# CHAPTER 1: THE HUMAN BODY

***AN ORIENTATION***

## 1.1: FORM (ANATOMY) DETERMINES FUCITON (PHYSIOLOGY)

***ANATOMY:*** the study of **body structure** - and their relationships to one another, is concrete (can be seen, felt, and examined closely)
***PHYSIOLOGY:*** study of **body function**, i.e. how the body parts work and carry out their life-sustaining activities (explainable only in terms of underlying anatomy), physiological value examples: body temperature, heart rate, etc.

- (reference man = 22 y/o, 155 pounds, reference woman = 22 y/o, 125 pounds)

## 3 MAIN SUBDIVISIONS/TOPICS OF ANATOMY

- (anatomy is broad field with many subdivions, each providing enough information to be a course itself)

1. **MACROSCOPIC (GROSS) ANATOMY,** ***study of large, visible structures, e.g. heart, lungs, kidneys***
   → **REGIONAL ANATOMY:** all structures in particular region of body, e.g. abdomen or leg, examined at same time
   → **SYSTEMIC ANATOMY:** body structure studied system by system, e.g. cardiovascular system: examining heart and blood vessels of entire body
   → **SURFACE ANATOMY:** A.K.A. superficial anatomy, study of internal structures as they relate to overlying skin surface - study of external features, anatomical features that can be studied by sight (without dissection) e.g. when identifying bulging muscles beneath skin or locating blood vessels to feel pulse and draw blood
2. **MICROSCOPIC ANATOMY,** ***deal with structures too small to be seen by naked eye***
   → **CYTOLOGY:** study of cells
   → **HISTOLOGY:** study of tissues
3. **DEVELOPMENTAL ANATOMY,** ***studies structural development that occurs throughout life***
   → **EMBRYOLOGY:** concerns developmental changes that occur before birth

- (required to master anatomy: mastering terminology, observation, manipulation (working it), palpation, and, ausculation)

## SUBDIVISIONS/TOPICS OF PHYSIOLOGY

- (physiology is also a broad field with many subdivions)
- most subdivisions are **based on organ systems** (i.e. they consider operation of specific organ systems)
  → e.g. **RENAL PHYSIOLOGY** concerns kidney function and urine production
  → e.g. **CARDIOVASCULAR PHYSIOLOGY** examines operation of heart and blood vessels
  → e.g. **NEUROPHYSIOLOGY** explains workings of nervous system
- physiology (often) focuses on events at cellular or molecular level
  → body's abilities depend on individual cells and cells' abilities depend on chemical reaction that occur within them
- **physiology rests on principles of physics → help explain electrical currents, blood pressure, muscle movement, etc.**
- **physiology also rests on principles of chemistry**

## PRINCIPLE OF COMPLEMENTARITY OF STRUCTURE AND FUNCTION

- can be studied separately, but anatomy and physiology are inseparable
  → **function always reflects structure, i.e. what a structure can do depends on its specific form**
  → e.g. bones are able to support and protect body organs *because* they contain hard mineral deposits
  → e.g. blood flows in one direction through heart *because* heart valves prevent backflow

## 1.2: BODY'S ORGANIZATION: ATOM → ORGANISM

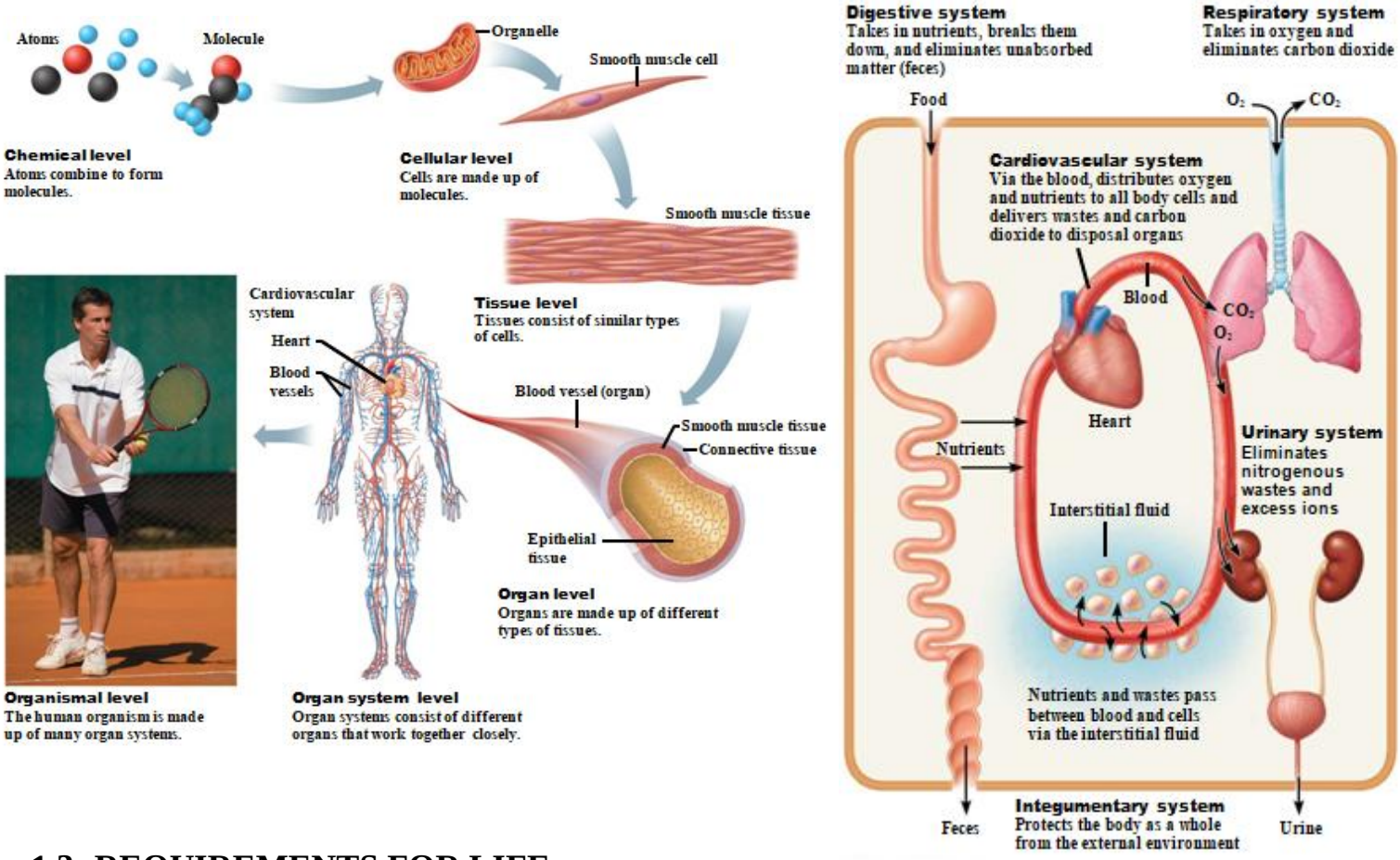
- body has many levels of structural organisation
  → smallest level is **chemical level**
- **chemical** level (**atoms** and molecules) → **cellular** level (**cells** and **organelles**) → **tissue** level → **organ** level → **organ system** level → **organism** level

***ATOMS:*** tiny building blocks of matter
***CELLS:*** smallest unit of living things, vary in size and shape (reflects unique functions in body), made up of molecules
***ORGANELLES:*** basic components of microscopic cell
***TISSUES:*** groups of similar cells that have common function

→ 4 basic types of tissues within humans are:

1. **EPITHELIUM:** covers body surface and lines its cavities
2. **MUSCLE:** provides movement
3. **CONNECTIVE TISSUE:** supports and protects body organs
4. **NERVOUS TISSUE:** provides means of rapid internal communication by transmitting electrical impulses

***ORGAN:*** structure composed of at least 2 tissue types (4 is more common), that performs a specific function for the body ; each organ is a specialized functional centre responsible for a necessary activity that no other organ can perform
***ORGAN SYSTEM:*** organs that work together to accomplish a common purpose, e.g. cardiovascular system, integumentary, nervous, etc.




# 1.3: REQUIREMENTS FOR LIFE

- all body cells are **interdependent**

## 8 REQUIREMENTS FOR THE MAINTANENCE OF LIFE

1. **MAINTAINING BOUNDARIES,** ***distinction of internal and external environments***
   - single celled organisms: external boundary is membrane that encloses its contents
   - body cells also surrounded by semi permeable membrane
   - body is also enclosed and protected by integumentary system (or skin)

   → protects internal organs (from drying out, bacteria, heat, sunlight, and chemicals from external environment)
2. **MOVEMENT,** ***manipulation of (external) environment***
   - movement includes those of internal things, e.g. blood, food, and urine

   ***CONTRACTILITY:*** muscle cell's ability to move by shortening
3. **RESPONSIVENESS/EXCITABILITY,** ***ability to sense changes in environment and respond to them***
   - e.g. reflex when touching something hot
   - e.g. ↑ $CO_2$ = chemical sensors cause ↑ breathing
   - (nerve cells are highly excitable so is most involved with responsiveness)
4. **DIGESTION,** ***breaking down of food to simple molecules that can be absorbed in blood***
   - in simple one-celled organisms, e.g. amoeba: cell itself is digestion factory
   - in multicellular organism: nutrient rich blood distributed by cells through cardiovascular system
5. **METABOLISM,** ***includes all chemical reactions that occur within body cells***
   - includes **catabolism** (breaking down), **anabolism** (building up) and **cellular respiration** (production of ATP from nutrients and $O_2$)
   - **regulated largely by hormones secreted by endocrine system**
6. **EXCRETION,** ***process of removing wastes from body***
   - getting rid of nonuseful substances produced from **digestion** and **metabolism**
   - (in humans, involves several organ systems)
7. **REPRODUCTION,** ***occurs at both cellular and organismal level***
   - cellular reproduction: cell division → identical daughter cells, etc.
   - binary fission, etc.
8. **GROWTH,** ***increase in size of body part or organism as whole***
   - usually accomplished by increasing number of cells
   - constructive activities > destructive activities

## SURVIVAL NEEDS, *factors needed for survival that must be <u>in appropriate amounts</u>*

**5 MAIN (*but there are obviously more*):**

1. **NUTRIENTS:** used for energy and **cell building** (carbs, protein, fats, vitamins, minerals)
2. **OXYGEN:** chemical reactions that release energy from foods are **oxidative**, human cells can only survive for few minutes without oxygen
3. **WATER:** provides necessary environment for chemical reactions and fluid based secretions and excretions
4. **APPROPRIATE BODY TEMPERATURE:** 37°C, too high or too low = death, **muscular system generates most body heat**
5. **APPROPROATE ATMOSPHERIC PRESSURE:** force that air exerts on surface of body, important in breathing

- **mere presence ≠ sufficient to sustain life, too much or too little is harmful**

## 1.2 CONT'D: 11 ORGAN SYSTEMS OF THE BODY

### 1. INTEGUMENTARY SYSTEM, *skin, hair and nails*

- external body covering
- protects deeper tissue from injury
- **synthesizes vitamin D**
- houses **cutaneous (pain, pressure, etc.) receptors** and sweat & oil glands

### 2. SKELETAL SYSTEM, *bones and joints*

- protects and supports body organs
- provides framework muscles use to cause movement
- **blood cells formed within bones**
- **bones store minerals**

### 3. MUSCULAR SYSTEM, *skeletal muscles*

- allows manipulation of environment, **locomotion,** and facial expression

***LOCOMOTION:*** movement or the ability to move from one place to another

- maintains posture
- **produces heat**

### 4. NERVOUS SYSTEM, *brain, nerves, spinal cord*

- fast-acting control system of body
- **responds to internal and external changes by activating appropriate muscles and glands**

### 5. ENDOCRINE SYSTEM, *refer to (e)*

- glands secrete hormones that **<u>regulate</u> processes such as growth, reproduction, and nutrient use** by body cells

### 6. CARDIOVASCULAR SYSTEM, *heart and blood vessels*

- blood vessels transport blood which carries $O_2$, $CO_2$, nutrients, wastes, etc.
- heart pumps blood

### 7. LYMPHATIC SYSTEM/IMMUNITY, *refer to (g)*

- **picks up fluid leaked from blood vessels and returns it to blood**
- **disposes of debris in lymphatic stream**
- houses while blood cells (lymphocytes) involved in immunity
- immune response mounts attack against foreign substances within body

### 8. RESPIRATORY SYSTEM, *nasal cavity, larynx, trachea, lung, bronchus*

- keeps blood constantly supplied with $O_2$ and removes $CO_2$
- **gaseous exchanges occur through walls of air sacs in lungs**

### 9. DIGESTIVE SYSTEM, *oral cavity, esophagus, liver, stomach, small and large intestines, rectus, anus*

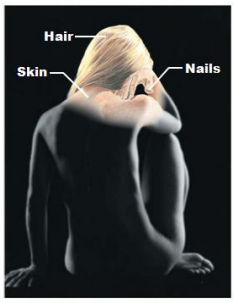
- **breaks down food into absorbable units** that enter blood for distribution to body cells
- indigestible foodstuffs eliminated as faeces

### 10. URINARY SYSTEM, *kidney, ureter, urinary bladder, urethra*

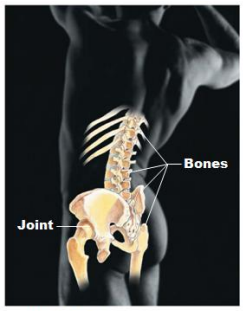
- **eliminates nitrogenous wastes from body**
- **regulates water, electrolyte, and acid-base balance of blood**

### 11. MALE REPRODUCTIVE SYSTEM, *prostate, penis, testes, ductus deferens, scrotum*

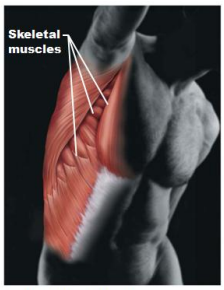
- function is production of offspring
- testes produce sperm and male sex hormone
- **male ducts and glands aid in delivery of sperm to female reproductive tract**



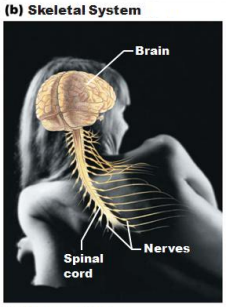
(a) Integumentary System



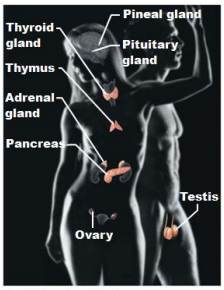
(b) Skeletal System



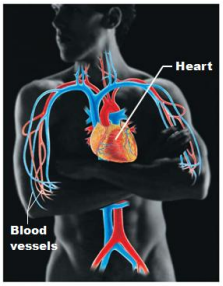
(c) Muscular System



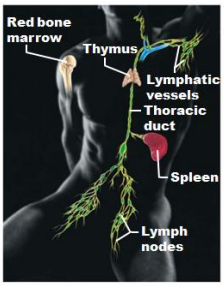
(d) Nervous System



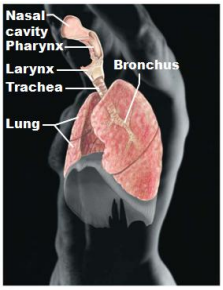
(e) Endocrine System



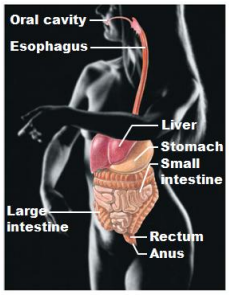
(f) Cardiovascular System



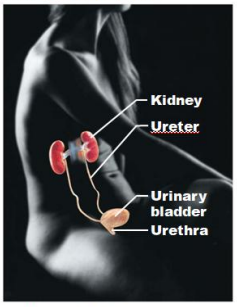
(g) Lymphatic System/Immunity



(h) Respiratory System



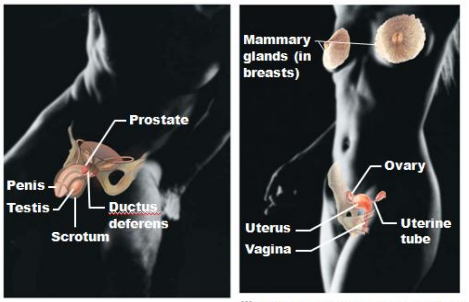
(i) Digestive System



(j) Urinary System

**FEMALE REPRODUCTIVE SYSTEM,** ***mammary glands (in breasts), ovary, uterus, uterine tube, vagina***

- function is production of offspring
- ovaries produce eggs and female sex hormones
- **remaining female structure serve as sites for fertilization and development of foetus**
- **mammary glands of female breasts produce milk to nourish newborn**



(I) Female Reproductive System

# 1.4: HOMEOSTASIS IS MAINTAINED BY NEGATIVE FEEDBACK

***HOMEOSTASIS:*** maintenance of relatively stable internal environment despite continuous outside changes; ***dynamic*** **state of equilibrium (of internal environment)**

## HOMEOSTATIC CONTROL MECHANISMS

- all body systems contribute but **communication of endocrine and nervous systems are most important**
  - → uses **electrical impulses** and **hormones**
- involves continuous monitoring and regulation of many **factors** (variable or event being regulated)
- all homeostatic control mechanisms are processes involving at least 3 components working together:
  1. **RECEPTOR(S):** sensor that monitors environment and responds to changes, sends information to **control centre** (input → receptor →**afferent pathway**→ control centre**)**
  2. **CONTROL CENTRE:** dertmines **set point**, analyzes input and determines response → sends information to **effector** (control centre →**efferent pathway**→ effector**)**

***SET POINT:*** level or range at which variable is to be maintained

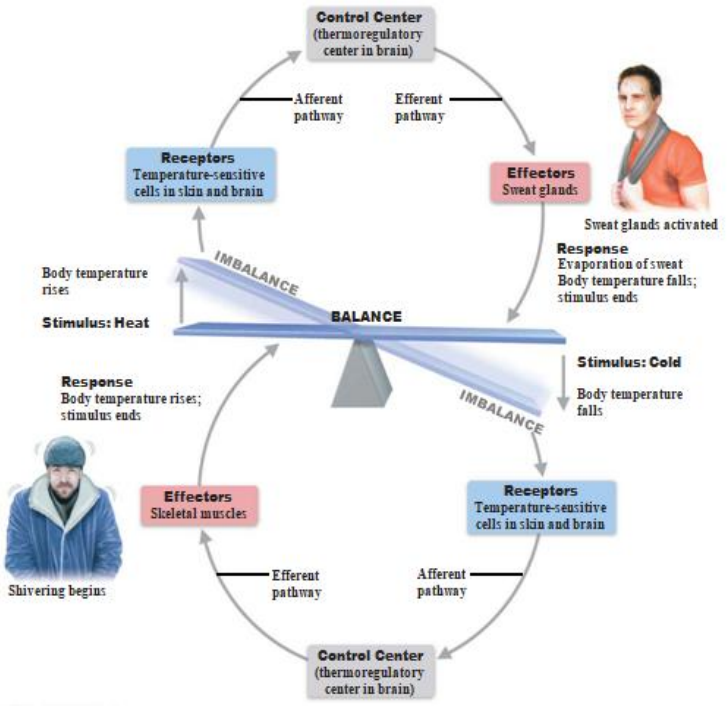
3. **EFFECTOR(S):** provides means for control cetnre's response to stimulus, results in **feedback** to influence effect of stimulus (either **reducing** or **enhancing** it)

## NEGATIVE FEEDBACK MECHANISMS, *systems where output shuts off or reduces intensity of original effect of stimulus*

- most homeostatic control mechanisms are **negative feedback mechanisms**
- causes variable to change in **opposite** direction of initial change to make 'ideal' value **(e.g. keeping variable within range)**

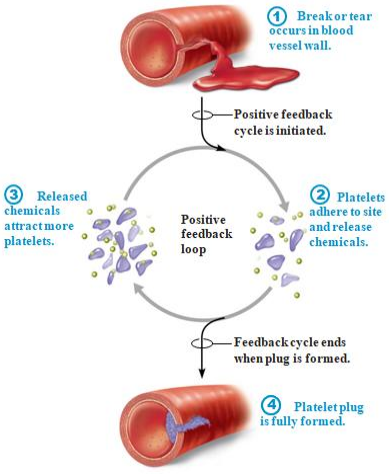
***DYNAMIC CONSTANCY:*** body tries to keep as close to **"set point"** as possible

- → e.g. thermoregulation: body's 'thermostat' located in **hypothalamus** and operates similarly to home heater
- → e.g. hormonal negative feedback: ↑ blood sugar level = body senses change (**receptors**) = pancreas (**control centre**) secretes insulin = cells absorb more glucose = ↓ blood sugar level ~ as blood sugar levels fall, stimulus for insulin release ends
- **goal of negative feedback mechanisms: prevent severe changes within body**




## REGULATION OF BLOOD VOLUME BY ADH

- ↓ in blood volume
  - → sensed by **receptors**
  - → hypothalamus **(control centre)** stimulates pituitary gland to release antidiuretic hormone (ADH)
  - → ADH causes kidneys **(effectors)** to return more water to blood




## POSITIVE FEEDBACK MECHANISMS, *systems where output enhances original stimulus = accelerated response*

- causes variable to change in **same** direction of initial change

∴ variable deviates further and further from original value or range, *away from "set point"*

- positive feedback mechanisms usually **control infrequent events** that do not require continuous adjustments
- often referred to as **cascades**; typically set off series of events that once initiated, have amplifying **waterfall effect**

→ e.g. blood clotting: damaged vessel = platelets begin to cling to site = ↑ release of chemical that attracts more platelets (by platelets) = ↑ platelets = "plug" tear and initiates clotting

→ e.g. ↑ contractions = ↑ release of oxytocin = ↑ contractions, etc.

other examples: depolarization phase of action potential, suckling reflex

## HOMEOSTATIC IMBALANCE, *source of most diseases*

- ↑ age = ↓ efficiency of body control systems = ↓ internal system stability = ↑ risk for illness and homeostatic imbalance
- also occurs when usual negative feedback mechanisms are overwhelmed and destructive positive feedback mechanisms take over

# 1.4: ANATOMICAL TERMS

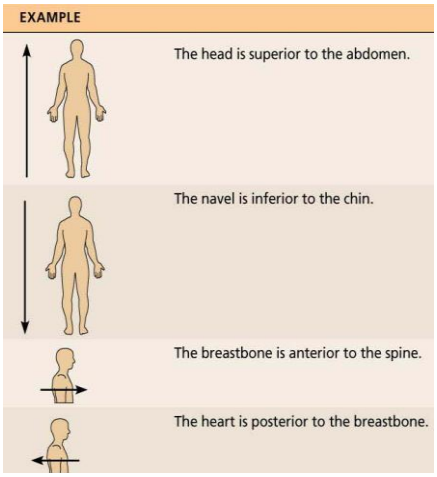
## ANATOMICAL POSITION AND DIRECITONAL TERMS

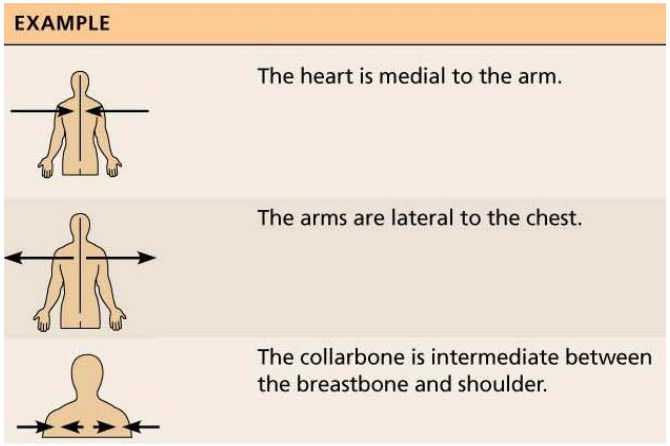
- all terms in anatomical position
- right and lefts of person, not observer

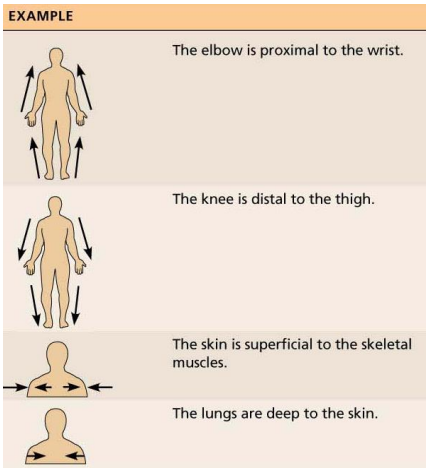
## DIRECTIONAL TERMS, *allows us to explain where one body structure is in relation to another*

***SUPERIOR (CRANIAL):*** above or nearer to head
***INFERIOR (CAUDAL):*** below or further away from head
***ANTERIOR (VENTRAL):*** in front of or nearer to front
***POSTERIOR (DORSAL):*** behind or nearer to back
***MEDIAL:*** closer to midline of body
***LATERAL:*** further away from midline of body

***INTERMEDIATE:*** between medial and lateral
***PROXIMAL:*** nearer to where limb attaches to body
***DISTAL:*** further from where limb attaches to body
***DEEP (INTERNAL):*** located inside or further from surface
***SUPERFICIAL (EXTERNAL):*** located or near the surface



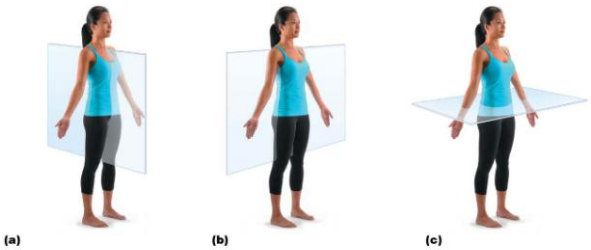

## REGIONAL TERMS, *used to designate specific areas of body*

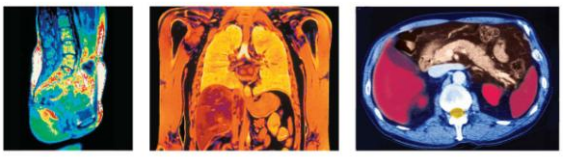
1. **AXIAL PART:** *axial* part of body, includes head, neck, and trunk
2. **APPENDICULAR PART:** consists of *appendages* or *limbs* which are attached to body's axis

## BODY PLANES AND SECTIONS

- section named for plane which it is cut, e.g. cut along sagittal plane = sagittal section

1. **SAGITTAL PLANE:** vertical plane that divides body into left and right
   → sagittal plane down middle = **median/midsagittal plane**
   → sagittal plane offset from midline = **parasagittal plane**
2. **FRONTAL PLANE:** lie vertically, but divide body by anterior and posterior (front and back)
   → also called a **coronal plane**
3. **TRANSVERSE PLANE: horizontal**, deciding body by superior and inferior (up and down)
   → also called **cross section**
4. **(OBLIQUE SECTIONS):** cuts made diagonally between horizontal and vertical planes
   → confusing and difficult to interpret ∴ seldom used



# 1.6: INTEGRAL ORGANS IN MEMRANE-LINED BODY CAVITIES

- 2 sets of internal body cavities: **dorsal body cavity** and **ventral body cavity**
  → cavities closed to outside and provide different degrees of protection to organs within them
  → 2 cavities differ in mode of embryonic development and lining membranes ∴ dorsal cavity not recognized as much in many anatomical references
  → however, idea of 2 sets of internal body cavities is useful learning concept and we use it here

## DORSAL BODY CAVITY

- protects fragile nervous system organs

**2 MAJOR SUBDIVISION:**

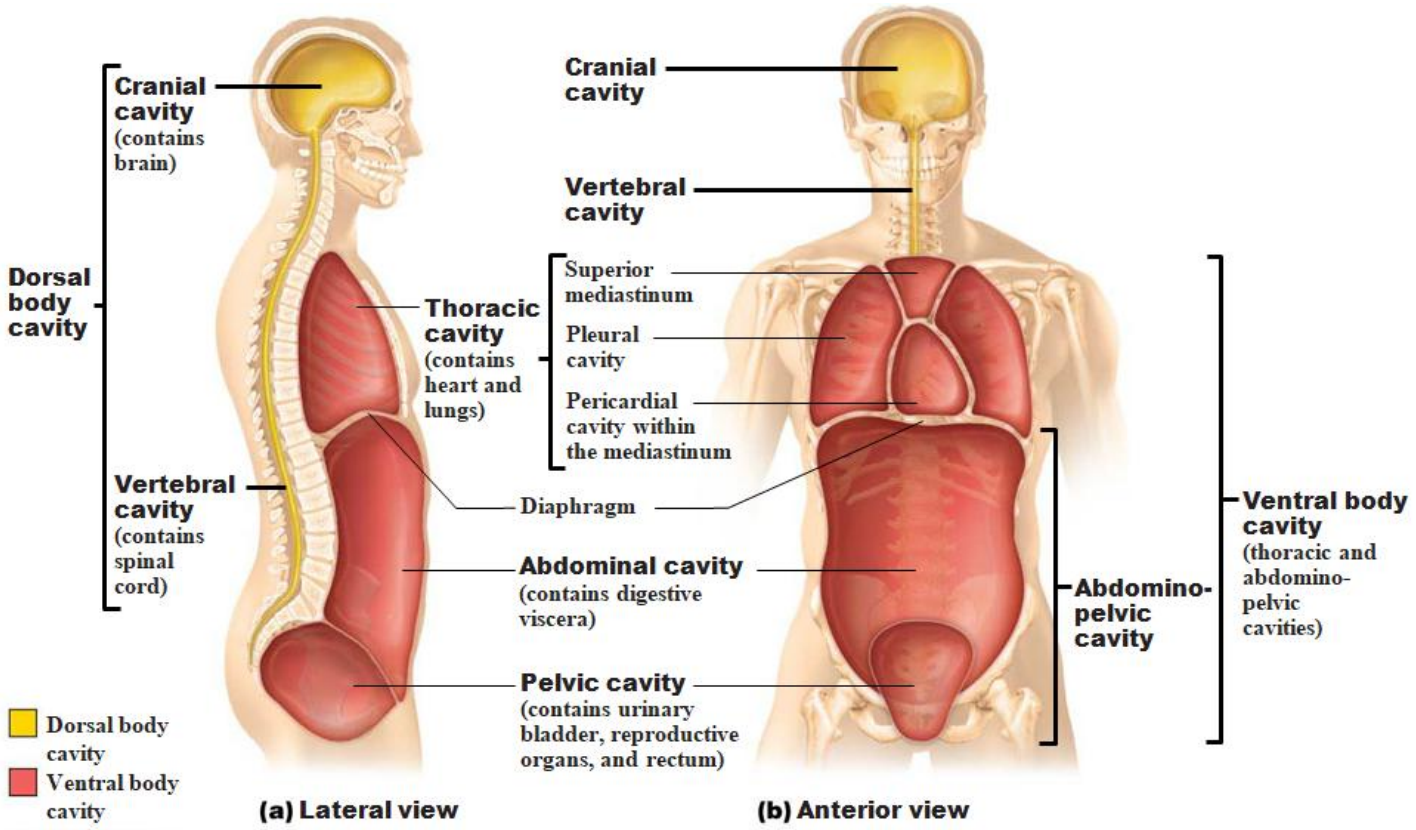
1. **CRANIAL CAVITY:** in skull and encases brain
2. **VERTEBRAL/SPINAL CAVITY:** runs within bony vertebral column, encloses delicate spinal cord
   → spinal cord essentially continuation of brain
   → cranial and spinal cavities are continuous with one another
   → both brain and spinal cord covered by membranes called **meninges**

## VENTRAL BODY CAVITY

- larger and more anterior
- cavity houses internal organs collectively called the **viscera/visceral organs**

**2 MAJOR SUBDIVISION:**

1. **THORACIC CAVITY:** superior subdivision, surrounded by ribs and muscles of chest
   a) **LATERAL PLEURAL CAVITIES:** each enveloping a lung
   b) **MEDIASTINUM:** contains **pericardial cavity** which encloses heart and *also* surrounds remaining thoracic organs (esophagus, trachea, and others)
2. **ABDOMINOPELVIC CAVITY:** inferior to mediastinum, separated from thoracic cavity by diaphragm
   a) **ABDOMINAL CAVITY:** superior portion containing stomach, intestines, spleen liver, and other organs
   b) **PELVIC CAVITY:** inferior part, lies in bony pelvis and contains urinary bladder, some reproductive organs, and rectum
      → (2 parts not physically separated by muscle nor membrane wall)



# CHAPTER 2: CHEMISTRY COMES ALIVE

## PART 2: BIOCHEMISTRY, *study of chemical composition and reactions of living matter*

- all chemicals are either **organic** or **inorganic**

## MAJOR ELEMENTS OF THE BODY

- Carbon (**C**), Hydrogen (**H**), Oxygen (**O**), Nitrogen (**N**) = about 96% of body mass

## 2.6: INORGANIC COMPOUNDS: (MOST) DO NOT CONTAIN CARBON

- **water, salts,** and many **acids and bases**

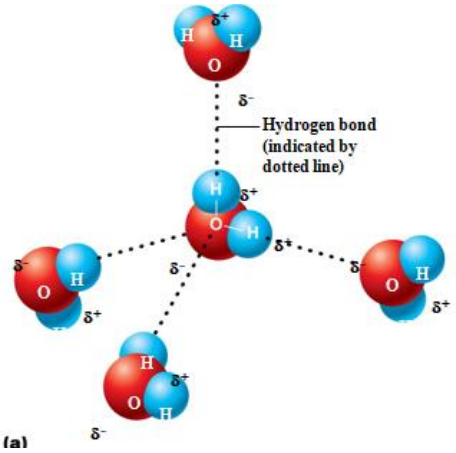
### WATER

- **HIGH HEAT CAPACITY:** absorbs and releases heat slowly, temp change ≠ easy
- **HIGH HEAT OF VAPORIZATION:** requires lots of energy to be converted to heat (due to **hydrogen bonds***)
- **POLAR SOLVENT PROPERTIES*:** universal solvent, ionic compounds dissociate in water
- participates in chemical reactions and cushions body organs

### **HYDROGEN BONDS*

- weaker than ionic and covalent bonds, *more like attractions than true bonds*
- attractive force between **electropositive hydrogen** of one molecule and electronegative atom of another **(H-NOF)** molecule
  - → common between dipoles such as water = films, i.e. **surface tension**
  - → also acts as **intramolecular bonds**, holding large molecule in 3D shape

**(b) A water strider can walk on a pond because of the high surface tension of water, a result of the combined strength of its hydrogen bonds.**




**The slightly positive ends (δ⁺) of the water molecules become aligned with the slightly negative ends (δ⁻) of other water molecules.**

## ACIDS AND BASES, *electrolytes; ionize and dissociate in water*

### ACIDS, *proton donors*

- **release $H^+$** (hydrogen ions = "naked" proton)
- e.g. $HCl \rightarrow H^+ + Cl^-$
- important acids: HCl (hydrochloric acid), **$HC_2H_3O_2$ (acetic acid, or HAc** - acidic part of vinegar) and **$H_2CO_3$ (carbonic acid)**

### BASES, *proton acceptors*

- **accept $H^+$**
- e.g. $NaOH \rightarrow Na^+ + OH^-$ and then $OH^- + H^+ \rightarrow H_2O$
- important bases: **bicarbonate ion ($HCO_3^-$** - important in blood) and **ammonia ($NH_3$)** - common waste product of protein breakdown in body

## pH: ACID-BASE CONCENTRATION

- pH scale is measurement of $[H^+]$ (concentration of $H^+$ ions in solution)
- ↑ $[H^+]$ = ↑ acidity = ↓ pH; ↓ $[H^+]$ = ↑ alkalinity = ↑ pH
- **pH = -log$[H^+]$** in moles per liter
- logarithmic scale = each pH unit represents 10-fold difference

## BUFFERS, *resist abrupt and large swings in pH, resist excessive changes in pH of body fluid*

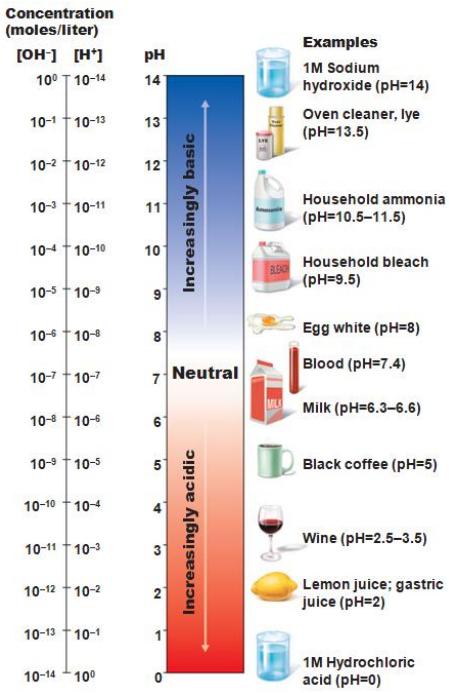
- homeostasis of pH carefully regulated by kidneys, lungs, and chemical system
- acidity involves only **free $H^+$** in solution
- **buffers can release $H^+$ if ↑ pH and can bind to $H^+$ if ↓ pH**
- **strong acids/bases**: dissociate completely in water
- **weak acids:** partly dissociate and remain in equilibrium with dissociated ions
- buffer system **converts strong acids/bases into weak ones**

important buffer system of blood: **carbonic acid - bicarbonate system ($pH_{blood}$ = 7.35-7.45)**

Response to rise in pH

$$H_2CO_3 \rightleftharpoons HCO_3^- + H^+$$

$H^+$ donor (weak acid) | Response to drop in pH | $H^+$ acceptor (weak base) | proton



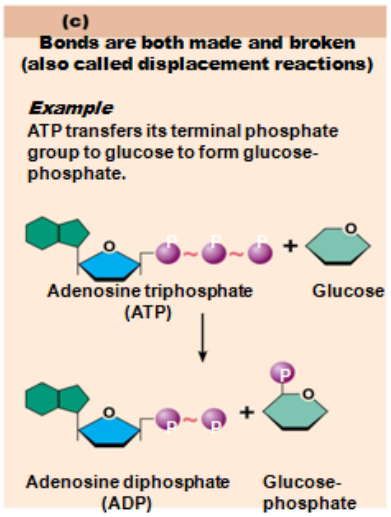
## 2.5: CHEMICAL EQUATIONS, *occur when chemical bonds are formed, rearranged, or broken*

- reaction written in form of chemical equation
  - → reactant(s)
  - → product(s)
  - → ratio (coefficient(s))

### 3 MAIN TYPES OF CHEMICAL REACTIONS

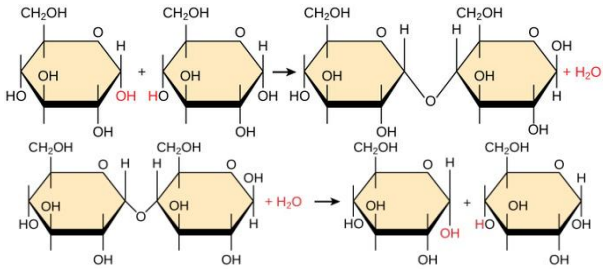
1. **SYNTHESIS REACTIONS (A.K.A. COMBINATION REACITONS)**
   - A + B → AB
   - **anabolic** (building up), e.g. amino acids → protein molecule
2. **DECOMPOSITION REACTIONS**
   - AB → A + B
   - **catabolic** (breaking down), e.g. glycogen → molecules of glucose
3. **EXHANGE OR DISPLACEMENT REACTIONS**
   - AB + C → AC + B and AB + CD → AD + CB
   - bonds are both made *and* broken
   - e.g. ATP + glucose → ADP + glucose phosphate

**Exchange reactions**




## 2.7: ORGANIC COMPOUNDS: CONTAIN CARBON

- **carbohydrates, lipids, proteins,** and **nucleic acids (C, H, O + N)**
- usually large and **covalently bonded**
- many are **polymers** (made up of **monomers** = building blocks)
- **synthesized by DEHYDRATION SYNTHESIS**
- **broken down by HYDROLYSIS REACTIONS**
- (carbon = **electroneutral** = never loses or gains $e^-$, only shares them)

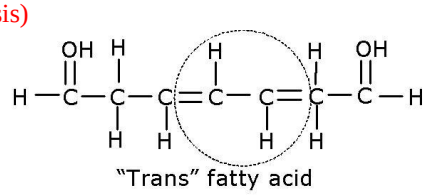


## 2.8: CARBOHYDRATES

- sugars and starches
- contain C, H, O; $[CH_2O]_n$

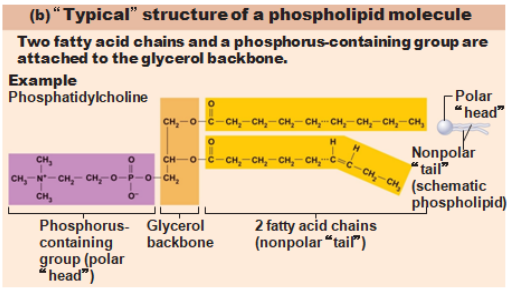
### 3 CLASSES:

1. **MONOSACCHARIDES, *simple sugars***
   - → 3 to 7 carbons, e.g. **hexoses: glucose, frcutose, galactose, and pentoses: ribose, deoxyribose**
2. **DISACCHARIDES, *double sugar (covalent bond)***
   - → monosaccharide + monosaccharide → disaccharide (through dehydration synthesis)
   - → e.g. **sucrose, lactose, maltose**
   - → must first be hydrolysed to be absorbed into digestive tract
3. **POLYSACCHARIDES, *polymers of simple sugars***
   - → fairly insoluble = good for storage
   - → e.g. **starch** and **glycogen** (polymers of glucose), unable to digest **cellulose**




**FUNCTION:**

- main source of cellular fuel, i.e. glucose = major energy fuel for forming ATP
- (small but important amount for) structural molecules, e.g. ribose sugar in RNA

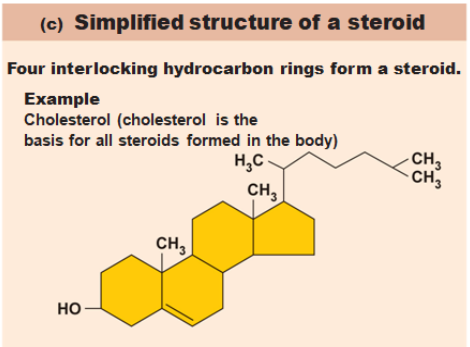



## 2.9: LIPIDS

- insoluble in water
- contain C, H, O (proportion of O much lower than carbs) and sometimes P

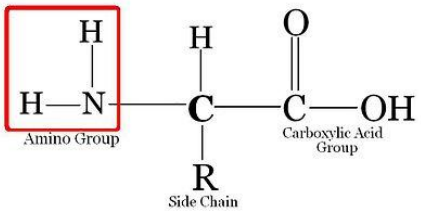
### 4 MAIN TYPES

1. **TRIGLYCERIDES**
   - → fats (solid) or oils (liquid)
   - → short or unsaturated fatty acids are oils
   - → **composed of glycerol and 3 fatty acids** (hydrocarbon chains with -COOH)
   - → **main functions: energy storage, insulation, protection**
2. **PHOSPHOLIPIDS**
   - → **modified triglycerides: glyecrol + phosphate head + 2 fatty acids**
   - → phosphate head = polar, hydrocarbon tail = non-polar
   - → important in **cellular membranes**
3. **STEROIDS**
   - → flat molecule made of 4 interlocking hydrocarbon rings
   - → **cholesterol found in cell membranes and is basis of steroid hormones,** bile salts, and vitamin D (is ingested through animal products and also produced by liver)



4. **EICOSANOIDS**
   → diverse and derived from 20-carbon fatty acid
   → found in all cell membranes
   → most important is **prostaglandins** = role in *blood clotting, blood pressure, inflammation, labour contractions, etc.*

## 2.10: PROTEINS

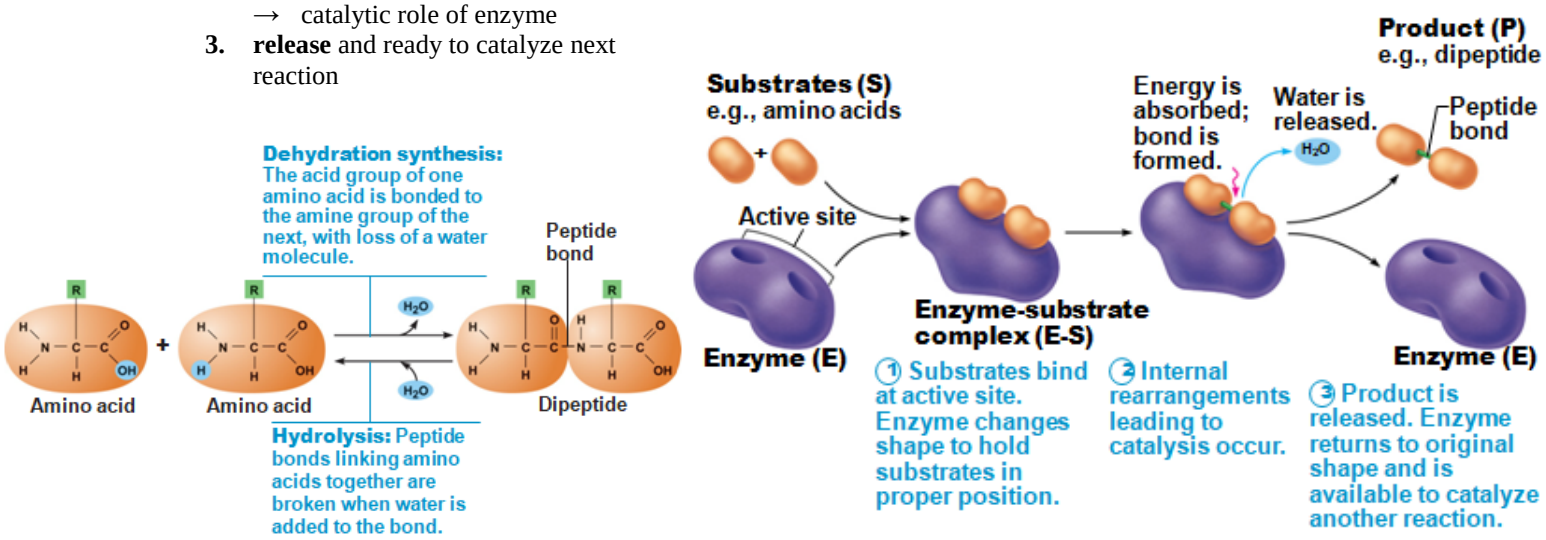



- polymers of amino acids (**20 amino acids**)
  → **peptide bonds** to make dipeptides and polypeptides
- contain C, H, O, N, and sometimes S and P
- includes **enzymes, haemoglobin, contractile proteins,** etc.

### ENZYMES, *biological catalysts*

***CATALYSTS:*** substances that regulate and accelerate rate of biochemical reactions but are not used up or changed in reactions

- enzymes are chemically specific; either they control only a specific reaction or small group of related reactions
- (some enzymes needs cofactors to function, i.e. vitamins and/or minerals)
- ***-ase*** names that describe catalyst reaction
- **enzymes lower activation energy *(in both directions)*** = ↑ speed (millions of reactions per minute)
  1. substrate binds to enzyme = **enzyme-substrate complex**
     → ***enzyme inhibitors***
  2. enzyme-substrate undergoes **internal rearrangements = changes shape = products**
     → catalytic role of enzyme
  3. **release** and ready to catalyze next reaction




## 2.11: NUCLEIC ACIDS (DNA AND RNA)

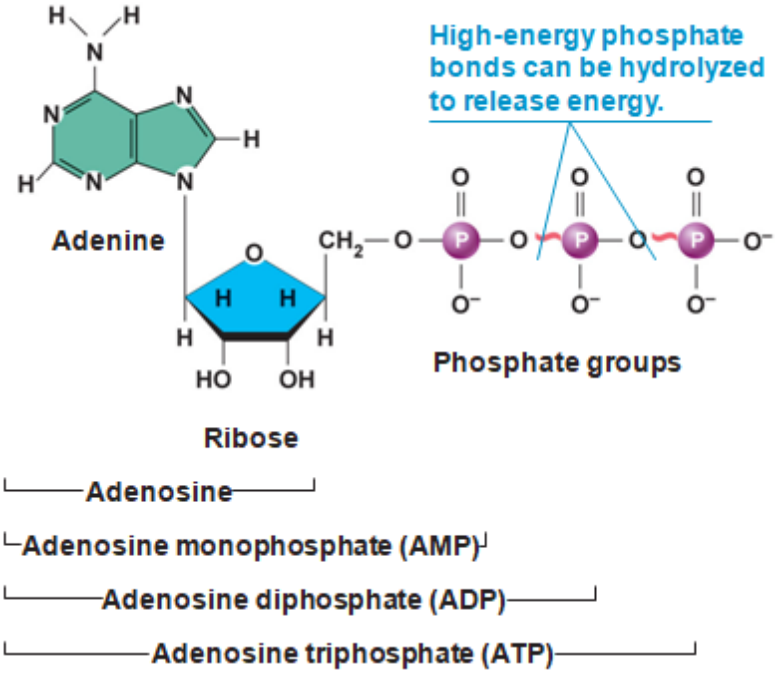
- composed of C, H, O, N, and P
- **largest molecules in body**
- composed of **nucleotides** (monomer)
- **NUCLEOTIDES:** nitrogenous base, pentose sugar, and phosphate
  → **DOUBLE RING NITROGENOUS BASES (PURINES):** adenine and guanine
  → **SINGLE RING NITROGENOUS BASES (PYRAMIDINES):** thymine, cytosine, and uracil
  → synthesis of nucleotides = base + phosphate group + pentose sugar

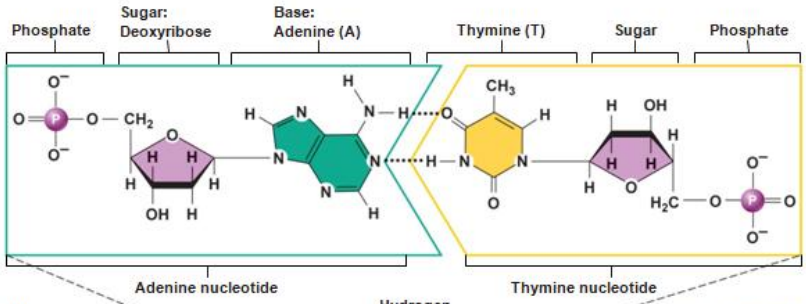
| DNA vs. RNA | | |
|---|---|---|
| | **DNA** | **RNA** |
| **MAJOR CELLULAR SITE** | nucleus | cytoplasm |
| **MAJOR FUNCTIONS** | (genetic material)<br>**directs** protein synthesis<br>replicates **before** cell division | carries out genetic instructions for protein synthesis: messenger RNA, tRNA, rRNA |
| **SUGAR** | **deoxyribose** | **ribose** |
| **BASES** | adenine, guanine, cytosine, **thymine** | adenine, guanine, cytosine, **uracil** |
| **STRUCTURE** | double helix | single stranded |

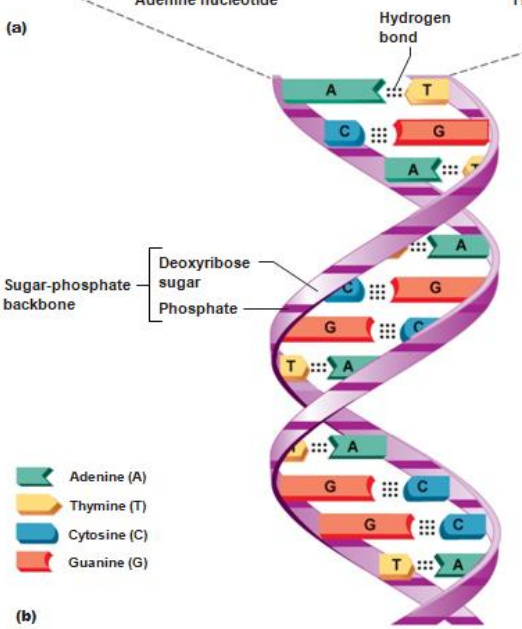
# 2.12: ADENOSINE TRIPHOSPHATE (ATP)

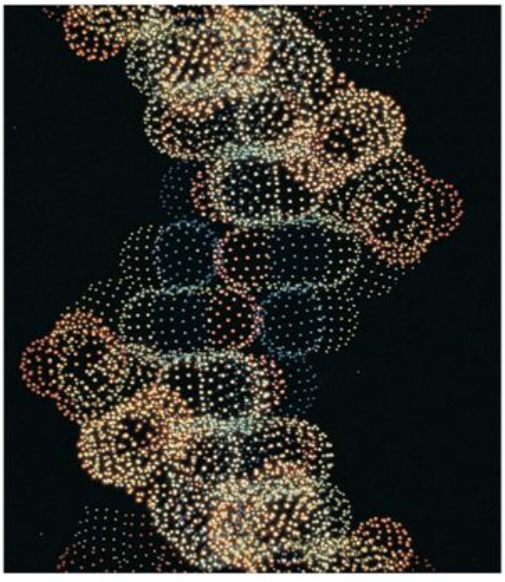
- gluose = most importnat cellular fuel **but none of chemical energy contained in glucose bonds used directly to power cellular work**
- **oxidation of glucose (glucose catabolism) = release of energy = synthesis of adenosine triphosphate (ATP)**
- **ATP = primary energy-transferring molecule and provides form of energy that is immediately usable by all body cells**
- ATP = adenine nucleotide + 2 additional phosphates
- ATP = unstable (repulsion of negatively charged phosphates) ∴ when broken = release of energy

***PHOSPHORYLATION:*** addition of phosphate (e.g. hydrolysis of ATP = phosphorylation of something else)



(c) Computer-generated image of a DNA molecule

# CHAPTER 3: CELLS

***THE LIVING UNITS***

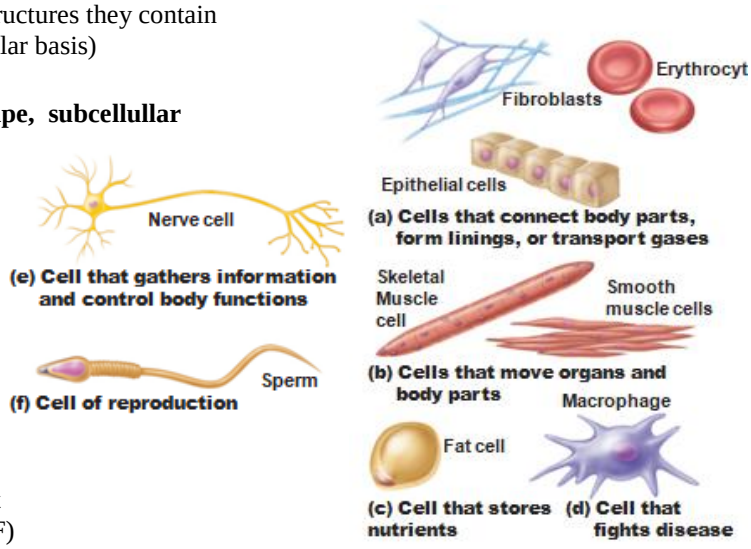
## 3.1: CELL THEORY

***CELLS:*** smallest unit of life

1. cell is basic structural and functional unit of living organisms
   → ∴ defining cell properties = defining properties of life
2. activity of organism depends on both individual and combined activities of its cells
3. ***PRINCIPLE OF COMPLEMENTARITY OF STRUCTURE AND FUNCTION:*** biochemical activities of cells dictated by their shapes or forms, and by relative number of subcellullar structures they contain
4. cells can only arise from other cells (continuity of life has cellular basis)

## CELL DIVERSITY

- over **250 different types** of human cells that **differ in size, shape, subcellullar components,** and **functions**




## GENERALIZED CELL

- all cells have same basic parts and functions

**3 PARTS:**

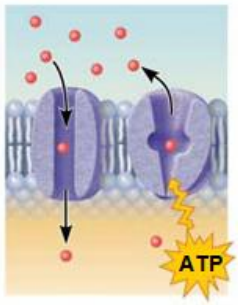
1. **PLASMA MEMBRANE*:** flexible outer boundary of cell, **selectively permeable**
2. **CYTOPLASM:** intracellular fluid containing **organelles**
3. **NUCLEUS:** organelle that **controls cellular activities**

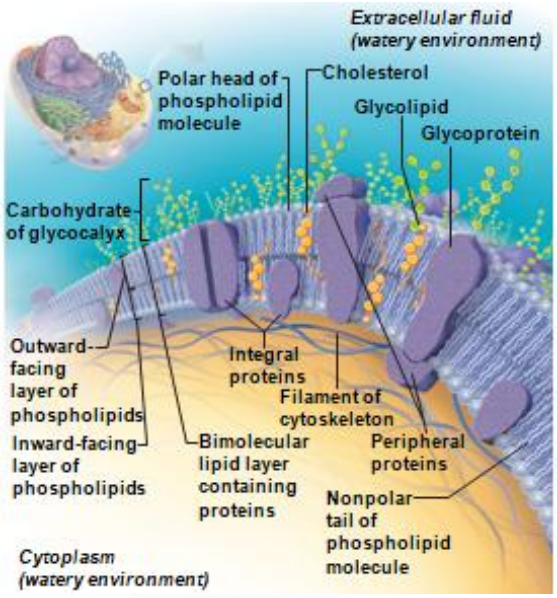
## 3.2: *PLASMA MEMBRANE, *A.K.A. cellular membrane*

- selectively permeable: some molecules pass easily, others don't
- separate's intracellular fluid (ICF) from extracellular fluid (ECF)
  → **interstitial fluid (IF) = extracellular fluid (ECF)**
- plays **dynamic** role in cellular activities
- **FLUID MOSAIC MODEL** of membrane: thin structure composed of bilayer of lipid molecules with protein molecules dispersed in it (bimolecular layer of lipids and proteins in constantly changing fluid mosaic)
  → proteins form constantly changing fluid mosaic

## 3 MEMBRANE LIPIDS

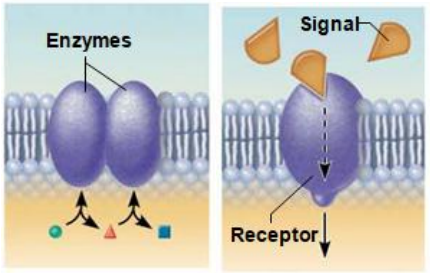
1. **PHOSPHOLIPIDS**
   - hydrophilic head: phosphate
   - hydrophobic tail: fatty acid tails
2. **GLYCOLIPIDS**
   - lipids with attached sugar groups
   - sugar group = polar, fatty acid tails = NP
3. **CHOLESTEROL**
   - hydroxyl group = polar
   - fused ring system = non-polar
   - wedges carbon rings between phospholipid tails = **stabilizes membrane**
   - also **decreases mobility of phospholipids and fluidity of membrane**



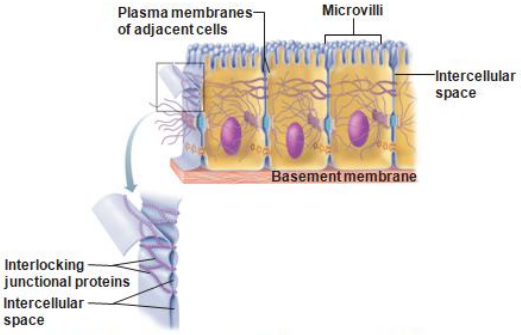

## 2 MEMBRANE PROTEINS

1. **INTEGRAL PROTEINS**
   - integrated into bilayer
   - have hydrophilic and hydrophobic regions
     → interaction with both NP tails and water inside and outside cell
   - **transmembrane** proteins = span entire membrane and protrude out both sides
     → **TRANSPORT:** hydrophilic channel or active transport
     → **ENZYMES:** catalysis
     → **RECEPTORS FOR SIGNAL TRANSDUCTION**
2. **PERIPHERAL PROTEINS**
   - attach loosely to integral proteins, easily removed
   - some are enzymes
   - others are motor proteins involved in mechanical functions, e.g. changing cell shape during cell division and muscle contraction
   - others link cells together

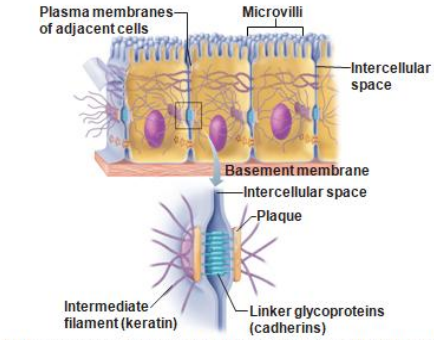


# 3 TYPES OF CELL JUNCTIONS

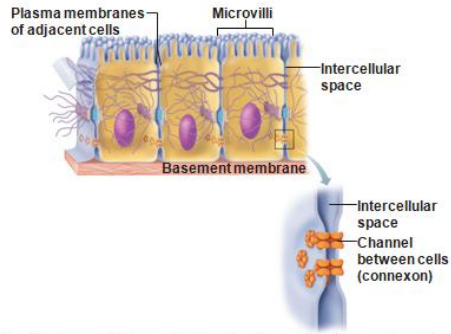
1. **TIGHT JUNCTIONS: impermeable**, forms continuous seals around cells preventing molecules from passinge.g. tight junctions between epithelial cells lining digestive tract keep digestive enzymes and microorganisms in intestine from seeping
2. **DESMOSOME: anchoring junctions**, binds adjacent cells together, and help form internal **tension-reducing network of fibres**
3. **GAP JUNCTIONS: communicating junctions,** allows ions and small molecules to pass, especially important in heart, smooth muscle, and embryonic cells




**(a) Tight junctions:** Impermeable junctions prevent molecules from passing through the intercellular space.




**(b) Desmosomes:** Anchoring junctions bind adjacent cells together and help form an internal tension-reducing network of fibers.




**(c) Gap junctions:** Communicating junctions allow ions and small molecules to pass from one cell to the next for intercellular communication.

# 3.3 PASSIVE TRANSPORT

- ATP not required
- **DIFFUSION:** high to low concentration (down concentration gradient)
- some forms require protein (**facilitated**)

## SIMPLE DIFFUSION

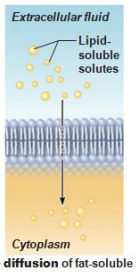
- lipid solubles (NP), e.g. oxygen, carbon dioxide, and fat soluble vitamins

## FACILITATED DIFFUSION: often highly selective

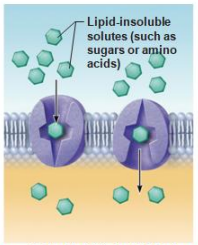
- **CARRIER-MEDIATED FACILITATED DIFFUSION:** lipid-insoluble (polar), glucose, other sugars, and amino acids
  → binding causes shape change allowing enveloping and release
- **CHANNEL-MEDIATED FACILITATED DIFFUSION:** mostly ions, sometimes water

## OSMOSIS

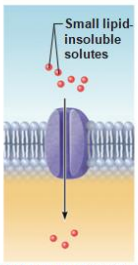
- **osmosis through lipid bilayer** or **aquporins (AQPs),** single file diffusion



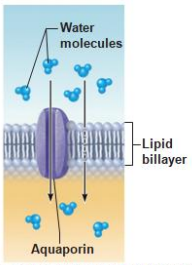

**(a) Simple diffusion** of fat-soluble molecules directly through the phospholipid bilayer




**(b) Carrier-mediated facilitated diffusion** via a protein carrier specific for one chemical; binding of substrate causes shape change in transport protein




**(c) Channel-mediated facilitated diffusion** through a channel protein; mostly ions selected on basis of size and charge



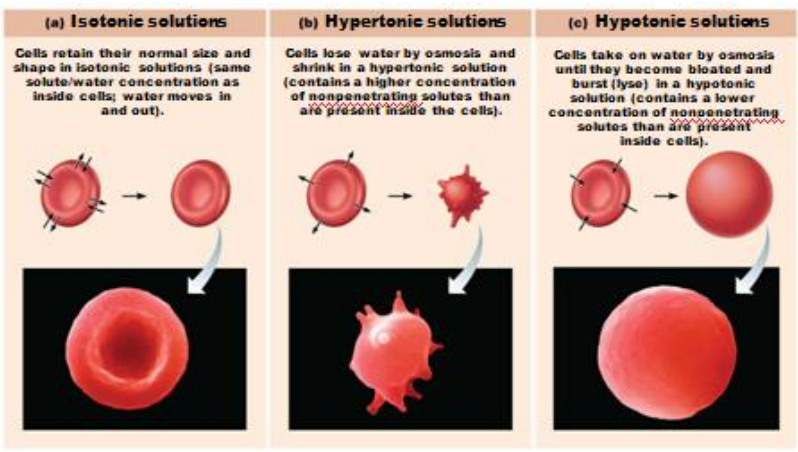

**(d) Osmosis**, diffusion of a solvent such as water through a specific channel protein (aquaporin) or through the lipid bilayer

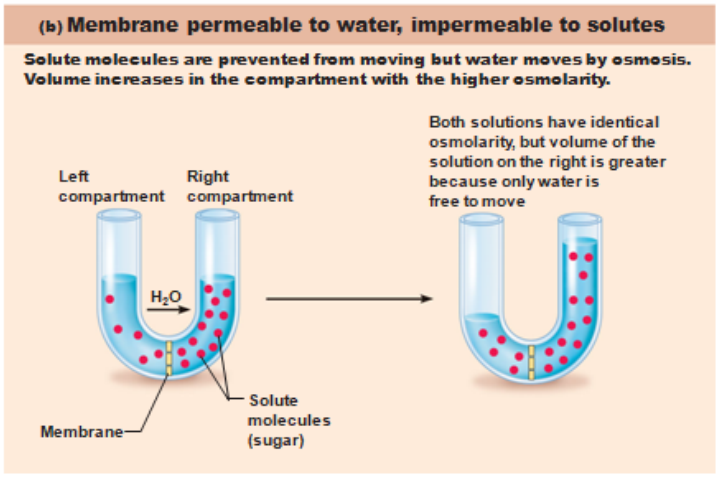
## TONICITY, *ability of solution to cause cell to shrink or swell (by altering cell's internal volume)*

***OSMOLARITY:*** total concentration of all solute particles in solution

- membrane permeable to **both solute and water = movement of both**
- membrane permeable to water but not solute: **movement of water**
- in plants: existence of water loss and sucking regulation, in animals there is not

***ISOTONIC:*** solutions with same concentration as cytosol
***HYPERTONIC:*** higher concentration than cytosol, cells immersed in **hypertonic solution** will lose water and shrink
***HYPOTONIC:*** lower concentration than cytosol, cells immersed in **hypotonic solution** will gain water



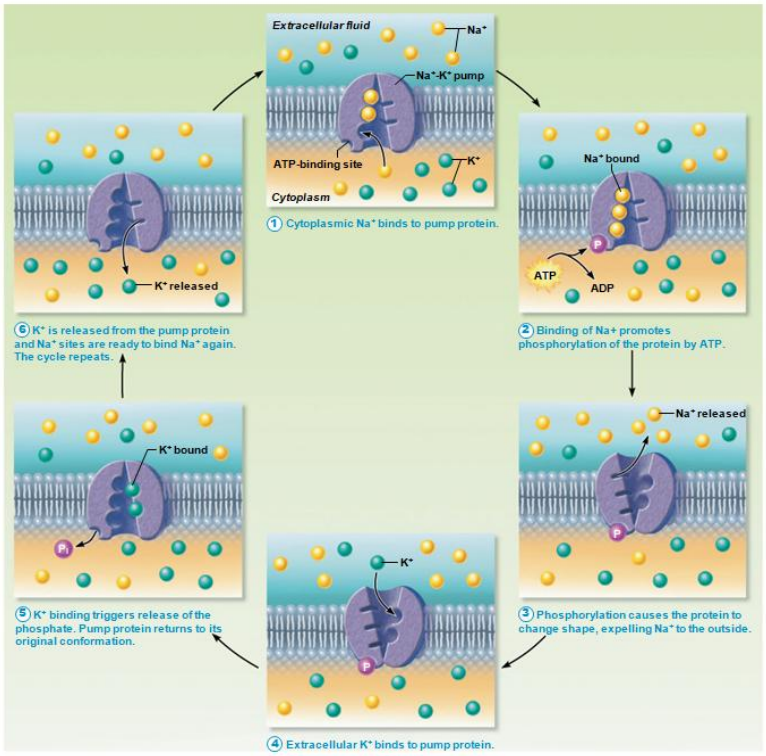
# 3.3 ACTIVE TRANSPORT

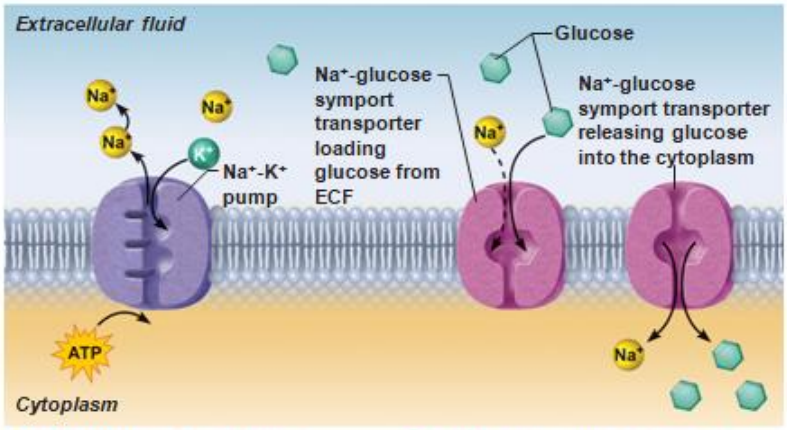
- requires ATP
- movement of solutes from low to high concentration (against concentration gradient)

## ACTIVE TRANSPORT:

- carrier proteins that combine **specifically** and **reversibly** with transported substances

1. **PRIMARY ACTIVE TRANSPORT: energy <u>directly</u> from hydrolysis of ATP**
   - hydrolysis of ATP = phosphorylation of transport protein
   - → causes shape change that it "pumps" bound solute (ions) across membrane
   - → e.g. sodium-potassium pump
   - → **$Na^+$ and $K^+$ leak** slowly but continuously through **leakage channels** in plasma membrane according to **electrochemical gradient**
2. **SECONDARY ACTIVE TRANSPORT: energy <u>indirectly</u> from energy stored in concentration gradients of ions**
   - depends on **ion gradient** created by primary active transport
   - **coupled systems** (move more than one substance at a time)
   - no pump = no transport



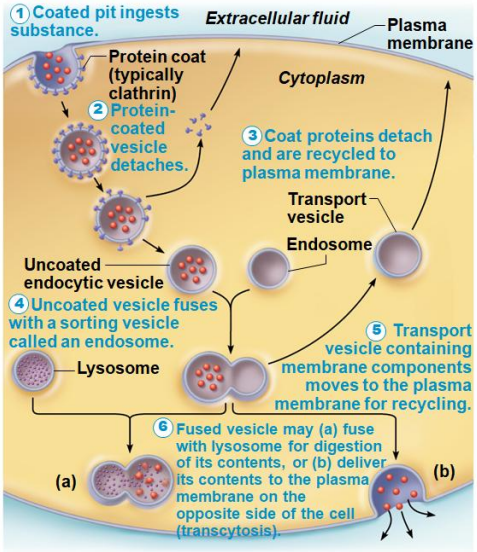




## VESICULAR TRANSPORT, *transportation through vesicles (requires ATP)*

- transport of large particles, macromolecules, and fluids **across plasma membranes**
- **<u>ENDOCYTOSIS</u>:** transport into cell

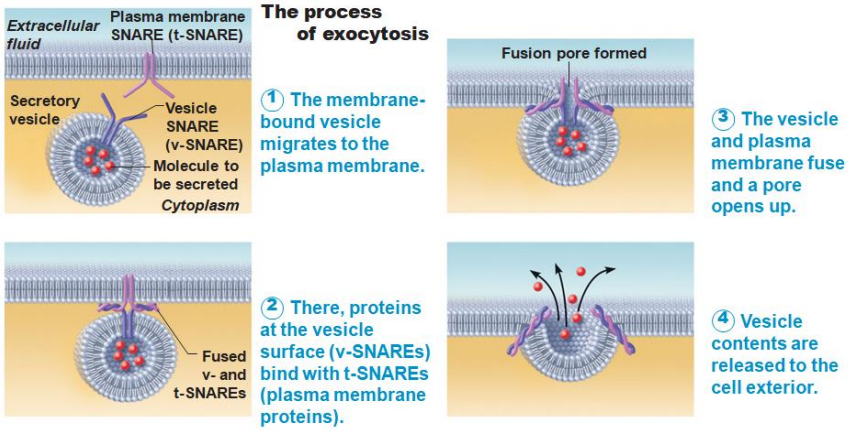
1. **PHAGOCYTOSIS: pseudopods** engulf **solids** and brings them into cell's interior, e.g. macrophages and WBCs
2. **PINOCYTOSIS:** plasma membrane infolds bringing in fluid and solutes (has no receptors ∴ non specific), e.g. nutrient absorption in small intestines
3. **RECEPTOR-MEDIATED ENDOCYTOSIS: clatrhin coated pits** provide main route for endocytosis and **transcytosis**, e.g. uptake of enzymes, low-density lipoproteins, iron, and insulin

***TRANSCYTOSIS:*** moving subst. into, across, and out of cell




- **<u>EXOCYTOSIS</u>:** transport out of cell, e.g. hormone **secretion**, neurotransmitter **release**, mucus **secretion**, **ejection** of cellular wastes

***SUBSTANCE (VESICULAR) TRAFFICKING:*** transport from one area in cell to another



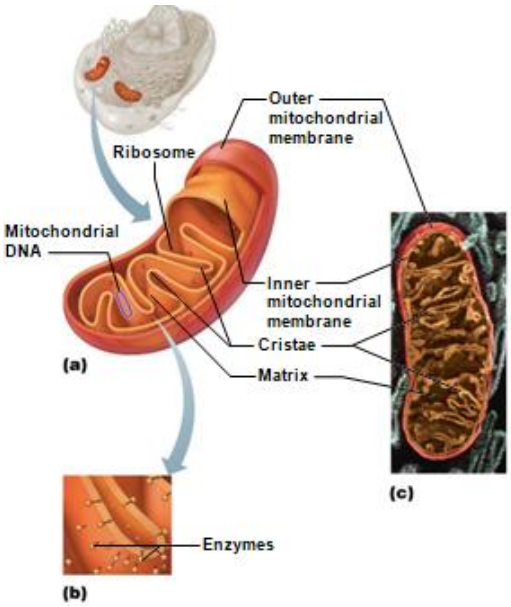
# THE CYTOPLASM, *located between plasma membrane and nucleus*

***CYTOSOL:*** water with solutes (protein, salts, sugars, etc.), aqueous component of cytoplasm

***CYTOPLASMIC ORGANELLES:*** metabolic machinery of cell

***INCLUSIONS:*** granules of glycogen or pigments, lipid droplets, vacuoles, and crystals

| CYTOPLASMIC ORGANELLES | |
|---|---|
| **MEMBRANOUS** | **NONMEMBRANOUS** |
| • mitochondria<br>• endoplasmic reticulum<br>• golgi apparatus<br>• lysosomes<br>• peroxisomes | • ribosomes<br>• cytoskeleton<br>• centrioles |




# MEMBRANOUS ORGANELLES

## MITOCHONDRIA

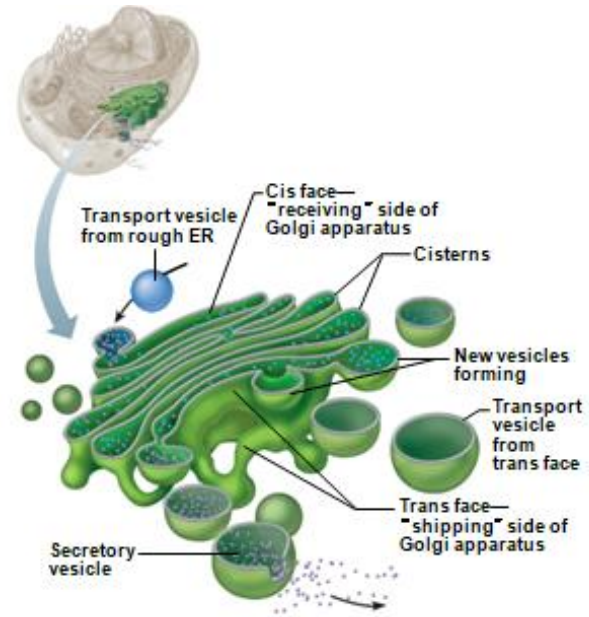
- **double membrane structure** with shelf-like **cristae**
- provides most of cell's ATP via **aerobic cellular respiration**
- complex organelles: contain own DNA, RNA, ribosomes, and are able to reproduce themselves (**fission**)

## ENDOPLASMIC RETICULUM (ER)

- interconnected tubes and parallel membranes enclosing **cisterns** (fluid filled cavities)
- continuous with nuclear membrane

**2 VARIETIES**

1. **ROUGH ER,** ***external surface studded with <u>ribosomes</u>***
   - **manufactures all <u>secreted</u> proteins**
     → assembled proteins move to ER interior and then via vesicle, to **golgi apparatus**
   - **"membrane factory"** where integral proteins and phospholipids of cellular membranes are synthesized
2. **SMOOTH ER,** ***network of tubules continuous with rough ER***
   - its **enzymes (integral proteins) catalyze reactions** involved in:
     → lipid metabolism, cholesterol and steroid based hormone synthesis and making lipids of lipoproteins
     → absorption, synthesis, and transport of fats
     → detoxification of drugs, some pesticides, and carcinogenic chemicals
     → converting glycogen to glucose
     → storage and release of calcium




**(a) Many vesicles in the process of pinching off from the Golgi apparatus.**

## GOLGI APPARATUS

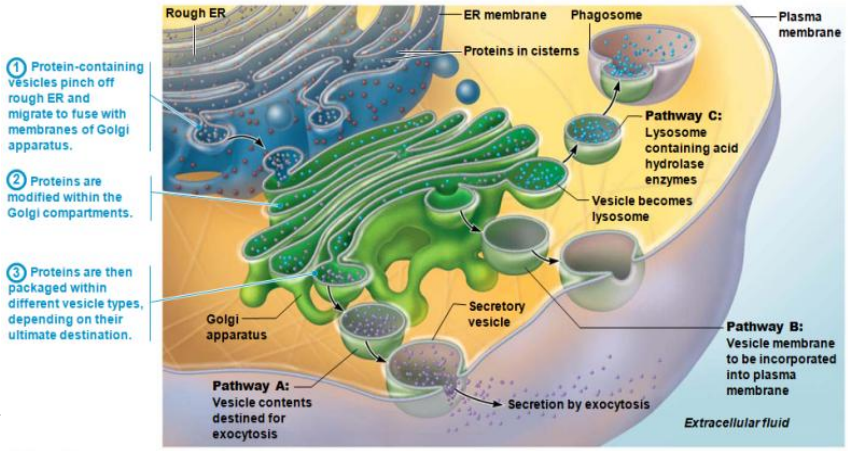
- stacked and flattened membranous sacs
- modifies, concentrates, and **packages proteins and lipids** in 3 steps:
  1. transport vesicles from rough ER fuse with membranes at convex **cis face** ("receiving" side) of Golgi apparatus
  2. inside apparatus, **proteins modified**
  3. various proteins 'tagged' for delivery to special places, budding from **trans face** ("shipping" side) of apparatus
     → proteins carried by **secretory vesicles**, leaving through **trans face** to designated parts of cell

## LYSOSOMES

- spherical membranous bags containing digestive enzymes that work best in acidic environments
  ∴ also called **acid hydrolases**

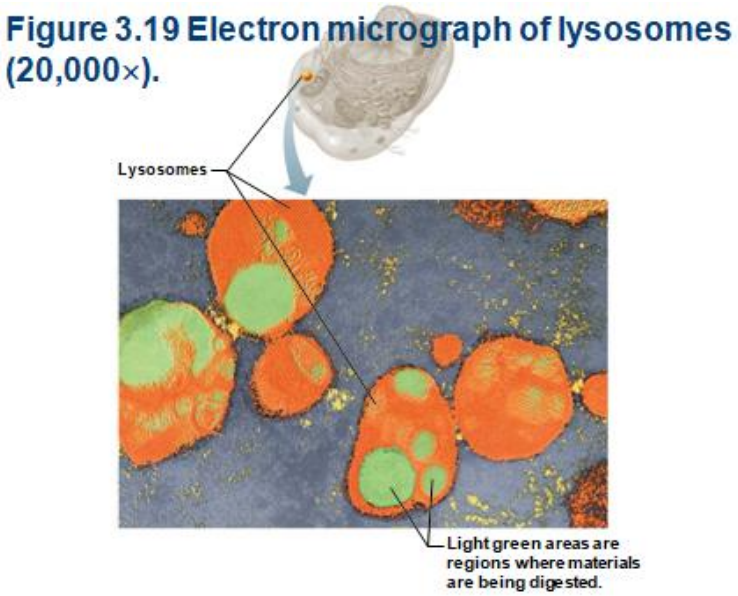
**FUNCTIONS AS CELL'S "DEMOLITION CREW":**

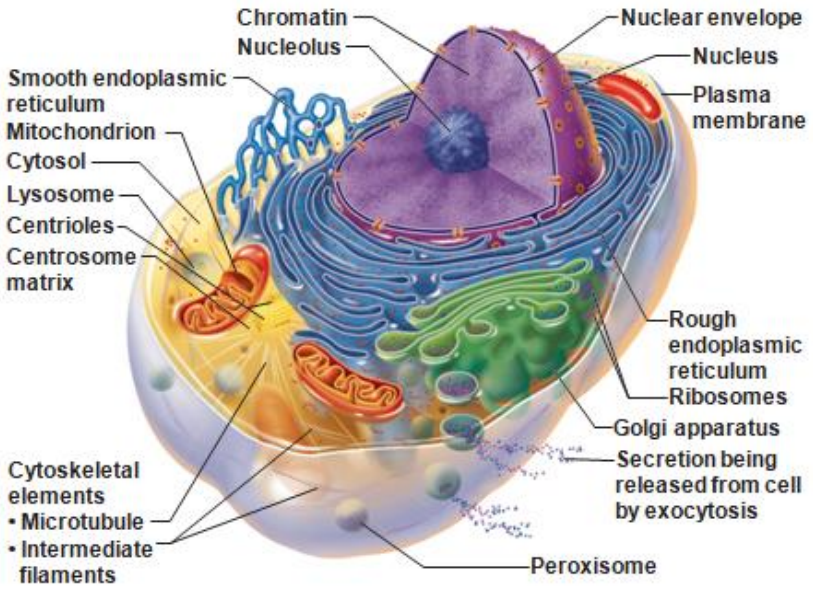
- digests ingested (through endocytosis) bacteria, viruses, and toxins
- degrades nonfunctional organelles ("self-eating")
- breaks down, and releases, glycogen
- breaks down bone to release $Ca^{2+}$
- when lysosomes rupture, cell digests itself through process called **autolysis**



**CLINICAL EXAMPLE**

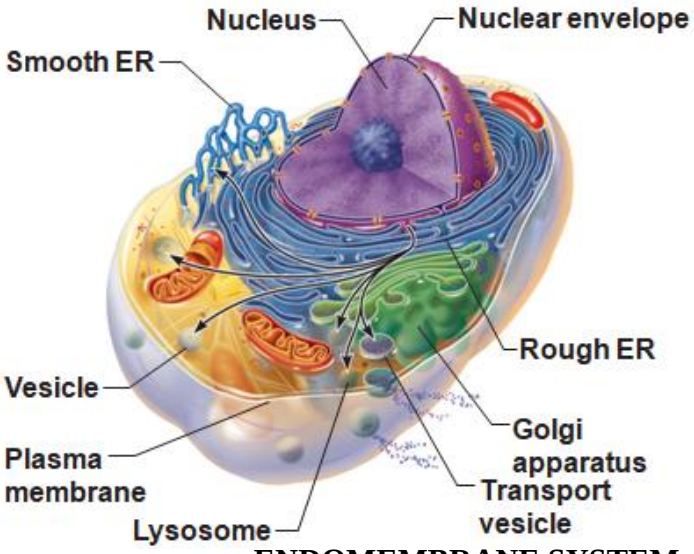
- when one or more lysosomal digestive enzymes are mutated and do not function properly = **lysosomal storage diseases**
- **Tay-Sachs disease** = condition where **patient lacks lysosomal enzyme needed to break down glycolipids in brain cells**
  - → glycolipids build up as result, interfering with nervous system functioning
  - → seen predominantly in infants of Central European Jewish descent (**inherited condition)**
  - → causes seizures, mental retardation, blindness, and death before age 5




## PEROXISOMES, *membranous sacs containing powerful enzymes: oxidases and catalases*

- detoxifies harmful or toxic substances
- **oxidases** convert to $H_2O_2$ (toxic)
  - → neutralizes dangerous **free radicals** (highly reactive chemicals with unpaired electrons)
- **catalases** convert $H_2O_2$ to water and oxygen
- catalyzes and synthesizes fatty acids




**ENDOMEMBRANE SYSTEM**

# NON-MEMBRANOUS ORGANELLES

## RIBOSOMES

- granules containing protein and rRNA
- site of protein synthesis
- **FREE RIBOSOMES**: synthesizes proteins to be used by cell
- **MEMBRENE-BOUND RIBOSOMES:** ribosomes on rough ER, synthesizes proteins to be incorporated into membranes or exported from cell

## CYTOSKELETON, *cell's "bones," "muscles", and "ligaments"*

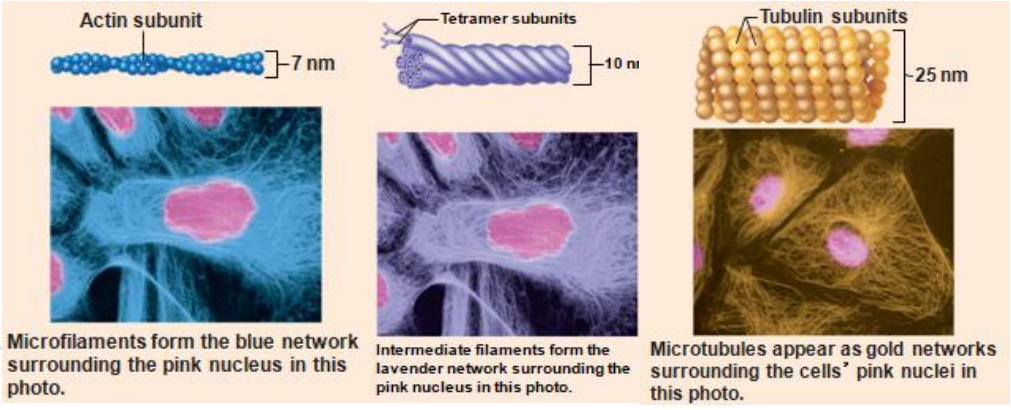
- elaborate network of rods that run throughout cytosol
- hundreds of different kinds of proteins link rods to other cell structures
- plays role in movement of cell components

**3 TYPES OF CYTOKELETON:**

1. **MICROFILAMENTS:** strands made of protein subunits called **actins**
2. **INTERMEDIATE FILAMENTS: toughest, insoluble** protein fibres, like woven ropes, composed of **teramer (4) fibrils**
3. **MICROTUBULES:** hollow tubes of protein called **tubulins**

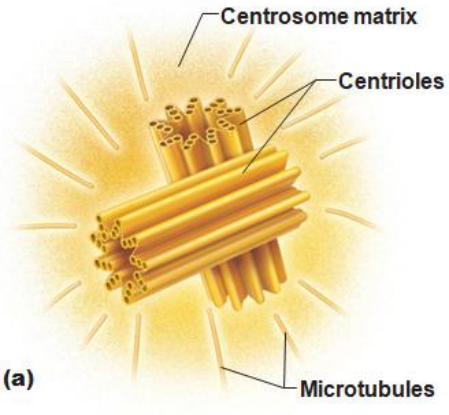
**EXAMPLE OF CYTOSKELETON: CENTROSOMES**

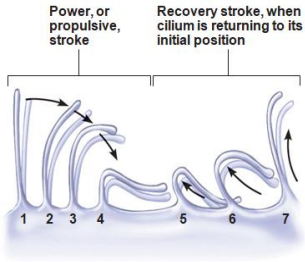
- "cell centre" near nucleus
- generates **microtubules**
- organizes mitotic spindle (in cell division)
- contains **centrioles** (small tube formed by microtubules)
- form bases of **cilia** and **flagella**



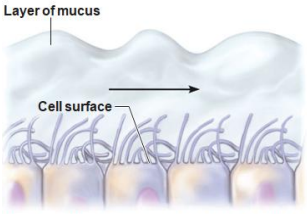
**EXAMPLE OF CYTOSKELETON: CELLULAR EXTENSIONS**

1. **CILIA AND FLAGELLA,** ***projections formed by centrioles***
   - whiplike, **motile** (capable of motion) extensions on surfaces of certain cells
   - contains microtubules and motor molecules
   - **CILIA:** propels other substances across cell surface (ciliary action)
   - (longer) **FLAGELLA:** propels whole cell itself (tail of sperm)
2. **MICROVILLI**
   - fingerlike extensions of plasma membrane
   - increase surface area for absorption
   - **core of actin filaments = "stiffener"**

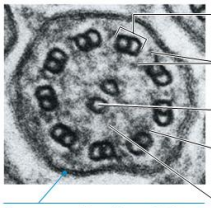


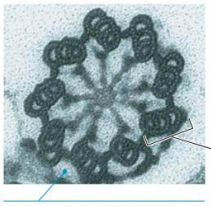



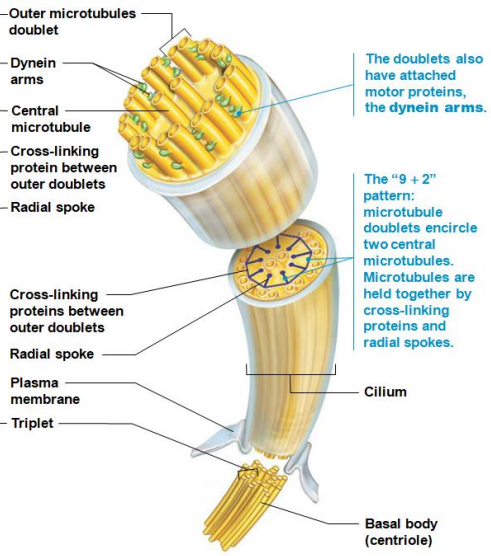
(a) Phases of ciliary motion.

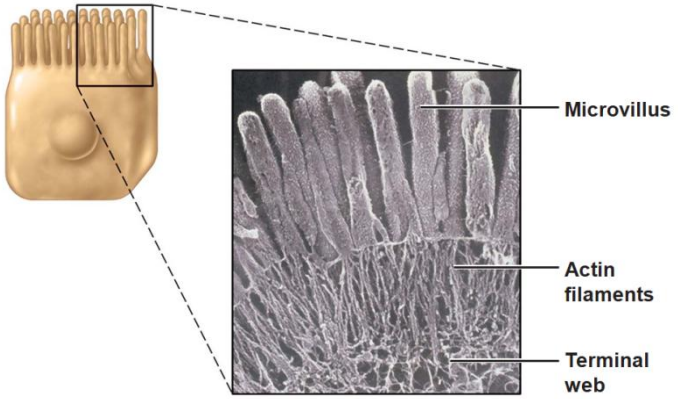


(b) Traveling wave created by the activity of many cilia acting together propels mucus across cell surfaces.


A cross section through the **cilium** shows the "9 + 2" arrangement of microtubules.


A cross section through the **basal body**. The nine outer doublets of a cilium extend into a basal body where each doublet joins another microtubule to form a ring of nine triplets.



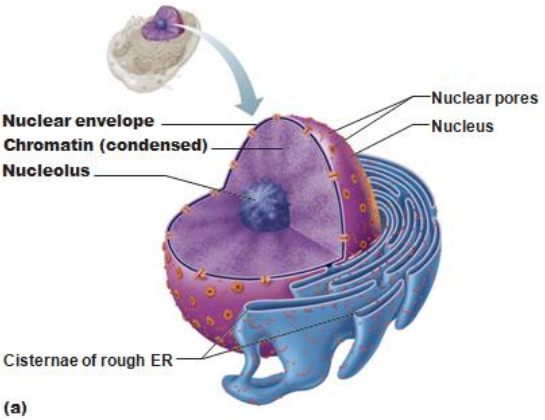




# NUCLEUS

- genetic library with blueprints for nearly all cellular proteins
- responds to signals and dictates kinds and amounts of proteins to be synthesized
- most cells are uninucleate, e.g. RBCs
- skeletal muscle cells, bone destruction cells, and some liver cells are multinucleate

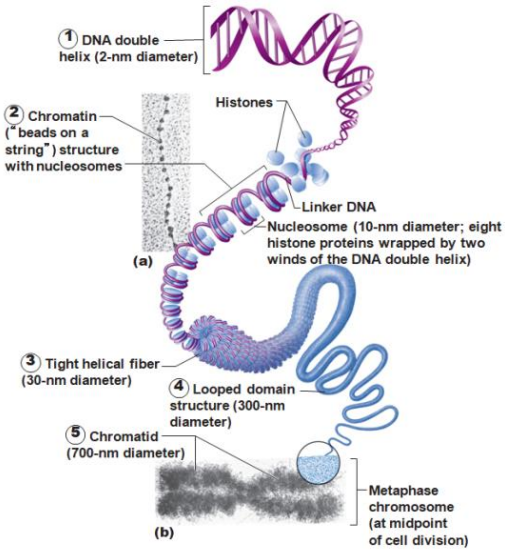
**NUCLEAR ENVELOPE**

- double-membrane barrier containing pores
- outer layer continuous with rough ER and bears ribosomes
- inner lining (nuclear lamina) maintains shape of nucleus
- **pore complex:** regulates transport of large molecules into and out of nucleus




**CHROMATIN**

- threadlike strands of DNA (30%), histone proteins (60%), and RNA (10%)
- arranged in fundamental units called nucleosomes
- when cell starts to divide: condenses into barlike bodies called chromosomes




# CELL CYCLE

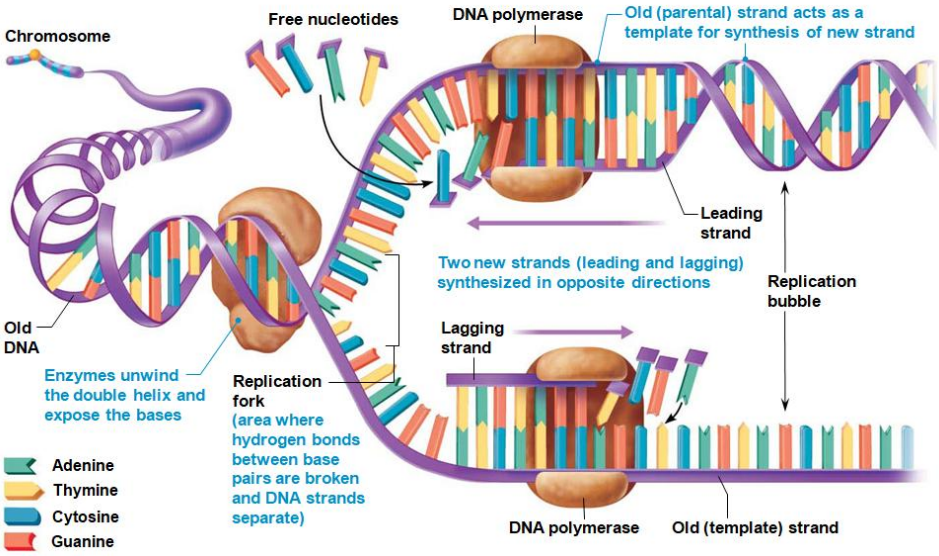
- includes **interphase** (changes until cell reproduces) and **mitotic phase** (cell division)

**DNA REPLICATION**

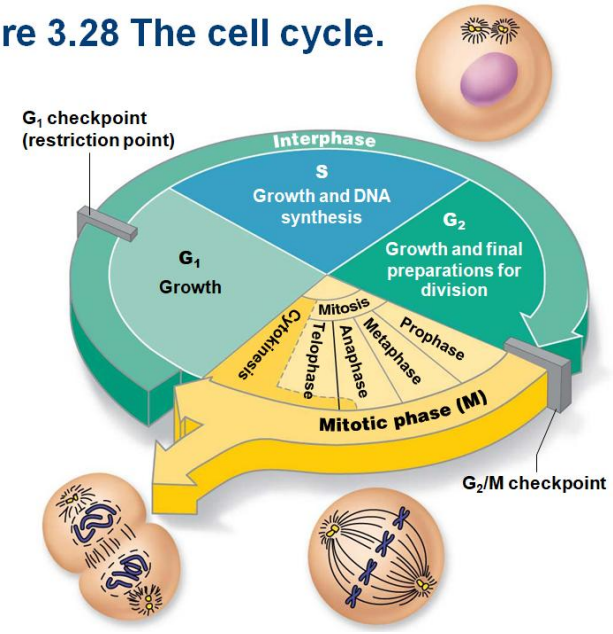
- prior to division, cell makes copy of DNA
- DNA helices separated into *replication bubbles* with *replication forks* at each end
- each strand acts as **template strand** for **complementary strand**
- synthesizes **one leading (continuous), one lagging strand (discontinuous)**

- **DNA polymerase** only works in one direction
- **DNA ligase splices** short segments of discontinuous strand together
- end result: 2 identical DNA molecules formed from original
- **semiconservative replication:** one complete copy given to new cell; one retained in original cell; each DNA made up of one old and one new strand

## Figure 3.29 Replication of DNA: summary.




## Figure 3.28 The cell cycle.




## CELL DIVISION

- mitotic (M) phase of cell cycle
- essential for growth and tissue repair
- does not occur in most mature cells of nervous tissue, skeletal muscle, and cardiac muscle

## CONTROL OF CELL DIVISION

- "go" and "stop" signals direct when a cell should and should not divide
- **GO SIGNALS:**
  - → critical surface-to-volume ratio of cell, when area of membrane becomes inadequate for exchange
  - → chemicals, e.g. growth factors, hormones
- **STOP SIGNALS:**
  - → availability of space; normal cells stop dividing when they come into contact with other cells
  - → **contact inhibition** (regulatory mechanism that keeps growing cells one layer thick, lost in cancer patients)

## 2 CRUCIAL GROUPS OF PROTEINS: S PHASE PRIOR TO MISTOSIS

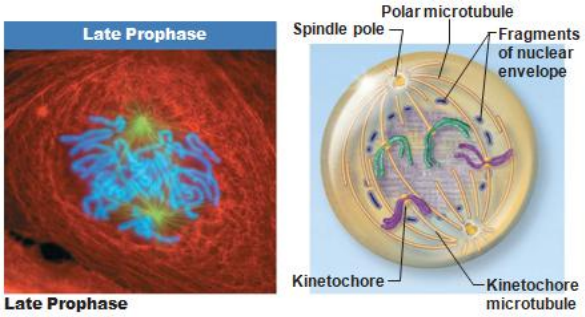
- crucial to cell's ability to accomplish S phase and enter mitosis:
- **CYCLINS: regulatory proteins** that accumulate during interphase
  - → Cdks (Cyclin-dependent kinases) binds to cyclins = activation
  - → cyclin-Cdk complex activates enzyme cascades that prepare cell for division
  - → cyclins destroyed after mitotic cell division, and process begins again

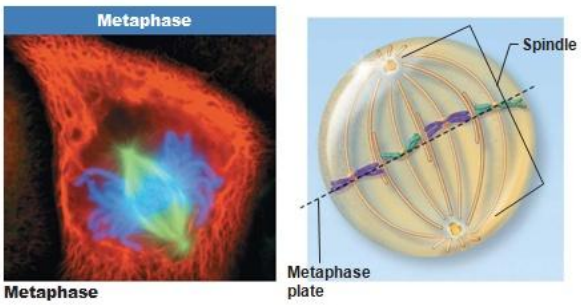
## CHECKPOINTS, *key events in cell cycle where cell division processes are checked and, if faulty, stopped until repairs are made*

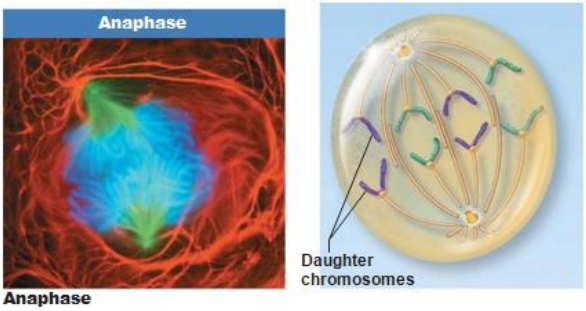
- **$G_1$ CHECKPOINT (RESTRICTION POINT):** most important of three major checkpoints
  - → if cell does not pass, it enters $G_0$, in which no further division occurs
- **"Other Controls" SIGNALS:**
- **repressor genes** inhibit cell division, e.g. P53 gene

### CELL DIVISION

- **MITOSIS: P**rophase, **M**etaphase, **A**naphase, **T**elophase
- **CYTOKINESIS:** division of cytoplasm by **cleavage** furrow

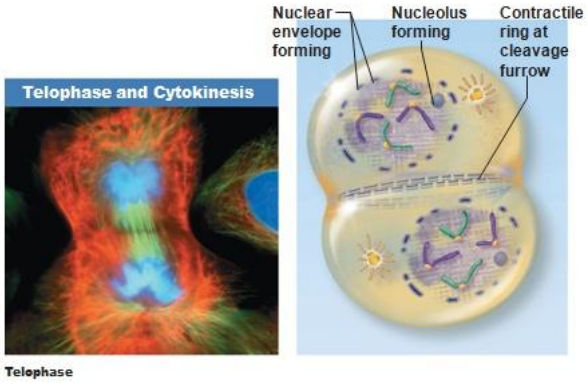


# PROTEIN SYNTHESIS

- **DNA:** master blueprint for protein synthesis
- ***GENE:*** segment of DNA with blueprint for **<u>one polypeptide</u>**
  - → composed of **exons** (code for amino acids) and **introns** (non-coding segment)
- triplets of nucleotide bases form genetic library, each triplet specifies coding for single amino acid
- eg: GGC codes for amino acid proline, whereas GCC codes for arginine

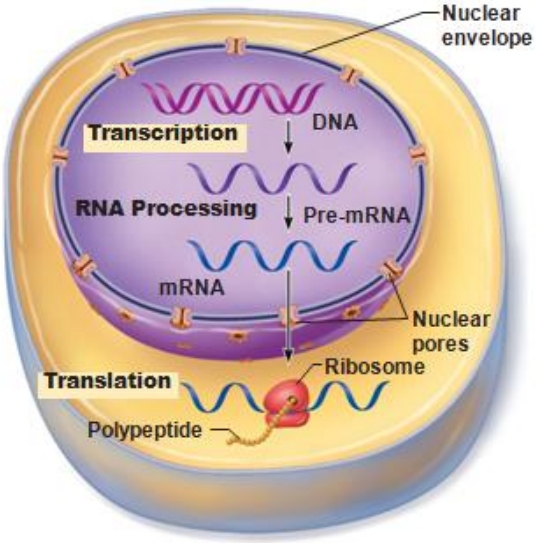



## ROLE OF RNA

- DNA **decoding mechanism and messenger**
- Three types–all formed on DNA in nucleus
- **messenger RNA (mRNA); ribosomal RNA (rRNA); transfer RNA (tRNA)**

## ROLES OF 3 MAIN TYPES OF RNA

1. **Messenger RNA (mRNA):** carries instructions for building a polypeptide, from gene in DNA → ribosomes (in cytoplasm)
2. **Ribosomal RNA (rRNA):** structural component of ribosomes that, along with tRNA, helps translate message from mRNA
3. **Transfer RNAs (tRNAs):** binds to amino acids and pairs with bases of codons of mRNA at ribosome to begin process of protein synthesis




# TRANSCRIPTION, *synthesis of mRNA from DNA*

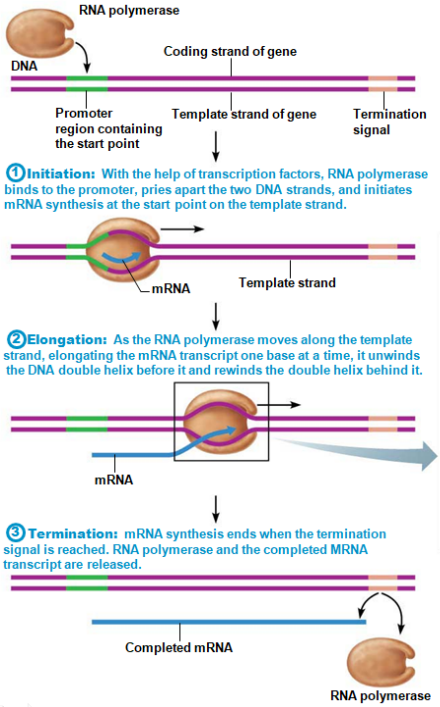
- transfers DNA gene base sequence to complementary base sequence of an mRNA

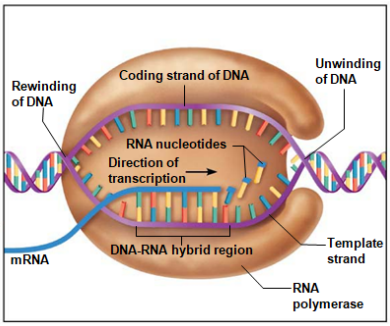
## TRANSCRIPTION FACTOR

- loosens histones from DNA in area to be transcribed
- binds to **promoter** (DNA sequence specifying start site of gene to be transcribed)
- mediates binding of **RNA polymerase** to promoter

## RNA POLYMERASE

- enzyme that **oversees synthesis of mRNA**
- unwinds DNA template
- adds complementary RNA nucleotides on DNA template and joins them together
- stops when it reaches **termination signal**
- mRNA pulls off DNA template, is further processed by enzymes, and enters cytosol




**The DNA-RNA hybrid:** At any given moment, 16–18 base pairs of DNA are unwound and the most recently made RNA is still bound to DNA. This small region is called the DNA-RNA hybrid.

## PROCESSING OF mRNA

- newl mRNA edited and processed before translation can begin (cap and poly-A tail)
- before processing = *pre-mRNA*
- **introns removed** by ***spliceosomes*** (special protein), leaving only exon coding regions

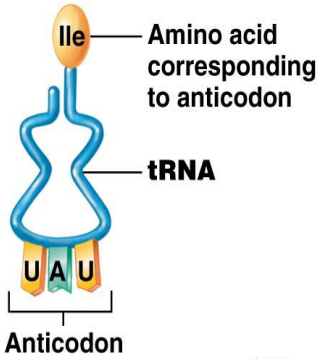
# TRANSLATION, *protein synthesis from mRNA*

- nucleic acids (base sequence) translated into proteins (amino acid sequence)
- involves **mRNA, genetic code, tRNA and ribosomes** (either attached to ER or unattached)

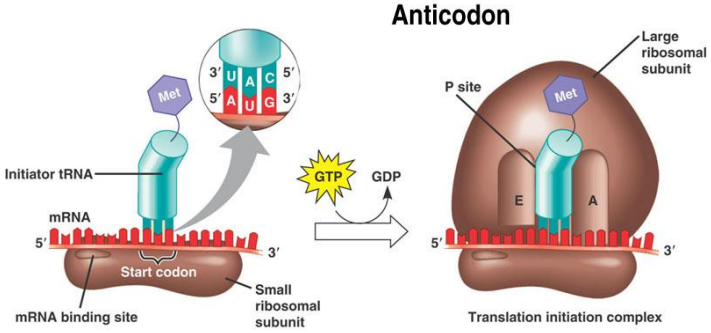
## GENETIC CODE

- each 3-base sequence on DNA (triplet code) represented by complementary three-base sequence on mRNA called **codon**
  - → 4 bases (A, U, C, G) and 3 places, so $4^3 = 64$ possible codons
  - → 64 codons but 20 amino acids; some amino acids represented by more than one codon
  - → redundancy helps protect against transcription errors
- 3 "stop" codons but rest are codons for amino acids

## ROLE OF tRNA



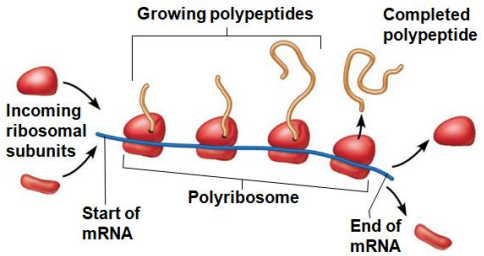

- tRNA binds to specific amino acid at one end (stem) = ***aminoacyl-tRNA***
- **anticodon** at other end (head) is triplet code that determines which amino acid will be bound at stem
  - → anticodon of tRNA will bind only to codon on mRNA that is complementary
  - → e.g. if codon is AUA, only a tRNA with anticodon UAU will be able to bond
- ribosome coordinates coupling of mRNA and tRNA
- ribosomes contain one binding site for mRNA and three binding sites for tRNA:
  - → **A**minoacyl site for incoming aminoacyl-tRNA
  - → **P**eptidyl site for tRNA linked to growing polypeptide chain
  - → **E**xit site for outgoing tRNA



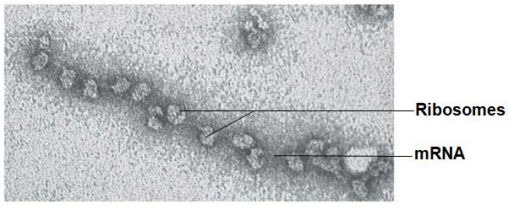

## SEQUENCE OF EVENTS IN TRANSLATION

**3 PHASES (**requires ATP, protein factors, and enzymes)

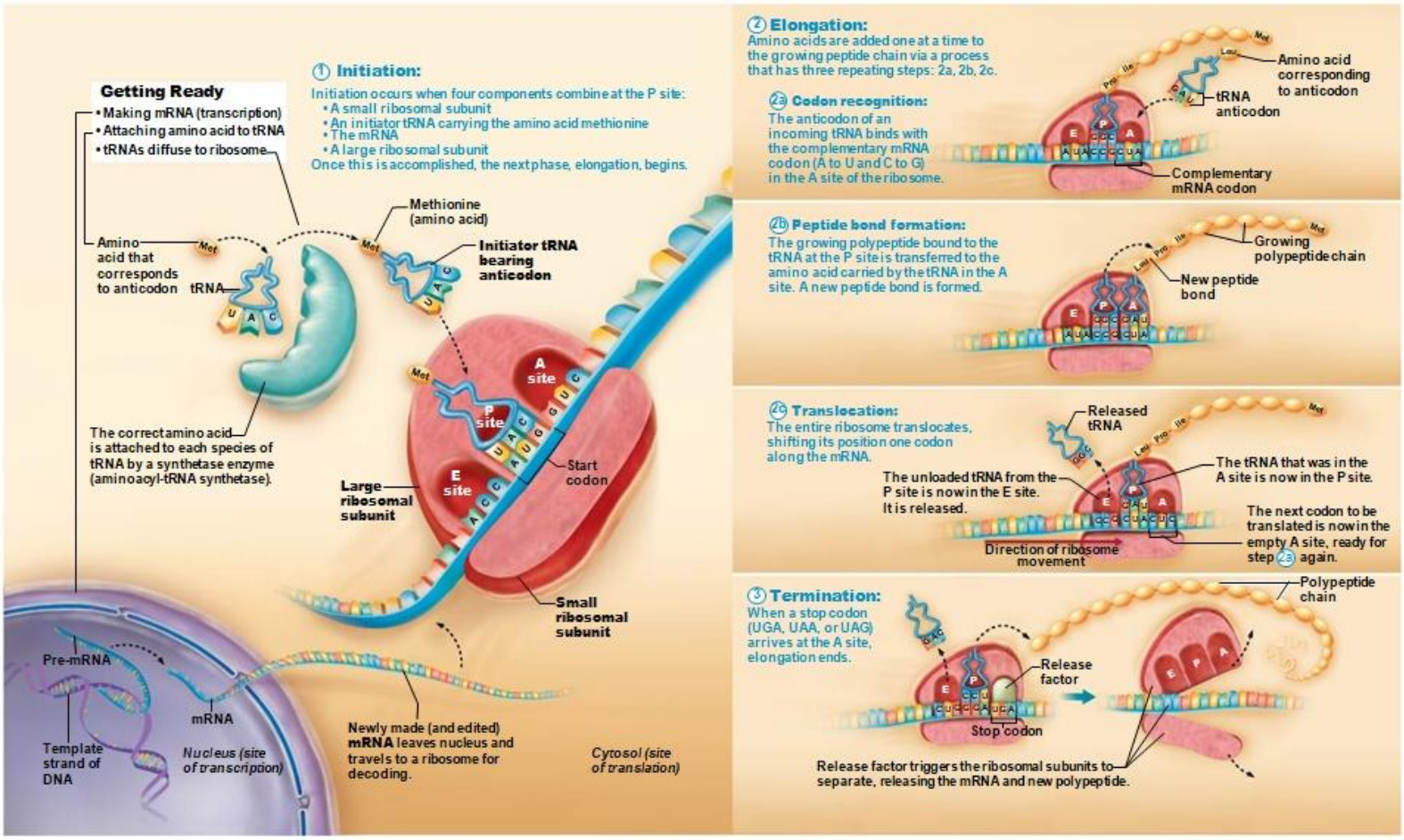
1. **INITIATION**
   - → small ribosomal subunit binds to special initiator tRNA (methionine) and then to the mRNA to be decoded
   - → ribosome scan mRNA looking for first methionine codon, which is referred to as the ***start codon***
   - → when anticodon of initiator tRNA binds to start codon, large ribosomal unit can then attach to small ribosomal unit forming a functional ribosome
   - → at end of initiation, initiator tRNA is in P site of rib osome, and A and E sites are empty
2. **ELONGATION**
   - **a) CODON RECOGNITION:** tRNA binds complementary codon in A site of ribosome
   - **b) PEPTIDE BOND FORMATION:** ribosomal enzymes transfer and attach growing polypeptide chain from tRNA in P site over to amino acid of tRNA in A site
   - **c) TRANSLOCATION:** ribosome shifts down three bases of mRNA, displacing tRNAs by one position
     - → tRNA in A site moves into P site
     - → tRNA in P site moves into E site
     - → tRNA in E site ejected from ribosome
   - once A site is empty, new tRNA can enter, bringing its amino acid cargo, and whole process starts over
   - after portion of mRNA is "read," additional ribosomes may attach to already read part and start another round of translation of same mRNA
   - **POLYRIBOSOME** = multiple ribosome-mRNA complex that produces multiple copies of same protein
3. **TERMINATION,** ***occurs when one of three stop codons (UGA, UAA, UAG) on mRNA enters A site, translation ends***
   - protein release factor binds to stop codon, causing water to be added to chain instead of another tRNA
   - causes release of polypeptide chain as well as separation of ribosome subunits and degradation of mRNA
   - final polypeptide product will be further processed by other cell structures into functional 3D protein




**(a) Each polyribosome consists of one strand of mRNA being read by several ribosomes simultaneously.** In this diagram, the mRNA is moving to the left and the "oldest" functional ribosome is farthest to the right.

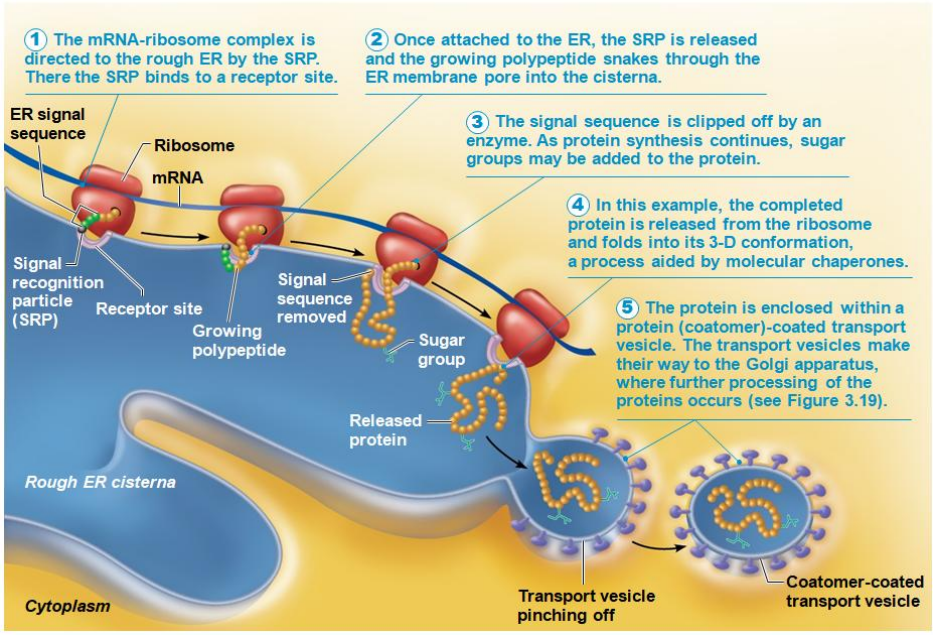



**(b) This transmission electron micrograph shows a large polyribosome (400,000×).**



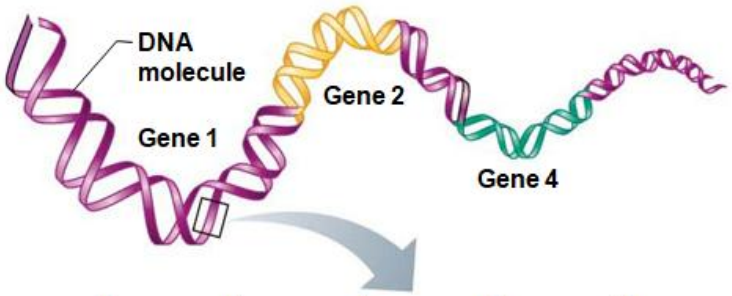

## ROLL OF ROUGH ER IN PROTEIN SYNTHESIS

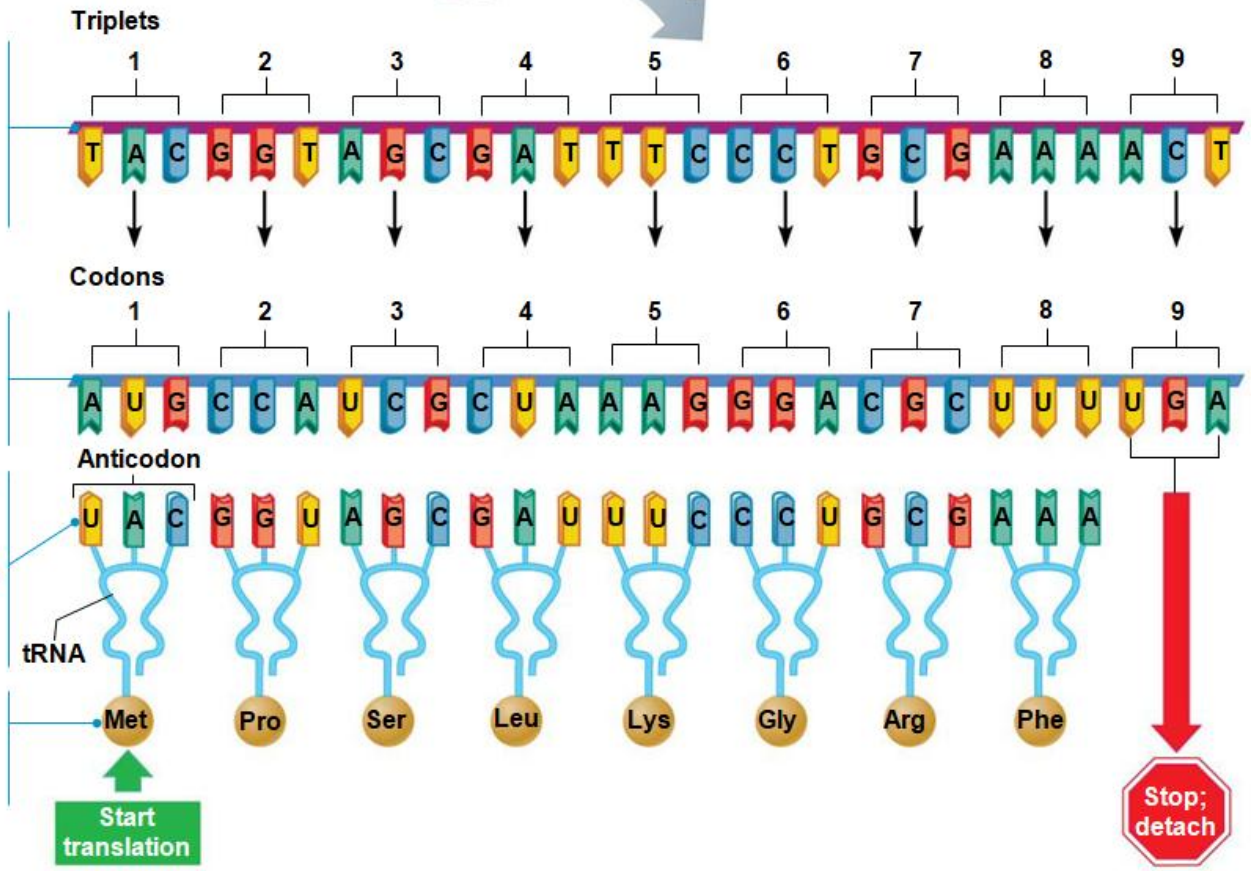
- mRNA–ribosome complex directed to rough ER by **signal-recognition particle (SRP)**
- forming protein enters ER
- sugar groups may be added to protein, and its shape may be altered
- protein is enclosed in a vesicle for transport to Golgi apparatus

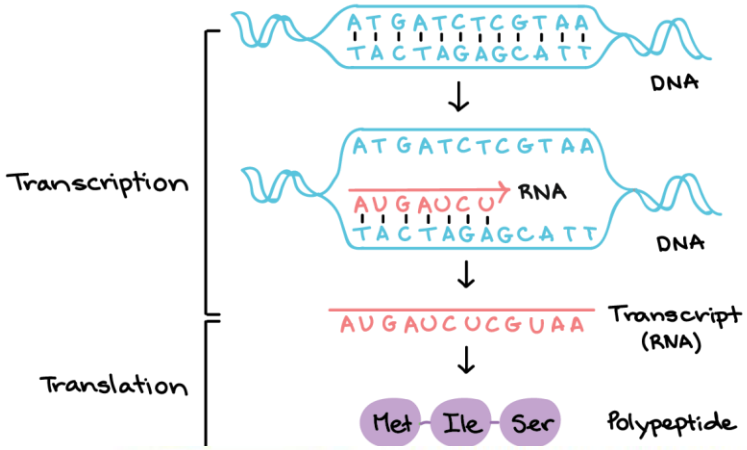


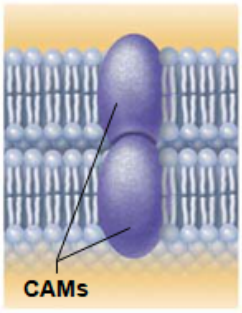

## SUMMARY: DNA TO PROTEINS

- **complementary base pairing** directs transfer of genetic information in D NA into amino acid sequence of protein
- DNA triplets coded to **mRNA codons**
- mRNA codons are base-paired with tRNA anticodons to ensure correct amino acid sequence
- **anticodon sequence of tRNA = identical to DNA sequence, except uracil is substituted for thymine**



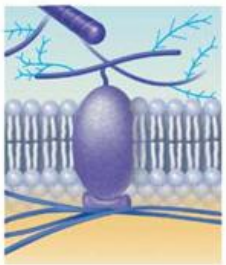



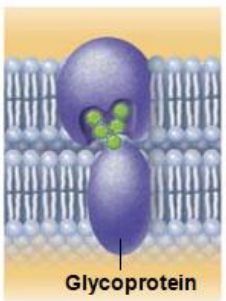

**(e) Intercellular joining**

- Membrane proteins of adjacent cells may be hooked together in various kinds of intercellular junctions.
- Some membrane proteins (cell adhesion molecules or CAMs) of this group provide temporary binding sites that guide cell migration and other cell-to-cell interactions.



**(c) Attachment to the cytoskeleton and extracellular matrix**

- Ele-ments of the cytoskeleton (cell's internal supports) and the extracellular matrix (fibers and other substances outside the cell) may anchor to membrane proteins, which helps main-tain cell shape and fix the location of certain membrane proteins.
- Others play a role in cell movement or bind adjacent cells together.




**(f) Cell-cell recognition**

- Some glycoproteins (proteins bonded to short chains of sugars which help to make up the glycocalyx) serve as identification tags that are specifically recognized by other cells.

# CHAPTER 4: TISSUE

***THE LIVING FABRIC***

## RECAP: TISSUES, *group of similar cells that have specific common function*

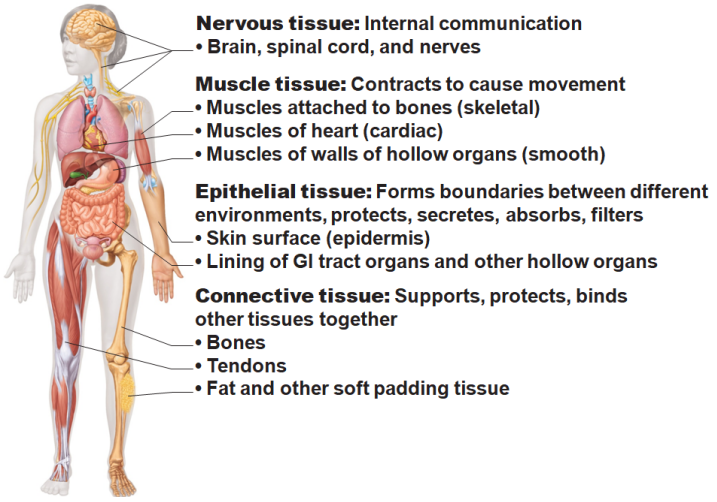
- individual body cells are specialized, labour = divided

***ORGAN:*** composed of at least 2 tissue types (4 is more common), that performs a specific function for the body ; each organ is a specialized functional centre responsible for a necessary activity that no other organ can perform

1. **EPITHELIUM:** covers body surface and lines its cavities
2. **MUSCLE:** facilitates movement
3. **CONNECTIVE TISSUE:** supports, protects, connects tissues together
4. **NEURAL TISSUE:** facilitates internal communication
   → usually all 4 make up organs, e.g. kidney and heart

- organs made up of tissues that cooperate together to work as a whole

***HISTOLOGY:*** study of tissues and their cellular organization




## EPITHELIAL TISSUE

- sheets of cells that covers body surface or lines body cavity (creates boundaries)

### 2 MAIN TYPES (BY LOCATION)

1. **COVERING AND LINING EPITHILIA**: on internal and external surfaces
2. **GLANDULAR EPITHELIA****:** secretory tissue in glands

### FUNCTIONS

- **PROTECTION:** skin ↓ rate of fluid loss, creates physical barrier, and provides protection against infectious microorganisms
- **ABSORPTION:** absorbs nutrients in lumen of GI tract
- **FILTRATION:** filters blood so that fluid containing waste products can enter kidney on their way to forming urine
- **EXCRETION:** waste is embedded into urine to be excreted via kidney
- **SECRETION:** glands (e.g. mucus)
- **SENSORY RECEPTION**: taste buds, olfactory membrane, sense of smell

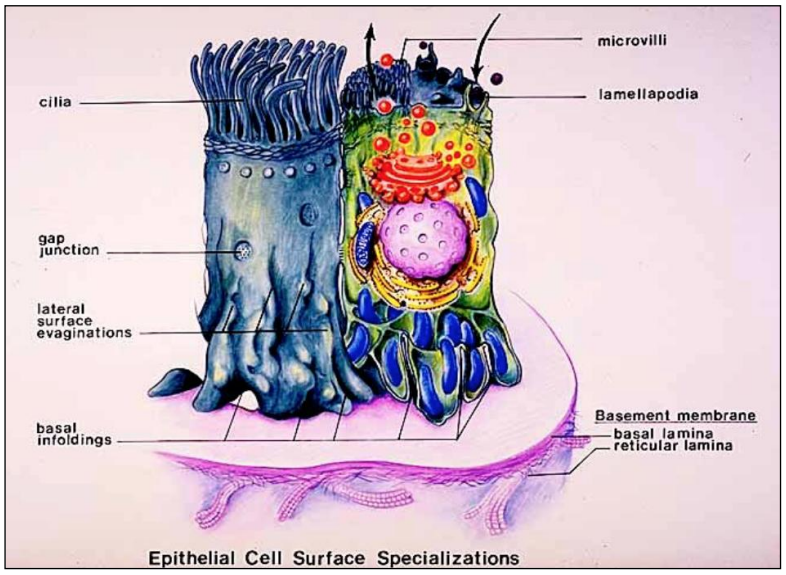
### 5 SPECIAL CHARACTERISTICS OF EPITHELIAL TISSUE

1. **POLARITY**

***APICAL SURFACE:*** upper surface exposed to exterior; free body/cavity of internal organ

***BASAL SURFACE:*** lower surface; bound

- **apical surface** often specialized such as having microvilli or cilia
- **epithelia exhibits apical-basal polarity**
- **basal lamina acts as selective filter** that determines which molecules **diffusing from underlying connective tissue** are allowed to enter the epithelium
  → basal lamina also acts as scaffolding where epithelial cells can migrate to repair wound
  → noncellular basal lamina of glycoprotein and collagen lies adjacent to basal surface



Epithelial Cell Surface Specializations

2. **SPECIALIZED CONTACTS** (COMPOSED OF CLOSELY PACKED CELLS)
   - continuous sheets held together by **tight junctions** and **desmosomes**
     → tight junctions prevent materials from penetrating into cells and getting to deeper tissues
     → desmosomes attach bottom of cell to **basement membrane**
3. **SUPPORTED BY CONNECTIVE TISSUE**
   - **basement membrane** composed of a **basal lamina** (underlying supportive sheet of mainly glycoproteins) sitting on top of a **reticular lamina** (primarily collagen fibres)
   - contains secreted material and collagen to keep fibre in place
   - basement membrane reinforces epithelial sheet, helps it resist stretching and tearing, and defines epithelial boundary

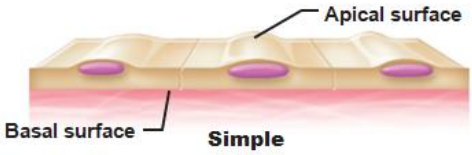
4. **INNERVATED BUT AVASCULAR**

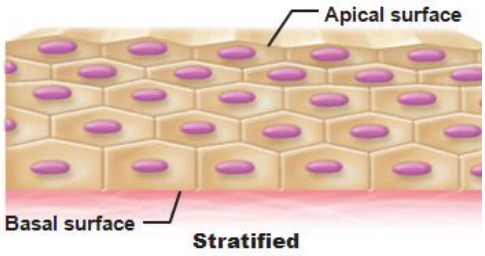
***INNERVATED:*** supplied with nerves

***AVASCULAR:*** lack of blood vessels

- **no blood capillaries** running through epithelial tissues, instead **supplied by nerve fibres**
- epithelial cells **nourished by substances diffusing from blood vessels in underlying connective tissue**

5. **REGENERATION**
   - **high rate of regeneration**
   - if and when **apical-basal polarity and lateral contacts are destroyed** (via friction or hostile substances) = epithelial cells reproduce themselves rapidly
   - as long as epithelial cells receive adequate nutrition, **they can replace lost cells by cell division**




## 2 CLASSIFICATION OF EPILITHIA

### 1. LAYERS

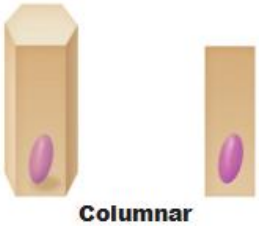
- **SIMPLE EPITHELIUM*** = 1 layer
  → found where absorption, secretion, and filtration occur
- **STRATIFIED EPITHELIUM**** = more than 1 layer
  → common in high abrasion areas where protection is necessary
  → named according to shape of cells in **apical layer**

### 2. CELL SHAPE/TYPE OF CELL

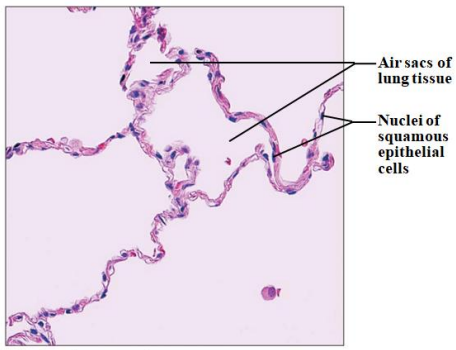
- **SQUAMOUS** : skinny, flattened cell
  → found in places where you do not want a thick barrier; allows for quick transport
- **CUBOIDAL** : boxlike, approximately as tall as they are wide
- **COLUMNAR:** tall and column shaped

### *4 TYPES OF <u>SIMPLE</u> EPITHELIA

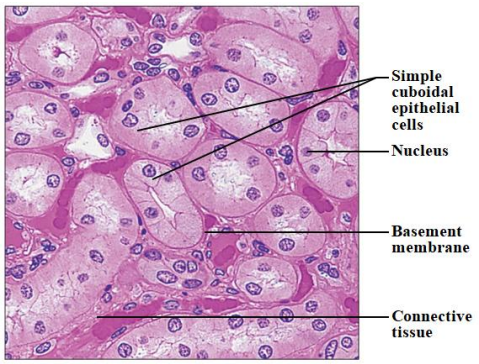




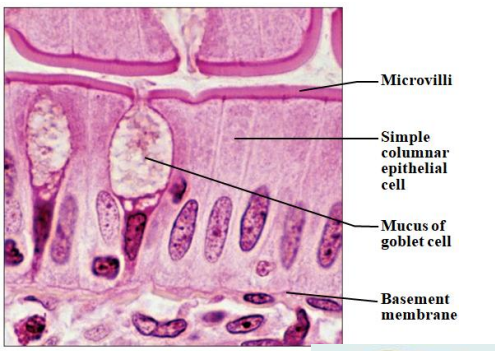

1. **SIMPLE SQUAMOUS EPITHELIA** , ***single layer of flattened (squamous) cells with <u>disc shaped nuclei</u> and sparse cytoplasm; simplest of epithelia***
   - **FUNCTION:** thin and **permeable**; filtration via **rapid diffusion** in sites where protection ≠ important**.** also **secretes lubricating substances** in **serosae** (lining of ventral body cavity)
   - **LOCATION:** kidneys, **lungs**, heart, blood vessels, lymphatic vessels, serosae
2. **SIMPLE CUBOIDAL EPITHELIUM** , ***single layer of cubelike (cuboidal) cells with large, <u>spherical nuclei</u>***
   - **FUNCTION: s**ecretion and absorption (digestion)
   - **LOCATION:** kidney tubules, small glands; **ovary surface**
   - (tougher and more selective than simple squamous, has lots of ion channels)
3. **SIMPLE COLUMNAR EPITHELIUM** , ***single layer of tall (columnar) cells with <u>round to oval nuclei</u>, some have cilia, and layer may contain mucus-secreting unicellular glands (<u>goblet cells</u>)***
   - **FUNCTION:** absorption (digestion), secretion of mucus, ciliated type propels mucus
   - **LOCATION:** non-cilia lines majority of **digestive tract**, gallbladder, ciliated type lines bronchi, uterine tubes, and some regions of uterus
4. **PSEUDOSTRATIFIED COLUMNAR EPITHELIUM** , ***single layer of cells of different heights, nuclei seen at different levels, may contain mucus secreting cells and bear cilia***
   - **FUNCTION:** secretes substances (mostly mucus), propulsion of mucus by ciliary action
   - **LOCATION:** non-cilia type in sperm carrying ducts of large glands, ciliated type lines **trachea**, **most of respiratory tract**



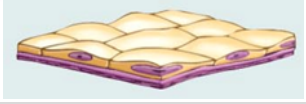
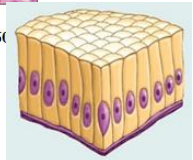

**Photomicrograph:** Simple squamous epithelium forming part of the alveolar (air sac) walls (140x).




**Photomicrograph:** Simple cuboidal epithelium in kidney tubules (430x).

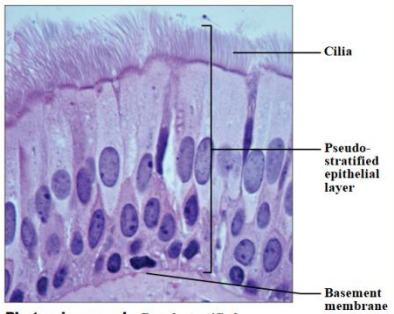



**Photomicrograph:** Simple columnar epithelium of the small intestine mucosa (66(

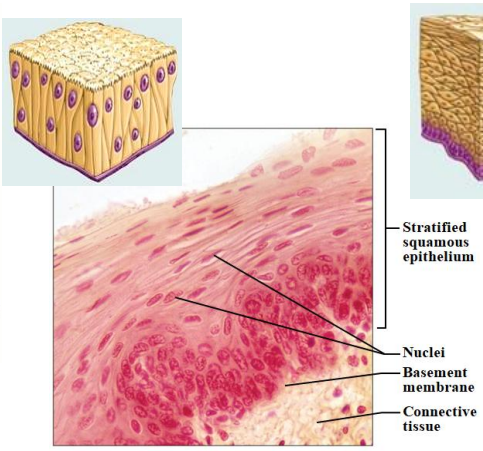
*****2***  ***TYPES OF***  ***<u>STRATIFIED</u>*** 

## *EPITHELIA*

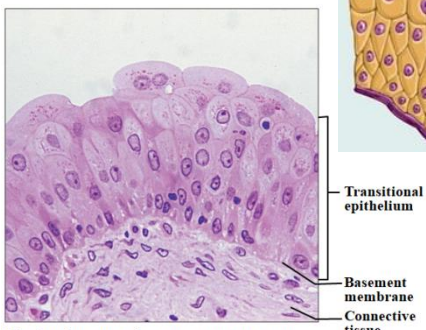
1. **STRATIFIED SQUAMOUS EPITHELIUM** , ***thick membrane composed of several cell layers; basal cells cuboidal or columnar and metabolically active, surface cells squamous (atrophied), basal cells active in mitosis and produce cells of more superficial layers***
   → in keratinized type: surface cells full of keratin and dead
   - **FUNCTION:** protect underlying tissues in areas subjected to **wear and tear** (abrasion)
   - **LOCATION:** non-keratinized type forms moist linings of **esophagus**, **mouth, and vagina**, keratinised type forms epidermis of skin (dry membrane)
2. **TRANSITIONAL EPITHELIUM** , ***resembles both stratified squamous and stratified cuboidal, basal cells cuboidal to columnar, surface cells dome shaped or squamous-like (depending on degree of stretch [distenstion])***
   - **FUNCTION: stretches readily**, permits stored urine to distend urinary organ
   - **LOCATION:** lines ureters, **bladder**, and part of urethra



**Photomicrograph:** Pseudostratified ciliated columnar epithelium lining the human trachea (800x).



**Photomicrograph:** Stratified squamous epithelium lining the esophagus (285x).



**Photomicrograph:** Transitional epithelium lining the bladder, relaxed state (360x); note the bulbous, or rounded, appearance of the cells at the surface; these cells flatten and elongate when the bladder fills with urine.

- **PROTECTIVE ROLE:** basal cells and cuboidal undergo mitosis to keep regenerating the layer from below
- **ENDOTHELIUM:** provides slick, friction-reducing lining in lymphatic vessels and in all hollow organs of cardiovascular system (blood vessels and heart)
- **MESOTHELIUM:** epithelium found in serous membranes, membranes lining ventral body cavity and covering its organs

## GLANDULAR EPITHELIA

***GLAND:*** one or more cells that makes and secretes aqueous fluid (derived from epithelial membrane ?)

- unicellular glands scattered within epithelial sheets
- by contrast, most multicellular epithelial glands form by **invagination** (inward growth) of epithelial sheet into underlying connective tissue
- at least initially, most have *ducts*, tubelike connections to the epithelial sheets

**CLASSIDFIED BY:**

- **SITE OF RELEASE:** endocrine vs. exocrine
  1. **ENDOCRINE,** ***releases products <u>outside</u> cell***
     - **ductless**: products are called **hormones**
     - product diffuses to neighbouring cell or travels to its target organ **via bloodstream**
  2. **EXOCRINE,** ***releases products on to <u>body surfaces</u> or in to <u>cavities</u>***
     - more numerous than endocrine glands
     - **secretes products into ducts**
     - e.g. mucous, sweat, oil, and salivary glands
- **RELATIVE NUMBER OF CELLS FORMING GLAND:** unicellular (e.g. goblet cells) vs. multicellular
  1. **UNICELLULAR EXOCRINE GLANDS,** ***found in epithelial linings of intestinal and respiratory tracts***
     - **no ducts** (one cell)
     - important ones are **goblet (digestive)** and **mucous (respiratory) cells**
     - app produce **mucin** → dissolves to form **mucus**
       → slimy protective, lubricating coat
     - **MODE OF SECRETION:** exocytosis
  2. **MULTICELLULAR EXOCRINE GLANDS,** ***composed of duct and secretory unit***
     - usually surrounded by supportive connective tissue

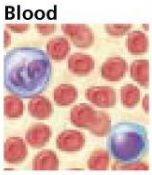
     **MODES OF SECRETION:**
     - **MEROCRINE:** secretion via **exocytosis**, e.g. pancreas, sweat, and salivary glands
     - **HOLOCRINE:** secretion via **rupture of gland cells**, i.e. **sebaceous glands**

**CONNECTIVE TISSUE,** ***supports, protects, connects tissues together; most abundant and widely distributed tissue type,***
**4 CLASSES: <u>CONNECTIVE TISSUE PROPER</u>, <u>CARTILAGE</u>, <u>BONE</u> TISSUE, and <u>BLOOD</u>**

**Table 4.1 Comparison of Classes of Connective Tissues**

| TISSUE CLASS AND EXAMPLE | SUBCLASSES | COMPONENTS: CELLS | COMPONENTS: MATRIX | GENERAL FEATURES |
|---|---|---|---|---|
| **Connective Tissue Proper**  *Dense regular connective tissue* | 1. Loose connective tissue<br>▫ Areolar<br>▫ Adipose<br>▫ Reticular<br>2. Dense connective tissue<br>▫ Regular<br>▫ Irregular<br>▫ Elastic | Fibroblasts<br>Fibrocytes<br>Defense cells<br>Adipocytes | Gel-like ground substance<br>All three fiber types: collagen, reticular, elastic | Six different types; vary in density and types of fibers<br>Functions as a binding tissue<br>Resists mechanical stress, particulary tension<br>Provides reservoir for water and salts<br>Nutrient (fat) storage |
| **Cartilage**  *Hyaline cartilage* | 1. Hyaline cartilage<br>2. Elastic cartilage<br>3. Fibrocartilage | Chondroblasts found in growing cartilage<br>Chondrocytes | Gel-like ground substance<br>Fibers: collagen, elastic fibers in some | Resists compression because of the large amounts of water held in the matrix<br>Functions to cushion and support body structures |

**Table 4.1 Comparison of Classes of Connective Tissues** *(continued)*

| TISSUE CLASS AND EXAMPLE | SUBCLASSES | COMPONENTS: CELLS | COMPONENTS: MATRIX | GENERAL FEATURES |
|---|---|---|---|---|
| **Bone Tissue**  *Compact bone* | 1. Compact bone<br>2. Spongy bone | Osteoblasts<br>Osteocytes | Gel-like ground substance calcified with inorganic salts<br>Fibers: collagen | Hard tissue that resists both compression and tension<br>Functions in support |
| **Blood**  | See Chapter 17 for details on blood cell formation and differentiation. | Erythrocytes (RBC)<br>Leukocytes (WBC)<br>Platelets | Plasma<br>No fibers | A fluid tissue<br>Functions to carry $O_2$, $CO_2$, nutrients, wastes, and other substances (hormones, for example) |

## MAJOR FUNCTIONS OF CONNECTIVE TISSUE

- binding and support, e.g. cartilage
- protection, e.g. bony tissue protecting brain
- insulation, e.g. adipose tissues
- transportation, e.g. **blood transport**

## CHARACTERISTICS OF CONNECTIVE TISSUE

- tissue of origing: **mesenchyme** (embryonic tissue)
- varying degrees of **vascularity**, e.g. cartilage = avascular, dense connective tissue = poorly vascularized, and other types of connective tissue have rich supply of blood vessels
  - → cells separate by nonliving **extracellular matrix** **(ground substance and fibres)** = (often wide) separation of living cells of tissue
  - → connective tissue can bear weight, withstand great tension, and endure abuse
- (fat cells, white blood cells, mast cells and macrophages are all found in connective tissue)

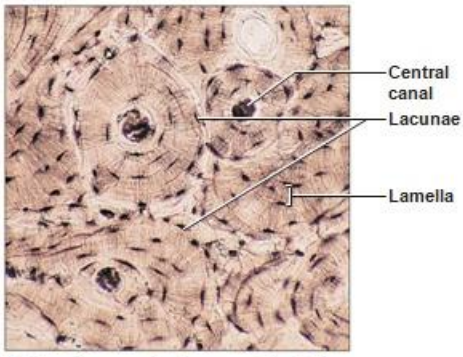
## STRUCTURAL ELEMENTS OF CONNECTIVE TISSUE

1. **CELLS:** mitotically active (dividing/synthesizing cells during growth and repair [secretes ground substances]) and secretory (immature) cells = "blasts" vs. mature cells = "cytes" e.g. fibroblasts (CTP), chrodoblasts and chrondcytes (cartilage), osetoblasts and osteocytes (bone), hematopoietic cells (bone marrow)
2. **EXTRACELLULAR MATRIX:**
   a) **GROUND SUBSTANCE:** medium which solutes diffuse between blood capillaries and cells
   **COMPONENTS:** interstital fluid, **adhesion proteins "glue"**," **proteoglycans**
   → **CELL ADHESION PROTEINS:** allow connective tissue cells to attach to matrix elements
   → **PROTEOGLYCANS:** protein core + large polysaccharides [chrondroiting sulfate and hyaluronic acid], traps water in varying amounts = affects viscosity of ground substance
   → (fibres embedded in ground substance make it less pliable and somewhat hinders diffusion)
   b) **3 TYPES OF FIBRES**
      1. **COLLAGEN:** strongest and most abundant type, high tensile strength
      2. **ELASTIC:** network of long, thin, elastin is protein that has coiled structure = allows (limited) stretching and recoiling
      3. **RETICULAR:** short, fine, highly branched collagen protein; fine network to support blood vessels, supports soft tissues of organs

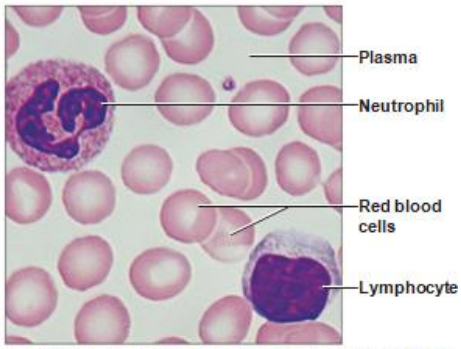
| TISSUE TYPE | "BLAST" | "CYTE" |
|---|---|---|
| CT proper | fibroblast | fibrocyte |
| Cartilage | chondroblast | chondrocyte |
| Bone | osteoblast | osteocyte |
| Blood | hemocytoblast | RBCs, WBCs, platelets |

## CONNECTIVE TISSUE: BONE TISSUE (OSSEUS), *hard calcified matrix containing many collagen fibres, lie in lacunae, very well vascularized (seen by central canal)*

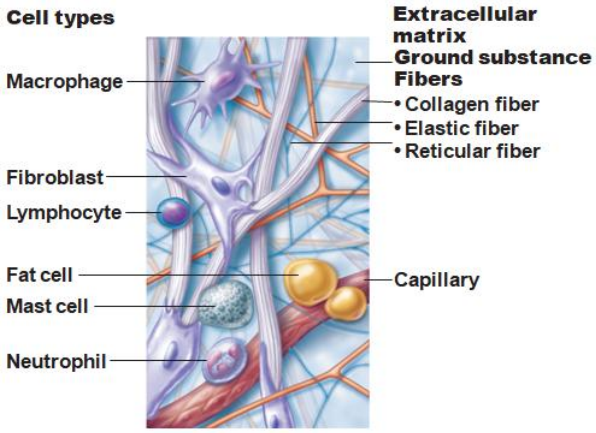
- **FUNCTION:** bone supports and protects, provide **levers** for muscles, stores calcium and other minerals, marrow inside bone = site for blood cell formation (**haematopoiesis**)
- **LOCATION:** bones



**Photomicrograph:** Cross-sectional view of bone (125x).



**Photomicrograph:** Smear of human blood (1860x); two white blood cells (neutrophil in upper left and lymphocyte in lower right) are seen surrounded by red blood cells.



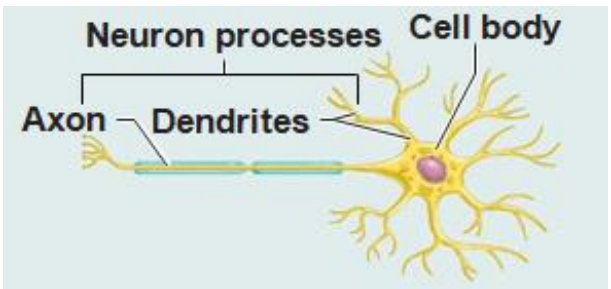

## CONNECTIVE TISSUE: BLOOD, *red and white blood cells in fluid matrix*

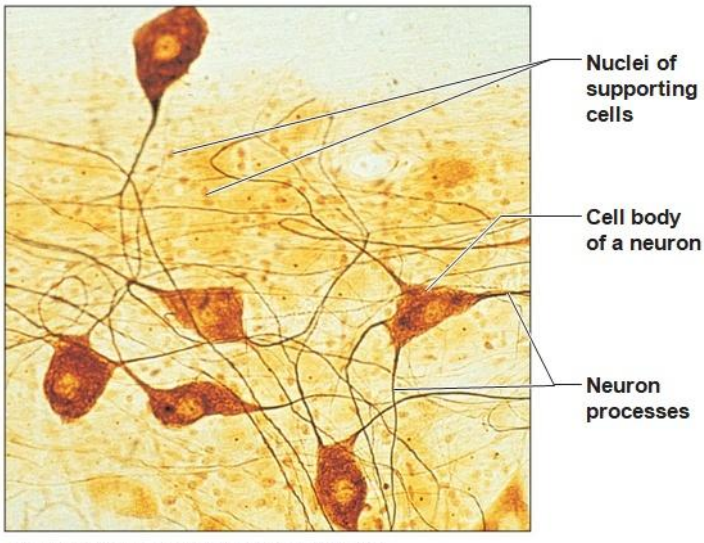
- **FUNCTION:** transport of respiratory gases, nutrients, **waste**, and other substances
- **LOCATION:** contained **within blood vessels**

## NERVOUS TISSUE

- **FUNCTION:** regulates and controls body function
- **LOCATION:** brain, spinal cord, nerves

***NEURONS:*** specialised nerve cells that generate and conduct nerve impulses
***NEUROGLIA:*** supporting cells that support, insulate, and protect neurons



**Photomicrograph:** Neurons (350x)

## MUSCLE TISSUE: SKELETAL MUSCLE, *long cylindrical <u>multi</u>nucleate cells, <u>striated</u>*

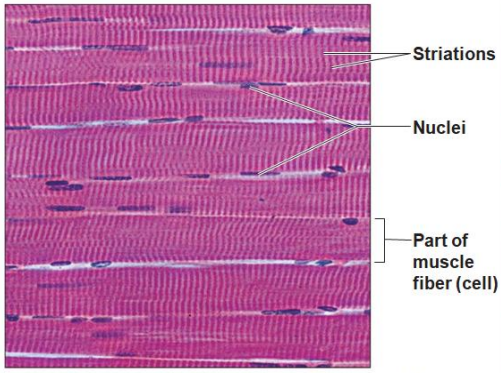
- **FUNCTION: voluntary movement**, manipulation of environment, facial expression, voluntary control
- **LOCATION:** in **skeletal muscles** attached to bones or occasionally to skin

## MUSCLE TISSUE: CARDIAC MUSCLE, *branching, <u>uni</u>nucleate cells, <u>striated</u>, <u>intercalated discs</u> (gap junctions between muscle cells)*

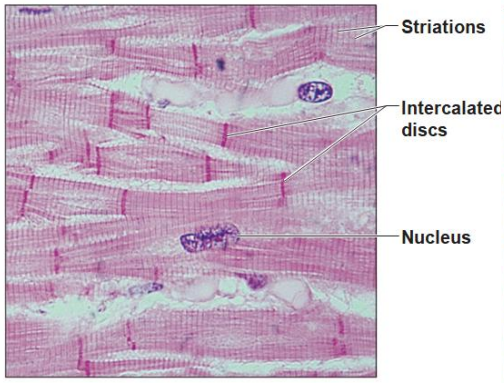
- **FUNCTION: involuntary movement**, propels blood to circulation
- **LOCATION:** walls of **heart**

## MUSCLE TISSUE: SMOOTH MUSCLE, *spindle shaped cells with central <u>uni</u>nucleate nuclei, <u>not striated</u>, cells arranged closely to form sheets*

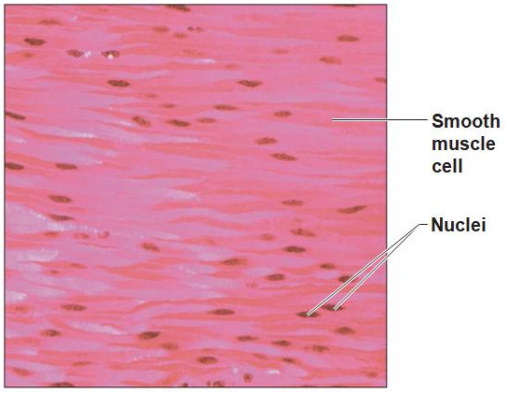
- **FUNCTION:** propels substances of objects (e.g. food, urine, baby) along internal passage, **involuntary control**
- **LOCATION:** walls of **hollow organs**




**Photomicrograph:** Skeletal muscle (approx. 460x). Notice the obvious banding pattern and the fact that these large cells are multinucleate.




**Photomicrograph:** Cardiac muscle (500X); notice the striations, branching of cells, and the intercalated discs.




**Photomicrograph:** Sheet of smooth muscle (200x).

## EPITHELIAL MEMBRANES

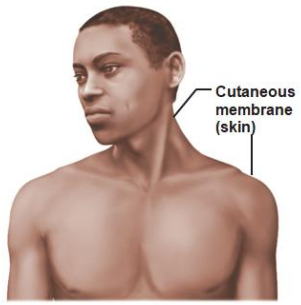
- **CUTANEOUS MEMBRANE** (skin): receptors
- **MUCOUS MEMBRANES: mucosae lines body cavities open to exterior**, e.g. digestive and respiratory tracts
- **SEROUS MEMBRANES:** lines body cavity **closed to exterior**
  - → **SEROSAE:** membrane (mesothelium + aerolar tissue) in closed ventral body cavity
  - → **PARIETAL SEROSAE:** lines internal body walls, parietel pleura attached to chest cavity wall
  - → **VISCERAL SEROSAE:** covers internal organs, visceral pleura attached to chest cavity wall

## TISSUE REPAIR

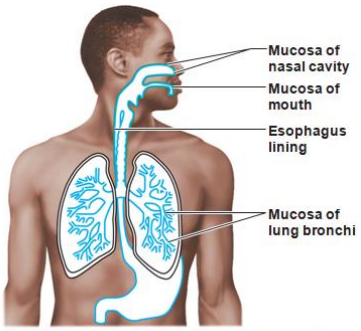
- inflammation → organization and restored blood supply → regeneration and fibrosis

### 1. INFLAMMATION: CRITICAL STEP

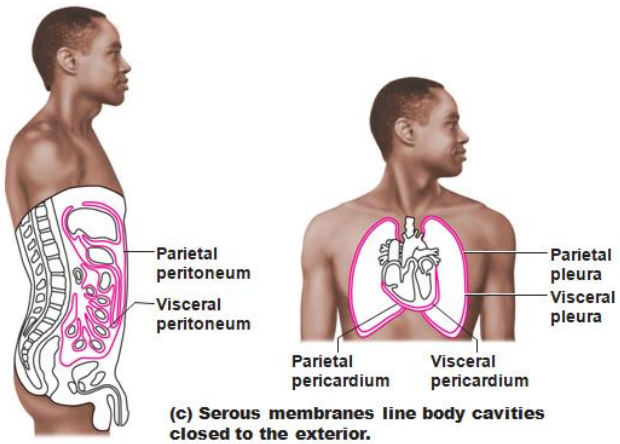
- severed blood vessel
  - → release of **inflammatory chemicals**
  - → local blood vessels become more permeable = easy access for WBCs, fluid, clotting proteins, and other plasma proteins to seep into injured area
  - → clotting occurs; surface dries and forms scab



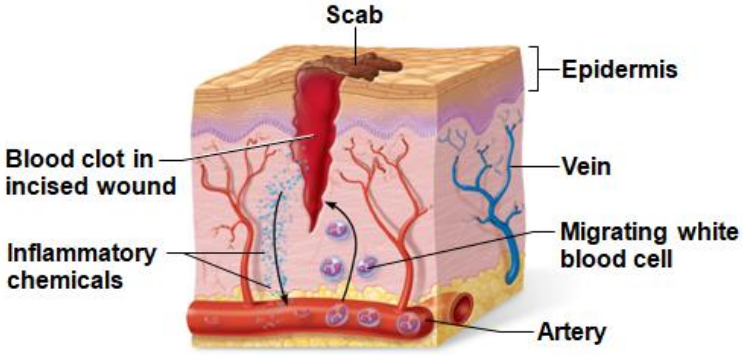

(a) Cutaneous membrane (the skin) covers the body surface.




(b) Mucous membranes line body cavities open to the exterior.




(c) Serous membranes line body cavities closed to the exterior.

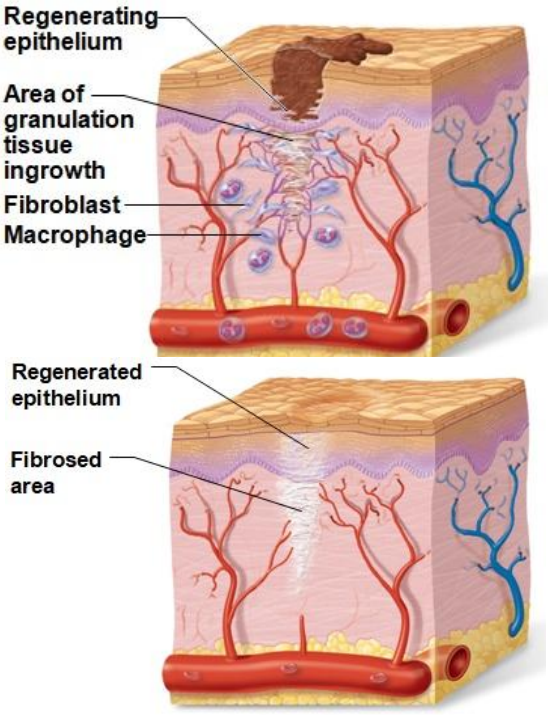


## 2. ORGANIZATION: RESTORES BLOOD SUPPLY

- clot replaced by **granulation tissue** = restores vascular supply
  - → **fibroblasts** produce collagen fibres that bridge gap
  - → **macrophages** phagocytize debris
  - → surface epithelial cells multiply and migrate over **granulation tissue**

## 3. REGENRATION: FIBROSIS EFFECT

- fibrosed area matures and contracts
  - → **epithelial thickens**
  - → fully generated epithelium with underlying area of scar tissue results
    - → Scar occurs if skin not brought together (e.g. stitches)



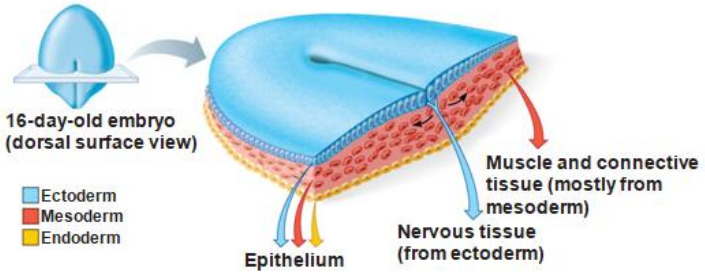

# TISSUES: DEVELOPMENTAL ASPECTS

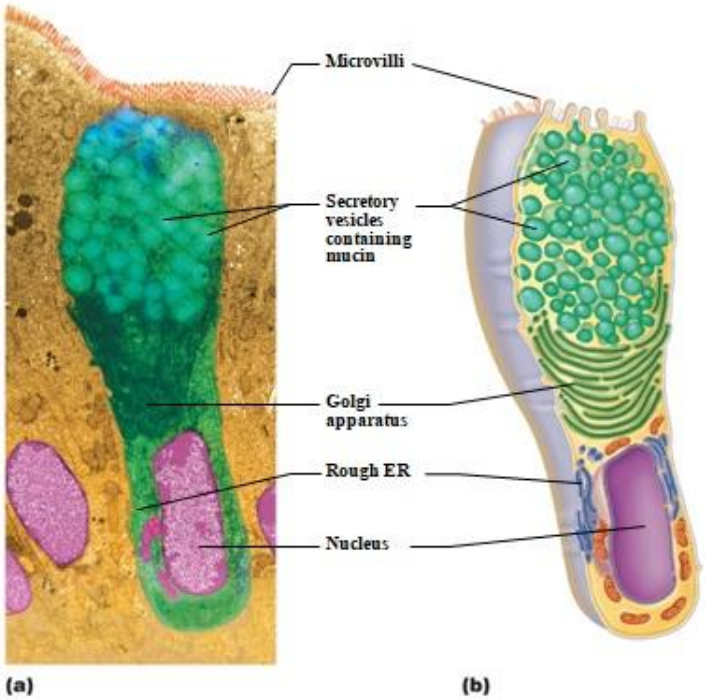
**PRIMARY GERM LAYERS**: ectoderm, mesoderm, and endoderm

- formed early in embryonic development
- specialize to form the four primary tissues
  - → nerve tissue arises from ectoderm
  - → muscle and connective tissues arise from mesoderm
  - → epithelial tissues arise from all three germ layers

# AGING TISSUES

- functions well through youth and middle age if adequate diet, circulation, and infrequent wounds and infections
- ↑ age = ↓ epithelia thickness
  - → tissue repair less efficient
  - → bone, muscle and nervous tissues begin to atrophy
  - → DNA mutations possible → increased cancer risk
  - → e.g. osteoporosis (atrophy) or demntia (nervous tissue waste)




### CHAPTER 1 ANSWERS

**Review Questions** 1. c; 2. a; 3. e; 4. a, d; 5. (a) wrist, (b) hip bone, (c) nose, (d) toes, (e) scalp; 6. c and d would not be visible in the median section; 7. (a) dorsal, (b) ventral, (c) dorsal, (d) ventral; 8. b; 9. b; 10. c

### CHAPTER 2 ANSWERS

**Review Questions** 1. d; 2. d; 3. b; 4. a; 5. b; 6. a; 7. a; 8. b; 9. d; 10. a; 11. b; 12. a, c; 13. (1)a, (2)c; 14. c; 15. d; 16. e; 17. d; 18. d; 19. a; 20. b; 21. b; 22. c

### CHAPTER 3 ANSWERS

**Review Questions** 1. d; 2. a, c; 3. b; 4. b; 5. e; 6. c; 7. d; 8. a; 9. d; 10. a; 11. b; 12. d; 13. c; 14. b; 15. d; 16. a; 17. b; 18. d; 19. c

### CHAPTER 4 AND CHAPTER 5 ANSWERS

**Review Questions** 1. (1)a, (2)c, (3)d, (4)b; 2. c, e; 3. (1)b, (2)f, (3)a, (4)d, (5)g, (6)d; 4. b; 5. c; 6. b

**Review Questions** 1. a; 2. c; 3. d; 4. d; 5. b; 6. b; 7. c; 8. c; 9. b; 10. a; 11. d; 12. b