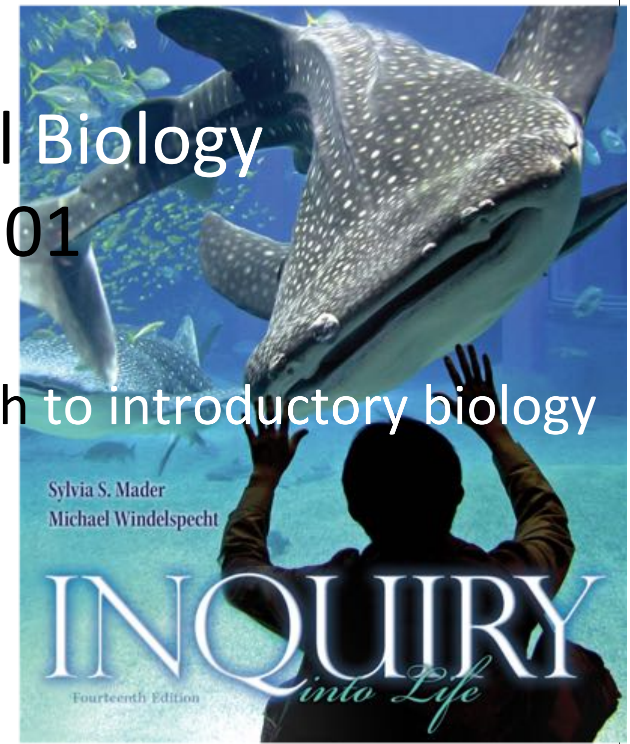
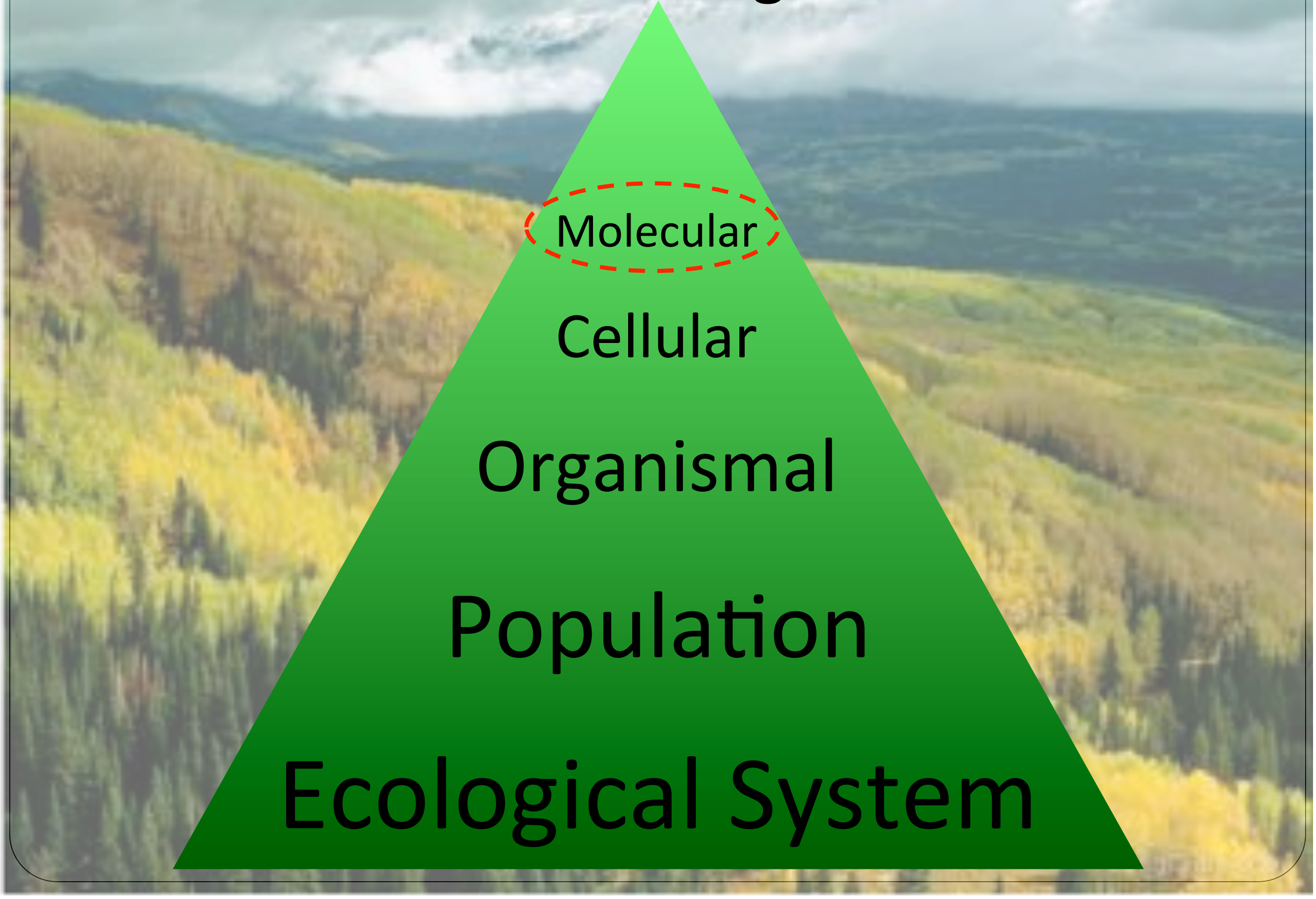
Fundamental Biology
BI 1101

an interdisciplinary approach to introductory biology



Anggraini Barlian,
Iriawati
Tjandra Anggraeni
SITH-ITB

Five Levels of Organization



Ch 02. MOLECULES IN CELLS

Learning outcomes

After this chapter, students are able to:

- Describe the molecules in living organisms
- Explain basic structure and function of protein in cells
- Explain basic structure and function of carbohydrate in cells
- Explain basic structure and function of lipid in cells
- Explain basic structure and function of nucleic acid in cells

Biological macromolecules

What is a Macromolecule?

- Organic molecules that weigh more than 100,000 daltons are referred to as macromolecules.
- These macromolecules are constructed of smaller units called polymers. These polymers are subdivided into their basic units called monomers.

Plant cell walls

Microfibrils – cellulose – glucose

MOLECULES IN CELLS

- Cells are constructed from a few simple molecular building blocks
- Four molecules of life:
  1. **Proteins** (considered *the workhorses of life*)
  2. **Carbohydrates**
  3. **Lipids**
  4. **Nucleic acids** (→ hereditary factors)
- These molecules are also the main constituents of the human diet, together with **minerals** and **vitamins**

Carbohydrates

- Carbo = carbon, hydrate = water;
- Molecular formula $(CH_2O)_n$

$$(CH_2O)_n \quad \text{or} \quad H-\overset{|}{\underset{|}{C}}-OH$$

- Sugars and associated polymers.
- Monomer is the monosaccharide
- Polymers include starch and cellulose.
- Synthesized by plants using sunlight to convert CO_2 and H_2O to glucose and O_2.

Functions:

- Store energy in chemical bonds
  - Glucose is the most common monosaccharide produced by photosynthetic organisms

Carbohydrates

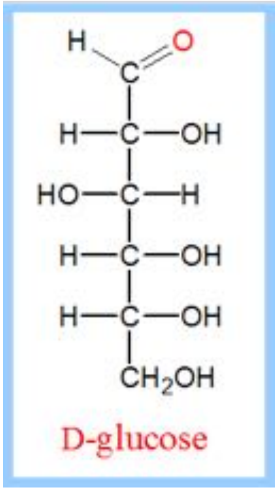
Classification of Carbohydrates

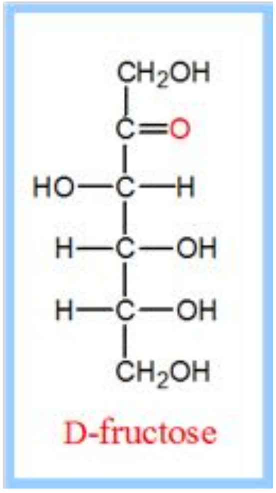
- Monosaccharides - simple sugars with multiple OH groups. Based on number of carbons (3, 4, 5, 6), a monosaccharide is a triose, tetrose, pentose or hexose.
- Disaccharides - 2 monosaccharides covalently linked.
- Oligosaccharides - a few monosaccharides covalently linked.
- Polysaccharides - polymers consisting of chains of monosaccharide or disaccharide units.

Carbohydrates: monosaccharides

Aldoses (e.g., glucose) have an aldehyde group at one end.

Ketoses (e.g., fructose) have a keto group, usually at C2.

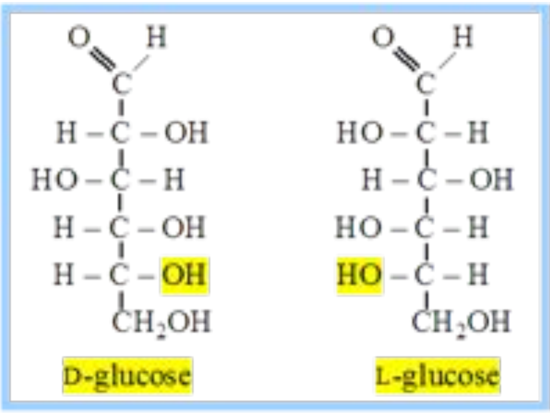


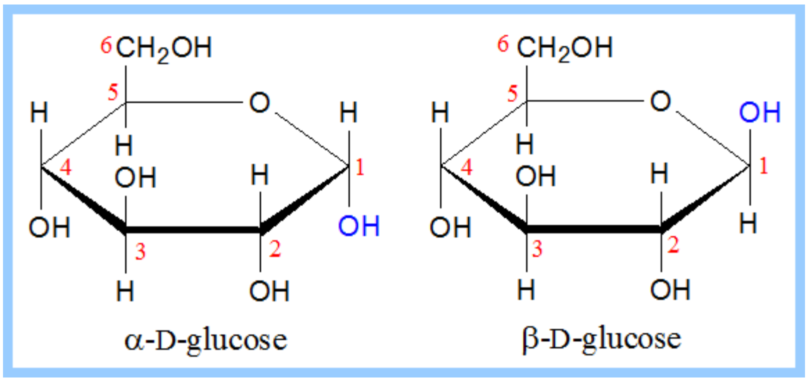


Carbohydrates

For sugars with more than one chiral center, **D** or **L** refers to the asymmetric **C** farthest from the aldehyde or keto group.

Most naturally occurring sugars are D isomers.





Cyclization of glucose produces a new asymmetric center at C1. The 2 stereoisomers are called anomers, α & β.

Haworth projections represent the cyclic sugars as having essentially planar rings, with the OH at the anomeric C1:

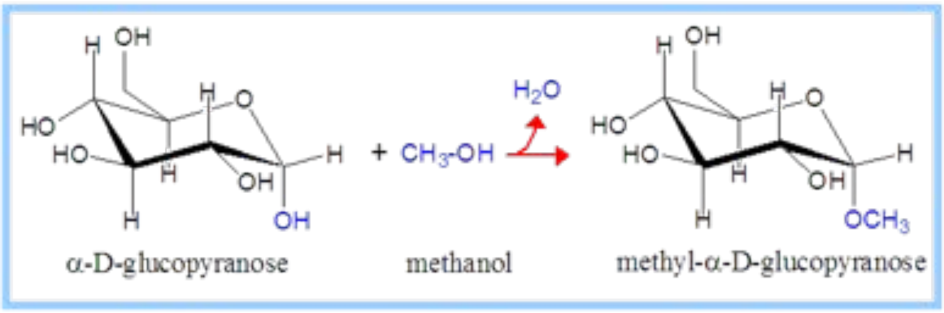
- α (OH below the ring)
- β (OH above the ring).

Glycosidic Bonds

The anomeric hydroxyl and a hydroxyl of another sugar or some other compound can join together, splitting out water to form a glycosidic bond:

R-OH + HO-R' → R-O-R' + H_2O

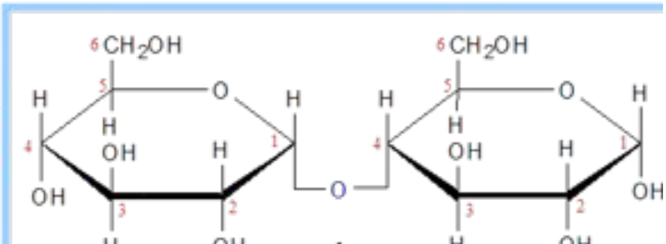
E.g., methanol reacts with the anomeric OH on glucose to form methyl glucoside (methyl-glucopyranose).



Disaccharides:

Maltose, a cleavage product of starch (e.g., amylose), is a disaccharide with an a(1® 4) glycosidic link between C1 - C4 OH of 2 glucoses.

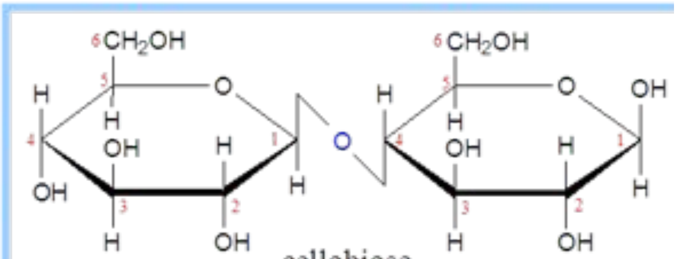
It is the a anomer (C1 O points down).



maltose

Cellobiose, a product of cellulose breakdown, is the otherwise equivalent β anomer (O on C1 points up).

The β(1→4) glycosidic linkage is represented as a zig-zag, but one glucose is actually flipped over relative to the other.



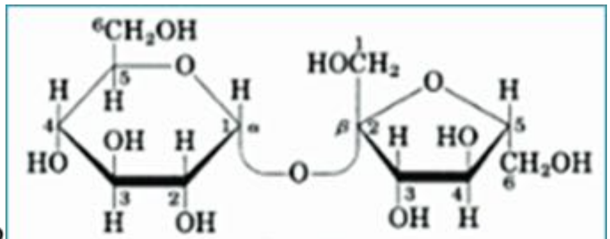
cellobiose

Other disaccharides :

- **Sucrose**, common table sugar, has a glycosidic bond linking the anomeric hydroxyls of glucose & fructose.

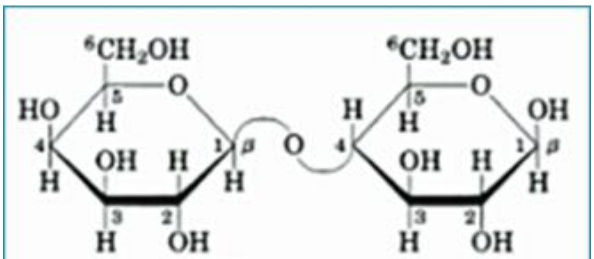
  Because the configuration at the anomeric C of glucose is a (O points down from ring), the linkage is α(1→2

  The full name of sucrose is a-D-glucopyranosyl-(1→2)-b-D-fructopyranose.)



Sucrose

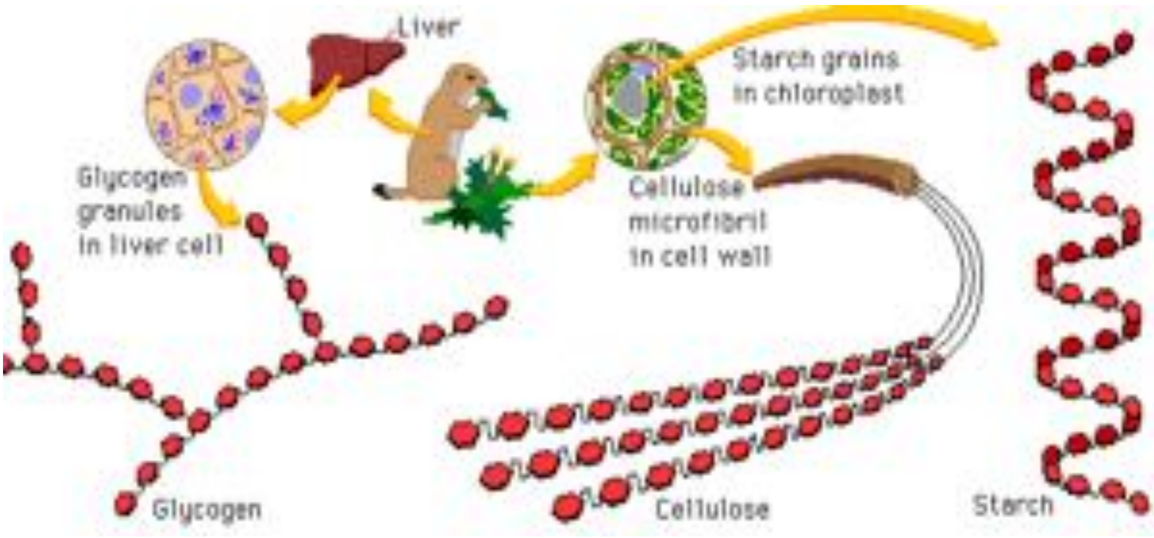
- **Lactose**, milk sugar, is composed of galactose & glucose, with β(1→4) linkage from the anomeric OH of galactose. Its full name is b-D-galactopyranosyl-(1→ 4)-a-D-glucopyranose



Lactose

Polysaccharides

- Structure: polymers made up from a few hundred to a few thousand monosaccharides.
- Functions: energy storage molecules or for structural support:



Polysaccharides – storage molecules

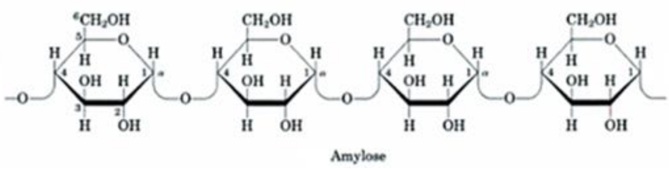
Plants store glucose as **amylose** or **amylopectin** → glucose polymers collectively called starch.

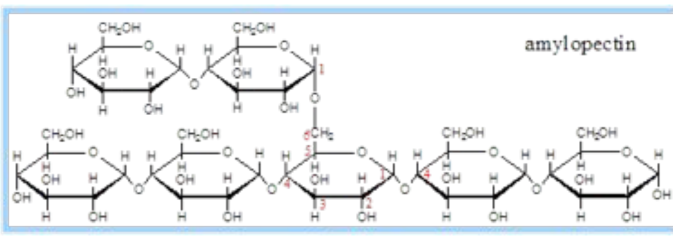
→ **polymeric** form **minimizes osmotic effects**.

a) **Amylose** is a glucose polymer with α (1→4) linkages

b) **Amylopectin** → glucose polymer with mainly α(1→ 4) linkages, but it also has **branches** formed by α(1→6) linkages. Branches are generally longer than shown above.

The branches produce a compact structure & provide multiple chain ends at which enzymatic cleavage can occur.





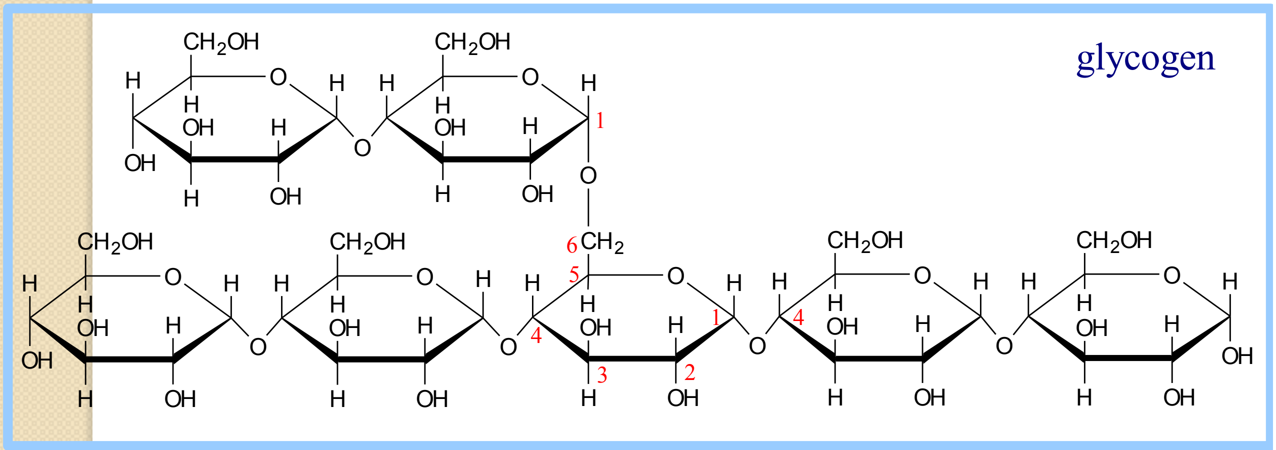
Polysaccharides – storage molecules

Glycogen, the glucose storage polymer in **animals**, is similar in structure to amylopectin

But glycogen has **more** $\alpha(1\rightarrow6)$ **branches**.

The highly branched structure permits rapid glucose release from glycogen stores, e.g., in muscle during exercise.

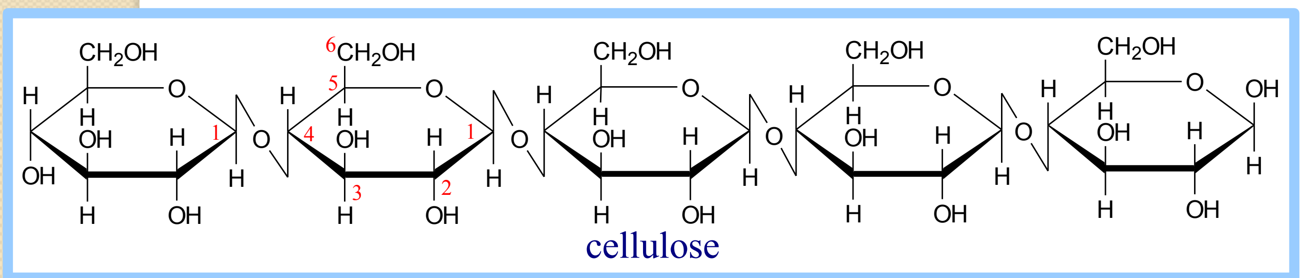
The ability to rapidly mobilize glucose is more essential to animals than to plants.



Polysaccharides – structural molecules

Cellulose, a major constituent of plant cell walls, consists of long linear chains of glucose with $\beta(1\rightarrow4)$ linkages.

Every other glucose is flipped over, due to β linkages ➔ promotes intra-chain and inter-chain H-bonds



CELL MOLECULES & HUMAN DIET: Carbohydrates

- Carbohydrates are essential as energy source.
- However, there are certain health complications related to sugar/carbohydrates:

Storage of excess blood sugar

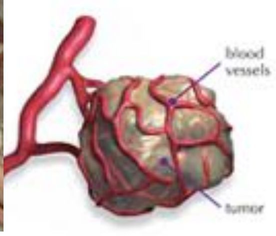
- High blood glucose → [insulin] increase → glucose enters:
  - Skeletal muscles cells:
    - Glucose converted into glycogen
    - Only a small amount can be stored as glycogen
  - Fat cells:
    - Glucose converted into triglycerides (fat)
    - Fat is the main form of food storage in humans

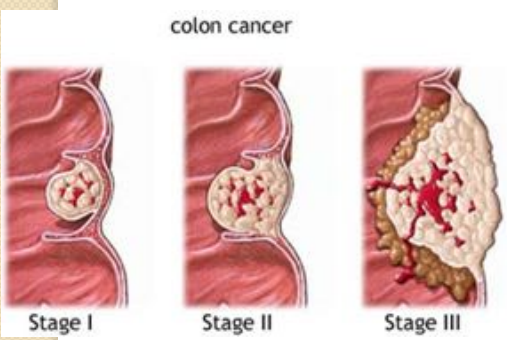
- Blood glucose high too often, cells become insulin resistant:
  - Higher insulin concentration needed to normalize blood glucose level
  - Unable to normalize blood glucose level → **type 2 diabetes**

http://collegelifestyles.org/

CELL MOLECULES & HUMAN DIET: Carbohydrates

Anaerobic respiration in cancer cells: sugar feeds cancer

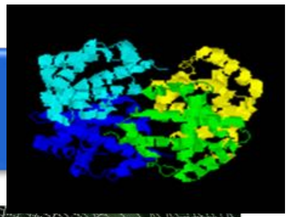




- **Normal cells**
  - complete aerobic oxidation of glucose
  - Yields 38 moles of ATP per mole of glucose
- **Cancer cells**
  - exhibit an increase in anaerobic glycolysis
  - glucose is used as a fuel by cancer cells → lactic acid
    - more acidic pH
    - physical fatigue
  - yields only 2 moles of ATP per mole of glucose
    - the cancer is "wasting" energy
    - the patient becomes tired and undernourished.

- Cancer cells induce growth of blood vessels to feed the cancer cells.
- 40 % of cancer patients die from malnutrition.

MOLECULES IN CELLS : Proteins



- Proteins:
  - Large molecule
  - Chain of amino acids
- Chemical bonding
  - Between two amino acids:
    - H bonds with OH
    - Forms H_2O
    - Forms peptide bond
  - → polypeptide chain
- Only 20 essential amino acids are found in living organisms

Trefill & Hazen, 2007

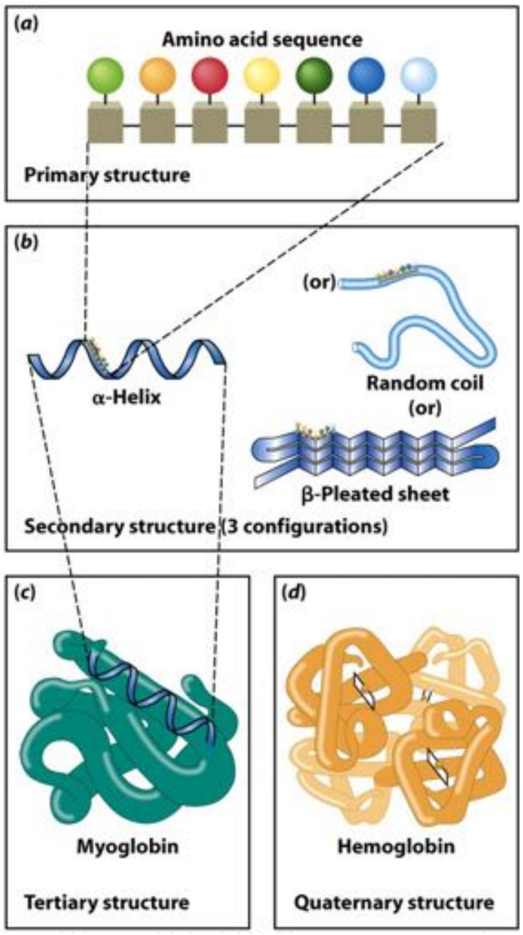
Functions of Proteins

- Enzymes, which can accelerate specific chemical reactions up to 10 billion times faster than they would spontaneously occur.
- Structural materials, including keratin (the protein found in hair and nails) and collagen (the protein found in connective tissue).
- Specific binding areas - such as antibodies that bind specifically to foreign substances to identify them to the body's immune system.
- Specific carriers - including membrane transport proteins that move substances across cell membranes, such as the blood protein hemoglobin which carries oxygen, iron, and other substances through the body.
- Enable contraction - such as actin and myosin fibers that interact in muscle tissue.
- Provide chemical signaling - including hormones such as insulin that regulate sugar levels in blood.

Protein Structures

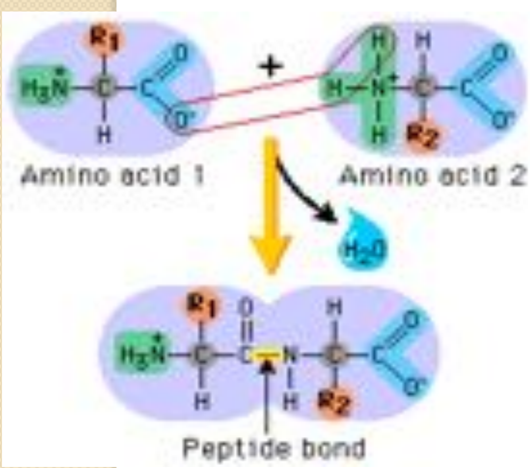
<u>Four</u> levels of protein structures:

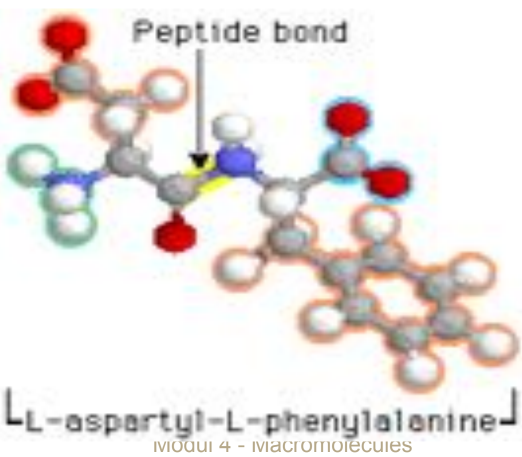
- primary (single chain structure)
- secondary (folded due to bonding)
- tertiary (3-D combinations)
- quaternary (combination of 2 or more polypeptides)



Primary Structure

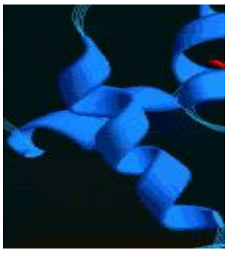
- Unique sequence of amino acids in a protein
- Slight change in primary structure can alter function
- Sequence is determined by genes
- Condensation synthesis reactions form the peptide bonds between amino acids

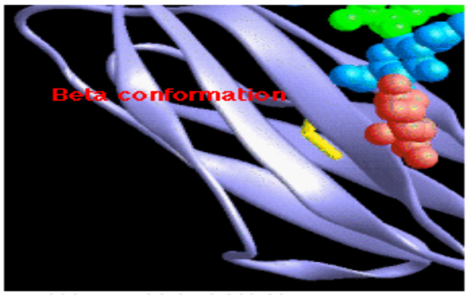




Secondary Structure

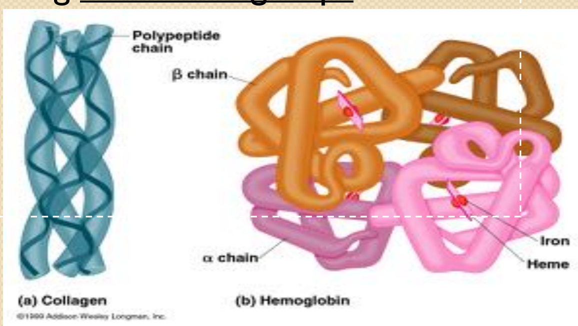
- Repeated folding of protein's polypeptide backbone
- Stabilized by H bonds between peptide linkages in the protein's backbone
- 2 types: alpha helix, beta pleated sheets





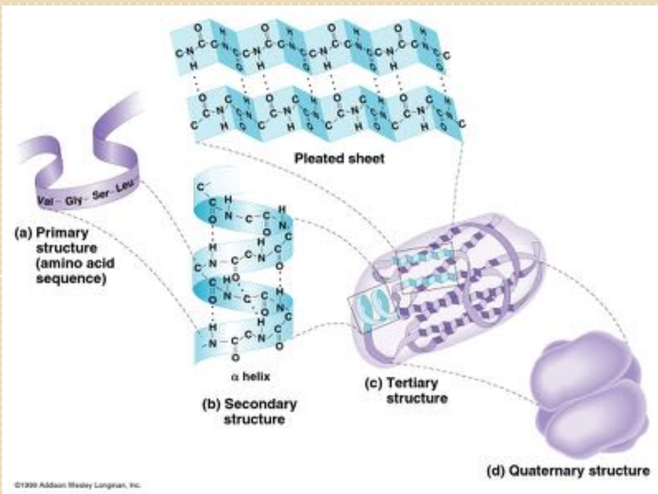
Tertiary Structure

- Irregular contortions of a protein due to bonding between R groups
- Weak bonds:
  - H bonding between polar side chains
  - ionic bonding between charged side chains
  - hydrophobic and van der Waals interactions
- Strong bonds:
  - disulfide bridges form strong covalent linkages



Quaternary Structure

Results from interactions among 2 or more separate polypeptide chains



CELL MOLECULES & HUMAN DIET : Proteins

- **High quality protein** supply amino acids in same proportion as human protein: meat, dairy products
- **Low quality protein**: plant proteins

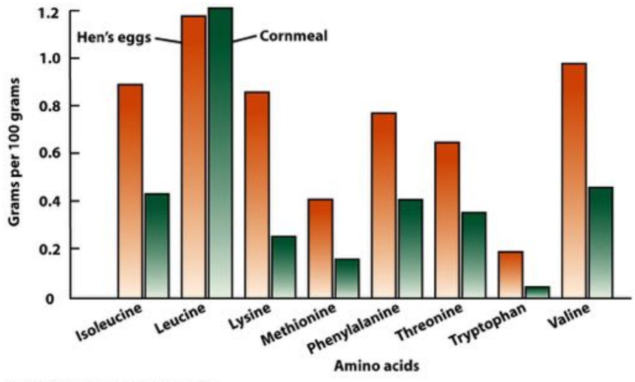


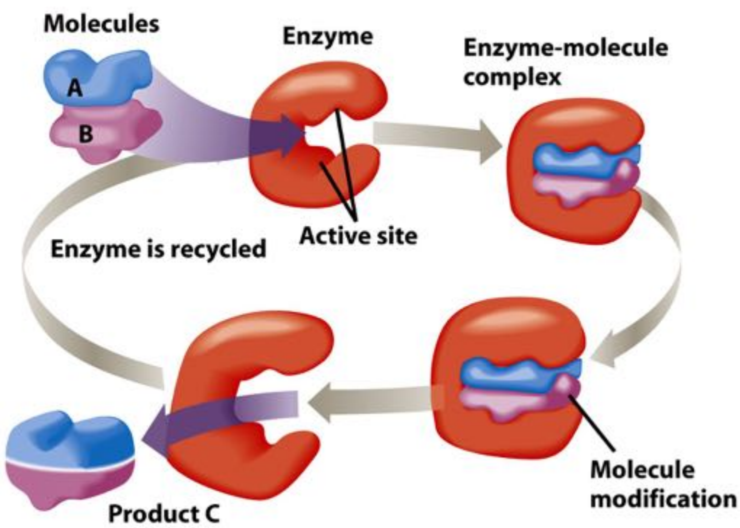
Figure 22-5 The Sciences: An Integrated Approach, 5/e © 2007 John Wiley & Sons

- Essential amino acids (8) cannot be synthesized by the body
- Right combination of food can provide the essential amino acids

Kwashiorkor is an acute form of childhood protein-energy malnutrition characterized by edema, irritability, anorexia, ulcerating dermatoses, and an enlarged liver with fatty infiltrates.

MOLECULES IN CELLS : Proteins as enzymes

- **Enzymes**
  - Have specific shape & structure
  - facilitate biochemical reactions



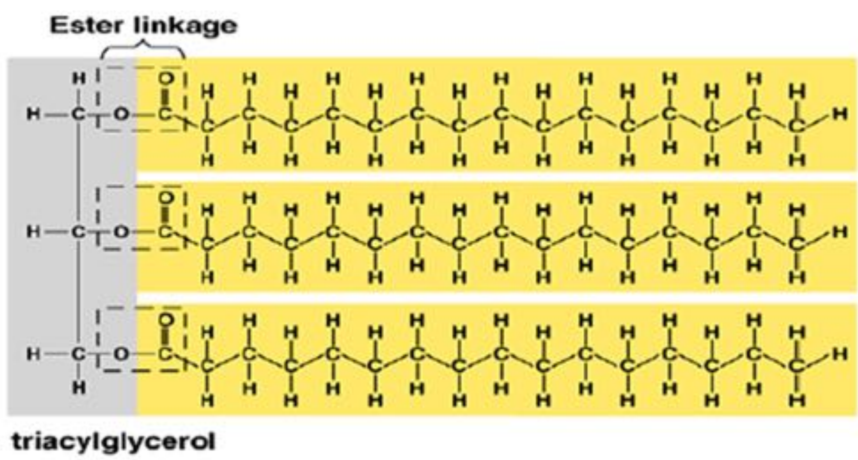
Trefill & Hazen, 2007

Lipids

- A group of polymers that have one characteristic in common, they do not mix with water ➔ hydrophobic.
- <u>Structure</u>: Greasy or oily, non-polar compounds
- <u>Functions</u>:
  - Energy storage (per gram = x 2 that of carbo)
  - Membrane structure
  - Protecting against desiccation (drying out).
  - Insulating against cold.
  - Absorbing shocks.
  - Regulating cell activities by hormone actions.
  - Have little to no affinity for water (hydrophobic)
- Some important groups are fats, phospholipids, and steroids.

Fats

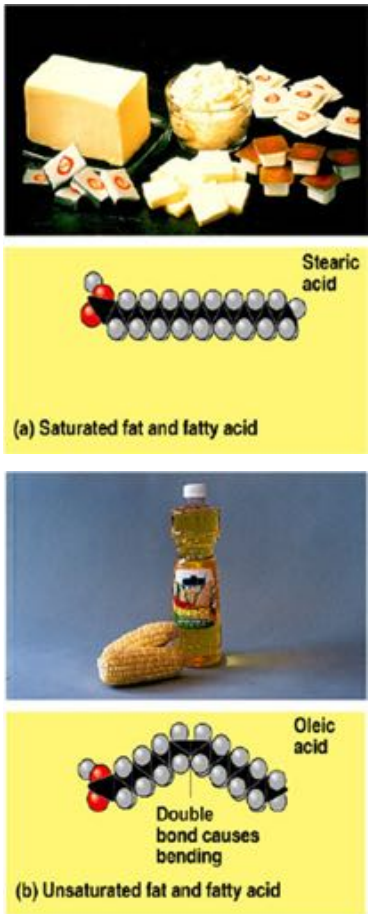
- Fats ➔ large molecules composed of 2 types of monomers, glycerol (an alcohol containing 3 carbons) and 3 fatty acid molecules.
- The bond connecting the glycerol and fatty acids in the fat molecule is called an ester bond.



Fats

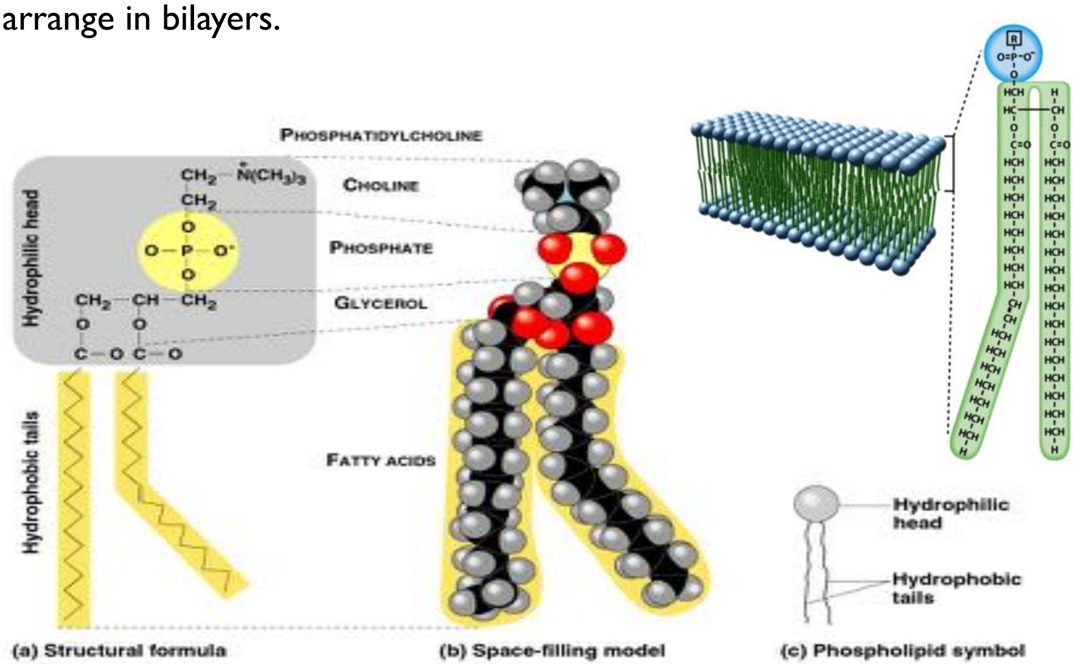
Two types of fatty acids : saturated and unsaturated.

- **Saturated fats:**
  - single C-C bonds in fatty acid tails
  - solid at room temp
  - most animal fats
- **Unsaturated fats :**
  - one or more double bonds between carbons in the fatty acids allows for "kinks" in the tails
  - liquid at room temp
  - most plant fats



Phospholipids

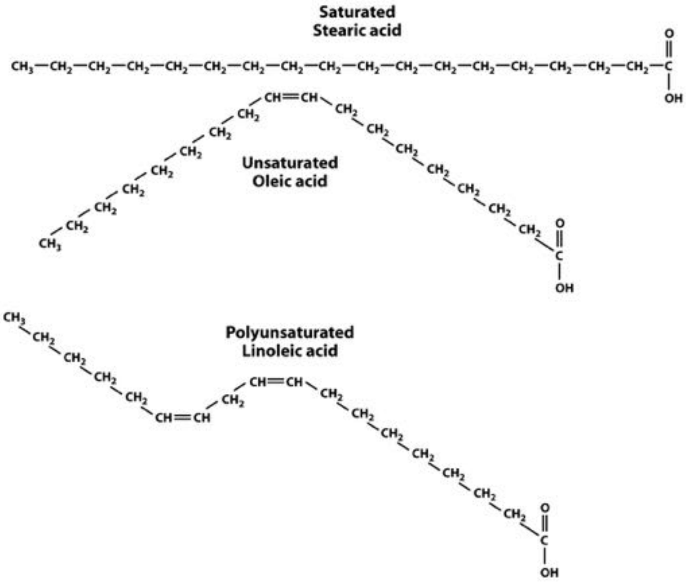
- Structure: Glycerol + 2 fatty acids + phosphate group.
- Function: Main structural component of cellular membranes, where they arrange in bilayers.



MOLECULES IN CELLS : Lipids

Saturated and Unsaturated Fats

- Saturated
  - C is fully bonded
  - Basis of cholesterol
  - Solid at 20°C
- Unsaturated
  - Monounsaturated
  - Polyunsaturated
  - Liquid at 20°C



Why is the melting temperature of unsaturated fatty acids lower than saturated fatty acids?

Note: nucleic acids will be discussed in the last section of this lecture.

CELL MOLECULES & HUMAN DIET : Lipids

Saturated fatty acids

- Long chain fatty acids (LCFA)
  - vegetable or seed oil
  - LCFAs are predominantly stored in the body as fat.
- Medium chain fatty acids (MCFA)
  - Coconut oil
  - MCFAs are sent directly to your liver, where they are immediately converted into energy rather than being stored as fat.
  - help stimulate our body's metabolism, leading to weight loss.

CELL MOLECULES & HUMAN DIET : Lipids

Derivative of lipids : cholesterol

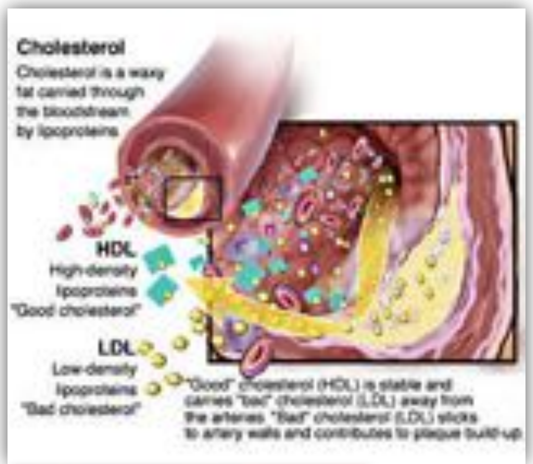
- Helps produce
  - cell membranes
  - hormones
  - vitamin D
  - bile acids that help us to digest fat.
- Helps in the formation of our memories
- Vital for neurological function
- Liver makes about 75 percent of our body's cholesterol

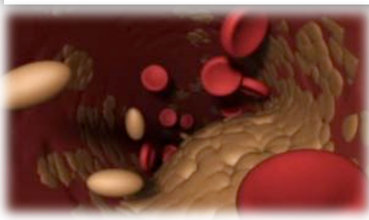
budayahidupsehat.files.wordpress.com

CELL MOLECULES & HUMAN DIET : Lipids

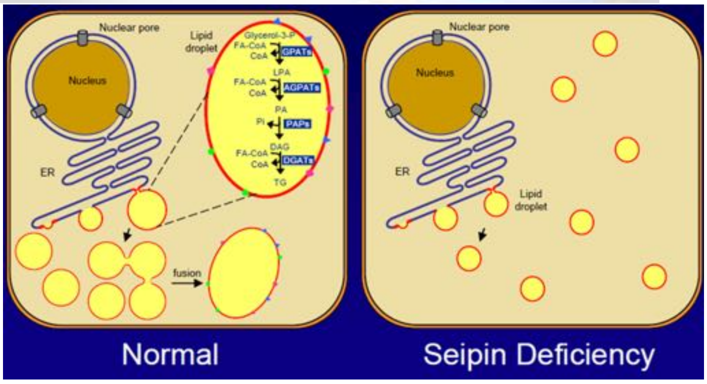
Derivative of lipids : cholesterol

- Cholesterol combines with other fats and proteins to be carried through the bloodstream
- **HDL**
  - high density lipoprotein
  - "good cholesterol"
  - helps to keep cholesterol away from our arteries and remove any excess from arterial plaque, which may help to prevent heart disease
- **LDL**
  - low density lipoprotein
  - "bad cholesterol"
  - may build up in our arteries, forming plaque that makes our arteries narrow and less flexible





Lipodistrophy



The Human Lipodystrophy Gene BSCL2/Seipin May Be Essential for Normal Adipocyte Differentiation

Steroids

- <u>Structure</u>: Four carbon rings with no fatty acid tails
- <u>Functions</u>:
  - Component of animal cell membranes (cholesterol)
  - Modified to form vertebrate sex hormones
- Precursor molecule for steroids: cholesterol
- Male and females: both have E & T

→ Aromatase enzyme P450: steroidogenesis enzyme

Androstenodion ⇒ Estradiol

Testoteron ⇓

P450 arom

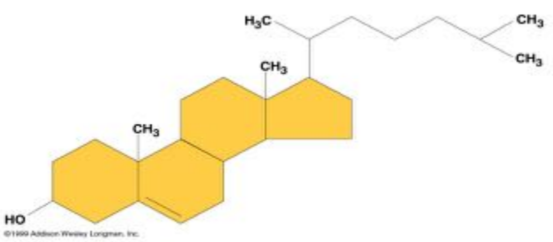
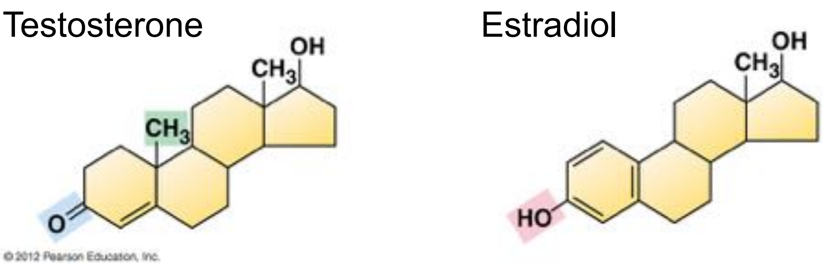


Figure 3.2



Anabolic steroids pose health risks

- Anabolic steroids are abused by some athletes with serious consequences, including
  - violent mood swings,
  - depression,
  - liver damage,
  - cancer,
  - high cholesterol, and
  - high blood pressure.

NUCLEIC ACIDS: Chemical structure

- Stretches of a DNA molecule called genes are passed from parent to offspring

Family resemblance
(ayahbunda.co.id, kemlu.co.id, 4.bp.blogspot.com)

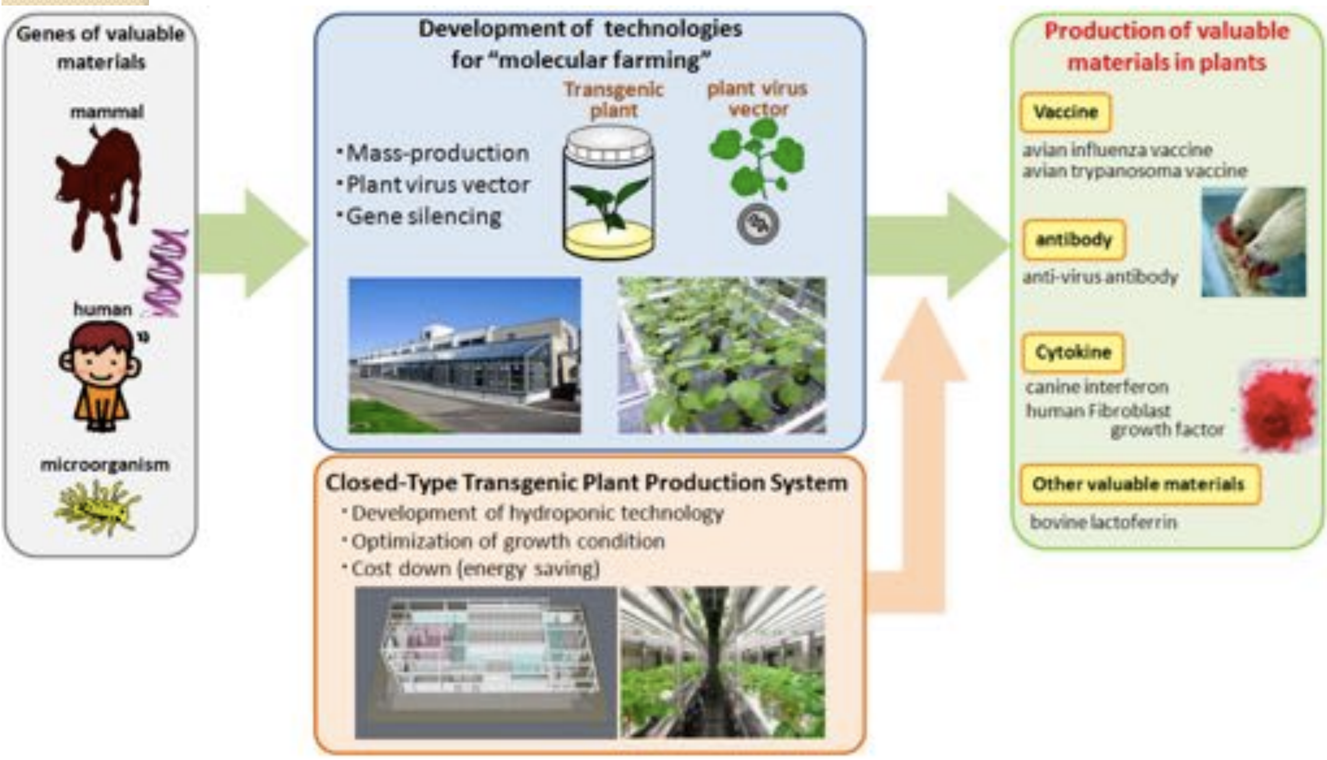
NUCLEIC ACIDS: DNA technology

- DNA technology has many useful applications:
  - the Human Genome Project
  - the production of vaccines, cancer drugs and pesticides
  - engineered bacteria to clean up toxic wastes
  - etc.

NUCLEIC ACIDS: DNA technology

- DNA technology is changing the pharmaceutical industry and medicine

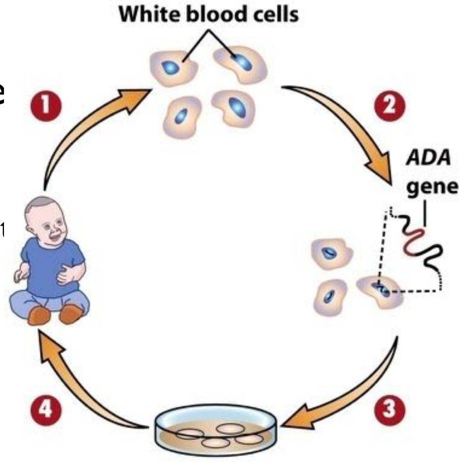
This lab equipment is used to produce
a vaccine against hepatitis B



NUCLEIC ACIDS: DNA technology

Gene therapy

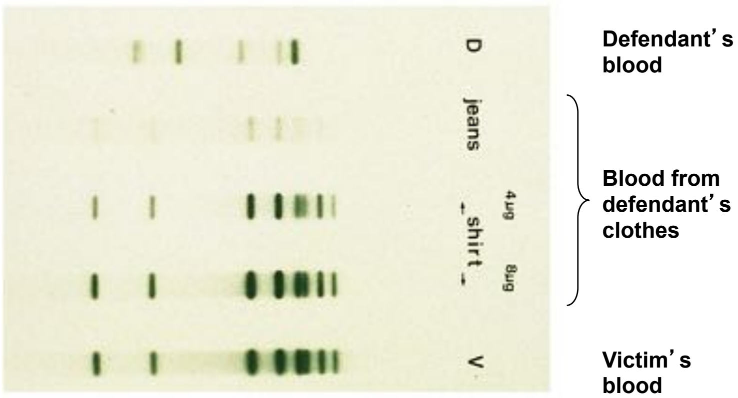
- A procedure for replacing a defective gene with a healthy one (*in vivo* or *in vitro*)
- Example:
  - SCID (severe combined immunodeficiency) – inability t produce adenosine deaminase (ADA) protein that is vital for immune system
- Problem:
  - Genes inserted randomly → no proteins made
- Currently being developed: therapeutic viruses



Trefill & Hazen, 2007

NUCLEIC ACIDS: DNA technology

- DNA technology is used in courts of law
  - DNA fingerprinting can help solve crimes by identifying criminals and victims



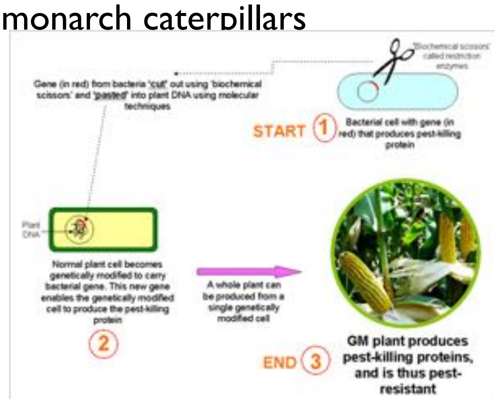
msnbcmedia4.msn.com

NUCLEIC ACIDS: DNA technology

- Genetically modified organisms are transforming agriculture
- *Golden rice* has been genetically modified to contain beta-carotene: this rice could help prevent vitamin A deficiency

NUCLEIC ACIDS: DNA technology

- Could genetically modified (GM) organisms harm human health or the environment?
- Genetic engineering involves some risks
  - possible ecological damage from pollen transfer between GM and wild crops
  - e.g., pollen from a transgenic variety of corn (Bt) that contains a pesticide may stunt or kill monarch caterpillars



Monarch Butterfly

Informasi terkait SAP, Materi Perkuliahan dan jadwal serta topik Presentasi dapat diakses di web sith.itb.ac.id mulai Jum’at 4 September 2015.

Password : bioDasar2015