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Matter & Energy: Thermodynamics, Enzymes, Membranes, Diffusion

EVPP 110 Lecture

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2 Energy

- ✓**Energy**
  - – capacity to do work
    - to move matter in a direction it would no move if left alone
  - – required by all organisms to survive
  - – exists in two states
    - **kinetic energy**
    - **potential energy**

3 Energy

- ✓**Energy** exists in two states
  - – **kinetic energy**
    - energy of motion
    - moving objects perform work by causing matter to move
  - – **potential energy**
    - stored energy
    - objects that are not actively moving but have capacity to do so possess energy

4 Energy

- ✓**Energy** exists in two states
  - – **potential energy vs kinetic energy**
    - boulder perched on a hilltop has potential energy
    - as it begins to roll down hill some of energy is converted into kinetic energy
  - –

5 Energy

- ✓energy exists in many forms
  - – mechanical energy
  - – heat
  - – sound
  - – electric current
  - – light
  - – radioactive radiation
  - – **chemical energy**
    - potential energy of molecules
    - most important type of energy for living organisms

6 Energy

✓many ways to measure energy
– most convenient is **heat**
• measure of random motion of molecules
– all other forms of energy can be converted into heat

7 Energy
✓Life depends on fact that energy can be converted from one form to another
✓thermodynamics
– study of energy transformations
✓**Laws of Thermodynamics**
– set of universal laws that govern all energy changes in the universe
•

8 Two laws govern energy conversion
✓**First Law of Thermodynamics**
– concerns amount of energy in universe
– energy can be changed from one form to another but can neither be created or destroyed
– total amount of energy in universe remains constant

9 Two laws govern energy conversion
✓**First Law of Thermodynamics**
– in any living system, potential energy can be shifted to other molecules, stored in different chemical bonds, convert into other forms
• during each conversion some energy dissipates into environment in form of heat
• although amount of energy in universe remains constant
– energy available to do work decreases as progressively more of it dissipates as heat

10 Two laws govern energy conversion
✓**Second Law of Thermodynamics**
– concerns transformation of potential energy into heat, or random molecular motion
– disorder (or **entropy**) in universe is continuously increasing; disorder is more likely than order
• **entropy** is a measure of disorder of a system
– heat is one form of disorder

11 Two laws govern energy conversion
✓**Second Law of Thermodynamics**
– entropy increases
– when universe was formed it had all potential energy it will ever have
• has become more disordered ever since
• every energy exchange has increased amount of entropy in universe
–

12 Chemical reactions either store or release energy
✓Chemical reactions, including those within cells, are of two types
– **endergonic reactions**
• “energy in”
• require a net input of energy

– **exergonic reactions**
  • “energy out”
  • release energy

13 Chemical reactions either store or release energy

✓**endergonic reactions**
– yield products rich in potential energy
  • start with reactants molecules that have little potential energy
  • absorb energy from surroundings as reaction occurs
  • products store more energy that reactants did
– don’t proceed spontaneously
  • requires input of energy
– example is **photosynthesis**

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15 Chemical reactions either store or release energy

✓**exergonic reactions**
– reactants store more energy than products
  • energy is released to surroundings as reaction proceeds
– tend to proceed spontaneously
  • does not require an input of energy
– example is **cellular respiration**
  •
  •

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17 Chemical reactions either store or release energy

✓**Cellular metabolism**
– sum of exergonic and endergonic reactions carried out by working cells

18 Energy and the Cell

✓**Energy coupling**
– using energy released from exergonic reactions to drive essential endergonic reactions
  • usable energy released from most exergonic reactions is stored in ATP
  • energy used in most endergonic reactions comes from ATP

✓**ATP** powers nearly all forms of cellular work

19 Energy and the Cell

✓**ATP (adenosine triphosphate)**
– has 3 parts, connected by covalent bonds
  • **adenine** = a nitrogenous base
  • **ribose** = a 5-carbon sugar

- **phosphate groups** = a chain of 3 phosphate groups

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22 Energy and the Cell

✓**The ATP cycle (ATP is renewable resource)**
- – hydrolysis of ATP to ADP + P
  - removes a phosphate
  - exergonic reaction
    - – releases energy for endergonic reactions
- – dehydration synthesis of ADP + P to ATP
  - adds a phosphate
  - endergonic reaction
    - – requires energy from exergonic reactions

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24 How Enzymes Work

✓**Energy of activation (E_A)**
- – amount of energy that reactants must absorb to start a chemical reaction
- – can be thought of as an energy barrier
- – since most reactions require energy to get started
  -

25 How Enzymes Work

✓**Energy of activation (E_A)**
- – illustrated with "jumping bean" (JB) analogy

26 How Enzymes Work

✓solution for speeding up a reaction lies in **enzymes**
- – protein molecules that serve as biological catalysts
- – increase rate of a reaction without being changed into a different molecule
- – does **not** add energy to a cellular reaction
  - speeds up reaction be lowering the **Energy of activation (E_A)**, or energy barrier

✓without enzymes, many reactions would occur too slowly to sustain life

27 How Enzymes Work

✓enzyme lowers energy barrier

– leading to speeding up of reaction

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30 How Enzymes Work

✓**enzymes**
- – can lower $\mathbf{E_A}$ by holding reactant molecules in a particular position
- – selective in which reactions they catalyze
- – have a unique 3-dimensional shape (since it's a protein) that determines specificity
- – recognize only **substrate**(s) of reaction it catalyzes
  - • **substrate** is substance enzyme acts on

31 How Enzymes Work

✓**catalyzing a reaction**
- – **enzyme binds to its substrate**
  - • at **active site**
    - – pocket or groove on surface of enzyme
      - » active site fits only one substrate molecule
- – while joined, substrate changes into product
- – enzyme releases products
- – enzyme emerges from reaction unchanged

32 How Enzymes Work

✓enzyme emerges from reaction unchanged
- – active site now ready for another substrate molecule and another cycle
- – single enzyme molecule may act upon thousands or millions of substrate molecules per second

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34 How Enzymes Work

✓Activity of an enzyme is affected by its environment
- – conditions under which it is most effective
- – any chemical or physical factor that alters an enzyme's three-dimensional shape can affect its ability to catalyze a reaction

35 How Enzymes Work

✓Factors affecting enzyme activity
- **temperature**
- **pH**
- **salinity**

36 How Enzymes Work

✓Factors affecting enzyme activity
- **temperature**
  - at optimum temperatures (35-40°C)
    - highest rate of contact occurs between enzyme's reactive site and substrate
    - because temperature affects molecule motion
  - at high temperatures
    - enzyme can be denatured, lose its 3-dimensional shape, and lose its function

37 How Enzymes Work

✓Factors affecting enzyme activity
- **pH and salinity**
  - cause variations in number of salt and hydrogen ions
    - can interfere with some of chemical bonds that maintain protein structure
    - optimum pH = 6-8
    - optimum salinity = cell salinity

38 How Enzymes Work

✓Factors affecting enzyme activity
- presence of non-protein helpers called **cofactors**
  - required by some enzymes
  - may be inorganic molecules, called **cofactors**
    -
  - may be organic molecules, called **coenzymes**
    -

39 How Enzymes Work

✓**inhibitor**
- chemical that interferes with an enzyme's activity
- two types of inhibitors
  - **competitive inhibitor**
  - **non-competitive inhibitor**

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41 How Enzymes Work

✓**competitive inhibitor**

– resembles enzyme's normal substrate

– competes with substrate for enzyme's active site

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43 How Enzymes Work

✓**non-competitive inhibitor**

– does not compete with active site

– binds to enzyme outside of active site

• binding causes shape of enzyme to change

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46 Membrane Structure and Function

✓Many metabolic reactions occur simultaneously in a cell

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• teams of enzymes function like assembly lines

• right enzymes have to be in right place at right time

✓Membranes provide the structural basis for metabolic order

47 Membrane Structure and Function

✓For all types of cells

– **plasma membrane** is edge of life

• forming boundary between living cell and its surroundings

✓For most eukaryotic cells

– **membranes** form

• most organelles

• compartments within cells that contain enzymes

48 Membrane Structure and Function

✓All membranes are **selectively permeable**

– control passage of molecules into and out of cell (or organelle)

• takes up substances needed by cell

• disposes of cell waste

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49 Membrane Structure and Function

✓**Plasma membrane** (cell membrane)

– very thin

• 20 times too small to be seen by light microscope

• can be seen by electron microscope

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50 Membrane Structure and Function

✓**Plasma membrane** (cell membrane) is composed mainly of phospholipids

– phospholipid molecule has two parts, which interact oppositely with water

• "head"

– glycerol and phosphate group

– polar = hydrophilic

• " tail"

– two fatty acid tails

– non-polar = hydrophobic

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52 Membrane Structure and Function

✓Structure of phospholipids is suited to their role in membranes

– in water, they spontaneously form a stable two-layer sheet, a **phospholipid bilayer**

• hydrophilic (polar) heads face outwards towards the water

• hydrophobic tails point inward, shielded from the water

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54 Membrane Structure and Function

✓membranes are **selectively permeable**

– partly due to hydrophobic interior of bilayer

• nonpolar , hydrophobic molecules are soluble in lipids

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• polar, hydrophilic molecules are not soluble in lipids

–

55 Membrane Structure and Function

✓Structure of plasma membrane is described as a **fluid mosaic**

– mosaic = surface made of small fragments

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– fluid = moveable

• most of the protein and phospholipid molecules can drift laterally w/in membrane

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56 Membrane Structure and Function

✓two surfaces of **plasma membrane** are different

– outer surface (exterior of cell)

- has carbohydrates covalently bonded to proteins and lipids in membrane
  –
– inner surface (interior of cell)
  •

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58 Diffusion and Osmosis

✓**Diffusion**

– tendency for particles of any kind to spread out spontaneously to regions where they are less concentrated
– requires no work, results from
  • random motion (kinetic energy)
  • universal tendency of order to deteriorate into disorder (entropy)

✓diffusion of molecules across a biological membrane is called **passive transport**

•

59 Diffusion and Osmosis

✓**passive transport**

– concentration affects direction in which a substance diffuses across a membrane
  • substance moves from area of higher concentration to area of lower concentration until equilibrium is reached
    – a substance diffuses **down** its **concentration gradient**
    – at equilibrium, there is no **net** change in concentration on either side of membrane

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62 Diffusion and Osmosis

✓**Passive transport**

– different substances diffuse independently of one another
  •
– is extremely important to all cells
  •
  •

63 Diffusion and Osmosis

✓**Osmosis**

– special case of passive transport
  • involving diffusion of water molecules across a selectively permeable membrane
  • water molecules move down their concentration gradient
– plays role because cells contain and are surrounded by aqueous solution
  • solution contains solutes
    – solutes also diffuse down their concentration gradient

64 Diffusion and Osmosis

✓**Osmosis**

– aqueous solution on either side of membrane can be described on basis of concentrations of their solutes

- solution with higher concentration of solutes, **hypertonic (hyperosmotic)**
- solution with lower concentration of solutes, **hypotonic (hypoosmotic)**
- when solutions on both sides of membrane have same concentration of solutes, **isotonic** (**isoosmotic)**

65 Diffusion and Osmosis

✓**Osmosis**

– as solutes diffuse

- from hypertonic solution (area of higher concentration) across membrane into hypotonic solution (area of lower concentration)

– water molecules will move via osmosis

- from hypotonic solution (area of higher concentration of water molecules) across membrane into hypertonic solution (area of lower concentration of water molecules)

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68 Diffusion and Osmosis

✓ If an animal cell is immersed in

– **isotonic** solution

- cell's volume remains constant
  - gains water at same rate it loses it

– hypotonic solution (lower solute conc than cell)

- cell gains water (loses solutes), swells, may lyse (pop)

– hypertonic solution (higher solute conc than cell)

- cell loses water (gains solutes), shrivels, may die

69 Diffusion and Osmosis

✓If a plant cell is immersed in

– **isotonic** solution

- cell is flaccid, plant wilts
  –

70 Diffusion and Osmosis

✓If a plant cell is immersed in

– hypotonic solution (lower solute conc than cell)

- cell is turgid, plant is healthiest
-

– hypertonic solution (higher solute conc than cell)

- cell loses water (gains solutes), shrivels, may die

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73 Active Transport

✓Substances **can** be moved across a membrane <u>against</u> its concentration

- process called **active transport**
  - requires a cell to expend energy
    - usually in the form of ATP
  - transport protein actively pumps a substance across the membrane against substance's concentration gradient

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76 The End