Matter & Energy:
Thermodynamics, Enzymes, Membranes, Diffusion

EVPP 110 Lecture
Dr. Largen
Fall 2003

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
七大方法来测量能量
- 最方便的是热
  - 措施是随机分子的运动
- 所有其他形式的能量可以转换成热

能量
- 生命取决于能量可以转换为另一种形式
- 热力学
  - 能量转换的研究
- 热力学定律
  - 一套通用的定律，规定宇宙中所有能量变化

8 两个定律统治能量转换
- 第一定律热力学
  - 关于宇宙中能量的量
  - 能量可以转换为另一种形式，但不能被创建或销毁
  - 宇宙中能量的总和保持不变

9 两个定律统治能量转换
- 第一定律热力学
  - 在任何生命系统中，潜在能量可以转换到其他分子，储存在不同的化学键中，转换成其他形式
  - 在每次转换中，一些能量以热的形式散失到环境中
  - 尽管宇宙中能量的总量保持不变，但可用以做功的能量逐渐减少，因为越来越多的能量以热的形式散失

10 两个定律统治能量转换
- 第二定律热力学
  - 关于潜在能量转换为热，或随机分子的运动
  - 宇宙中的无序（熵）持续增加；无序比有序更可能
    - 熵是系统无序的度量
    - 热是无序的一种形式

11 两个定律统治能量转换
- 第二定律热力学
  - 熵增加
  - 当宇宙形成时，它拥有了它将永远拥有的所有潜在能量
  - 宇宙的熵一直在增加，因为它变得更无序，使它更容易混乱
  - 每一个能量转换都增加了宇宙的熵

12 化学反应要么存储要么释放能量
- 化学反应，包括细胞中的，分为两种类型
  - 能量变大反应
    - “能量存入”
    - 要求输入净能量
Chemical reactions either store or release energy

**Exergonic reactions**
- "energy out"
- release energy

**Endergonic reactions**
- yield products rich in potential energy
  - start with reactant molecules that have little potential energy
  - absorb energy from surroundings as reaction occurs
  - products store more energy than reactants did
- don't proceed spontaneously
  - requires input of energy
- example is **photosynthesis**

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
  - doesn't require an input of energy
- example is **cellular respiration**

Chemical reactions either store or release energy

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

**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

**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

20

21

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

23

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 by 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
How Enzymes Work

- leading to speeding up of reaction

✓ enzymes
- can lower $E_A$ 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

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

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

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
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

- **pH**
  - optimum pH = 6-8
  - optimum salinity = cell salinity

- **salinity**

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

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**

**inhibitor**

- chemical that interferes with an enzyme’s activity
- two types of inhibitors
  - competitive inhibitor
  - non-competitive inhibitor
✔competitive inhibitor
  – resembles enzyme’s normal substrate
  – competes with substrate for enzyme’s active site

✔non-competitive inhibitor
  – does not compete with active site
  – binds to enzyme outside of active site
    • binding causes shape of enzyme to change

✓Many metabolic reactions occur simultaneously in a cell
  – 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

✓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

✓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
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

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

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

Membrane Structure and Function

- membranes are **selectively permeable**
  - partly due to hydrophobic interior of bilayer
    - nonpolar, hydrophobic molecules are soluble in lipids
    - polar, hydrophilic molecules are not soluble in lipids

Membrane Structure and Function

- Structure of plasma membrane is described as a **fluid mosaic**
  - mosaic = surface made of small fragments
    - fluid = moveable
      - most of the protein and phospholipid molecules can drift laterally w/in membrane

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)

57

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

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
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)

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)

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

Diffusion and Osmosis

If a plant cell is immersed in

- isotonic solution
  - cell is flaccid, plant wilts

Active Transport

Substances can be moved across a membrane against 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

74

75

76 The End