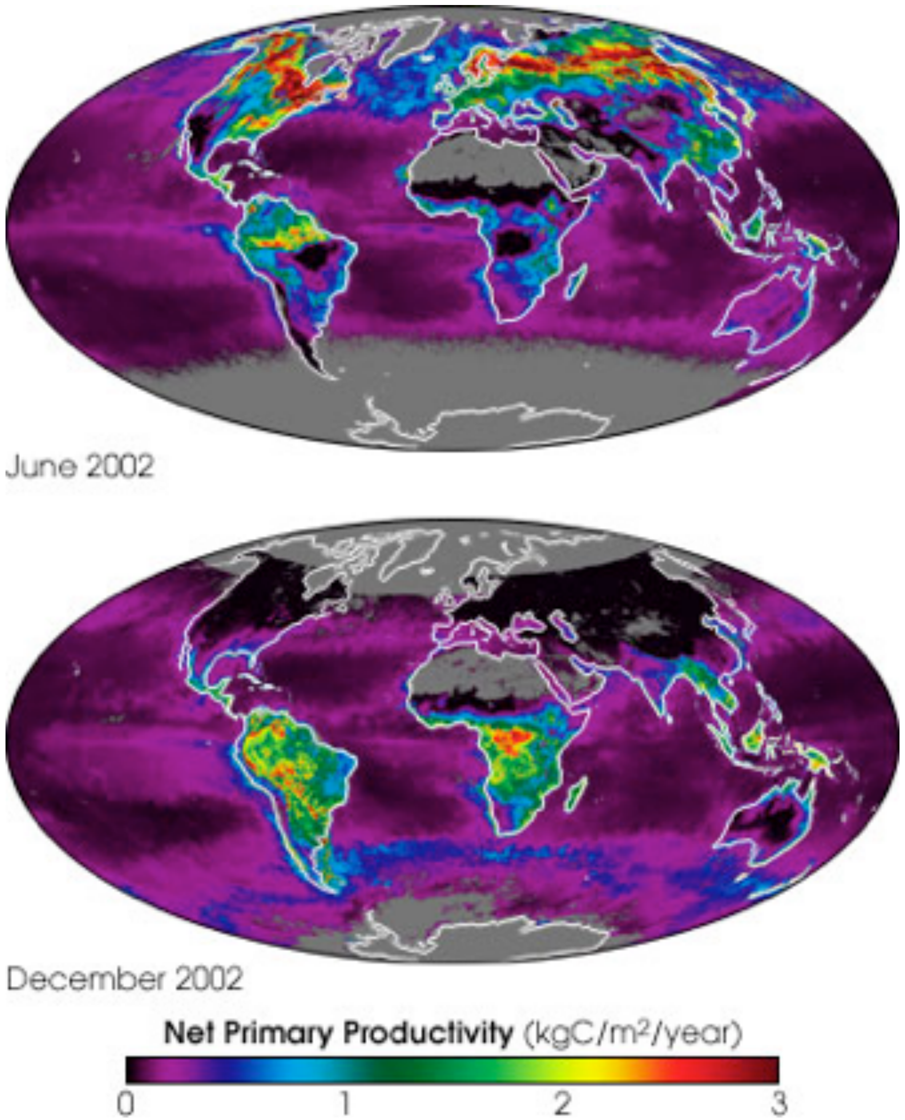
Be careful! Do not confuse *standing crop* (**total biomass**) with *primary production* (**new biomass** per unit time)

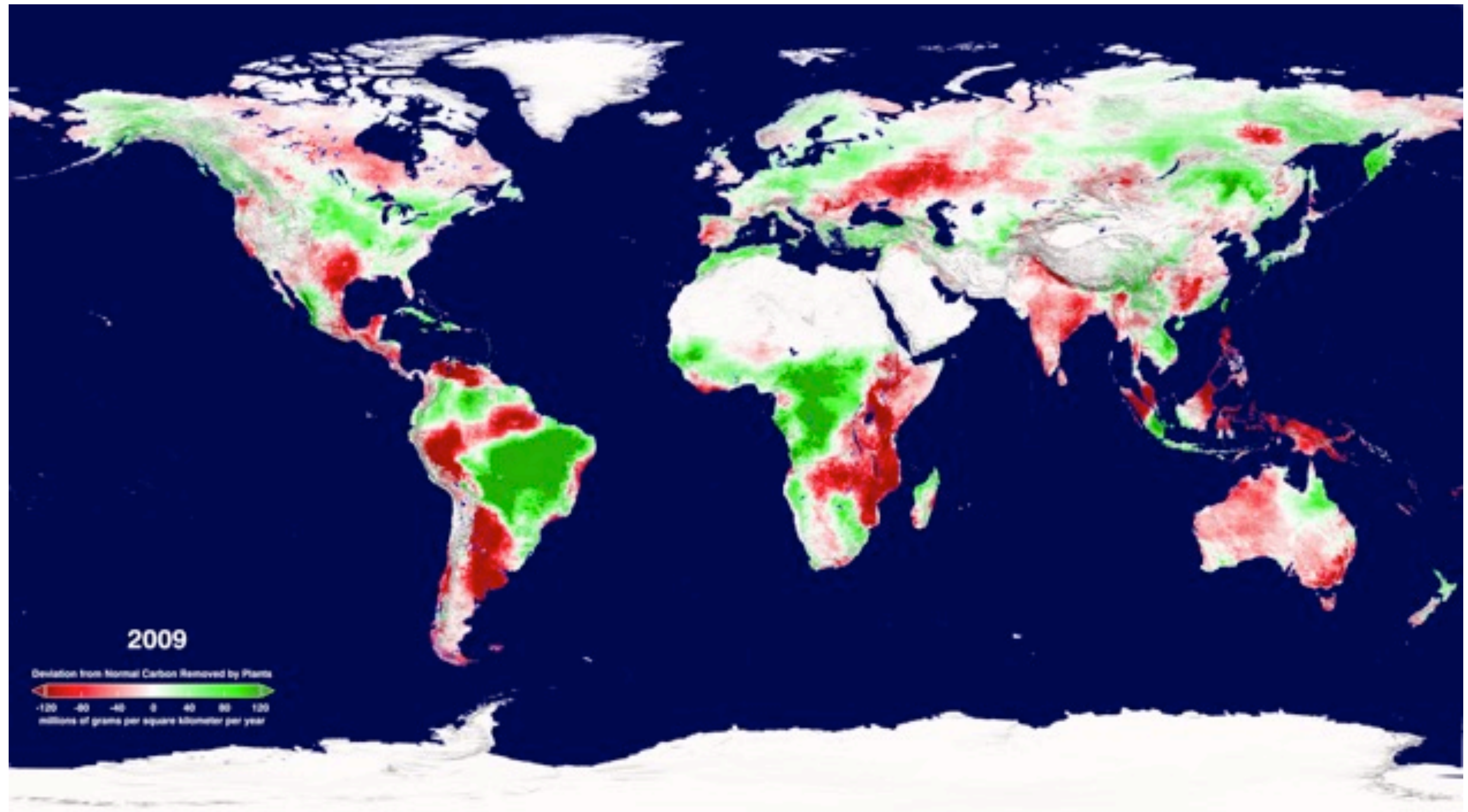


Open ocean
Continental shelf
Estuary
Algal beds and reefs
Upwelling zones
Extreme desert, rock, sand, ice
Desert and semidesert scrub
Tropical rain forest
Savanna
Cultivated land
Boreal forest (taiga)
Temperate grassland
Woodland and shrubland
Tundra
Tropical seasonal forest
Temperate deciduous forest
Temperate evergreen forest
Swamp and marsh
Lake and stream
65.0
5.2
0.3
0.1
0.1
4.7
3.5
3.3
2.9
2.7
2.4
1.8
1.7
1.6
1.5
1.3
1.0
0.4
0.4
0 10 20 30 40 50 60
Percentage of Earth's surface area
(a)
125
360
1,500
2,500
500
3.0
90
2,200
900
600
800
600
700
140
1,600
1,200
1,300
2,000
250
0 500 1,000 1,500 2,000 2,500
Average net primary production g/(m2)(yr)
24.4
5.6
1.2
0.9
0.1
0.04
0.9
22
7.9
9.1
9.6
5.4
3.5
0.6
7.1
4.9
3.8
2.3
0.3
0 5 10 15 20 25
Percentage of Earth's net primary production
Key
Marine
Terrestrial
Freshwater (on continents)

Net Primary Productivity

Summer





The change from normal of the annual net primary productivity of the world's land areas for the period 2000-2009 as calculated from Terra's MODIS instrument. This version adds a date and colorbar to the animation.

Winter

How are satellites able to measure productivity?

Ecosystems

Main Idea: Energy transfer is not efficient, most energy is lost.

ENERGY TRANSFER BETWEEN TROPHIC LEVELS IS TYPICALLY AROUND 10% (WITH 90% LOST)

- **Secondary production**: the amount of chemical energy in consumers food that is actually converted to their own *new biomass* during some time period.

A. Production Efficiency

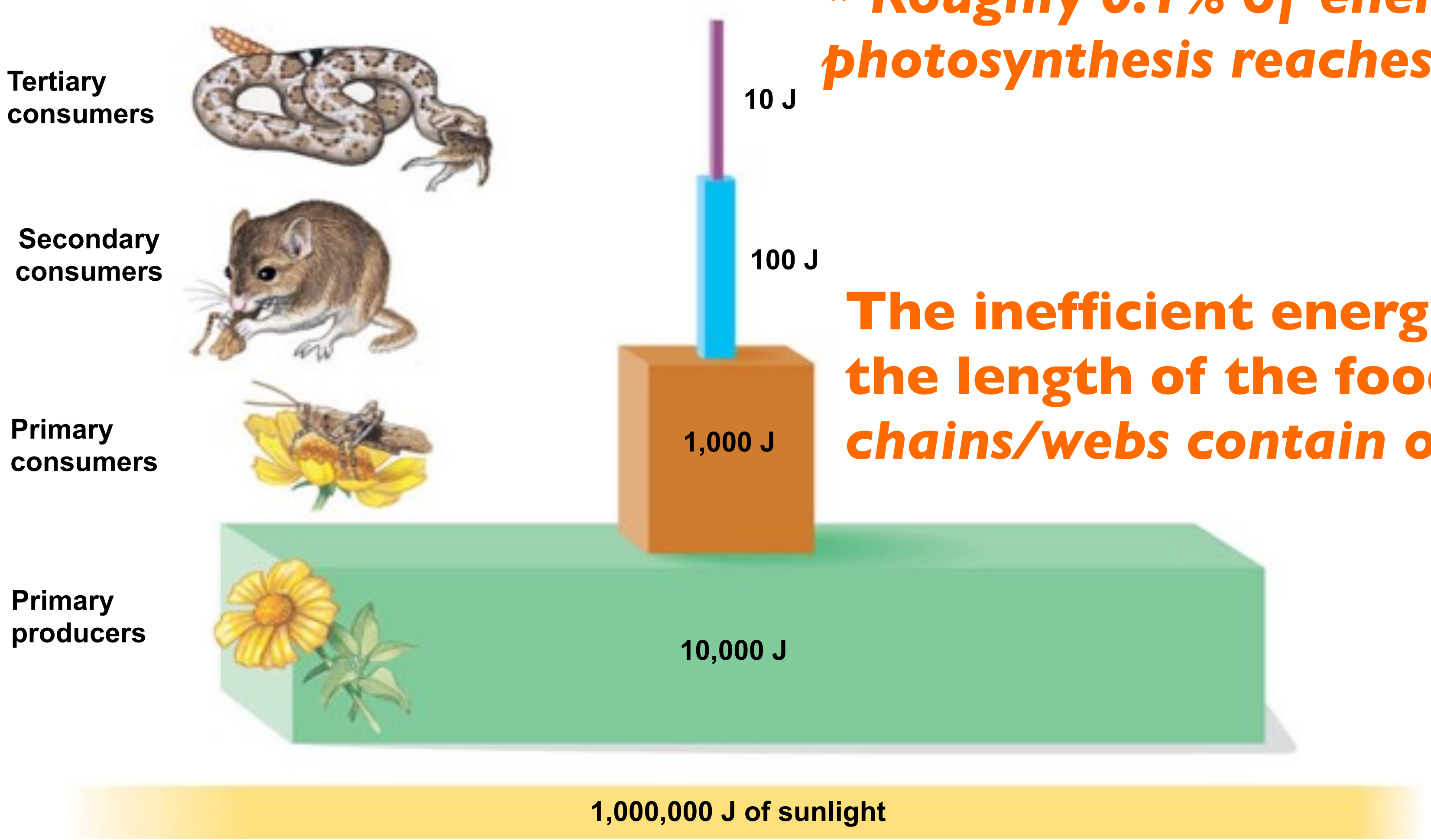
- **Think about it...** only the chemical energy stored by herbivores is biomass (either in their own growth or reproduction of offspring) This is only energy available to secondary consumers

- We can measure production efficiency.

$$\text{Production Efficiency} = \frac{\text{Net Secondary Production X 100\%}}{\text{Assimilation of Primary Production}}$$

Trophic Efficiency & Ecological Pyramids

- **Trophic Efficiency**, the percent of production transferred one trophic level to the next. (Ranges between 5-20%)
  - Trophic efficiency must be less than production efficiency.



Roughly 0.1% of energy fixed by photosynthesis reaches top consumers

The inefficient energy transfer is multiplied over the length of the food chain. *Thus most food chains/webs contain only 4 or 5 trophic levels.*

Which trophic level is most vulnerable to extinction? Why?

Learning Objectives:

LO 2.1 The student is able to explain how biological systems use free energy based on empirical data that all organisms require constant energy input to maintain organization, to grow, and to reproduce. [See SP 6.2]

LO 2.2 The student is able to justify a scientific claim that free energy is required for living systems to maintain organization, to grow, or to reproduce, but that multiple strategies for obtaining and using energy exist in different living systems. [See SP 6.1]

LO 2.3 The student is able to predict how changes in free energy availability affect organisms, populations, and/or ecosystems. [See SP 6.4]