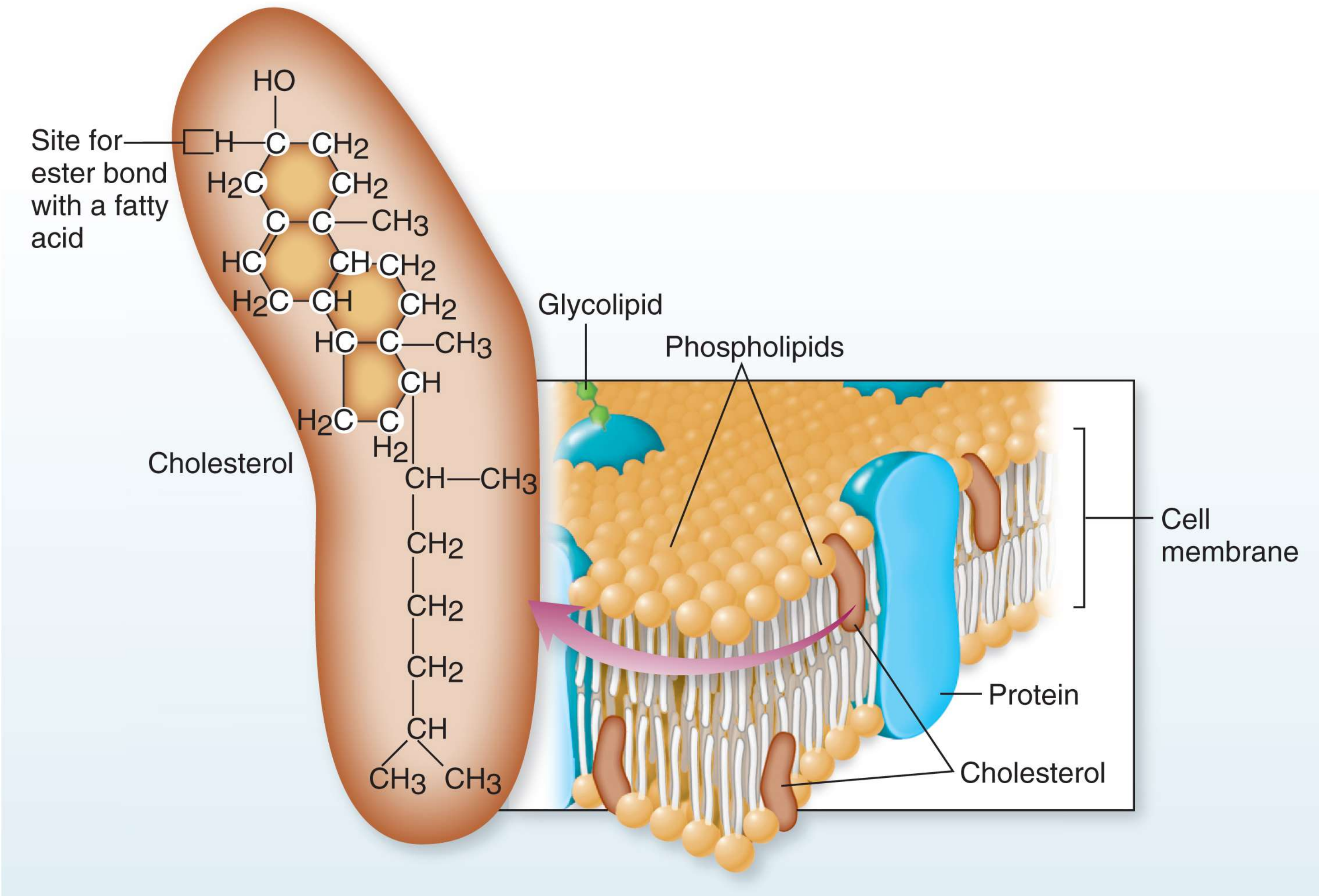
Chapter 2

Organic Chemistry



Organic Chemistry

- **Study of compounds containing carbon and hydrogen**

- **Four categories of organic compounds**

  - carbohydrates
  - lipids
  - proteins
  - nucleic acids

  - See Web Site PowerPoint = “Know Your Molecules”

Monomers VS Polymers

- **Monomers –** a small identical molecules (similar subunits) - e.g. amino acid or glucose molecule

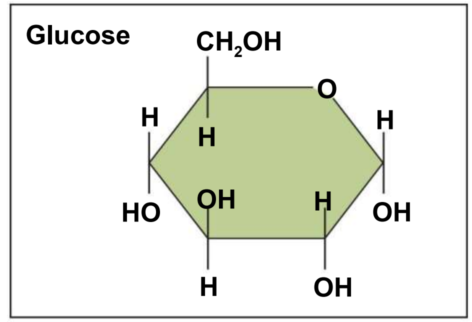
- **Polymers –** molecules made of a repetitive series of identical subunits // e.g. polypeptide

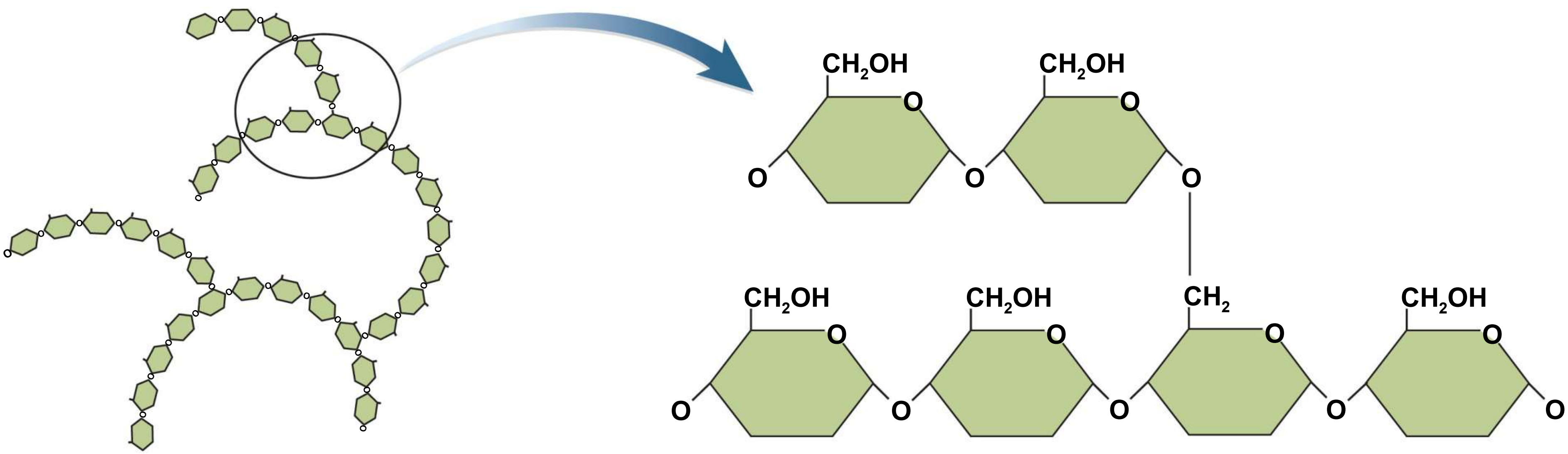
- **Macromolecules –** polymers which continue to "enlarge" to form very large organic molecules // high molecular weights /// e.g. protein

Monomers and Polymers

Glucose is a monomer

Glycogen is a polymer of glucose





What is the carbon cycle?

Carbon to Carbon Molecules

- Organic = molecules with carbon and hydrogen

- Carbon has 4 valence electrons

  - may bind with four other atoms
  - these atoms provide carbon with four more electrons to fill its valence shell // making carbon's valence orbit "stable"
  - *forms covalent bonds with* hydrogen, oxygen, nitrogen, sulfur, and other elements

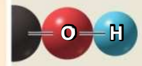
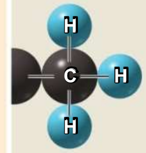
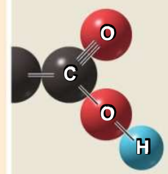
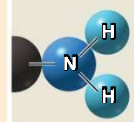
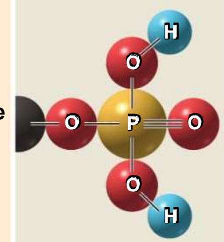
- Carbon atoms also bind readily with each other

  - forms branches and ring structures /// forms a carbon chain or carbon backbones
  - able to form 3D matrix (e.g. pencils & diamonds)

- Carbon is the backbone that carries a variety of functional groups

Functional Groups

- small clusters of atoms attached to carbon backbone
- determines many of the properties of organic molecules
- E.g. = hydroxyl, methyl, carboxyl, amino, phosphate

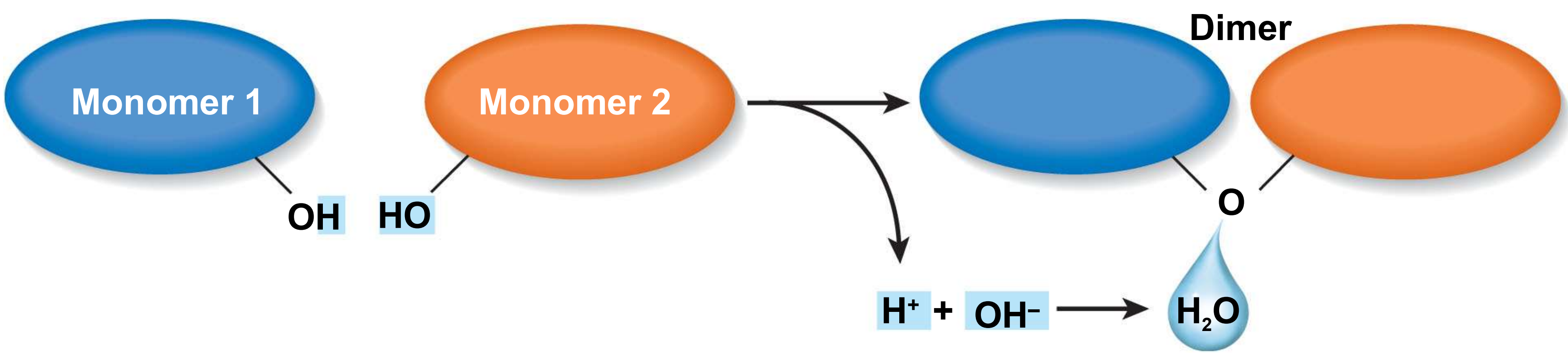
Name and Symbol	Structure	Occurs in
Hydroxyl (—OH)		Sugars, alcohols
Methyl (—CH_3)		Fats, oils, steroids, amino acids
Carboxyl (—COOH)		Amino acids, sugars, proteins
Amino (—NH_2)		Amino acids, proteins
Phosphate (—H_2PO_4)		Nucleic acids, ATP

Dehydration Synthesis VS Hydrolysis

- Process where monomers are joined together to form a polymer
- Dehydration synthesis (condensation) is how living cells form polymers
  - a hydroxyl (-OH) group is removed from one monomer, and a hydrogen (H+) from another /// producing water as a by-product
- Hydrolysis – opposite of dehydration synthesis
  - a water molecule ionizes into –OH and H+
  - the covalent bond linking one monomer to the other is broken
  - the –OH is added to one monomer
  - the H+ is added to the other

Dehydration Synthesis

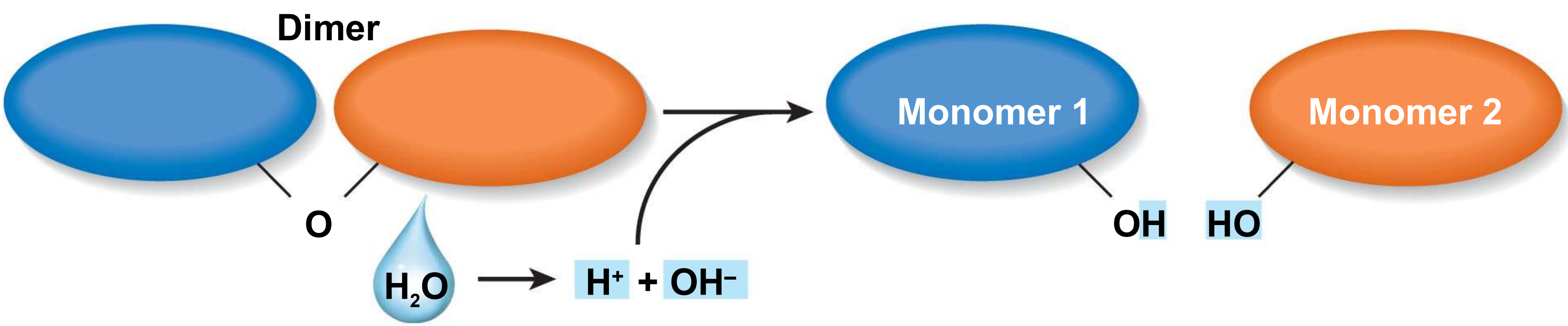
- **Monomers covalently bond together to form a polymer with the removal of a water molecule**
  - A hydroxyl group is removed from the blue monomer and a hydrogen is removed from the orange monomer to form water



Hydrolysis

- **Splitting a polymer** (lysis) **by the addition of a water molecule** (hydro) // a covalent bond is broken

- All digestion reactions consists of hydrolysis reactions



Organic Molecules: Carbohydrates

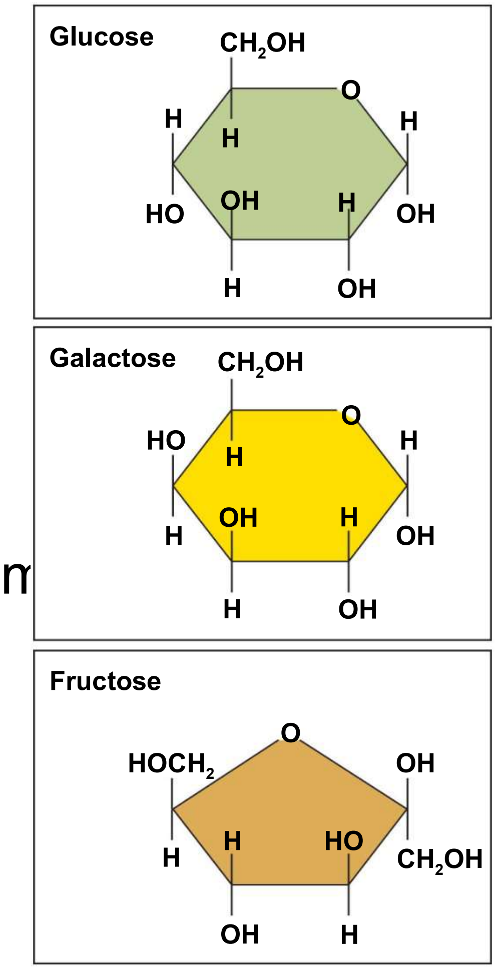
- A hydrophilic organic molecule

- **general formula // note: 2:1 ratio for hydrogen to oxygen**
  - **$(CH_2O)_n$ //** n = number of carbon atoms
  - for glucose, n = 6, so formula is $C_6H_{12}O_6$

- **names of carbohydrates** often built from:
  - word root '***sacchar-'***
  - the suffix '***-ose'***
  - both mean '*sugar*' or '*sweet*' // monosaccharide or glucose

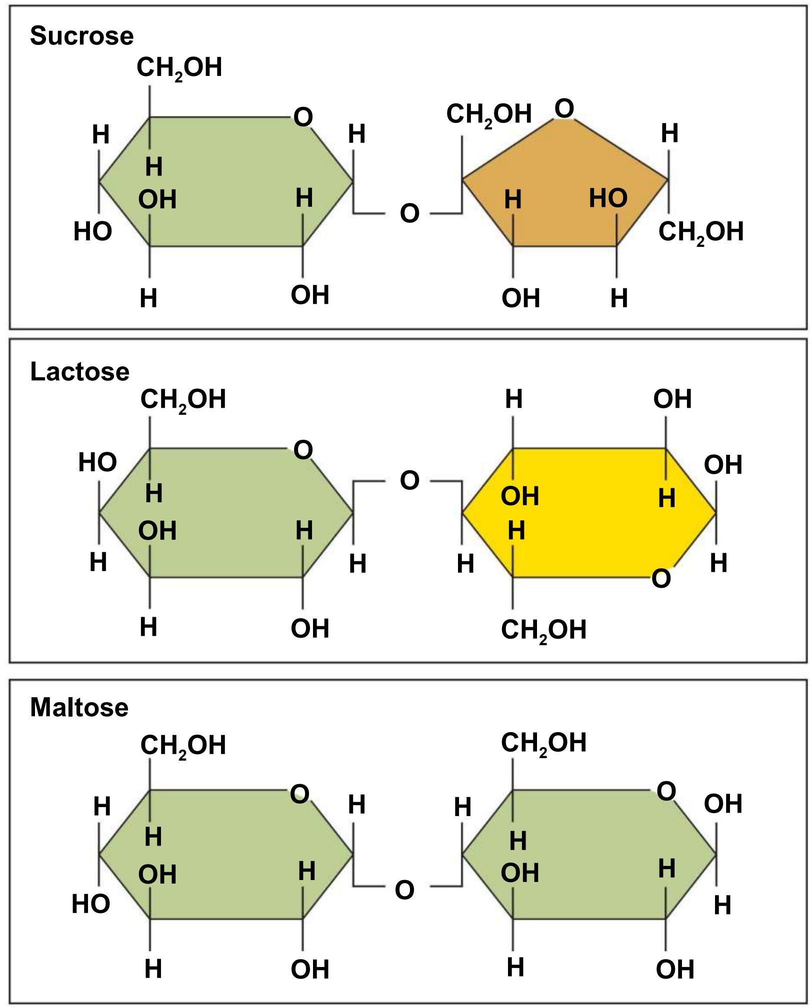
Monosaccharides

- Simple carbohydrates = simple sugars
- Three important monosaccharides
  - glucose, galactose and fructose
  - same molecular formula - $C_6H_{12}O_6$
  - They have same number of atoms but atom are arranged differently = isomers
  - produced by digestion of complex carbohydrates (e.g. starch, glycogen)
  - Note: glucose is blood sugar



Disaccharides

- Sugar molecule composed of 2 monosaccharides
- 3 important disaccharides
  - sucrose - table sugar // glucose + fructose
  - lactose - sugar in milk // glucose + galactose
  - maltose - grain products // glucose + glucose



Polysaccharides

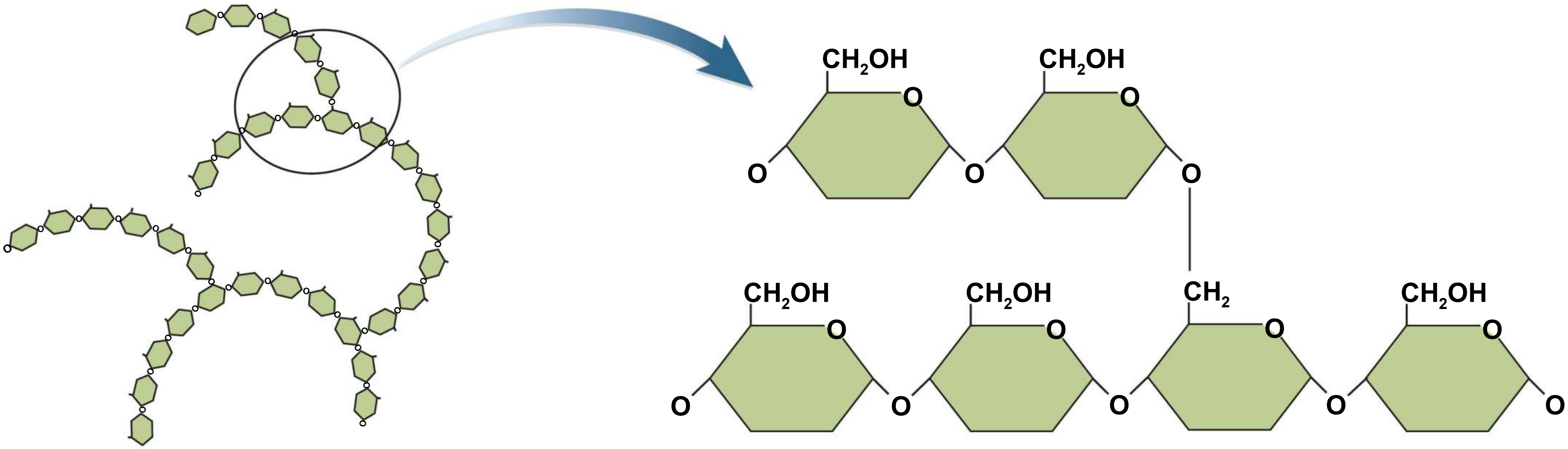
- Long chains of glucose molecules
- Three important polysaccharides (glycogen – starch - cellulose)
  - Glycogen: energy storage polysacharide in animals
    - made by cells of liver, muscles, brain, uterus, and vagina
    - liver produces glycogen after a meal when glucose level is high, then breaks it down between meals to maintain blood glucose levels
    - muscles store glycogen for own energy needs
    - uterus “sweats” glycogen to nourish embryo

Polysaccharides

- **Starch:** energy storage polysaccharide in plants /// only significant digestible polysaccharide in the human diet

- **Cellulose:** structural molecule of plant cell walls /// this is the “fiber” in our diet our digestive system lack enzymes to breakdown this polymer passes out of our digestive system as food residue

Glycogen



(a) (b)

Carbohydrate Functions

- Source of energy // all digested carbohydrates converted to glucose // oxidized to make ATP
- Structural molecule when conjugated (i.e. bonded to) with lipids or proteins
  - glycolipids // e.g. component of cell membrane with lipid inserted into membrane and sugar projecting from surface of membrane
  - glycoproteins // e.g. component of cell membrane with protein inserted into membrane and surgar projecting from surface of membrane

Carbohydrate Functions

- proteoglycans (mucopolysaccharides) // forms gel between cells – its the “glue that binds cells and tissues together
  - forms gelatinous filler in umbilical cord and eye
  - joint lubrication
  - seen as the tough, rubbery texture of cartilage

TABLE 2.6 Carbohydrate Functions

Type	Function
Monosaccharides	
Glucose	Blood sugar—energy source for most cells
Galactose	Converted to glucose and metabolized
Fructose	Fruit sugar—converted to glucose and metabolized
Disaccharides	
Sucrose	Cane sugar—digested to glucose and fructose
Lactose	Milk sugar—digested to glucose and galactose; important in infant nutrition
Maltose	Malt sugar—product of starch digestion, further digested to glucose
Polysaccharides	
Cellulose	Structural polysaccharide of plants; dietary fiber
Starch	Energy storage in plant cells
Glycogen	Energy storage in animal cells (liver, muscle, brain, uterus, vagina)
Conjugated Carbohydrates	
Glycoprotein	Component of the cell surface coat and mucus, among other roles
Glycolipid	Component of the cell surface coat
Proteoglycan	Cell adhesion; lubrication; supportive filler of some tissues and organs

Lipids

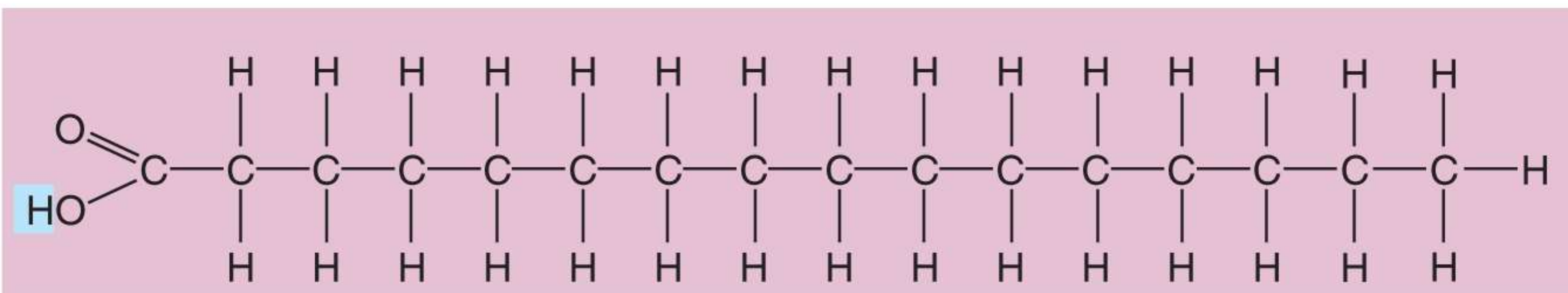
- **Hydrophobic** organic molecule
  - composed of carbon, hydrogen and oxygen
  - with high ratio of hydrogen to oxygen
- Less oxidized than carbohydrates, and therefore has more calories/gram
- Five primary human lipids
  - **fatty acids**
  - **triglycerides**
  - **phospholipids**
  - **eicosanoids**
  - **steroids**

TABLE 2.7 Lipid Functions

Type	Function
Bile acids	Steroids that aid in fat digestion and nutrient absorption
Cholesterol	Component of cell membranes; precursor of other steroids
Eicosanoids	Chemical messengers between cells
Fat-soluble vitamins	Involved in a variety of functions including blood clotting, wound healing, vision, and calcium absorption
Fatty acids	Precursor of triglycerides; source of energy
Phospholipids	Major component of cell members; aid in fat digestion
Steroid hormones	Chemical messengers between cells
Triglycerides	Energy storage: thermal insulation; filling space; binding organs together; cushioning organs

Fatty Acids

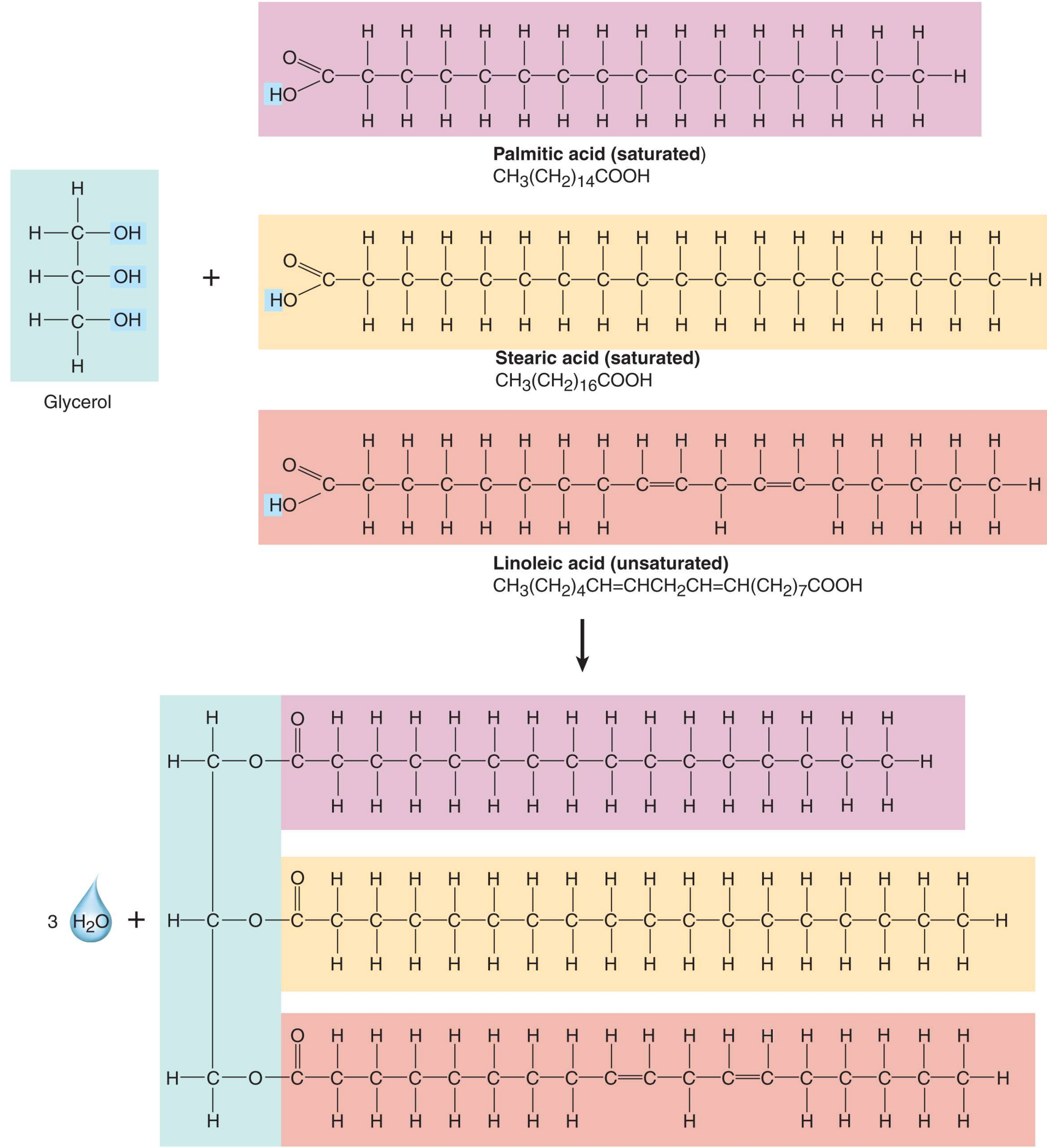
- Chains of 4 to 24 carbon atoms // carboxyl (acid) group on one end, methyl group on the other and hydrogen bonded along the sides
- Classified as:
  - saturated – all carbon atoms saturated with hydrogen
  - unsaturated - contains C=C bonds without hydrogen
  - polyunsaturated – contains many C=C bonds
  - essential fatty acids – obtained from diet, body can not synthesize



Palmitic acid (saturated)
$CH_3(CH_2)_{14}COOH$

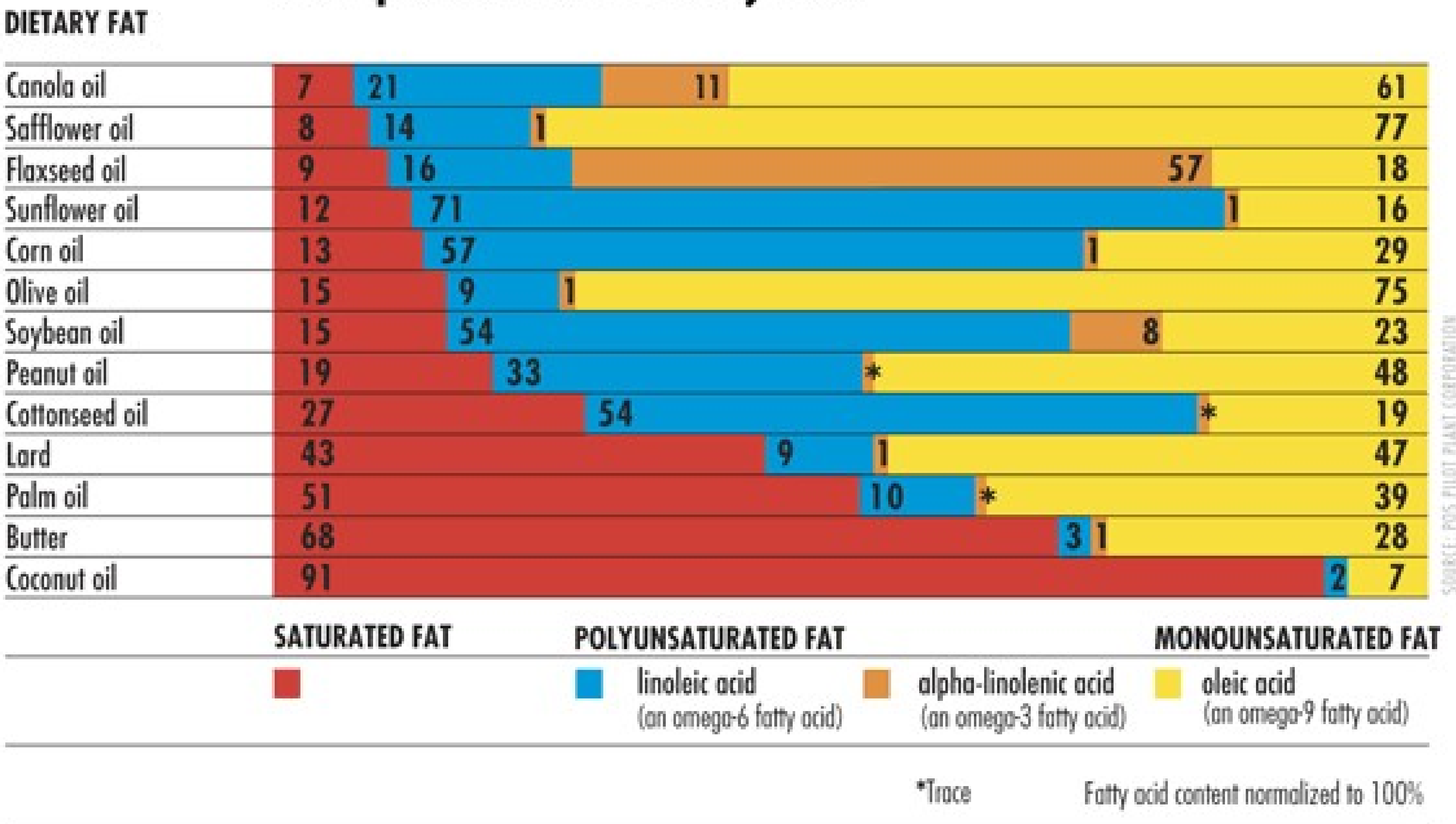
Triglycerides (Neutral Fats)

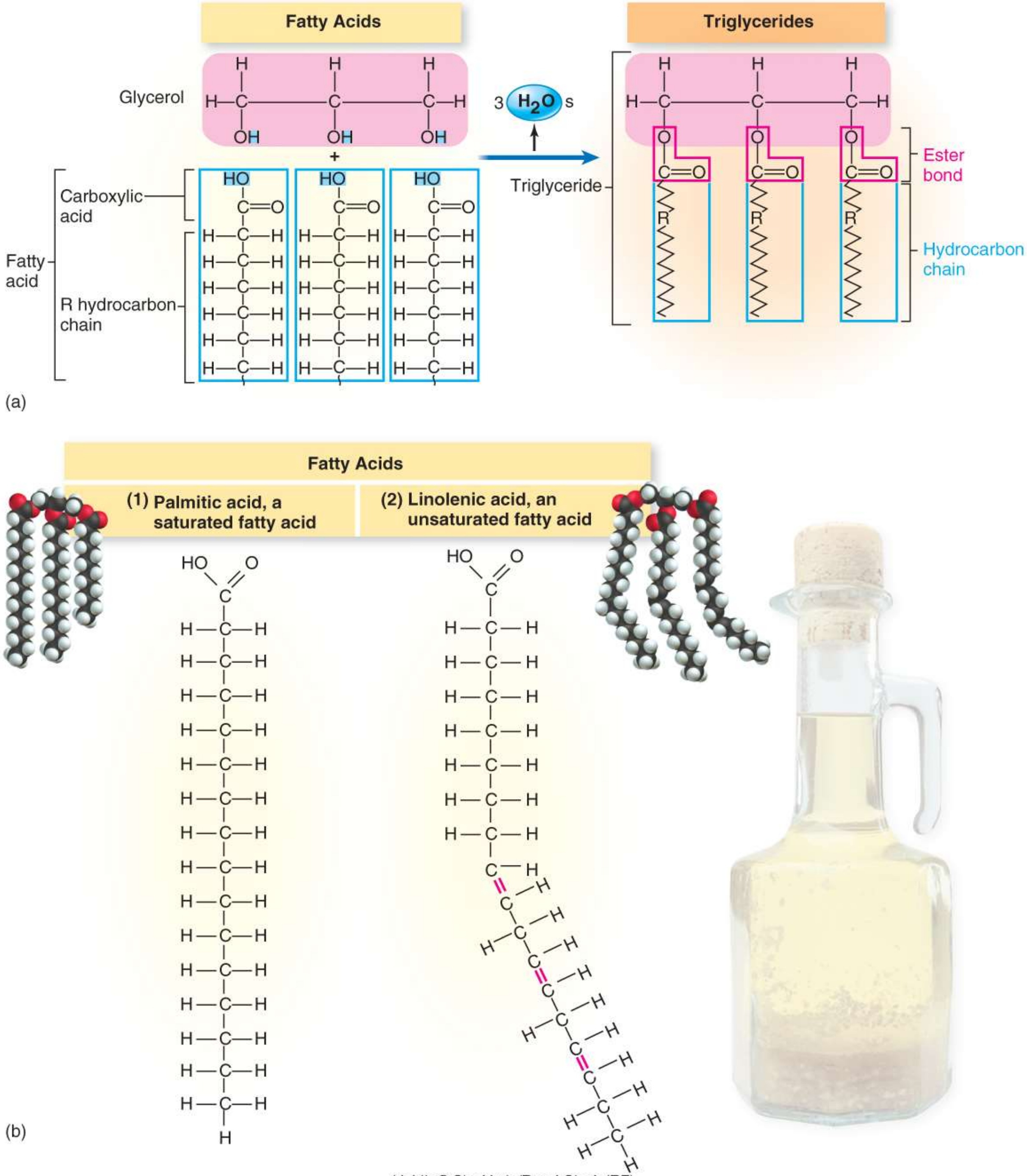
- Three fatty acids covalently bonded to a three carbon alcohol (a glycerol molecule)
  - each bond formed by dehydration synthesis
  - once joined to glycerol /// fatty acids can no longer donate protons – it is a neutral fats
  - maybe broken down by hydrolysis
- Triglycerides when at room temperature
  - If liquid its called an oils // often polyunsaturated fats from plants
  - If solid its called a fat // saturated fats from animals
- Primary Function - energy storage, insulation and shock absorption (adipose tissue)



Unsaturated fat

Comparison of Dietary Fats

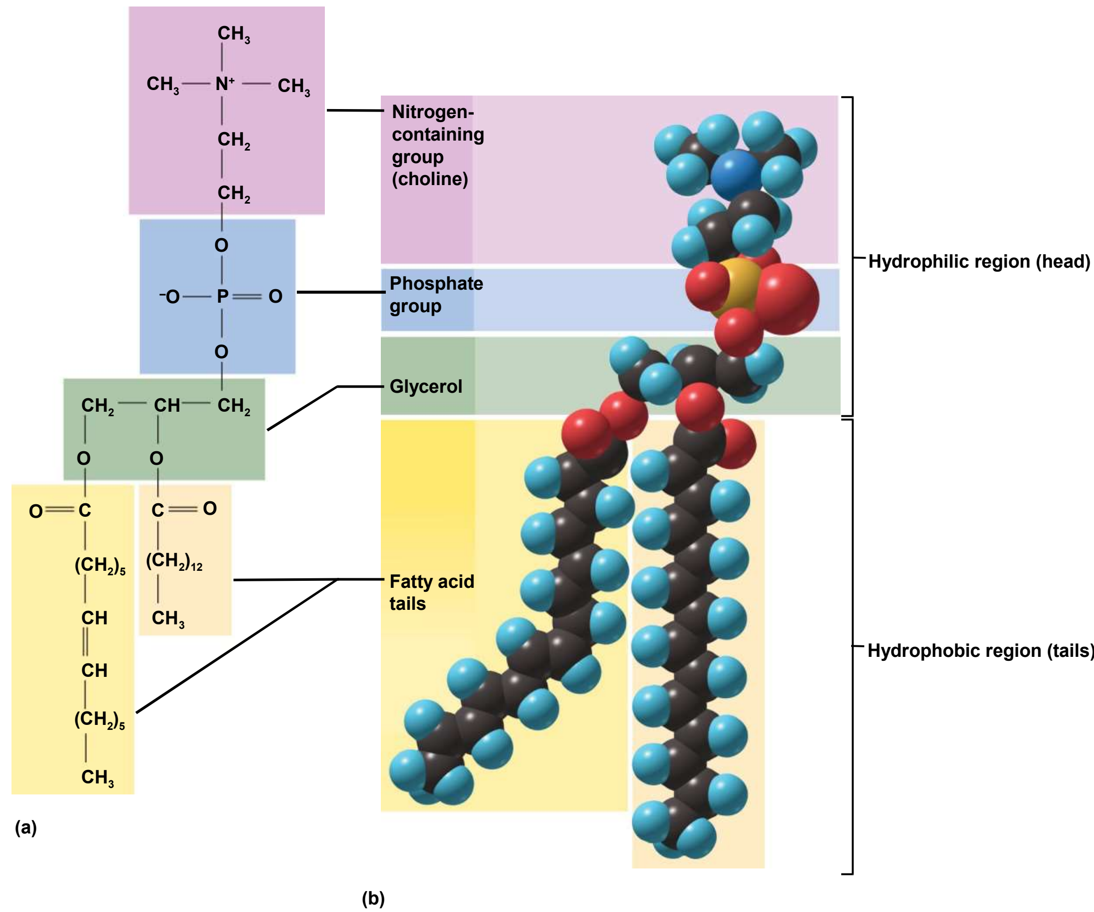


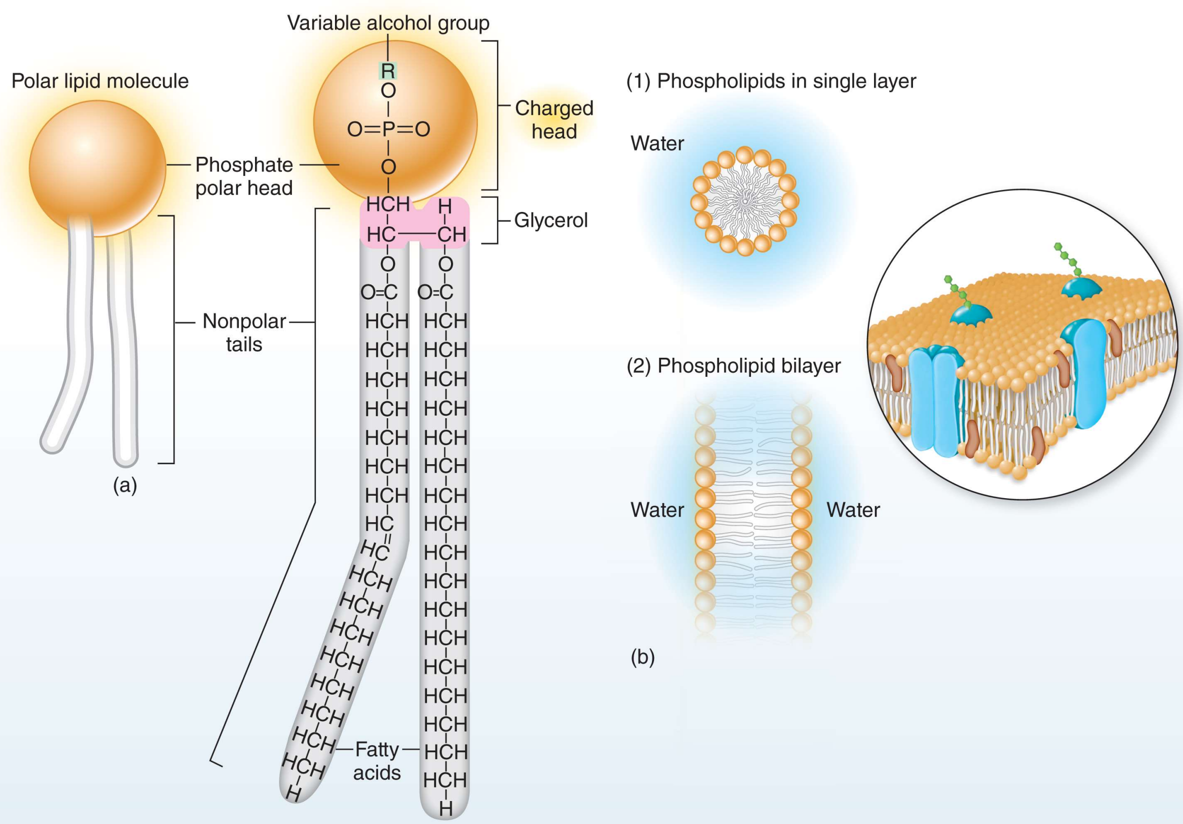


(right): © Stockbyte/PunchStock (RF)

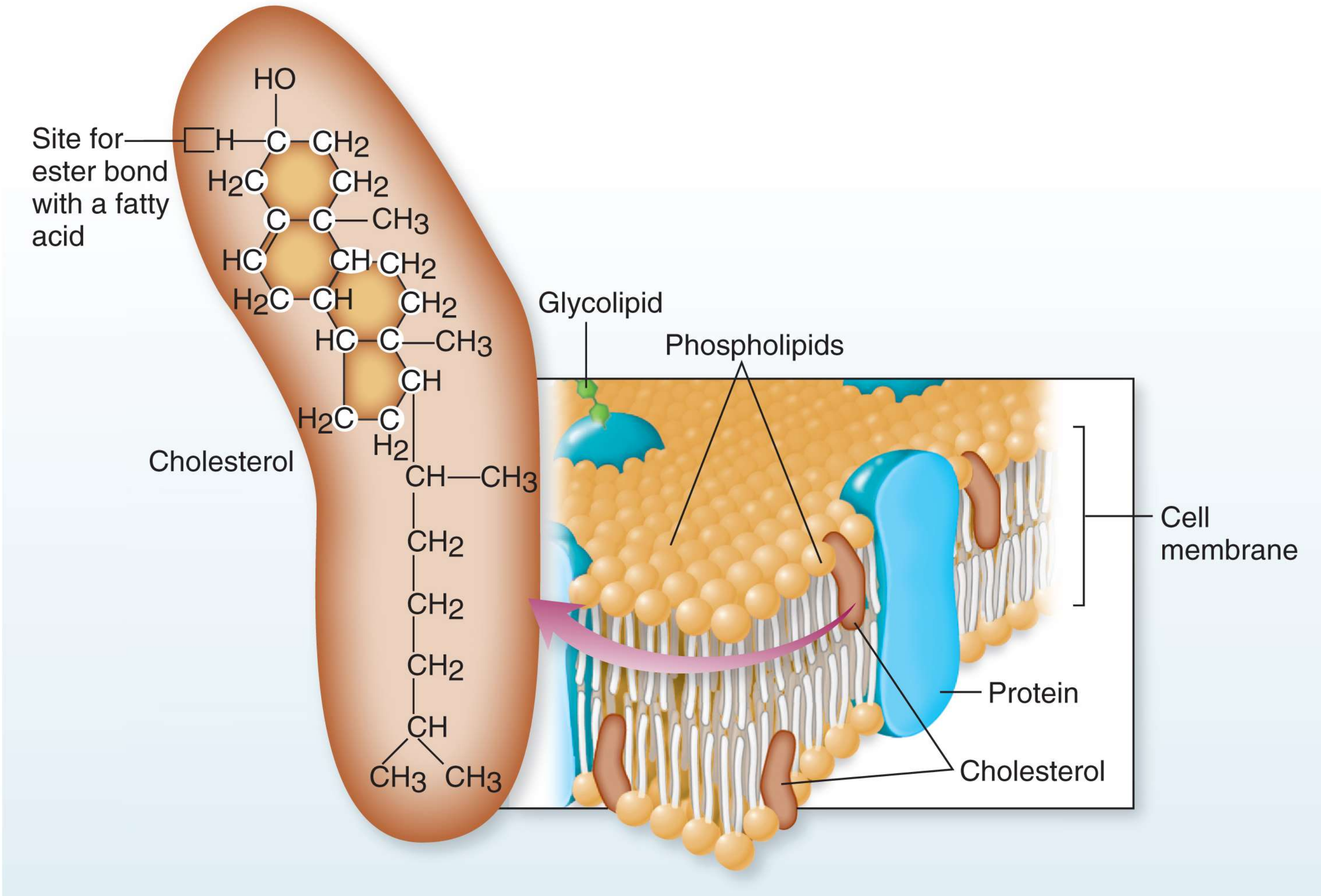
Phospholipids

- similar to neutral fat except that one fatty acid replaced by a phosphate group
- structural foundation of cell membrane
- Amphiphilic // single molecule containing both a neutral and charged region
  - fatty acid "tails" are hydrophobic // water fear
  - phosphate "head" is hydrophilic // water seaking



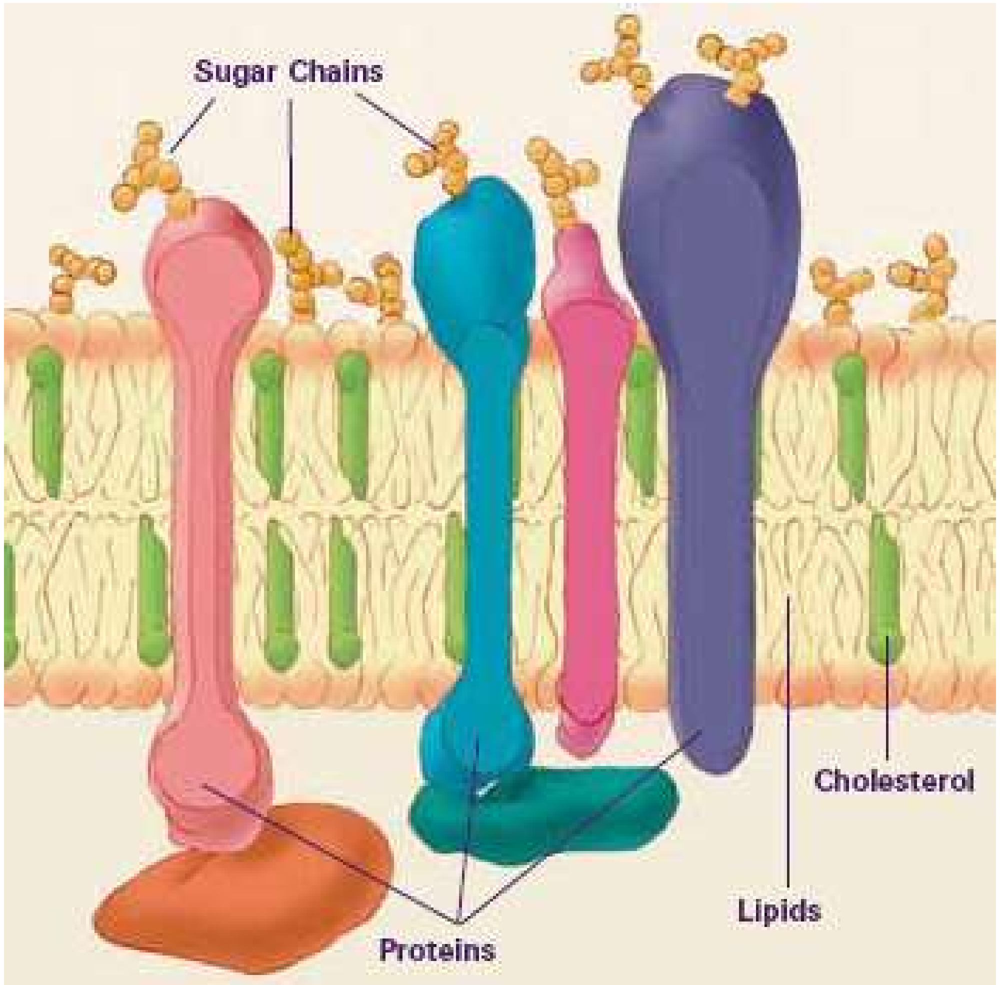


Polar lipid molecule
Phosphate polar head
Nonpolar tails
(a)
Variable alcohol group
R
O
O=P=O
O
HCH
H
HC
CH
Charged head
Glycerol
Fatty acids
(1) Phospholipids in single layer
Water
(2) Phospholipid bilayer
Water
Water
(b)



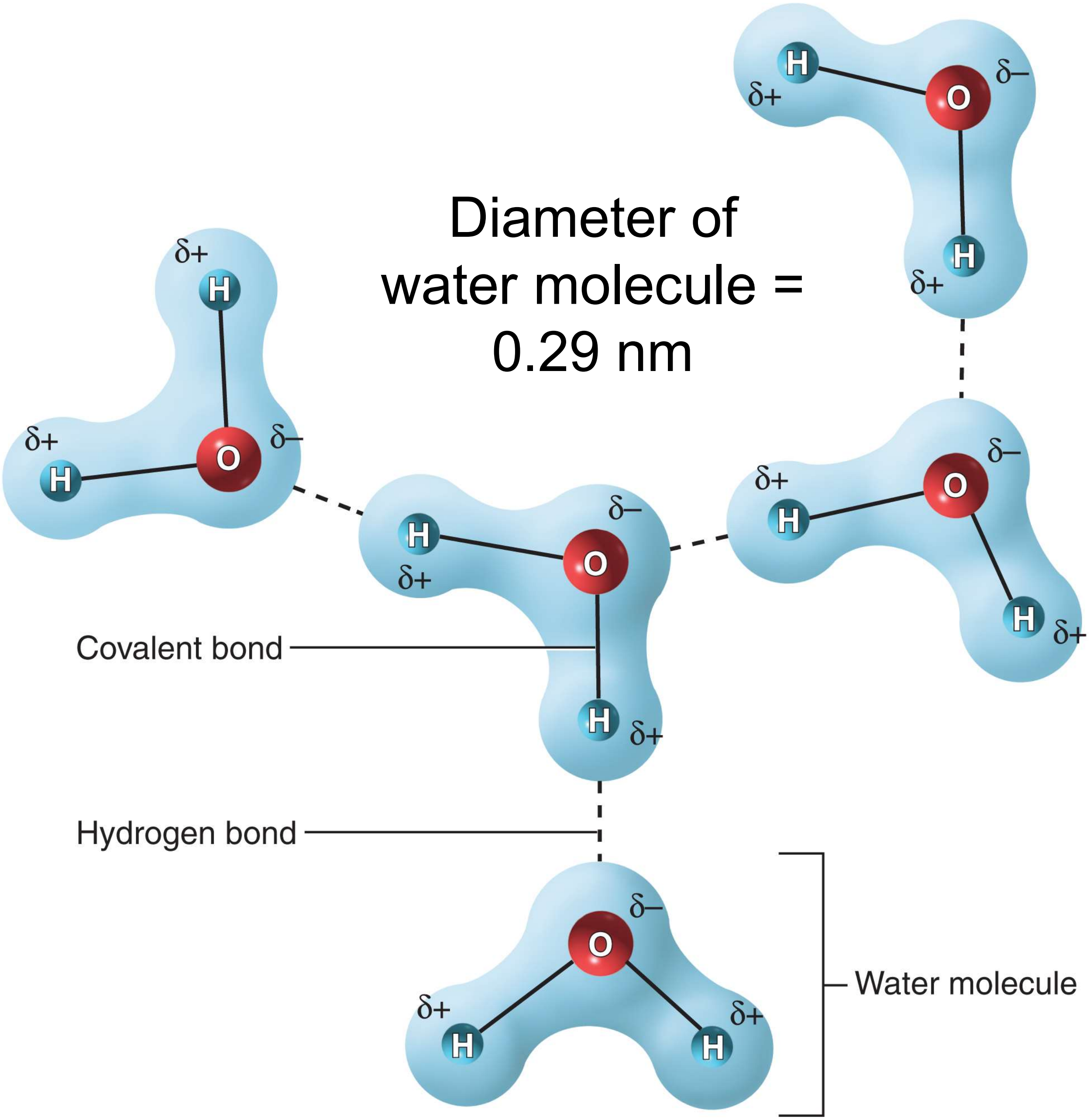
Site for ester bond with a fatty acid
HO
H
C
CH2
H2C
CH2
C
C
CH3
HC
CH
CH2
H2C
CH
CH2
HC
C
CH3
CH
H2C
C
H2
CH
CH3
CH2
CH2
CH2
CH
CH3
CH3
Cholesterol
Glycolipid
Phospholipids
Cell membrane
Protein
Cholesterol

Width of a Plasma Membrane



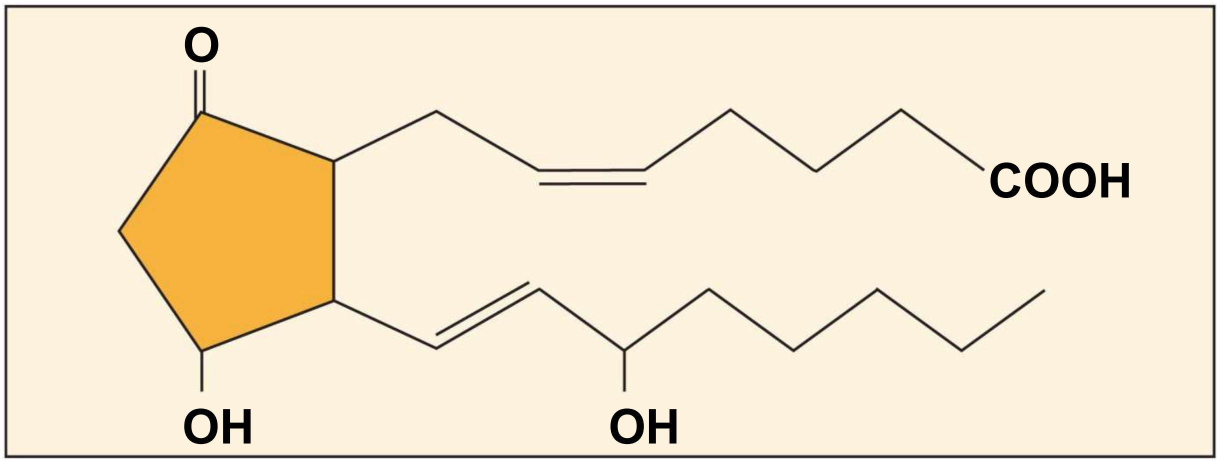
5.5 to 7.5 nm Thick

Approximately 25 water molecules are needed to span the width of a plasma membrane!


H
δ+
O
δ−
H
δ+
Diameter of
water molecule =
0.29 nm
δ+
H
δ+
H
O
δ−
H
δ+
O
δ−
δ+
H
O
δ−
H
δ+
Covalent bond
H
δ+
Hydrogen bond
O
δ−
δ+
H
δ+
H
Water molecule

Eicosanoids

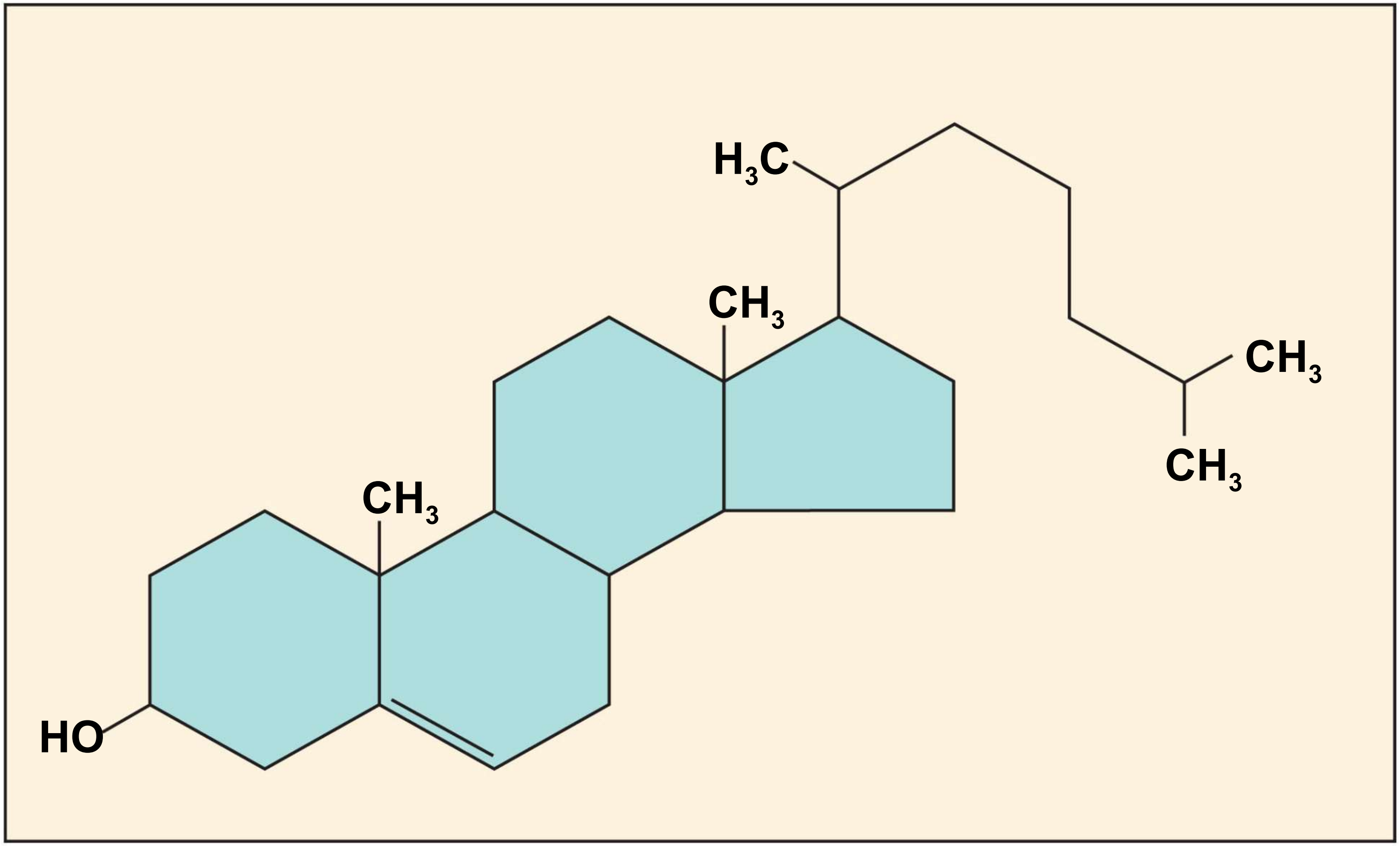
- 20 carbon compounds derived from a fatty acid called arachidonic acid
- hormone-like chemical signals between cells
- includes prostaglandins – produced in all tissues
  - role in inflammation, blood clotting, hormone action, labor contractions, blood vessel diameter



Steroids and Cholesterol

- **Steroid** – a lipid with 17 of its carbon atoms in four rings
- **Cholesterol** - the ‘parent’ steroid from which the other steroids are synthesized
  - E.g. cortisol, progesterone, estrogens, testosterone and bile acids
- Cholesterol
  - synthesized only by animals // especially liver cells // 15% from diet, 85% internally synthesized
  - important component of cell membranes
  - required for proper nervous system function
  - never metabolized for energy!

Cholesterol



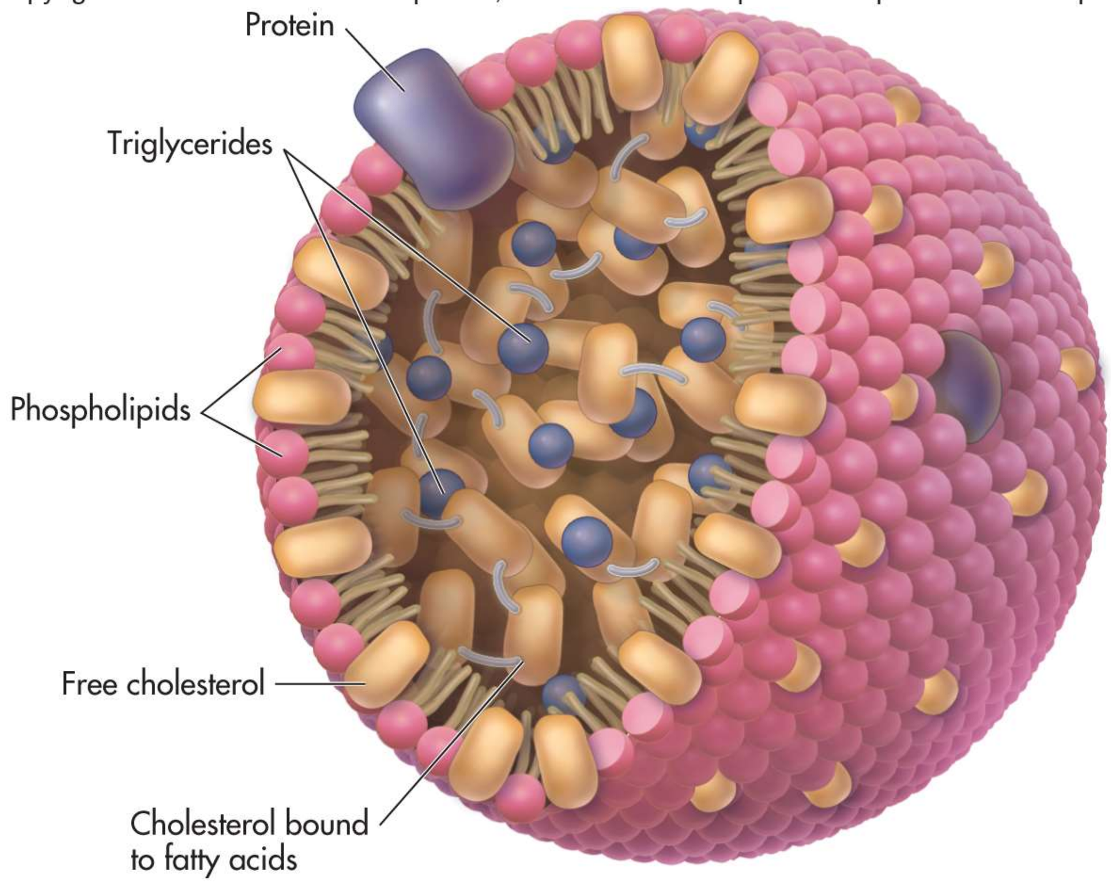
“Good” and “Bad” Cholesterol

- *Good and bad is in reference to phospholipids “transporters”*
- *Transport structures (i.e. shells) are constructed of phospholipids and proteins*
- *Transporters move triglycerides, fatty acids, fat soluble vitamins, and cholesterol in the blood or across digestive system's basal absorptive cell surface and into lacteals.*
- ‘Good’ and ‘bad’ cholesterol refers to two different transporter “types” associated with the blood

“Good” and “Bad” Cholesterol

- The actual transporters are complexes of cholesterol, fat, phospholipids, and protein
- The transporters form a “hollow” shell
- **HDL** – high-density lipoprotein – “good” cholesterol”
  - lower ratio of lipid to protein in its shell
  - may help to prevent cardiovascular disease
- **LDL** – low-density lipoprotein – “bad” cholesterol”
  - high ratio of lipid to protein in its shell
  - contributes to cardiovascular disease

Structure of Lipoprotein Transporter

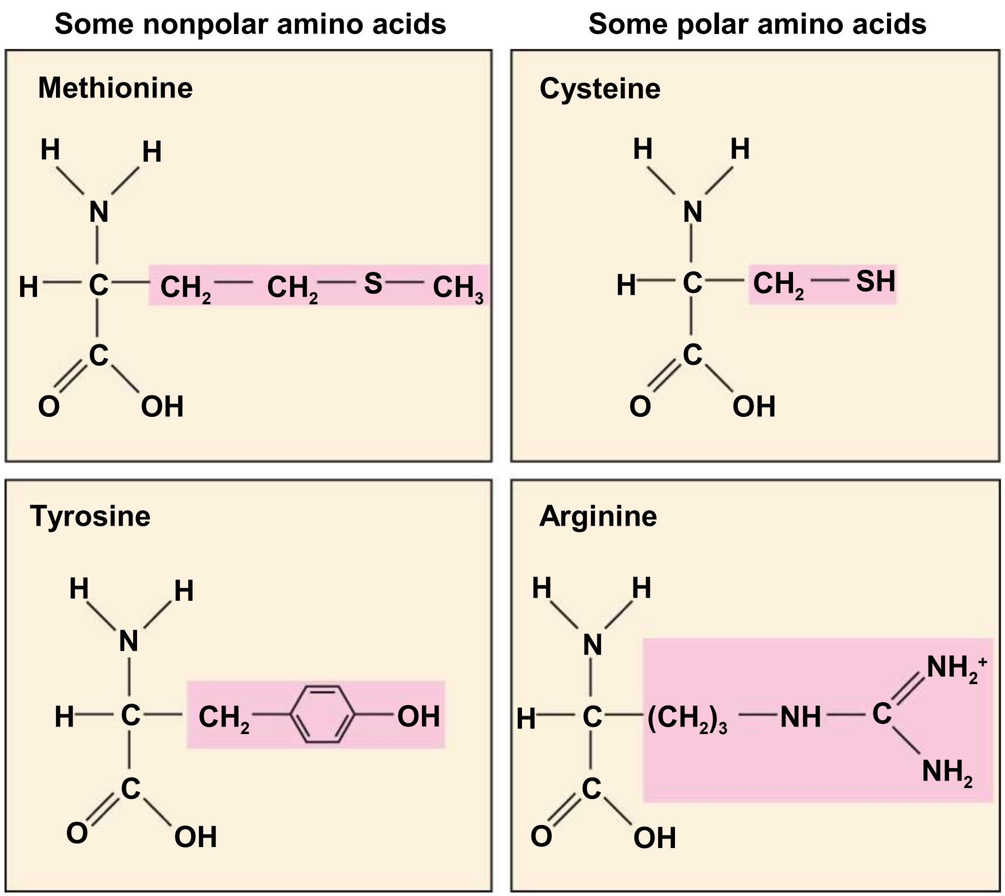


Note: fat soluble products are transported inside the shell // pink hydrophillic phosphate heads of the phospholipid make shell water soluble

Proteins

- Greek word meaning “of first importance” // most versatile molecules in the body /// organic molecule
- **Protein** - a polymer of amino acids
- **Amino acid** – central carbon with 3 attachments // amino group (NH2), carboxyl group (COOH) and radical group (R group)
- 20 amino acids used similar “backbone” to make the proteins but unique radical (R) group
  - properties of amino acid determined by -R group
  - amino acids are defined as either essential or non-essential

Representative Amino Acids

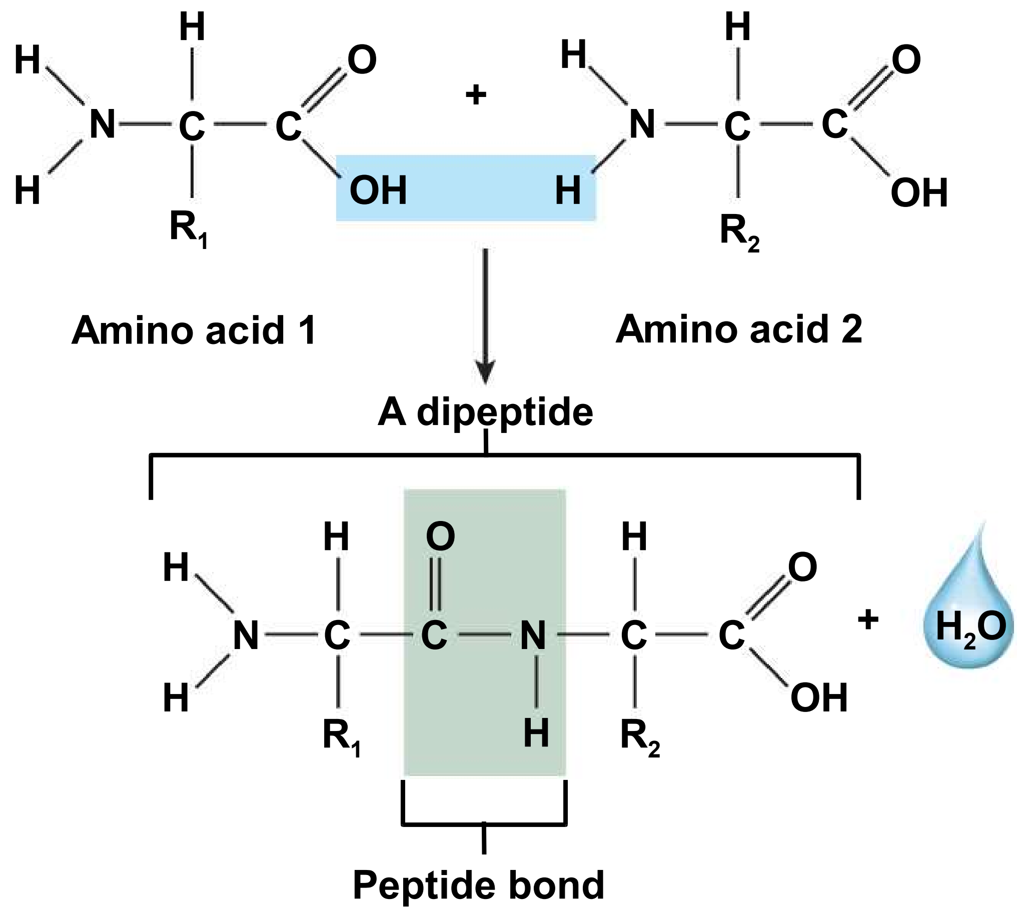


- Note: they differ only in the R group

Naming Peptides

- **Peptide –** any molecule composed of two or more amino acids joined by peptide bonds
- **Peptide bond** – joins the amino group of one amino acid to the carboxyl group of the next
  - formed by dehydration synthesis
- **Peptides named for the number of amino acids**
  - **dipeptides** have 2
  - **tripeptides** have 3
  - **oligopeptides** have fewer than 10 to 15
  - **polypeptides** have more than 15
  - **proteins** have more than 50

Dipeptide Synthesis



Dehydration synthesis creates a peptide bond that joins amino acids // covalent bond between carbon and nitrogen = peptide bond

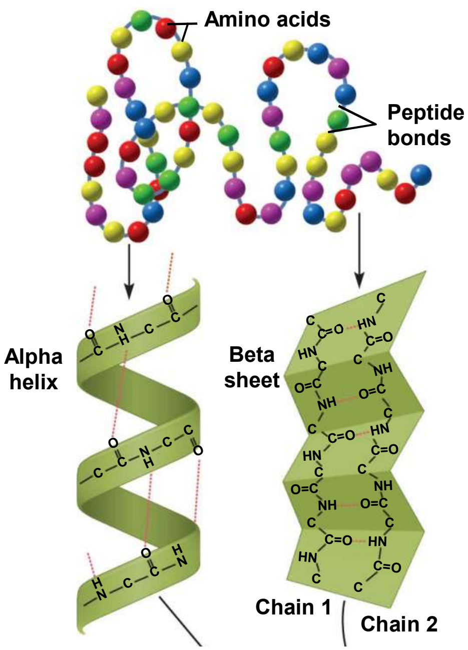
Protein Structure and Shape

- **Primary structure**
  - protein's sequence amino acid which is encoded in the genes
- **Secondary structure**
  - coiled or folded shape held together by hydrogen bonds
  - hydrogen bonds between slightly negative C=O and slightly positive N-H groups
  - most common secondary structure are:
    - alpha helix – springlike shape
    - beta helix – pleated, ribbonlike shape

Protein Structure and Shape

- **Tertiary structure**
  - further bending and folding of proteins into globular and fibrous shapes
    - **globular proteins** –compact tertiary structure well suited for proteins embedded in cell membrane and proteins that must move about freely in body fluid
    - **fibrous proteins** – slender filaments better suited for roles as in muscle contraction and strengthening the skin
- **Quaternary structure**
  - associations of two or more separate polypeptide chains
  - functional conformation – three dimensional shape

Structure of Proteins

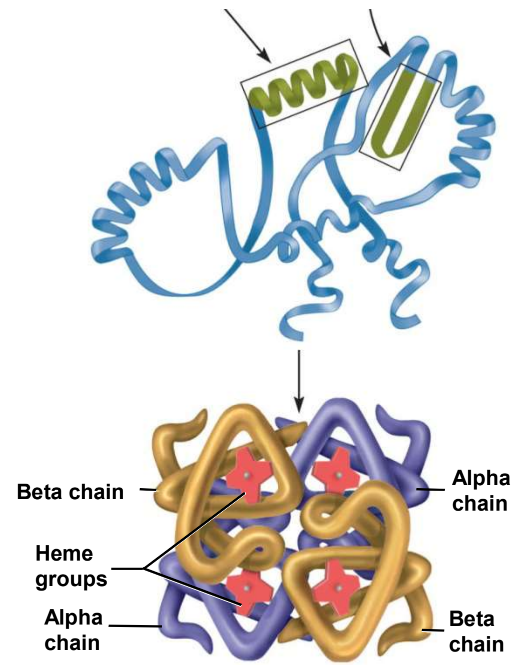


Primary structure

Sequence of amino acids joined by peptide bonds

Secondary structure

Alpha helix or beta sheet formed by hydrogen bonding



Tertiary structure

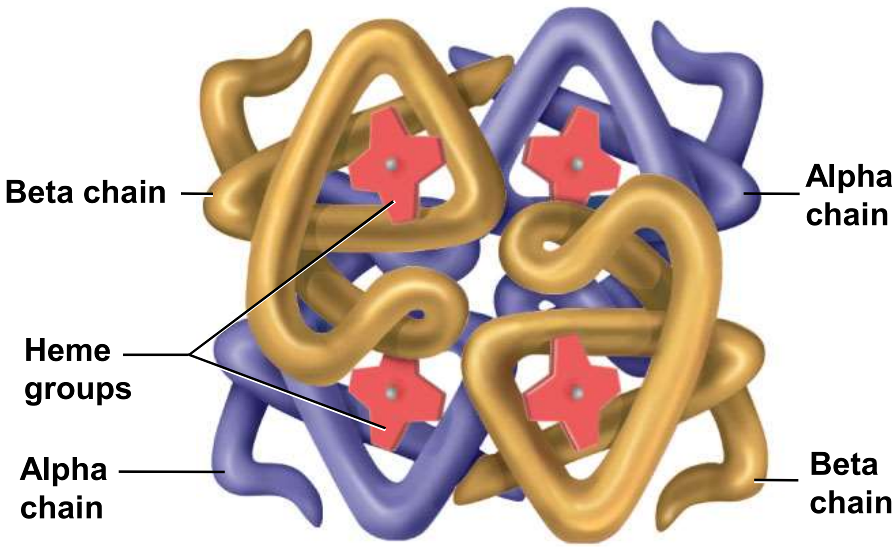
Folding and coiling due to interactions among R groups and between R groups and surrounding water

Quaternary structure

Association of two or more polypeptide chains with each other

Conjugated Proteins

- Proteins that contain a non-amino acid moiety are called a **prosthetic group**
- Hemoglobin contains four complex iron containing rings called a ***heme* moieties**



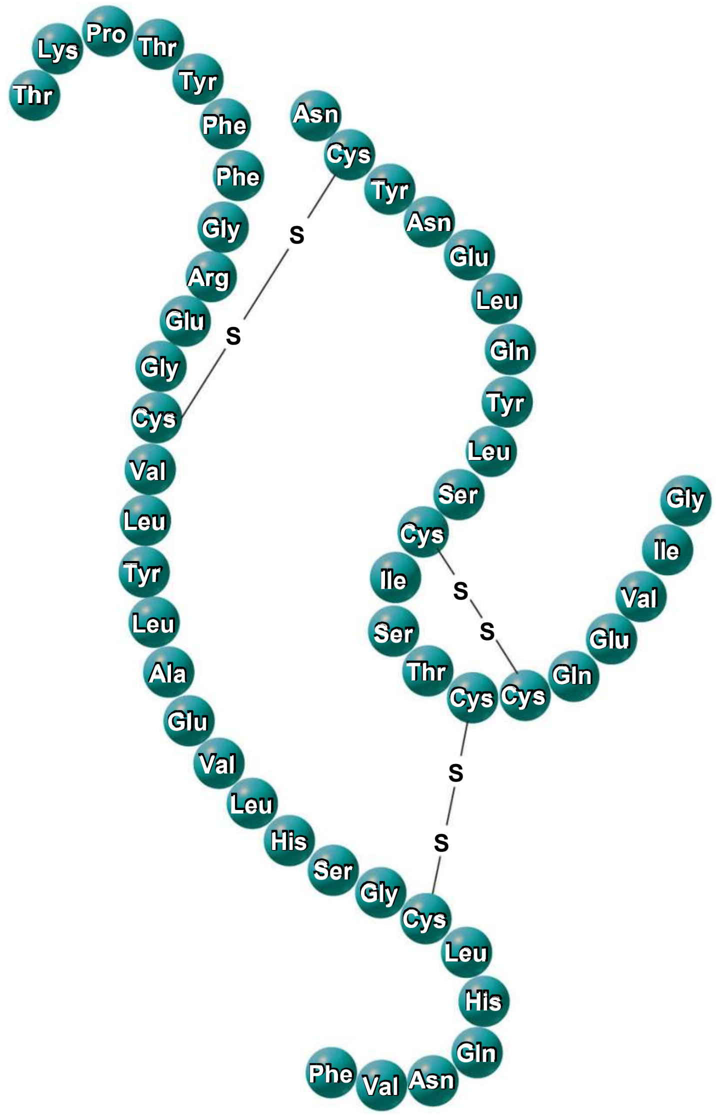
Quaternary structure

Association of two or more polypeptide chains with each other

Protein Conformation and Denaturation

- **Conformation –** unique three dimensional shape of protein crucial to function
  - Some proteins have ability to reversibly change their conformation – important in:
    - enzyme function
    - muscle contraction
    - opening and closing of cell membrane pores
- **Denaturation //** extreme conformational change that destroys function and protein can not revert back to its original shape // caused by extreme heat, pH or agitation

Primary Structure of Insulin



Proteins Have Many Functions

- **Structure**
  - keratin – tough structural protein
    - gives strength to hair, nails, and skin surface
  - collagen – durable protein contained in deeper layers of skin, bones, cartilage, and teeth
- **Communication**
  - some hormones and other cell-to-cell signals
  - receptors to which signal molecules bind
    - ligand – any hormone or molecule that reversibly binds to a protein
- **Membrane Transport**
  - channels in cell membranes that governs what passes through
  - carrier proteins – transports solute particles to other side of membrane
  - turn nerve and muscle activity on and off

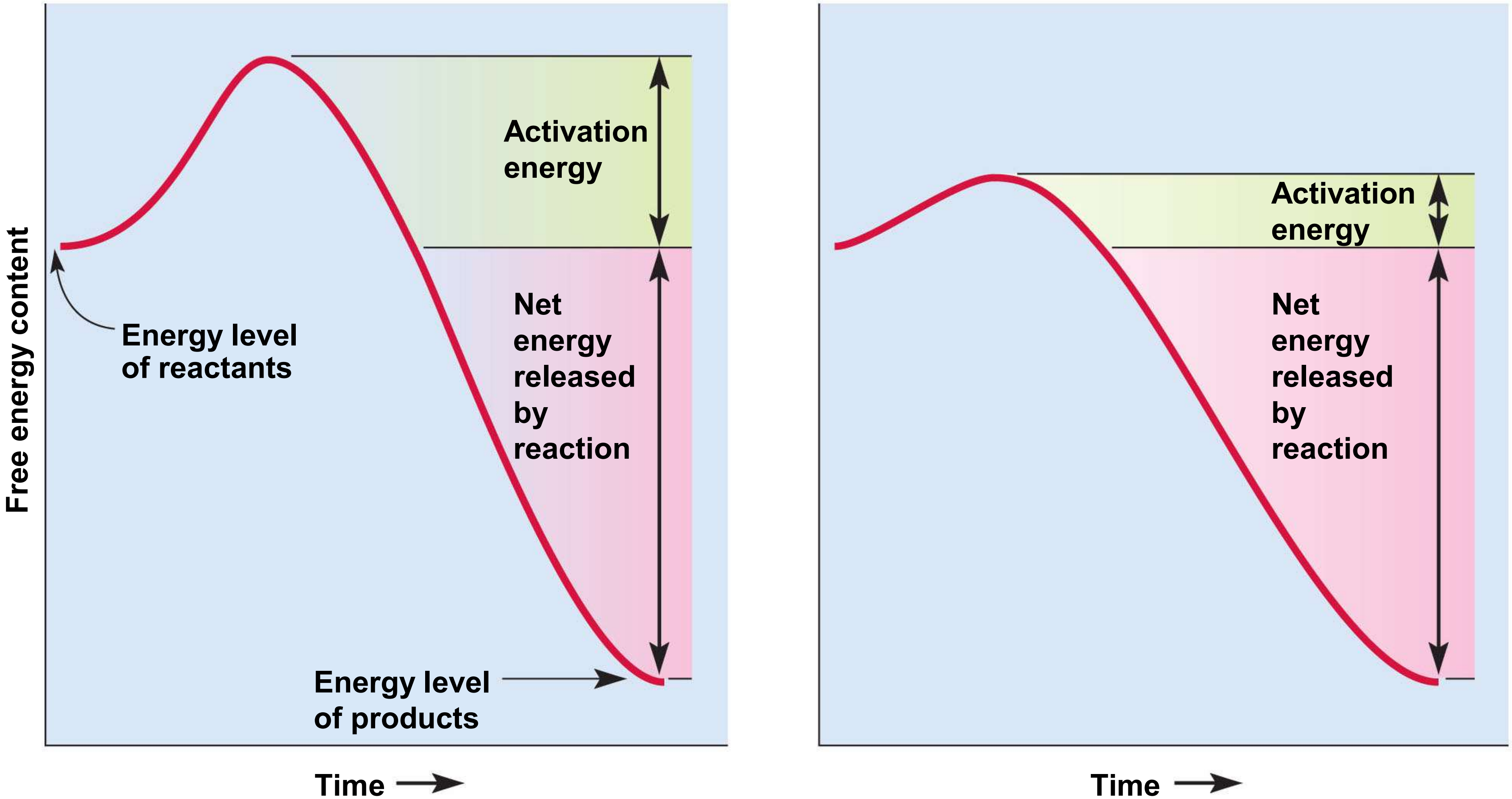
Proteins Have Many Functions

- **Catalysis**
  - enzymes
- **Recognition and Protection**
  - immune recognition
  - antibodies
  - clotting proteins
- **Movement**
  - **motor proteins** - molecules with the ability to change shape repeatedly
- **Cell adhesion**
  - proteins bind cells together
  - immune cells to bind to cancer cells
  - keeps tissues from falling apart

Enzymes

- Enzymes - proteins that function as biological catalysts
  - permit reactions to occur rapidly at normal body temperature
- Substrate - substance that the enzyme acts upon
- Naming Conventions
  - named for substrate with -ase as the suffix (e.g. amylase = enzyme that digests starch (note difference for amylose /// "ose" indicates sacharide – amylose polymer of glucose)
- Enzymes lowers **activation energy** - energy needed to get reaction started /// enzymes facilitate molecular interaction

Enzymes and Activation Energy



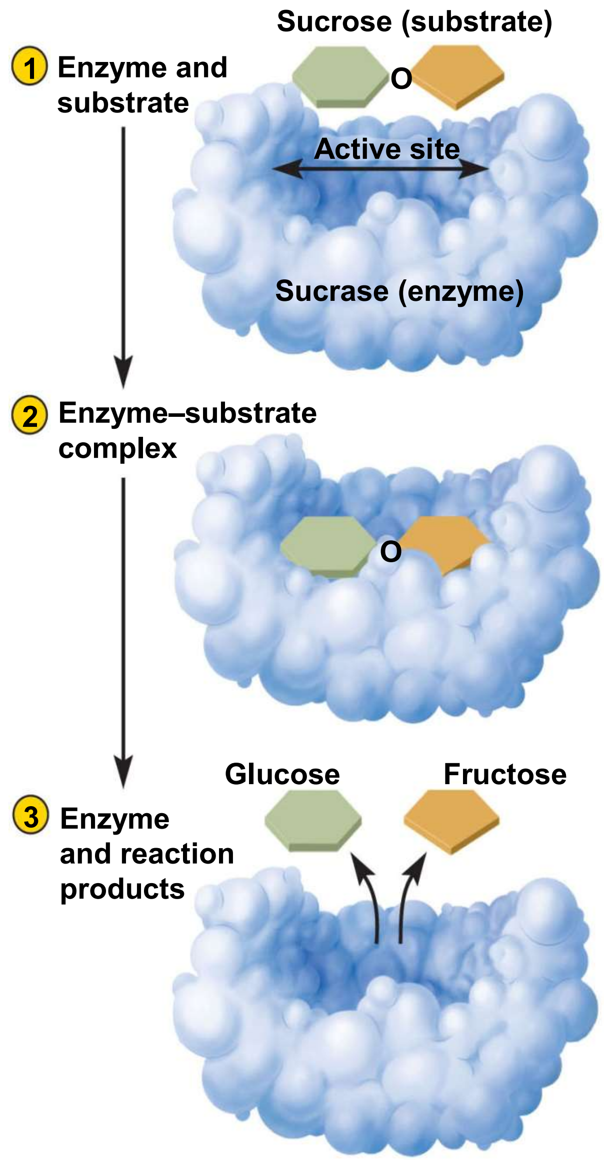
(a) Reaction occurring without a catalyst

(b) Reaction occurring with a catalyst

Enzyme Structure and Action

- Substrate approaches active site on enzyme molecule
- Substrate binds to active site forming enzyme-substrate complex
  - highly specific fit – like a ’lock and key’
  - enzyme-substrate specificity
- Enzyme breaks covalent bonds between monomers in substrate
- adding H+ and OH- from water – Hydrolysis
- Reaction products released – glucose and fructose
- Enzyme remains unchanged and is ready to repeat the process

Enzymatic Reaction Steps



About Enzymatic Action

- Enzymes are reusable /// enzymes are not consumed by the reactions
- Astonishing speed /// one enzyme molecule may consume millions of substrate molecules per minute
- Factors that change enzyme shape
  - pH, temperature, agitation
  - alters or destroys the ability of the enzyme to bind to substrate
  - enzymes action have optimum pH /// salivary amylase works best at pH 7.0 /// pepsin works best at pH 2.0
  - temperature optimum for human enzymes – body temperature (37 degrees C)

Enzymes Control Metabolic Pathways

- Chain of reactions // each step catalyzed by a different enzyme

- $$\overset{\alpha}{A \rightarrow} B \overset{\beta}{\rightarrow} C \overset{\gamma}{\rightarrow} D$$

- A is initial reactant, B+C are intermediates and D is the end product

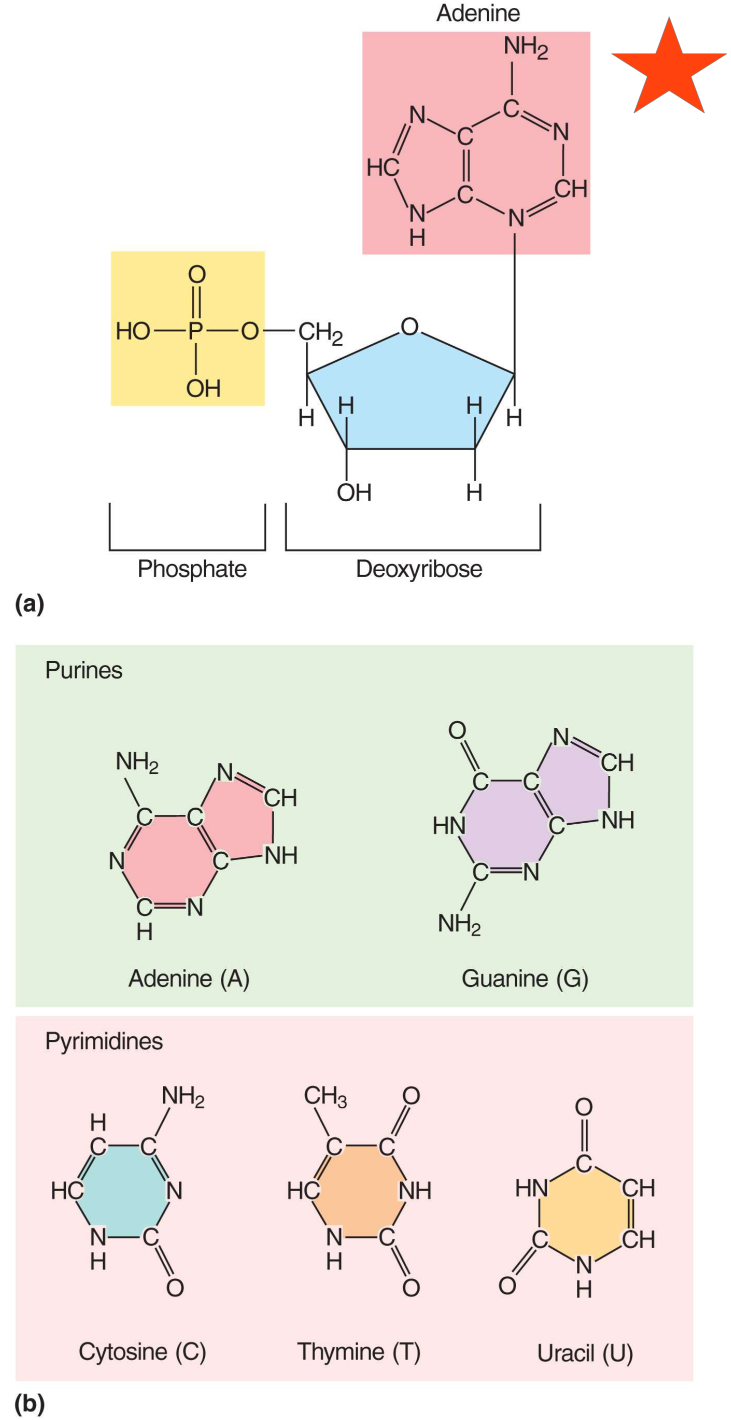
- Regulation of metabolic pathways // involves the activation or deactivation of the enzymes

  – cells can regulate pathways /// turn on when end products are needed or turn off when the end products are not needed

  – E.g. enzyme “a” maybe inhibited by end product “D”

Nucleotides

- Organic Molecules
- Three components of a nucleotide
  - nitrogenous base (single or double carbon-nitrogen ring)
  - sugar (monosaccharide)
  - one or more phosphate groups
- DNA = A, T, G, C
- RNA = A, U, G, C
- ATP – best know nucleotide /// adenine (nitrogenous base) + ribose (sugar) + Three phosphate groups



DNA Nucleotides

- **DNA (deoxyribonucleic acid)**
  - 100 million to 1 billion nucleotides long
  - Our genes are constructed from DNA
    - instructions for synthesizing all of the body's proteins
    - transfers hereditary information from cell to cell and generation to generation
    - DNA codes for protein // either a structural molecule or an enzyme (enzymes can make other organic molecules)

RNA Nucleotides

- **RNA (ribonucleic acid)** – 3 types associated with protein synthesis
  - messenger RNA, ribosomal RNA, transfer RNA
  - 70 to 10,000 nucleotides long
  - carries out genetic instruction for synthesizing proteins
  - assembles amino acids in the right order to produce proteins
  - single strand // not double stranded like DNA
  - Micro-RNA // functions as a biocatalyst

Adenosine Triphosphate (ATP)

- body's most important energy-transfer molecule // the molecule which provides energy for all cellular work // "molecular money"

- briefly stores energy gained from exergonic reactions

- releases it within seconds for physiological work // ATP not used to store energy

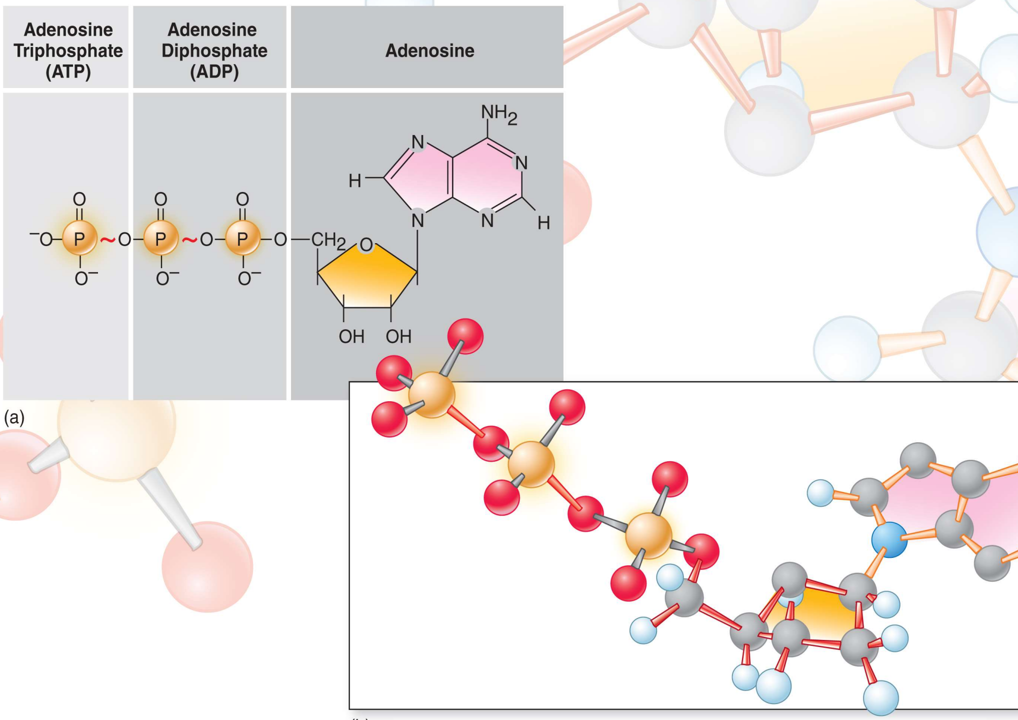
- holds energy in covalent bonds

  - 2nd and 3rd phosphate groups have high energy bonds // denoted by this symbol " ~ "

  - most energy transfers to and from ATP involve adding or removing the 3rd phosphate

Adenosine Triphosphate (ATP)

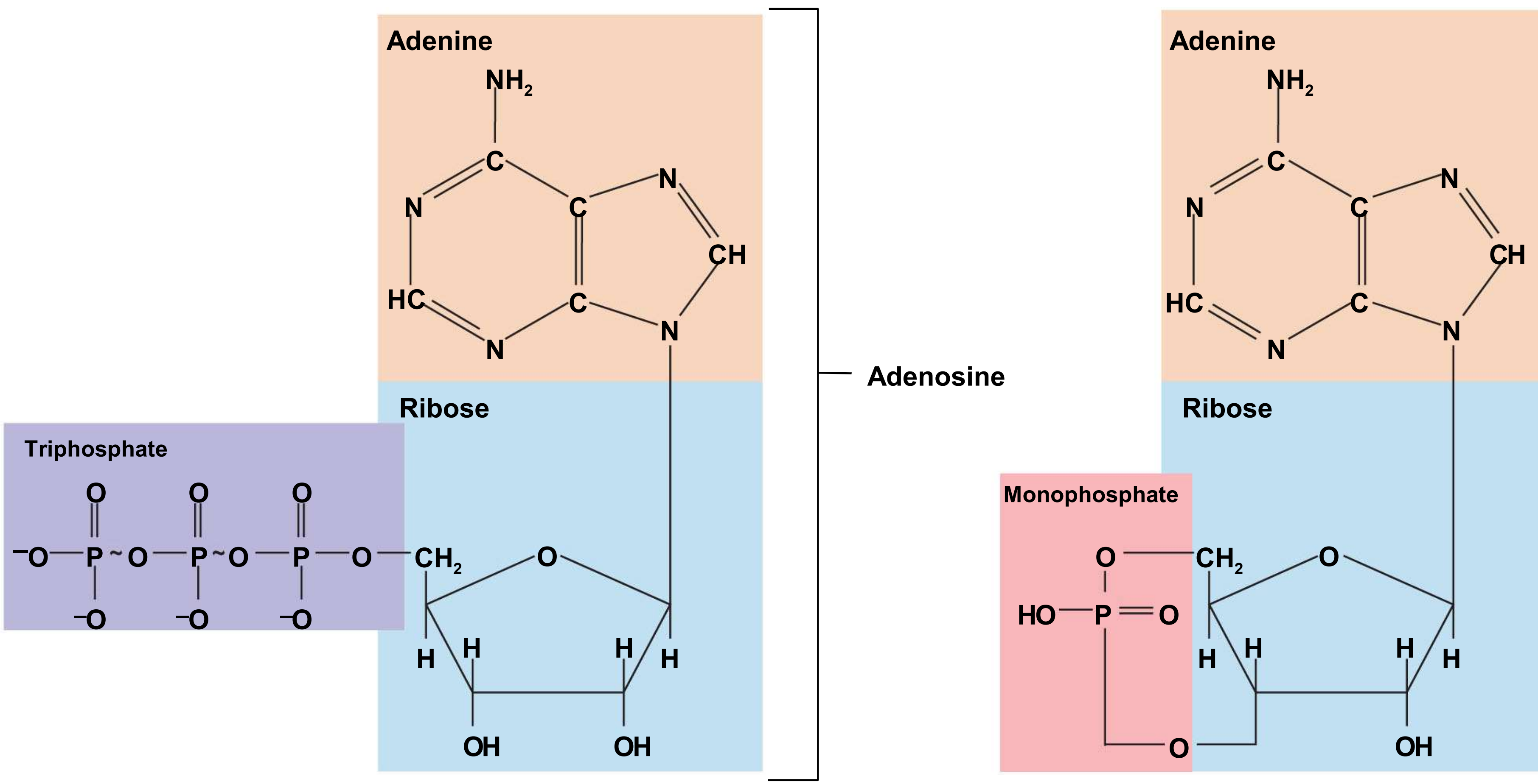
- **Adenosine triphosphatases (ATPases)** hydrolyze the 3rd high energy phosphate bond
  - separates into ADP + P_i + energy
- **Phosphorylation**
  - addition of free phosphate group to ADP molecule
  - carried out by enzymes called **kinases** (phosphokinases)
  - ATP can be formed by directly phosphorylation of ADP (substrate level phosphorylation) or by a mechanism within mitochondria called oxidation-phosphorylation which requires using an electron chain and ATP-synthetase


Adenosine Triphosphate (ATP)
Adenosine Diphosphate (ADP)
Adenosine
NH2
N
N
H
N
N
H
O
O
O
−O
P
O
P
O
P
O
CH2
O
O−
O−
O−
OH
OH

(a)

(b)

ATP (Adenosine Triphosphate)

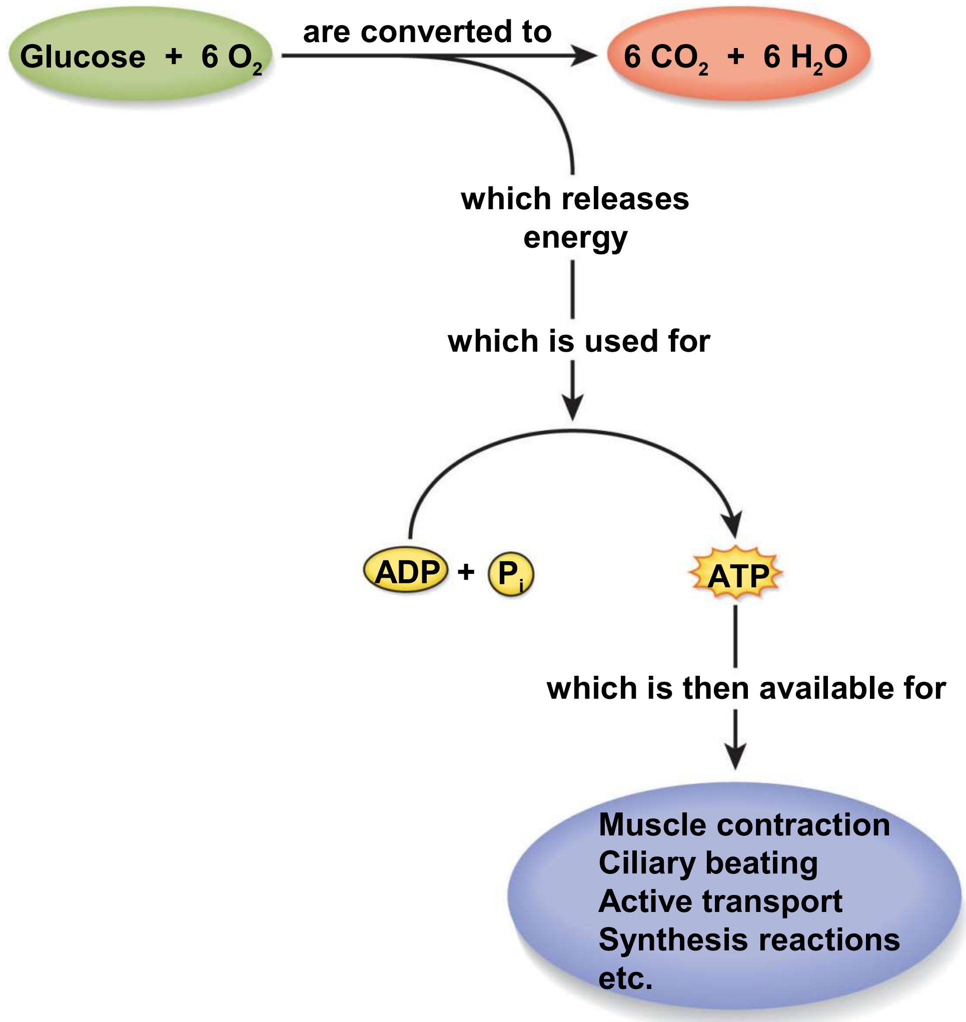


(a) Adenosine triphosphate (ATP)

(b) Cyclic adenosine monophosphate (cAMP)

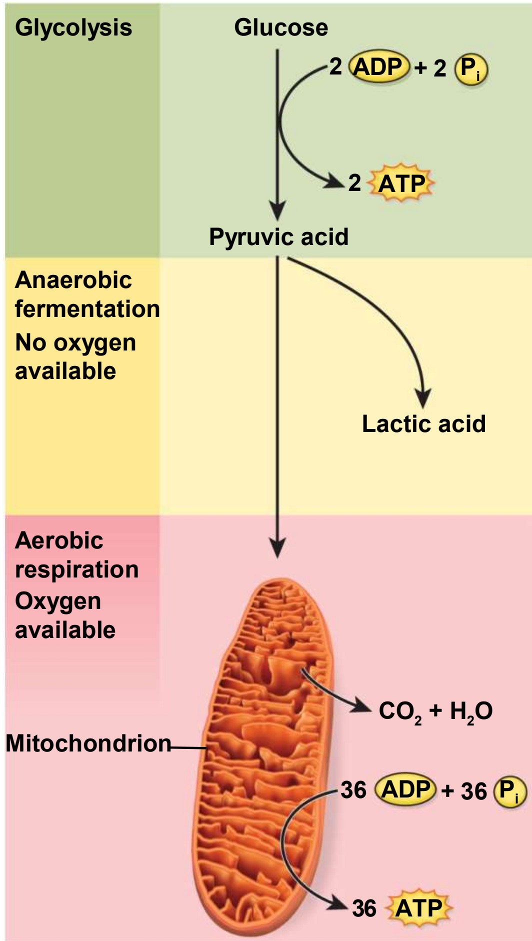
ATP contains adenine, ribose and 3 phosphate groups

Sources and Uses of ATP



Overview of ATP Production

Stages of glucose oxidation



- ATP consumed within 60 seconds of formation
- entire amount of ATP in the body would support life for less than 1 minute if it were not continually replenished
- cyanide halts ATP synthesis // stops electrons from moving down electron transport chain which is inside the mitochondria

Other Nucleotides

- **Guanosine triphosphate (GTP)**
  - another nucleotide involved in energy transfer
  - donates phosphate group to other molecules

- **Cyclic adenosine monophosphate (cAMP)**
  - nucleotide formed by removal of both second and third phosphate groups from ATP
  - formation triggered by hormone binding to cell surface
  - cAMP becomes “second messenger” within cell
  - activates metabolic effects inside cell

Cofactors and Coenzymes

- *Some enzymes require one or both of these co-factors for the enzyme to function*

- Cofactors

  - about 2/3rds of human enzymes require a non-protein cofactor

  - inorganic partners (iron, copper, zinc, magnesium and calcium ions)

  - some bind to enzyme and induces a change in its shape, which activates the active site

  - essential to function

Coenzymes

- Coenzymes = organic cofactors derived from water-soluble vitamins (niacin, riboflavin)

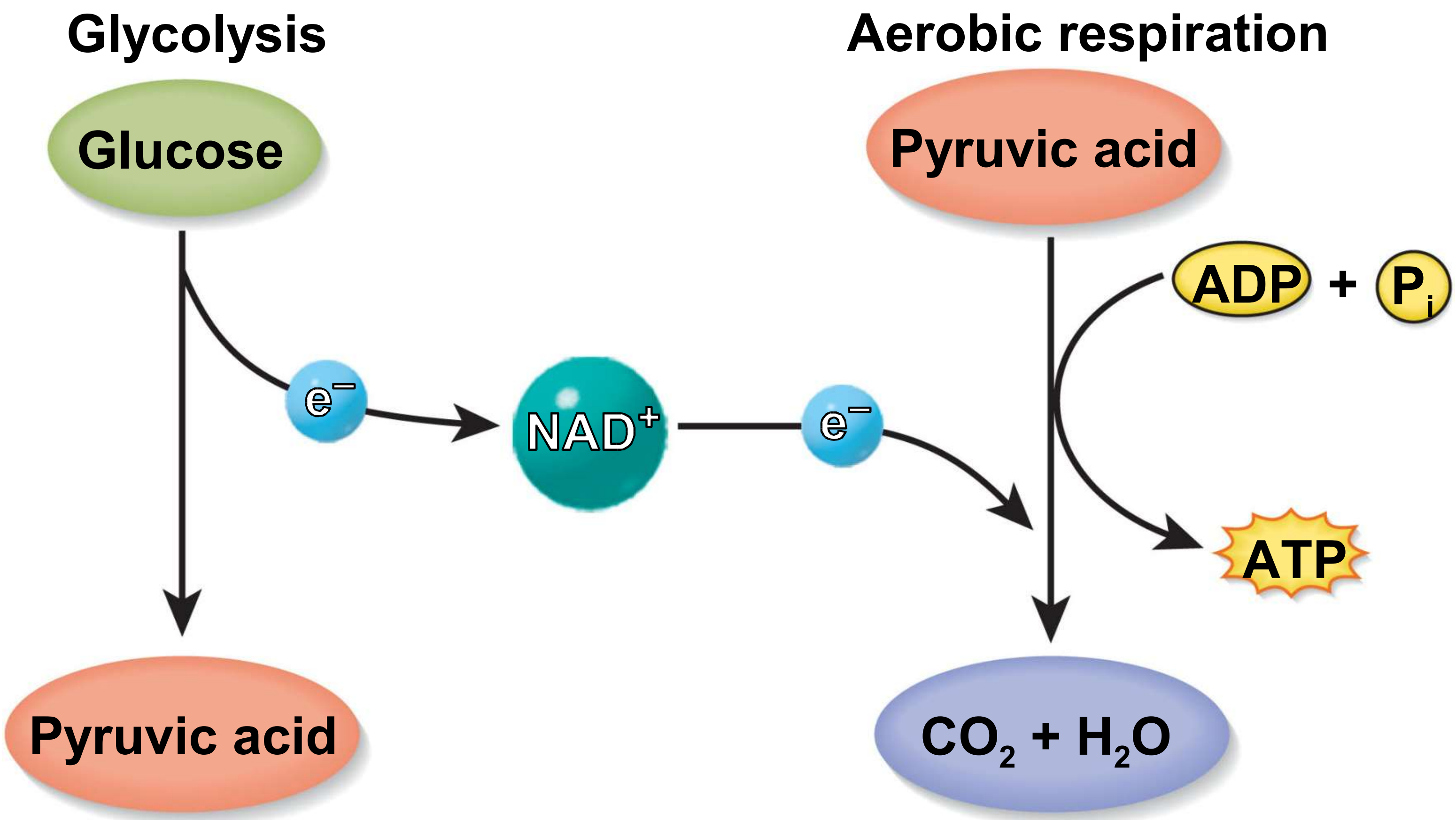
  – they accept electrons from an enzyme in one metabolic pathway and transfer them to an enzyme in another metabolic pathway /// This is an Oxidation-Reduction Reaction

  – the molecule losing the electron is “oxidized” and the molecule gaining the electron is “reduced” (i.e. redox reaction)

  – The electron carrier is reqired by the enzyme to catalyze the reaction reaction (e.g AB -----> A + B)

  – NAD to NADH or FAD to FADH are examples of electron carriers

Coenzyme NAD^+



- NAD^+ transports electrons from one metabolic pathway to another