1 EVPP 110 Lecture
Dr. Largen - Fall 2002

Matter & Energy:
Thermodynamics, Enzymes, Membranes, Diffusion

2 Energy

✓**Energy**
- the capacity to do work
- to move matter in a direction it would no move if left alone
- all organisms require energy to stay alive
- energy exists in two states
  - **kinetic energy**
  - **potential energy**

3 Energy and the Cell
5.1: Energy is the capacity to perform work

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

4 Energy work

✓**Energy** exists in two states
- **potential energy vs kinetic energy**
  - a boulder perched on a hilltop has potential energy
  - as it begins to roll down the hill some of the energy is converted into kinetic energy
- much of the work that living organisms carry out is involves transforming potential energy to kinetic energy

5 Energy

✓energy exists in many forms
- mechanical energy
- heat
- sound
- electric current
- light
- radioactive radiation
- **chemical energy**
  - the potential energy of molecules

    - most important type of energy for living organisms

6 Energy

- ✓there are many ways to measure energy
  - – most convenient way to measure energy is in the form of **heat**
    - =a measure of the random motion of molecules
  - – because all other forms of energy can be converted into heat

7 Energy

- ✓Life depends on the fact that energy can be converted from one form to another
- ✓thermodynamics
  - – the study of energy transformations that occur in a collection of matter
- ✓**Laws of Thermodynamics**
  - – a set of universal laws that govern all energy changes in the universe
    - from nuclear reactions to buzzing of a bee

8 Two laws govern energy conversion

- ✓**First Law of Thermodynamics**
  - – concerns the amount of energy in the universe
  - – states that energy can be changed from one form to another but can neither be created or destroyed
  - – total amount of energy in the 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 of the energy dissipates into the environment in the 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 the transformation of potential energy into heat, or random molecular motion
  - – states that the disorder (or **entropy**) in the universe is continuously increasing; disorder is more likely than order
    - **entropy** is a measure of the 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 10-20 billion years ago it had all the potential energy it will ever have
    - has become more disordered ever since
    - every energy exchange has increased the amount of entropy in the universe
  - – more likely that a column of bricks will tumble over than spontaneously arrange themselves to form a column

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 the surroundings as the reaction occurs
  - such that the products store more energy that the 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 the surroundings as reaction proceeds
- tend to proceed spontaneously
  - does not require an input of energy
- example is **cellular respiration**
  - the energy-releasing breakdown of glucose molecules
  - storage of energy in a form the cell can use to perform work

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17 Chemical reactions either store or release energy

✓**Cellular metabolism**
- the sum of the 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
- is an exergonic reaction
  – releases energy for endergonic reactions

– dehydration synthesis of ADP + P to ATP
- adds a phosphate
- is an endergonic reaction
  – that requires energy from exergonic reactions

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24 How Enzymes Work

✓**Energy of activation (E_A)**

– the 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
- ATP and other vital molecules in our cells do not break down spontaneously

25 How Enzymes Work

✓**Energy of activation (E_A)**

– illustrated with "jumping bean" (JB) analogy
- JBs in left side of container represent reactants of a chemical reaction that must have enough energy to jump over the "energy barrier" to make it to product side
- beans vary in amount of energy they have
- may take a very long time for a significant number of "reactant" beans to get over barrier to become "product" beans

– and reaction may take too long to be of any use to cell

26 How Enzymes Work

✓solution for speeding up a reaction lies in **enzymes**
- – protein molecules that serve as biological catalysts
- – increase the 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

✓In jumping bean analogy, an enzyme would lower the partition between containers, or lower the energy barrier
- – making it possible for beans with less energy to clear the barrier
  - resulting in more beans being able to clear the barrier in a given amount of time
    - – leading to the speeding up of the reaction

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30 How Enzymes Work

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

31 How Enzymes Work

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

32 How Enzymes Work

✓enzyme emerges from the reaction unchanged

– its active site now ready for another substrate molecule and another cycle
– a 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
– for each enzyme, there are 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
  – that can interfere with some of the 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**
- <u>required</u> by some enzymes

– **cofactors**
  - may be inorganic molecules, called **cofactors**
    – such as zinc, iron, copper
  - may be organic molecules, called **coenzymes**
    – such as vitamins or vitamin products

39 How Enzymes Work

✓A chemical that interferes with an enzyme's activity is called an **inhibitor**
– 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
  - when bound to active site it prevents enzyme from acting

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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
    – such that active site no longer fits substrate

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46 Membrane Structure and Function

✓Many metabolic reactions occur simultaneously in a cell
– chaos would result if cell were not highly organized and able to time reactions precisely
  - 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
- the **plasma membrane** is the edge of life
    - forming the 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

✓<u>All</u> 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
- allows some substances to cross more easily
- blocks passage of some substances entirely

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
        - shows up as three zones
- much knowledge of plasma membranes come from study of red blood cells
    - obtaining plasma membrane from “ghosts”
        - split and emptied red blood cells

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
- this is the arrangement of membrane phospholipids in aqueous environment living

organisms

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54 Membrane Structure and Function

✓membranes are **selectively permeable**

- partly due to hydrophobic interior of the bilayer
  - nonpolar, hydrophobic molecules are soluble in lipids
    - can easily pass through membranes
  - polar, hydrophilic molecules are not soluble in lipids
    - passage of polar molecules is dependent on protein molecules within the phospholipid bilayer

55 Membrane Structure and Function

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

- mosaic = surface made of small fragments
  - membrane has diverse protein molecules embedded w/in framework of phospholipids
- fluid = moveable
  - most of the protein and phospholipid molecules can drift laterally w/in membrane
    - "kinked" tails of fatty acids keeps phospholipids from packing tightly together, helps maintain fluidity

56 Membrane Structure and Function

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

- outer surface (exterior of cell)
  - has carbohydrates covalently bonded to proteins and lipids in the membrane
    - glycoproteins, glycolipids
- inner surface (interior of cell)
  - has microfilaments of cytoskeleton, proteins

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58 Diffusion and Osmosis

✓**Diffusion**

- the tendency for particles of any kind to spread out spontaneously to regions where they are less concentrated
- it 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**
  - since it requires no work

59 Diffusion and Osmosis

✓**passive transport**

- concentration affects the 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 substances 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
    - each down its own concentration gradient
  - is extremely important to all cells
    - oxygen passes from lungs into red blood cells
    - carbon dioxide passes from red blood cells into lungs

63 Diffusion and Osmosis

- **Osmosis**
  - is a 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**
  - the aqueous solution on either side of the membrane can be described on the basis of the concentrations of their solutes
    - solution with higher concentration of solutes is said to be **hypertonic**
    - solution with lower concentration of solutes is said to be **hypotonic**
    - when solutions on both sides of membrane have same concentration of solutes, they're said to be **isotonic**

65 Diffusion and Osmosis

- **Osmosis**
  - as solutes diffuse
    - from the hypertonic solution (area of higher concentration) across the membrane into the hypotonic solution (area of lower concentration)
  - water molecules will move via osmosis
    - from hypotonic solution (area of higher concentration of water molecules) across the membrane into the hypertonic solution (area of lower concentration of water molecules)

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68 Diffusion and Osmosis

- If an animal cell is immersed in
  - an **isotonic** solution

- cell's volume remains constant
  - gains water at same rate it loses it
- a hypotonic solution (lower solute conc than cell)
  - cell gains water (loses solutes), swells, may lyse (pop)
- a 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

- an **isotonic** solution
  - cell is flaccid, plant wilts
    - needs a net inflow of water (to balance transpiration), has no net change in water conc in this scenario

70 Diffusion and Osmosis

✓If a plant cell is immersed in

- a hypotonic solution (lower solute conc than cell)
  - cell is turgid, plant is healthiest
  - has net inflow of water (balances transpiration) (loses solutes), cell wall helps prevent cell from bursting
- a 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 against its concentration

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

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