Cell Physiology

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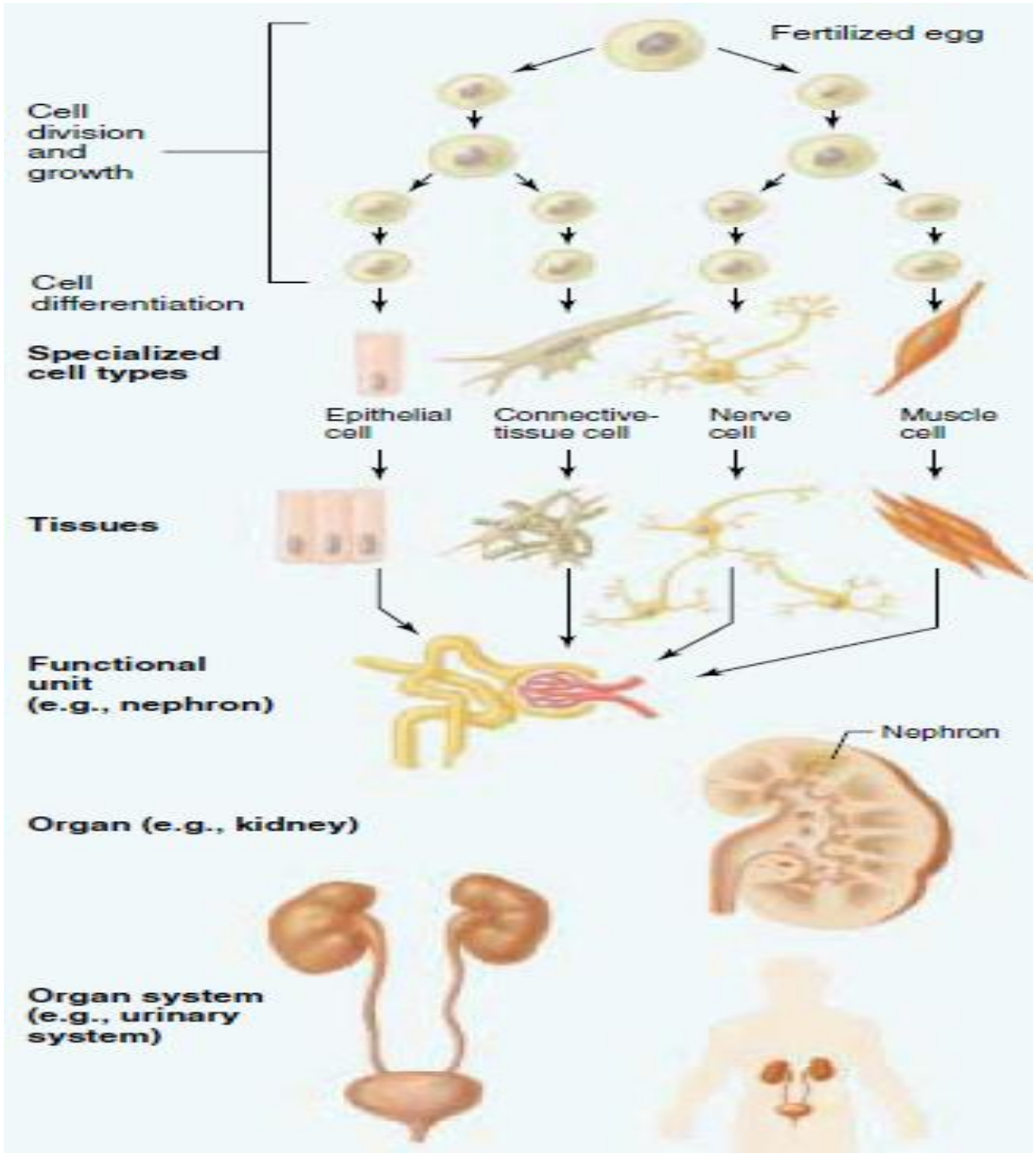
MBBS; PhD

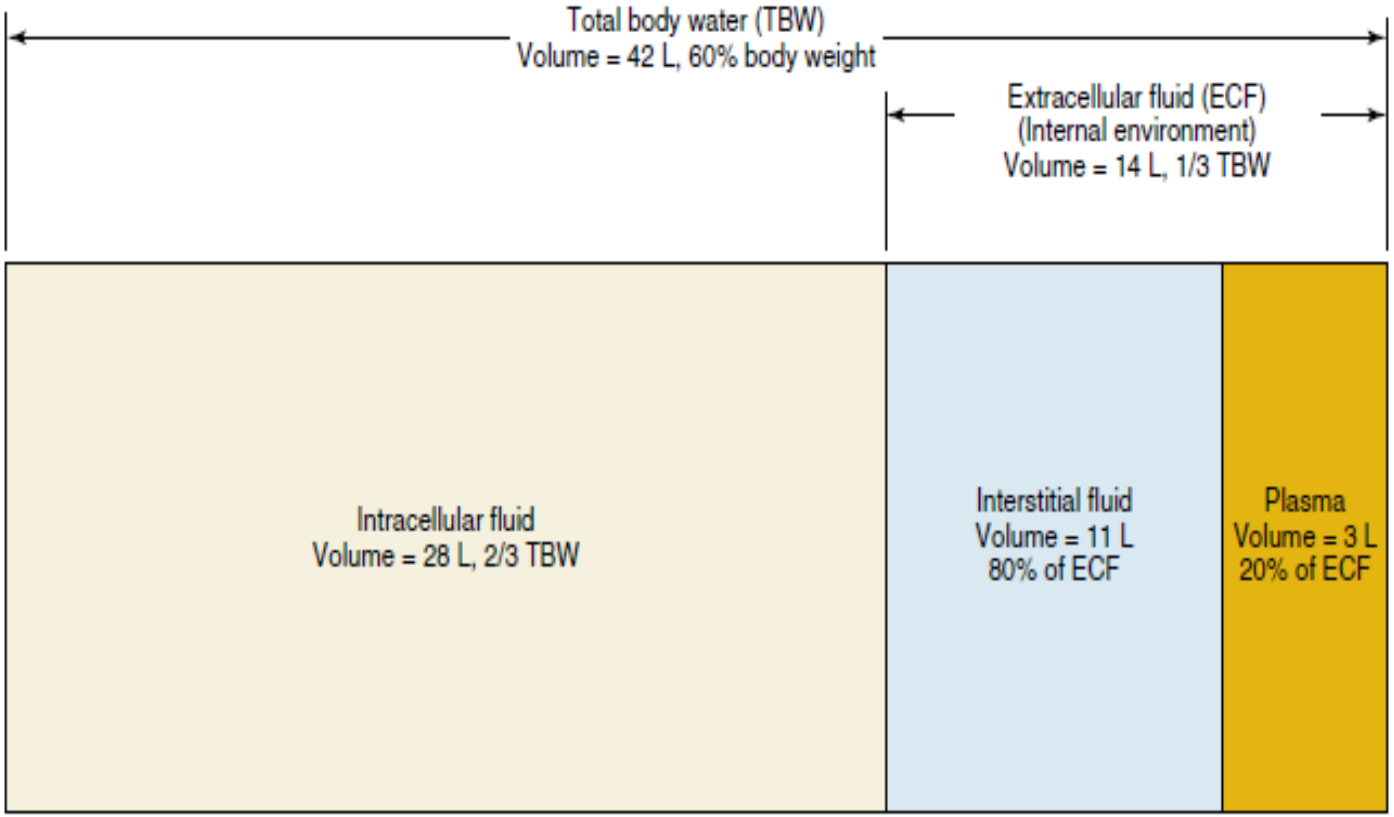
Levels of Organization

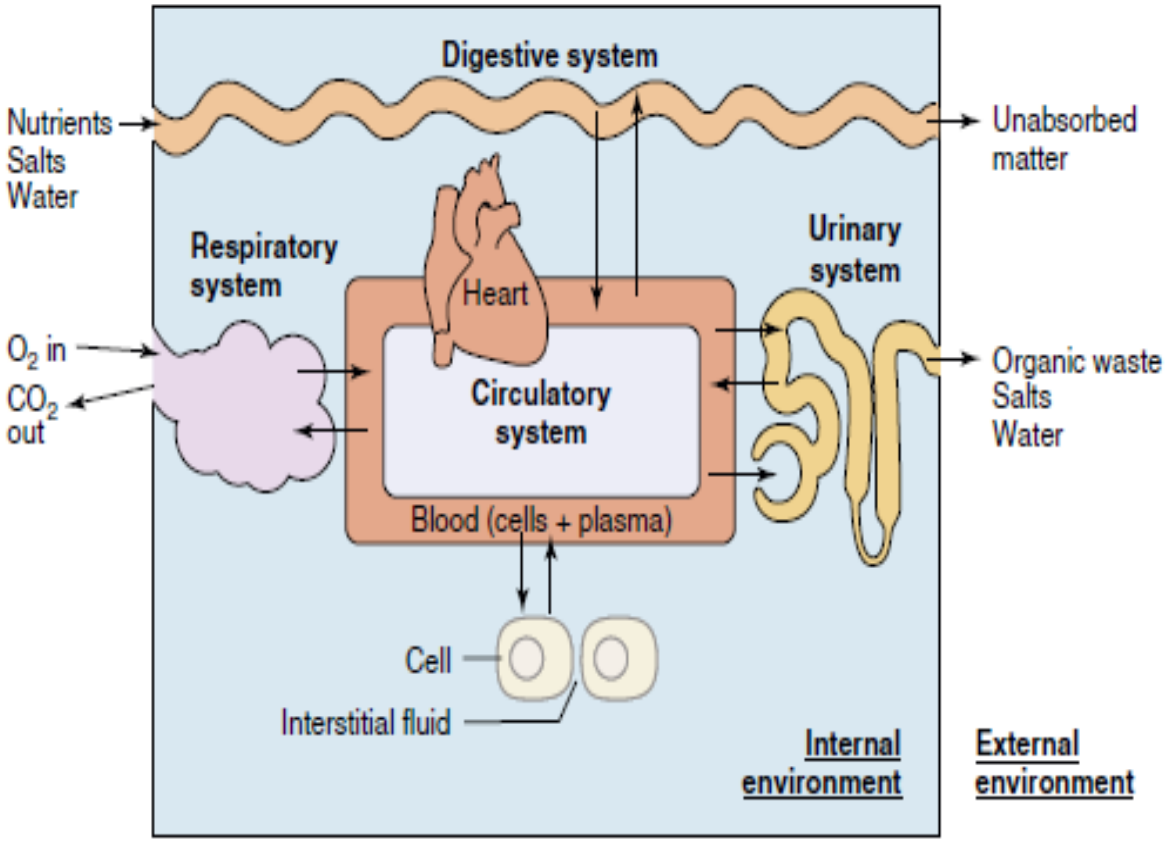


Organ systems of the body

System	Major Organs or Tissues	Primary Functions
Circulatory	Heart, blood vessels, blood (Some classifications also include lymphatic vessels and lymph in this system.)	Transport of blood throughout the body's tissues
Respiratory	Nose, pharynx, larynx, trachea, bronchi, lungs	Exchange of carbon dioxide and oxygen; regulation of hydrogen-ion concentration
Digestive	Mouth, pharynx, esophagus, stomach, intestines, salivary glands, pancreas, liver, gallbladder	Digestion and absorption of organic nutrients, salts, and water
Urinary	Kidneys, ureters, bladder, urethra	Regulation of plasma composition through controlled excretion of salts, water, and organic wastes
Musculoskeletal	Cartilage, bone, ligaments, tendons, joints, skeletal muscle	Support, protection, and movement of the body; production of blood cells
Immune	White blood cells, lymph vessels and nodes, spleen, thymus, and other lymphoid tissues	Defense against foreign invaders; return of extracellular fluid to blood; formation of white blood cells
Nervous	Brain, spinal cord, peripheral nerves and ganglia, special sense organs	Regulation and coordination of many activities in the body; detection of changes in the internal and external environments; states of consciousness; learning; cognition
Endocrine	All glands secreting hormones: Pancreas, testes, ovaries, hypothalamus, kidneys, pituitary, thyroid, parathyroid, adrenal, intestinal, thymus, heart, and pineal, and endocrine cells in other locations	Regulation and coordination of many activities in the body
Reproductive	Male: Testes, penis, and associated ducts and glands Female: Ovaries, uterine tubes, uterus, vagina, mammary glands	Production of sperm; transfer of sperm to female Production of eggs; provision of a nutritive environment for the developing embryo and fetus; nutrition of the infant
Integumentary	Skin	Protection against injury and dehydration; defense against foreign invaders; regulation of temperature

Concept of Homeostasis

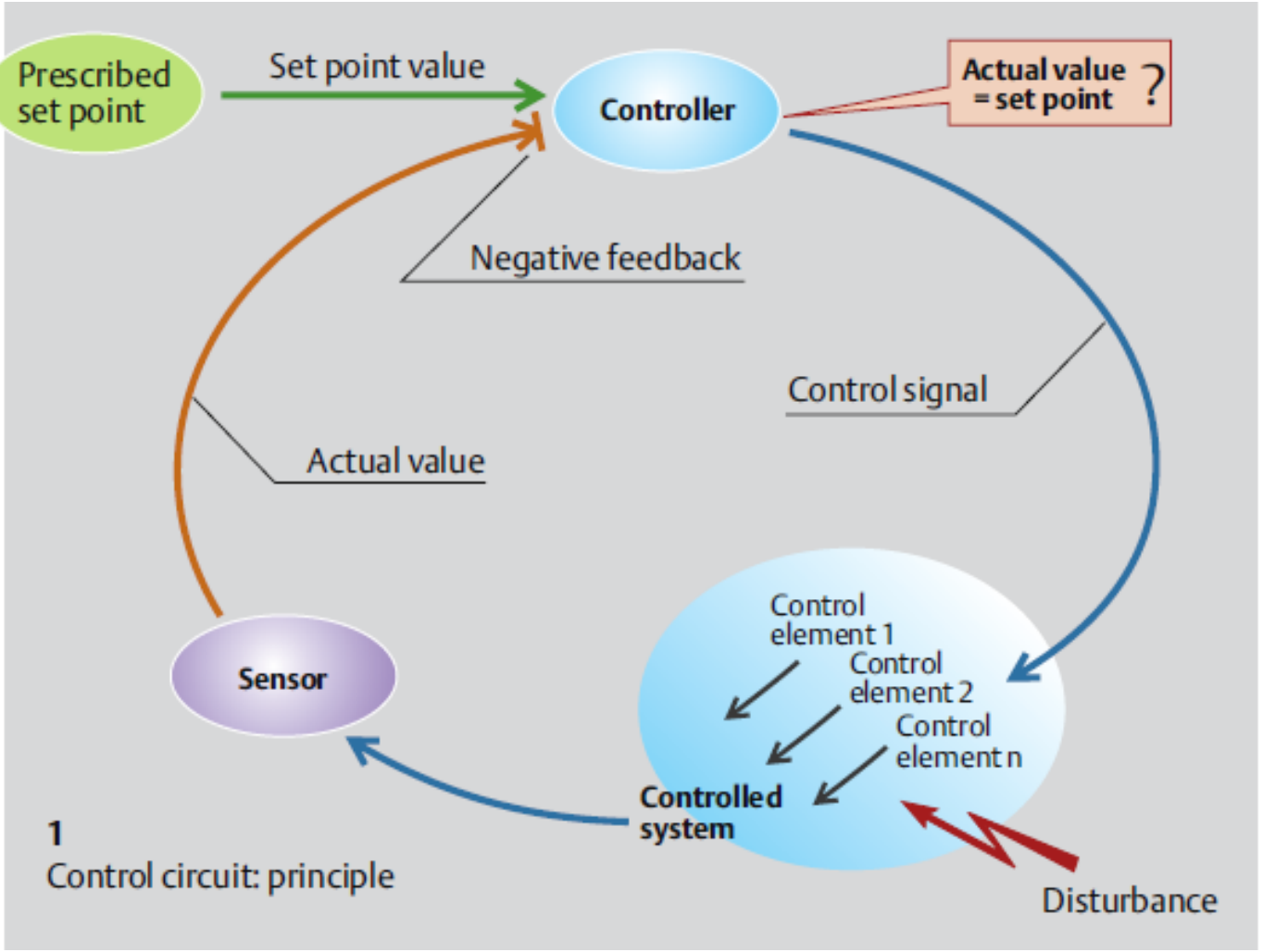



Digestive system
Nutrients
Salts
Water
Unabsorbed
matter
Respiratory
system
Heart
Urinary
system
O_2 in
CO_2
out
Circulatory
system
Organic waste
Salts
Water
Blood (cells + plasma)
Cell
Interstitial fluid
Internal
environment
External
environment

Homeostatic control systems

- Homeostatic control systems may operate locally or bodywide
- Negative feedback opposes initial change and is widely used to maintain homeostasis
- Positive feedback amplifies an initial change
- Feedforward mechanisms initiate responses in anticipation of a change
- Disturbance in homeostasis can lead to illness and death

Negative Feedback

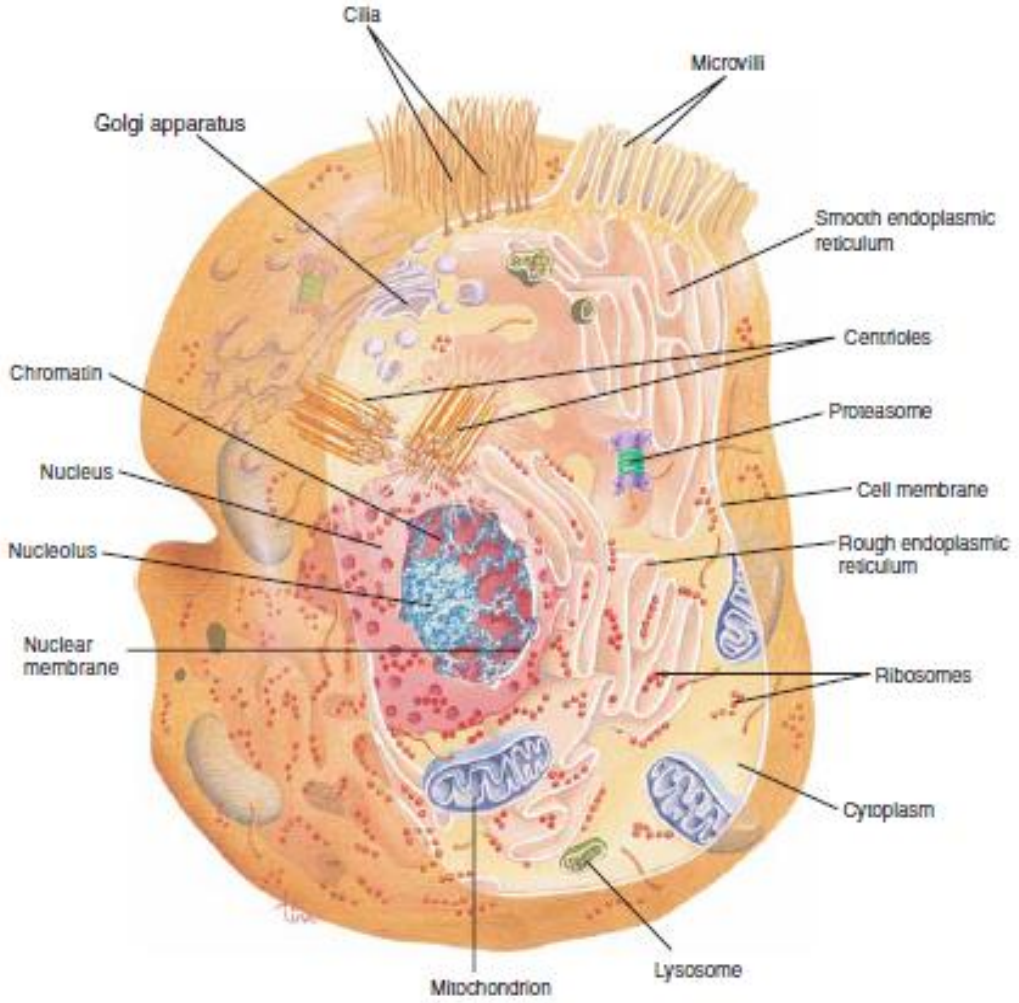


1
Control circuit: principle

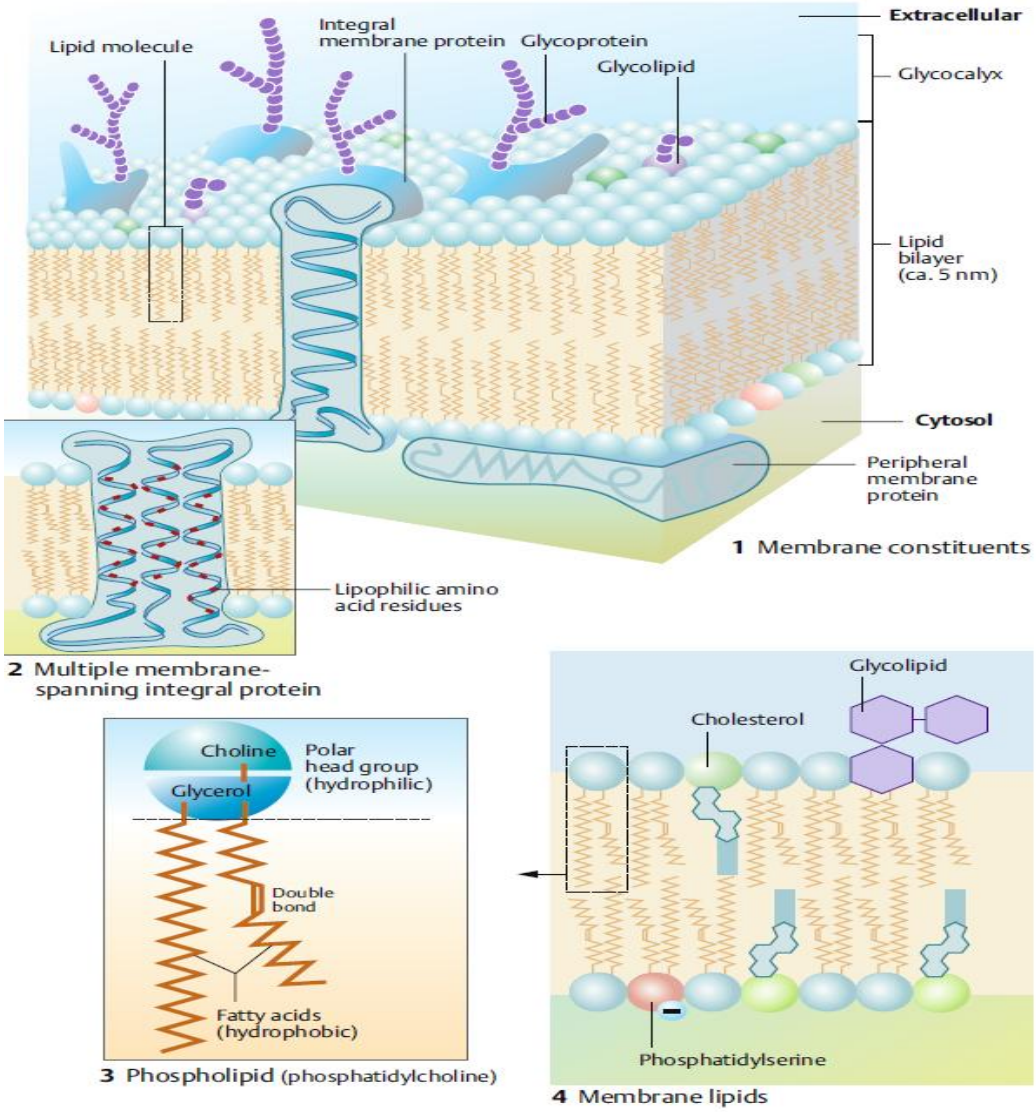
An overview of Cell structure

- Plasma membrane bounds the cell
- The nucleus contains the DNA
- The cytoplasm consists of various organelles, the cytoskeleton and cytosol

Cell

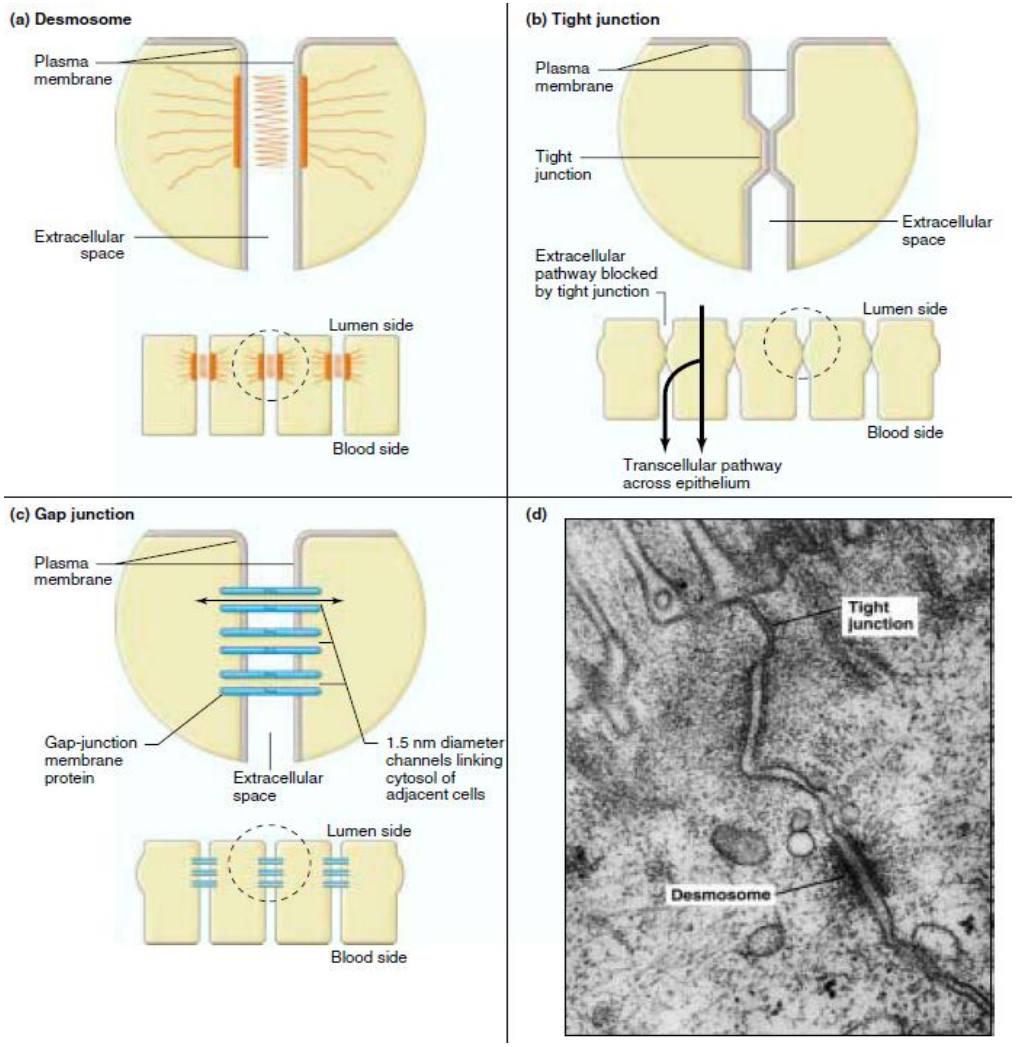

Cilia
Microvilli
Golgi apparatus
Smooth endoplasmic reticulum
Centrioles
Chromatin
Proteasome
Nucleus
Cell membrane
Nucleolus
Rough endoplasmic reticulum
Nuclear membrane
Ribosomes
Cytoplasm
Lysosome
Mitochondrion

Cell Membrane



- The lipid bilayer forms the basic structural barrier that encloses the cells
- The membrane proteins perform various specific membrane functions
- The membrane carbohydrates serve as self-identity markers

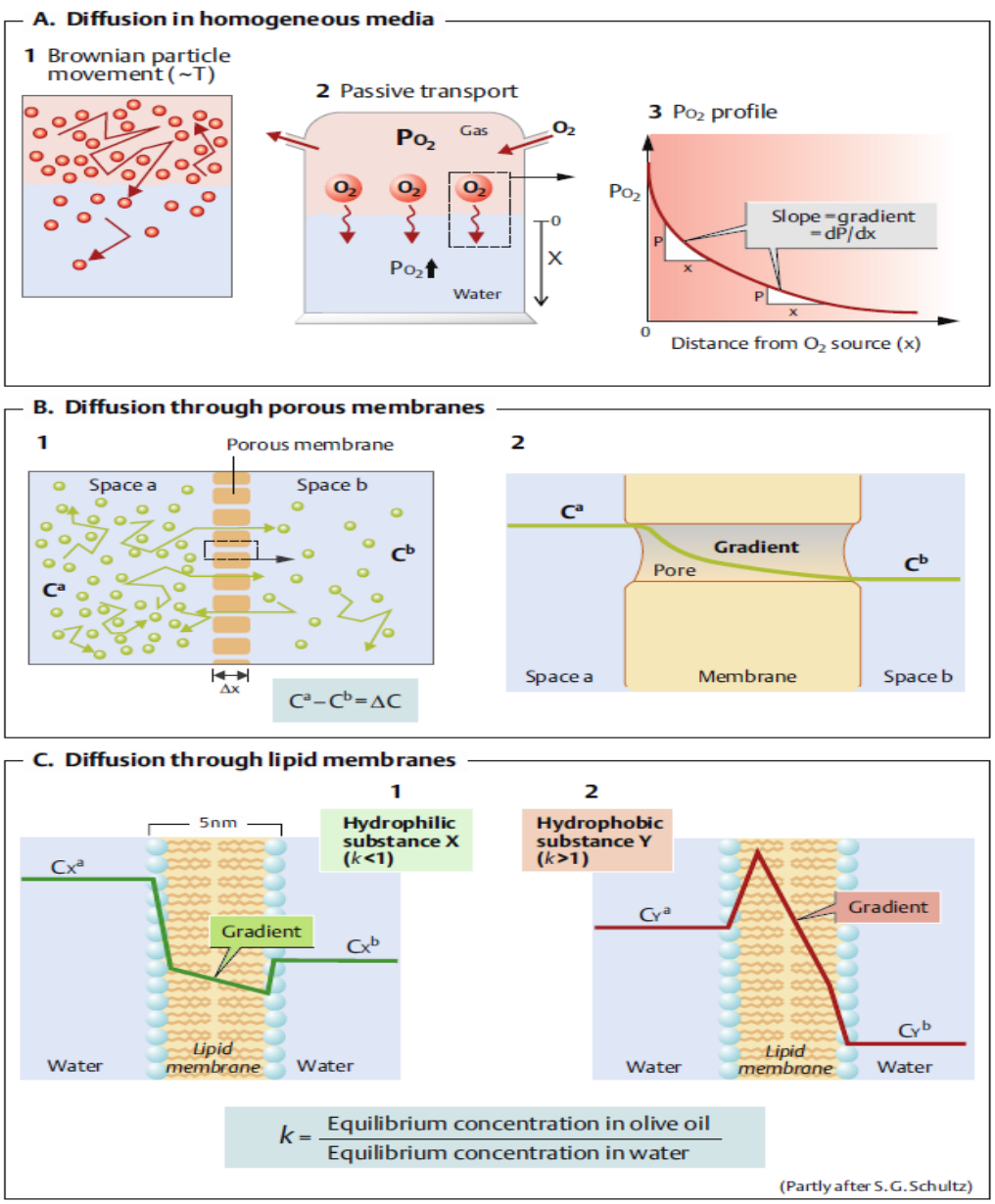
Cell-to-Cell adhesions



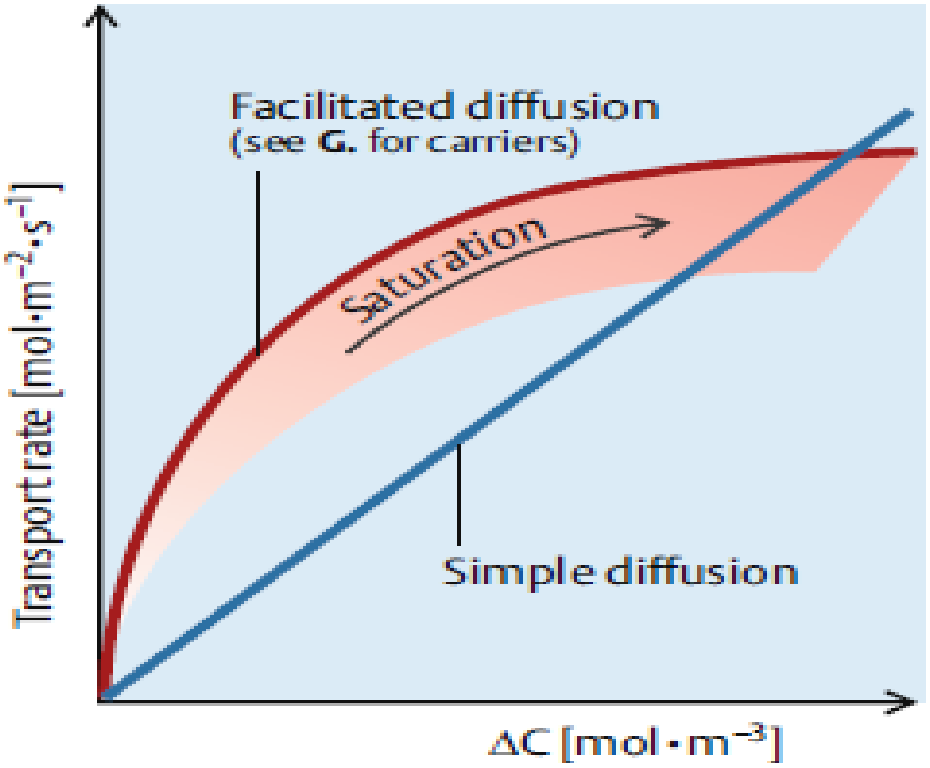
Cellular transport mechanisms

Mechanism	Definition	Example in the Body
Diffusion	Movement of molecules from an area of greater concentration to an area of lesser concentration.	Exchange of gases in the lungs or body tissues.
Osmosis	The diffusion of water.	Absorption of water by the small intestine or kidneys.
Facilitated diffusion	Carrier and transporter enzymes move molecules across cell membranes.	Intake of glucose by most cells.
Active transport	Movement of molecules from an area of lesser concentration to an area of greater concentration (requires ATP).	Absorption of amino acids and glucose from food by the cells of the small intestine. Sodium and potassium pumps in muscle and nerve cells.
Filtration	Movement of water and dissolved substances from an area of higher pressure to an area of lower pressure (blood pressure).	Formation of tissue fluid; the first step in the formation of urine.
Phagocytosis	A moving cell engulfs something.	White blood cells engulf bacteria.
Pinocytosis	A stationary cell engulfs something.	Cells of the kidney tubules reabsorb small proteins.

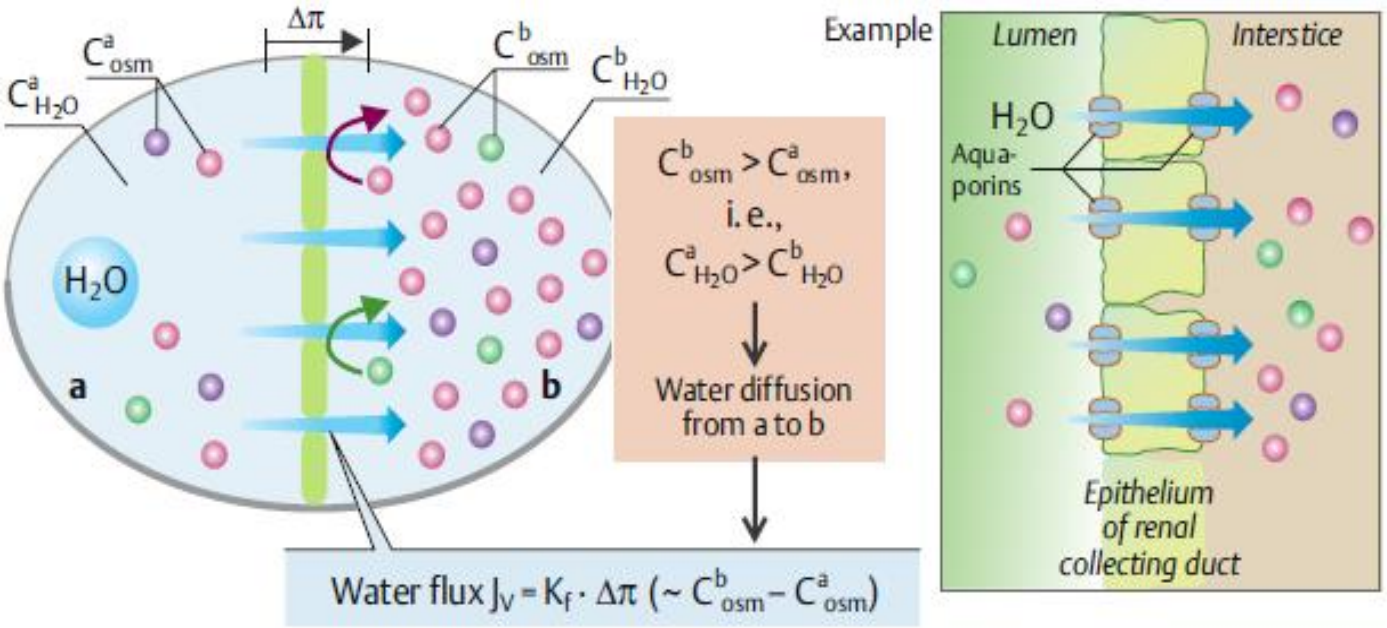
Membrane Transport

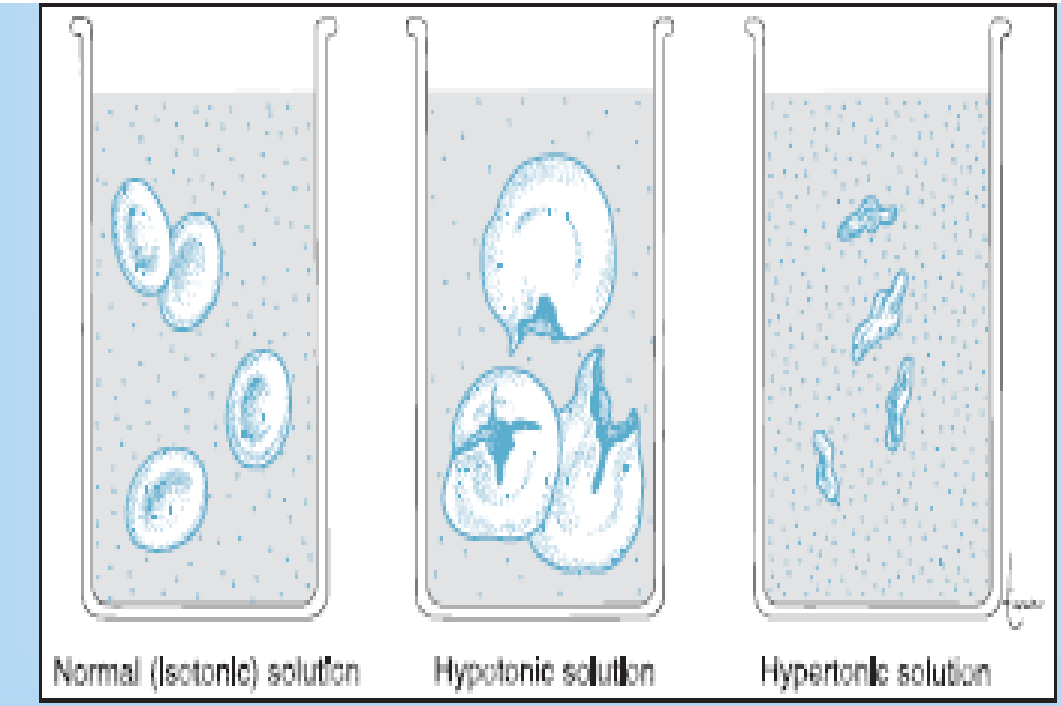


Diffusion

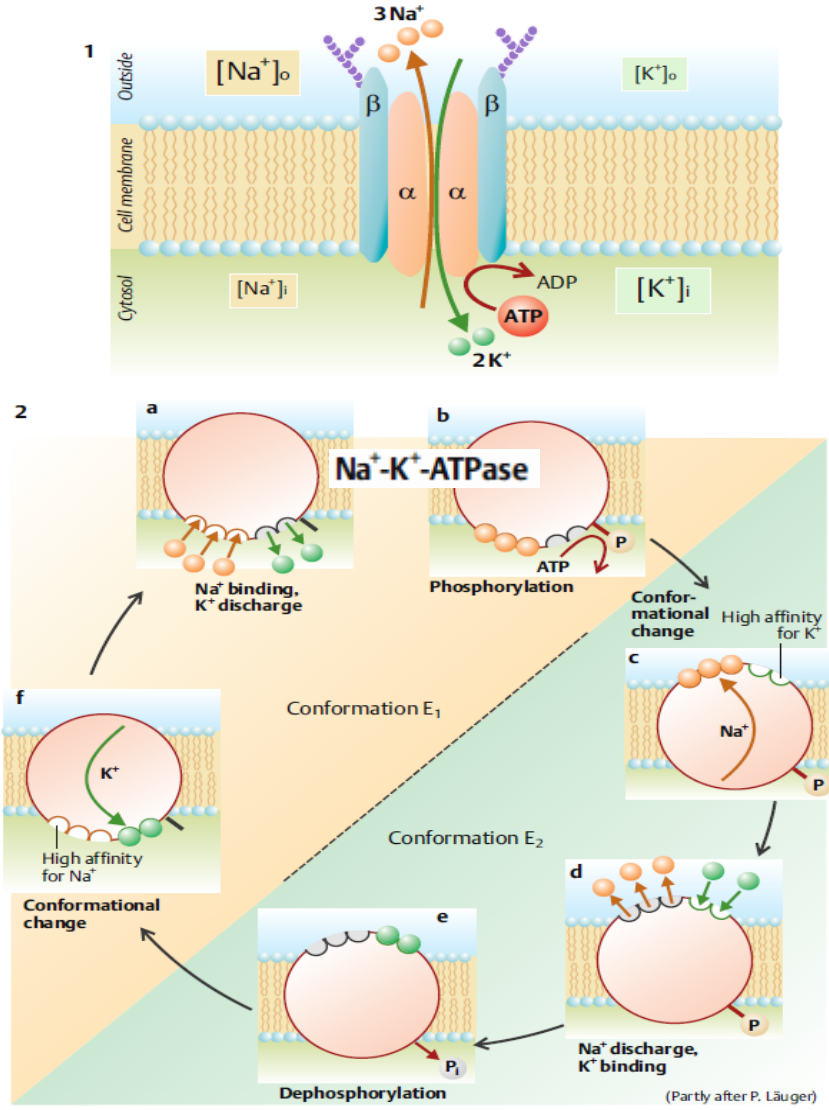

Facilitated diffusion
(see G. for carriers)
Saturation
Simple diffusion
Transport rate [mol·m⁻²·s⁻¹]
ΔC [mol·m⁻³]

Osmosis

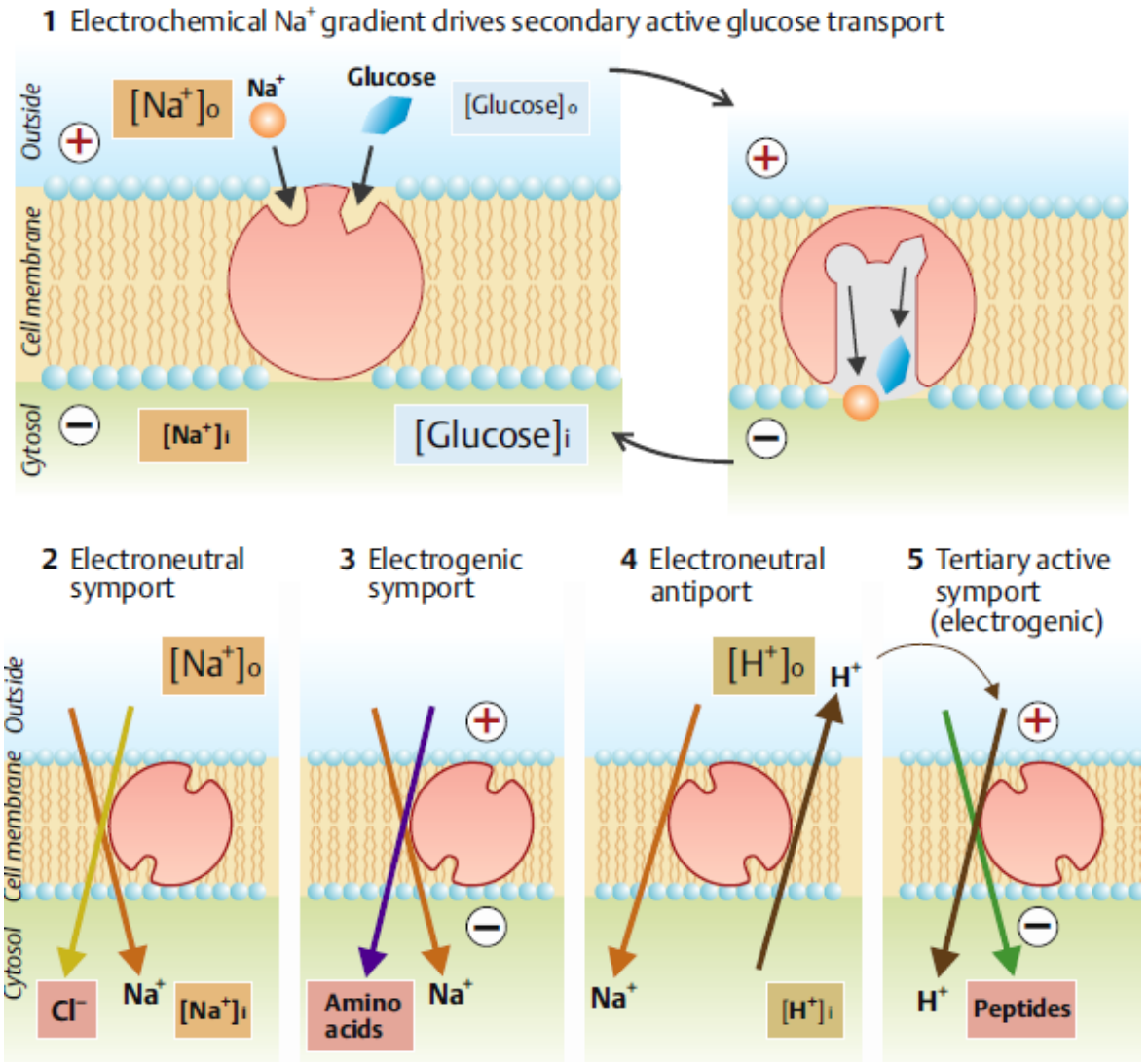

Δπ
C^a_{osm}
C^b_{osm}
$C^a_{H_2O}$
$C^b_{H_2O}$
H_2O
a
b
$C^b_{osm} > C^a_{osm}$,
i.e.,
$C^a_{H_2O} > C^b_{H_2O}$
Water diffusion from a to b
Water flux $J_V = K_f \cdot \Delta\pi$ ($\sim C^b_{osm} - C^a_{osm}$)
Example
Lumen
Interstice
H_2O
Aqua-porins
Epithelium of renal collecting duct


Normal (isotonic) solution
Hypotonic solution
Hypertonic solution

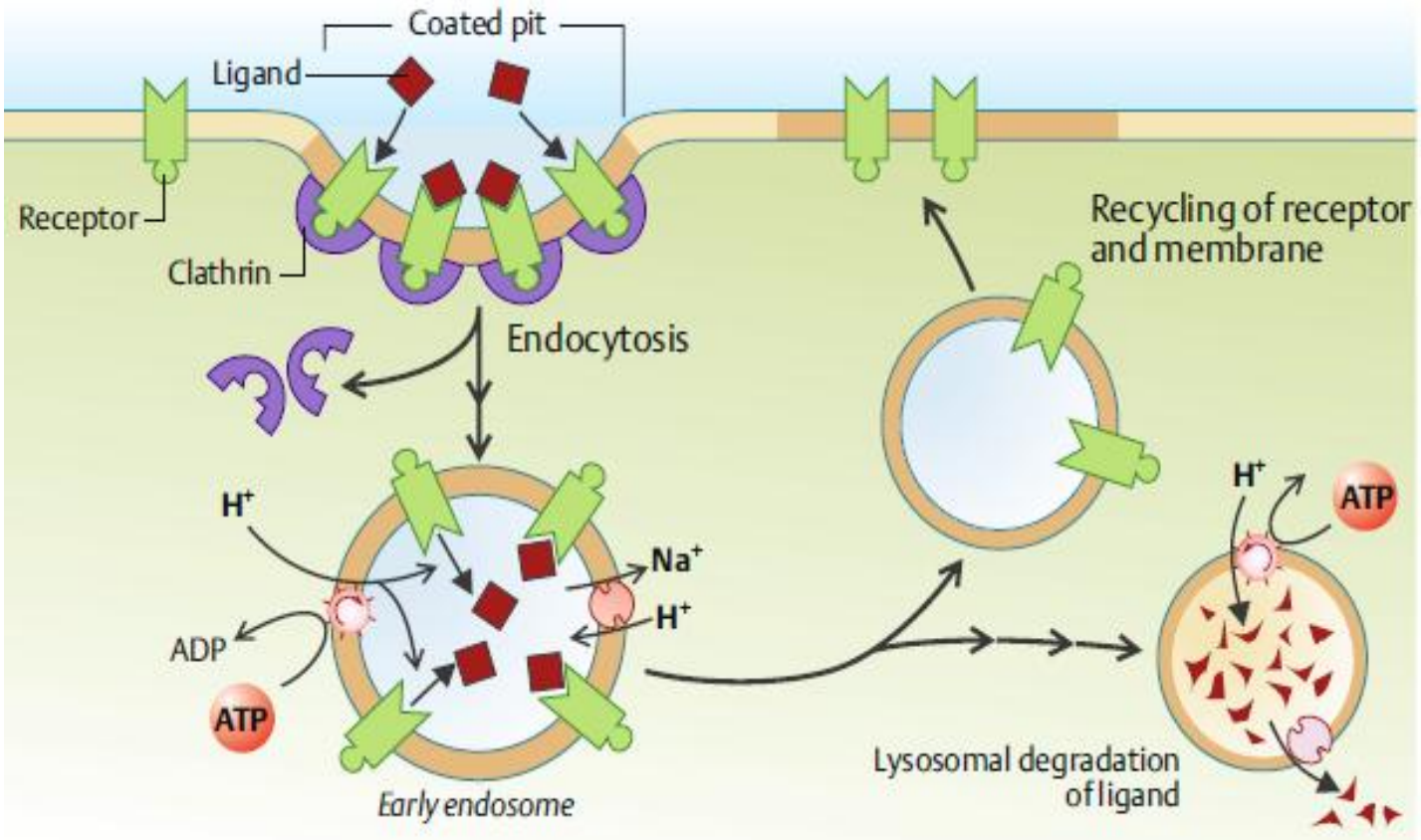
Active transport-Na^+-K^+-ATPase



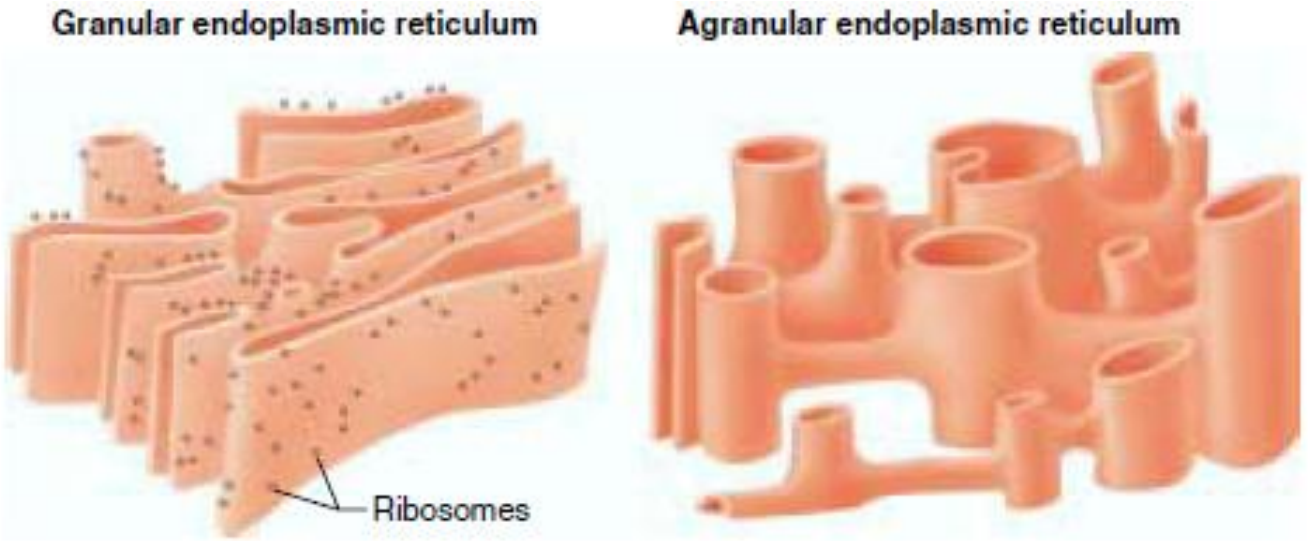
Secondary and tertiary active transport



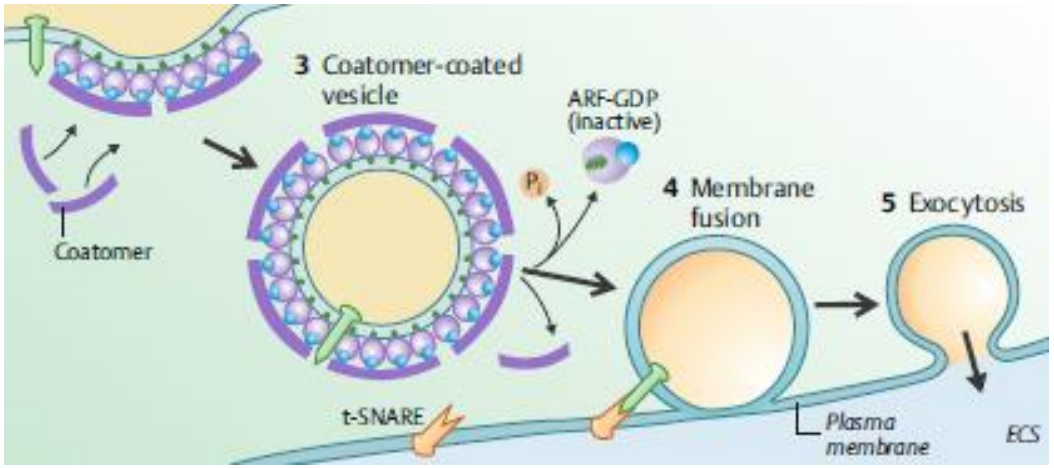
Receptor-mediated endocytosis



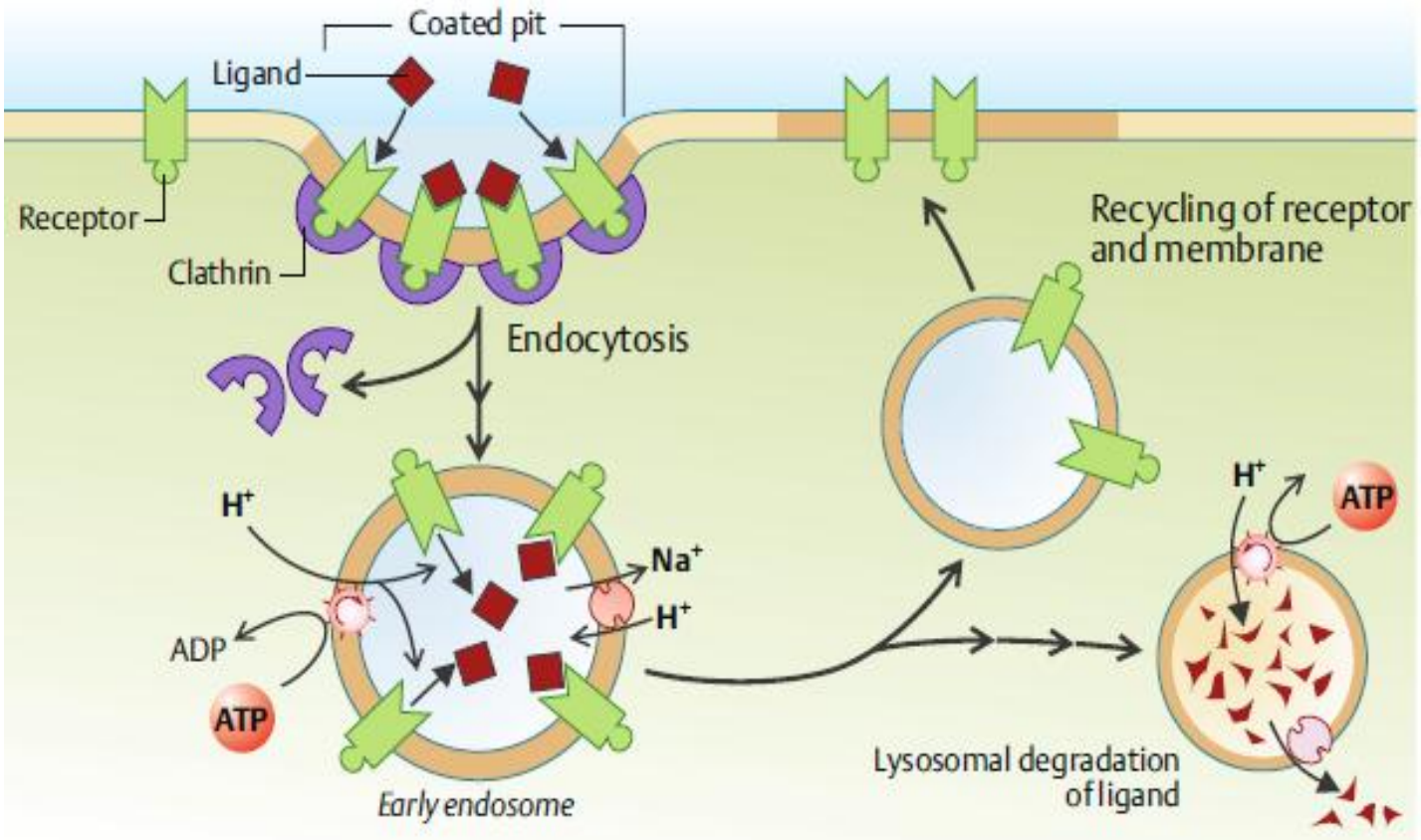
Endoplasmic reticulum and segregated synthesis



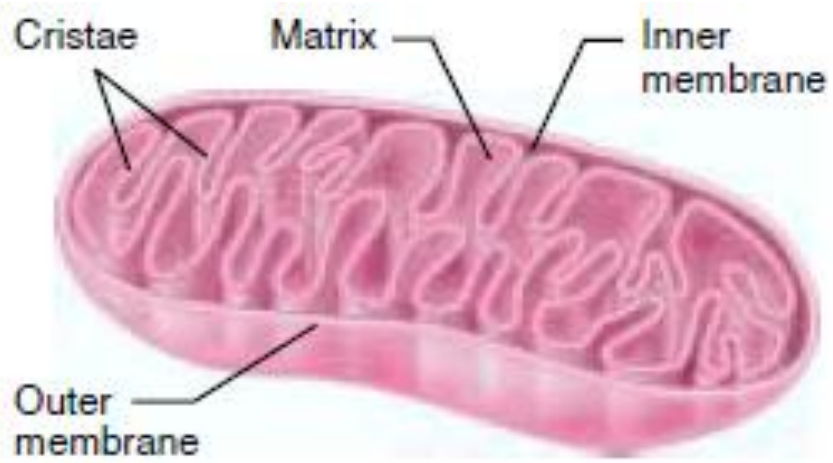
Golgi complex and Exocytosis

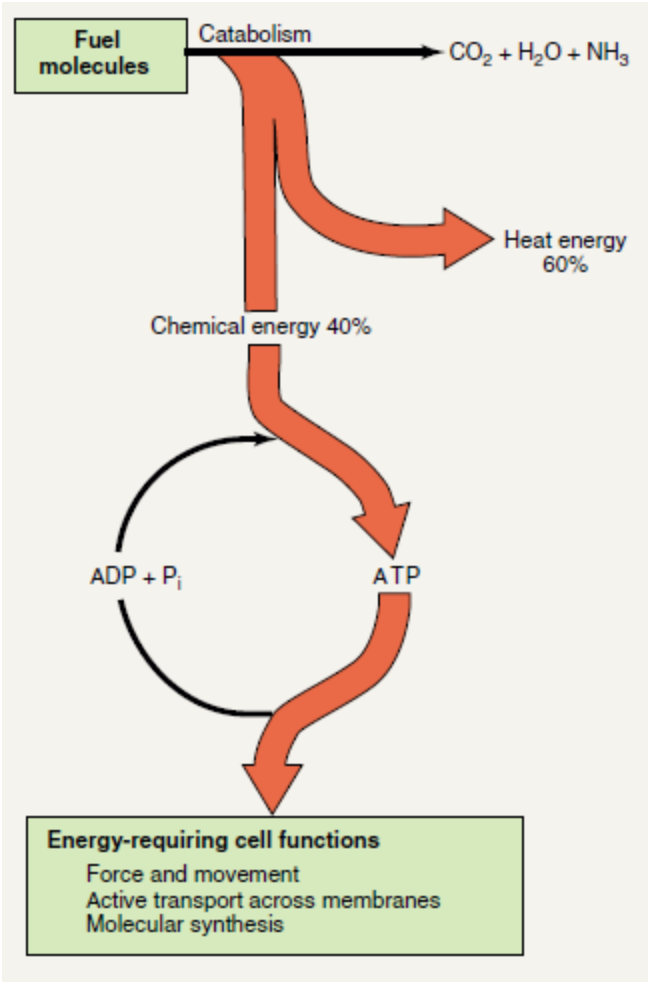


Lysosomes and Endocytosis

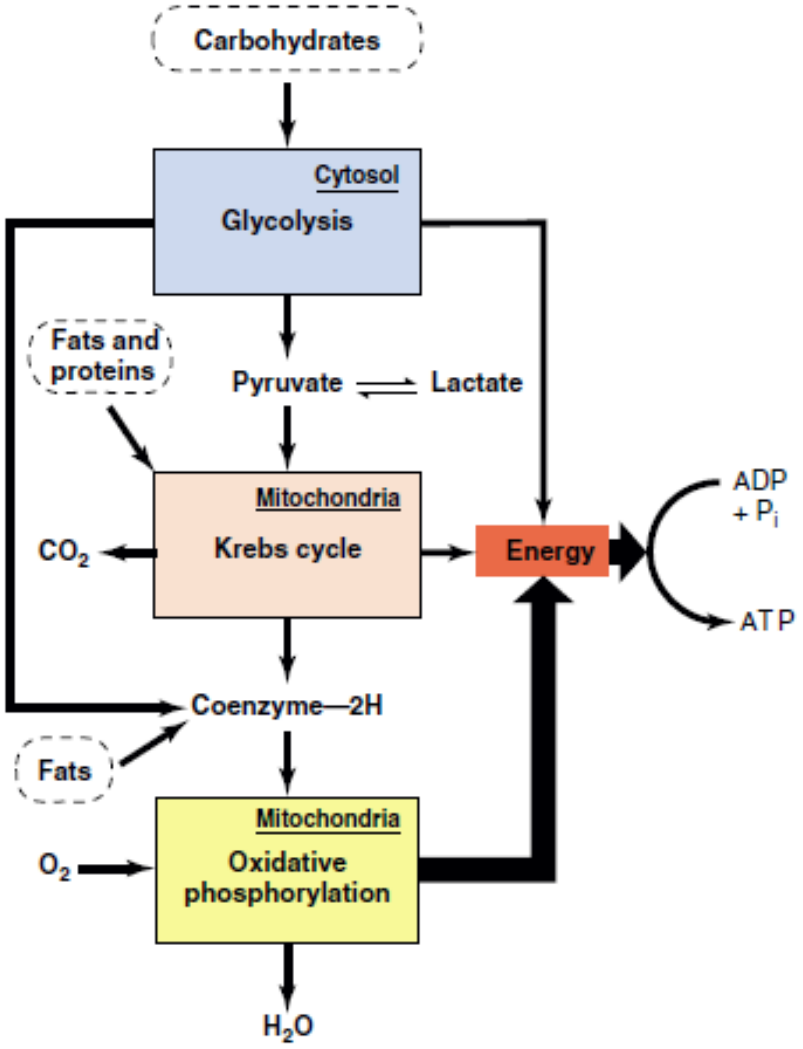


Mitochondria and ATP production





Metabolic pathways



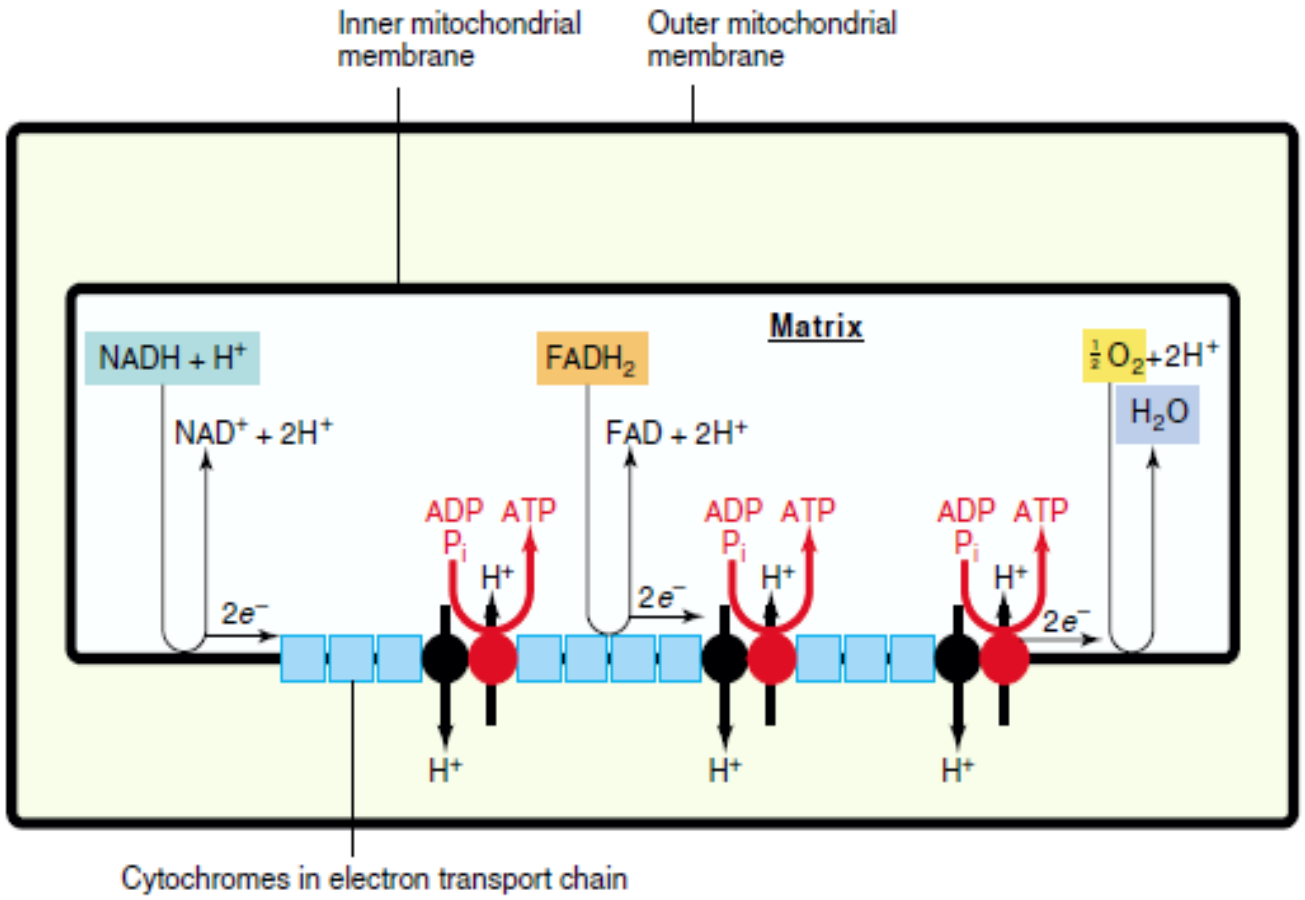
Glycolysis

Entering substrates	Glucose and other monosaccharides
Enzyme location	Cytosol
Net ATP production	2 ATP formed directly per molecule of glucose entering pathway Can be produced in the absence of oxygen (anaerobically)
Coenzyme production	2 NADH + 2 H^+ formed under aerobic conditions
Final products	Pyruvate—under aerobic conditions Lactate—under anaerobic conditions
Net reaction	
Aerobic:	Glucose + 2 ADP + 2 P_i + 2 NAD^+ $\longrightarrow$ 2 pyruvate + 2 ATP + 2 NADH + 2 H^+ + 2 H_2O
Anaerobic:	Glucose + 2 ADP + 2 P_i $\longrightarrow$ 2 lactate + 2 ATP + 2 H_2O

Krebs cycle

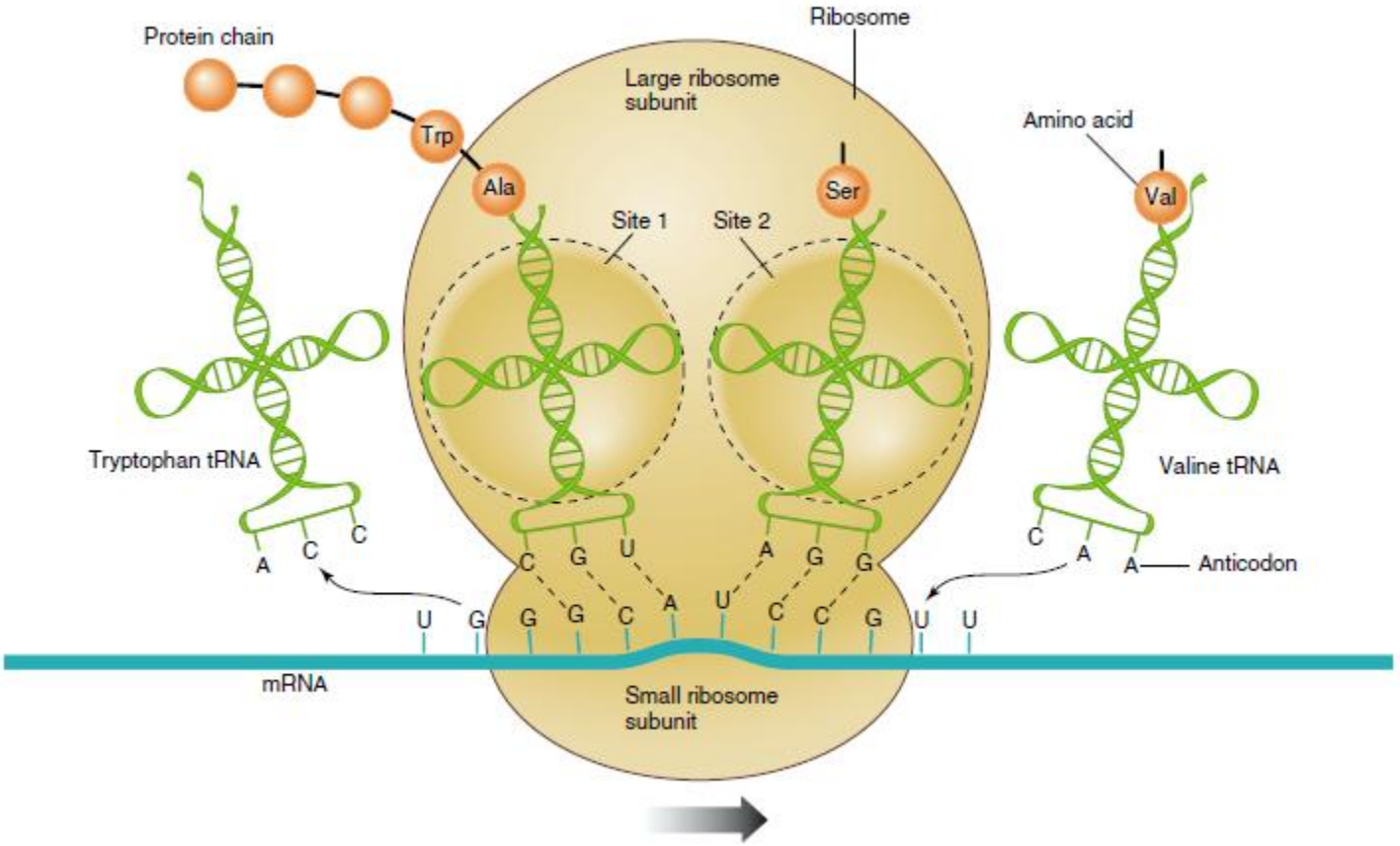
Entering substrate	Acetyl coenzyme A—acetyl groups derived from pyruvate, fatty acids, and amino acids Some intermediates derived from amino acids
Enzyme location	Inner compartment of mitochondria (the mitochondrial matrix)
ATP production	1 GTP formed directly, which can be converted into ATP Operates only under aerobic conditions even though molecular oxygen is not used directly in this pathway
Coenzyme production	3 NADH + 3 H^+ and 2 $FADH_2$
Final products	2 CO_2 for each molecule of acetyl coenzyme A entering pathway Some intermediates used to synthesize amino acids and other organic molecules required for special cell functions
Net reaction	Acetyl CoA + 3 NAD^+ + FAD + GDP + P_i + 2 H_2O $\longrightarrow$ 2 CO_2 + CoA + 3 NADH + 3 H^+ + $FADH_2$ + GTP

Oxidative phosphorylation

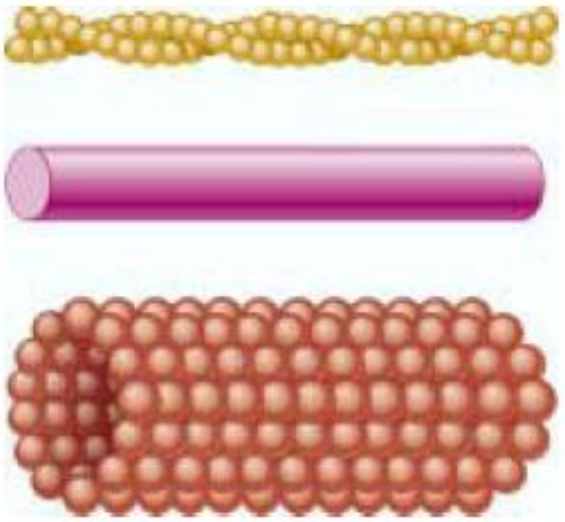


Entering substrates	Hydrogen atoms obtained from $NADH + H^+$ and $FADH_2$ formed (1) during glycolysis, (2) by the Krebs cycle during the breakdown of pyruvate and amino acids, and (3) during the breakdown of fatty acids Molecular oxygen
Enzyme location	Inner mitochondrial membrane
ATP production	3 ATP formed from each $NADH + H^+$ 2 ATP formed from each $FADH_2$
Final products	H_2O—one molecule for each pair of hydrogens entering pathway.
Net reaction	$\frac{1}{2} O_2 + NADH + H^+ + 3\ ADP + 3\ P_i \longrightarrow H_2O + NAD^+ + 3\ ATP$

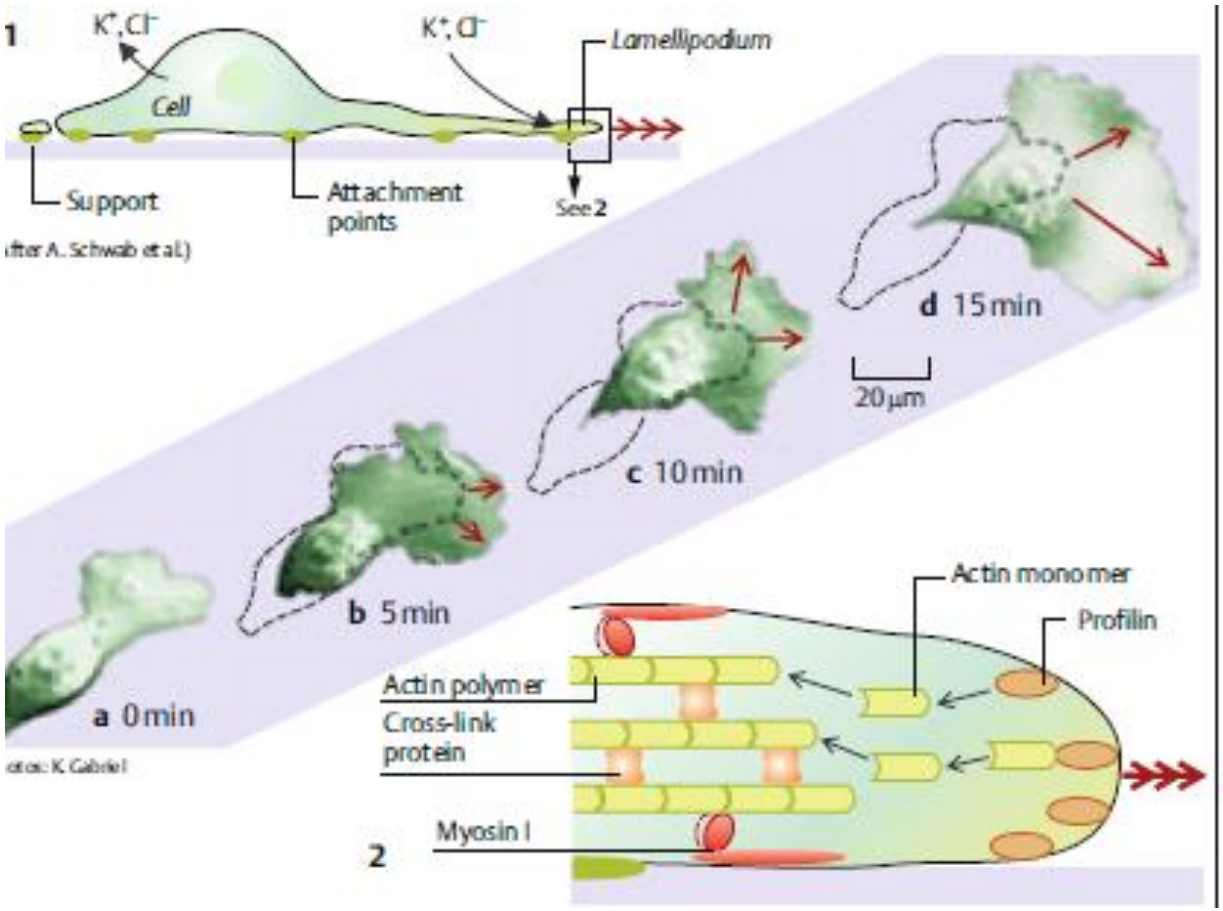
Ribosomes and protein synthesis



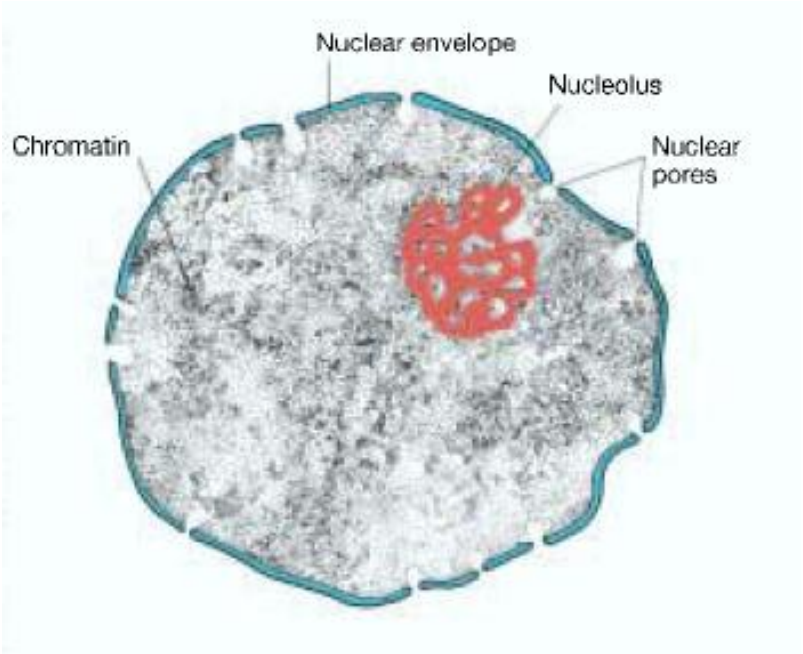
Cytoskeleton

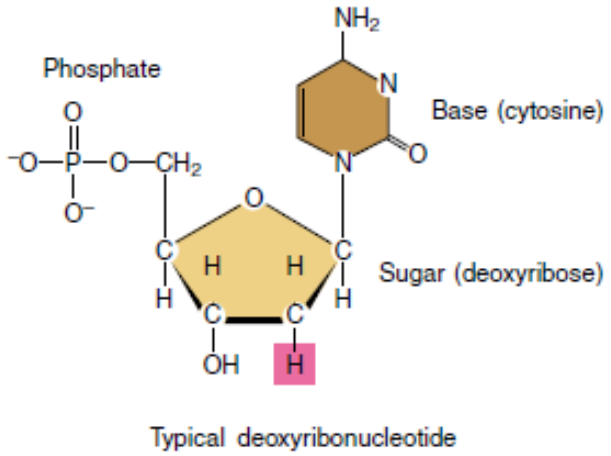


Cytoskeletal filaments	Diameter (nm)	Protein subunit
Microfilament	7	Actin
Intermediate filament	10	Several proteins
Microtubule	25	Tubulin

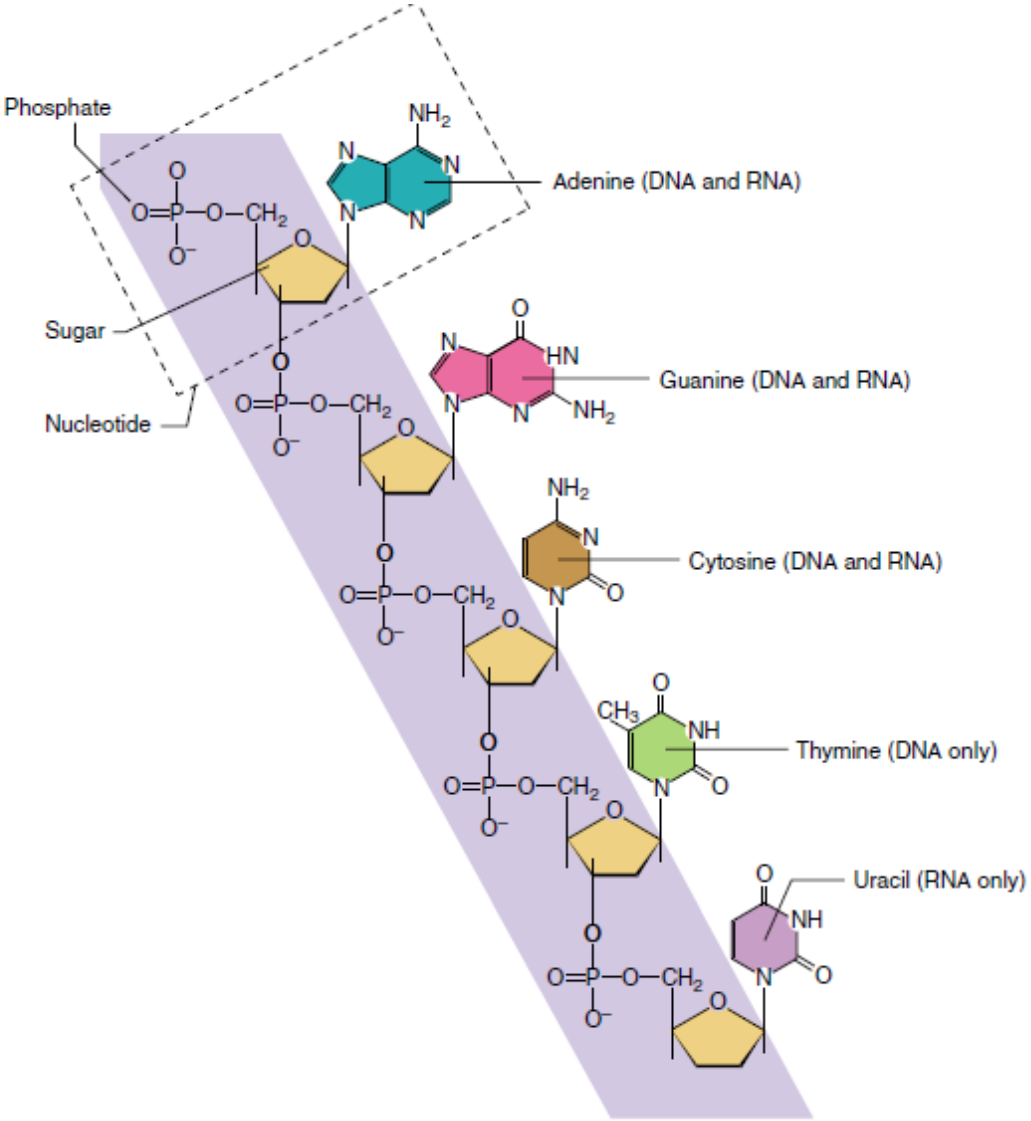

1
K⁺, Cl⁻
K⁺, Cl⁻
Lamellipodium
Cell
Support
Attachment points
See 2
(after A. Schwab et al.)
d 15 min
20 µm
c 10 min
b 5 min
a 0 min
(photos: K. Gabriel)
Actin monomer
Profilin
Actin polymer
Cross-link protein
Myosin I
2

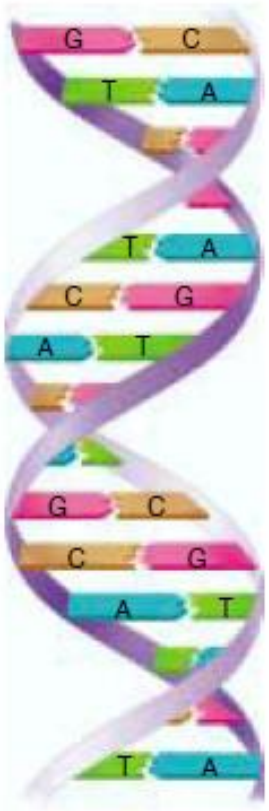
Nucleus and DNA



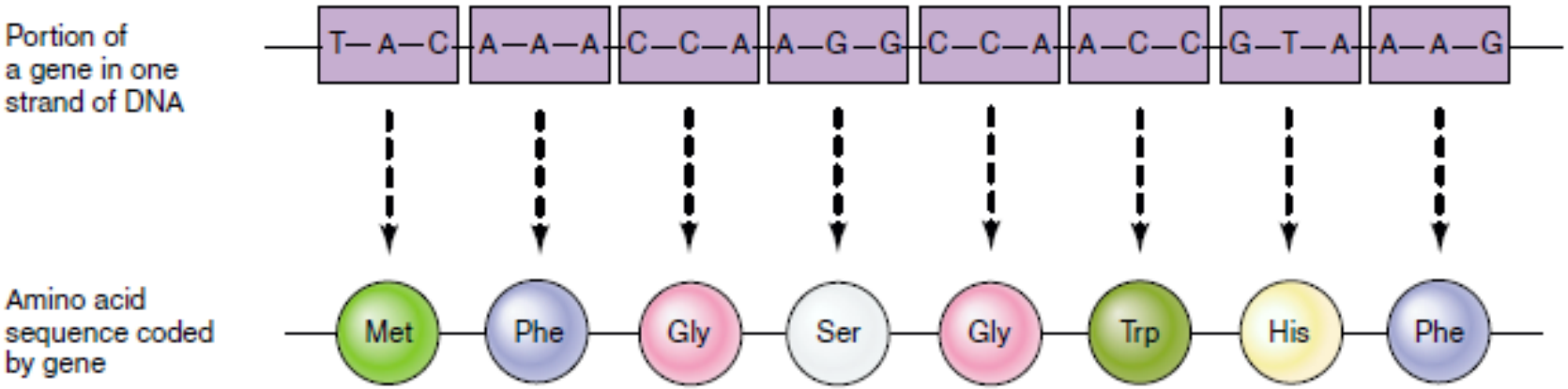


Typical deoxyribonucleotide

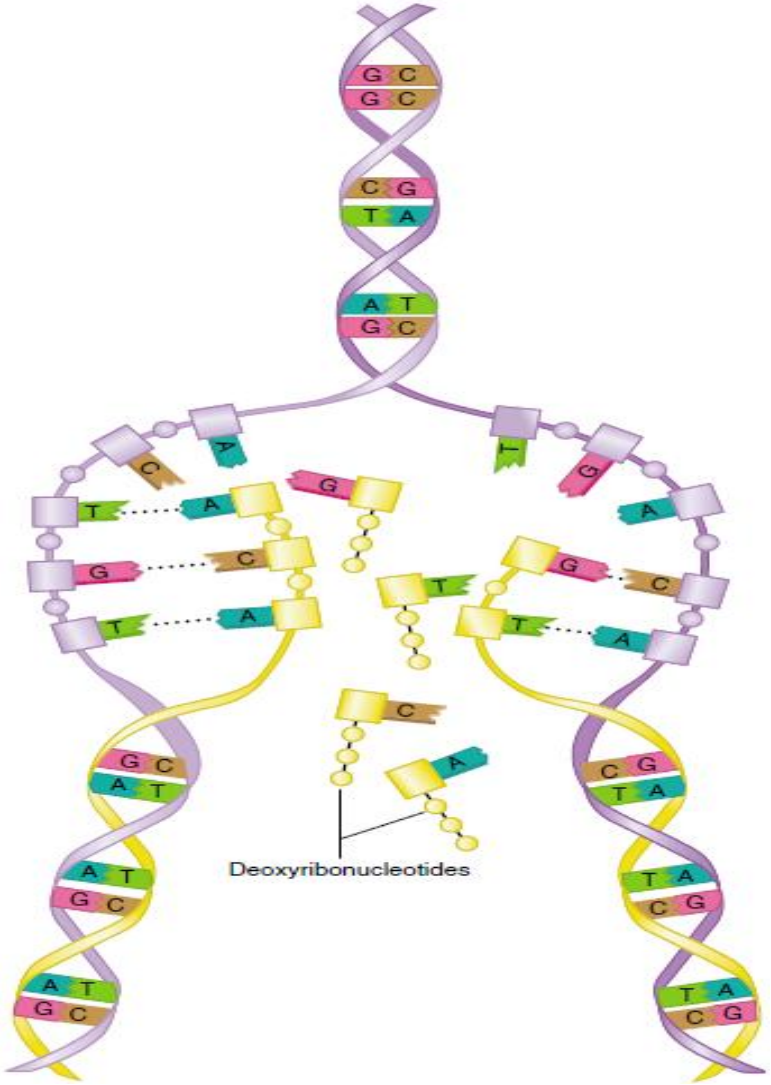

Phosphate
Sugar
Nucleotide
Adenine (DNA and RNA)
Guanine (DNA and RNA)
Cytosine (DNA and RNA)
Thymine (DNA only)
Uracil (RNA only)

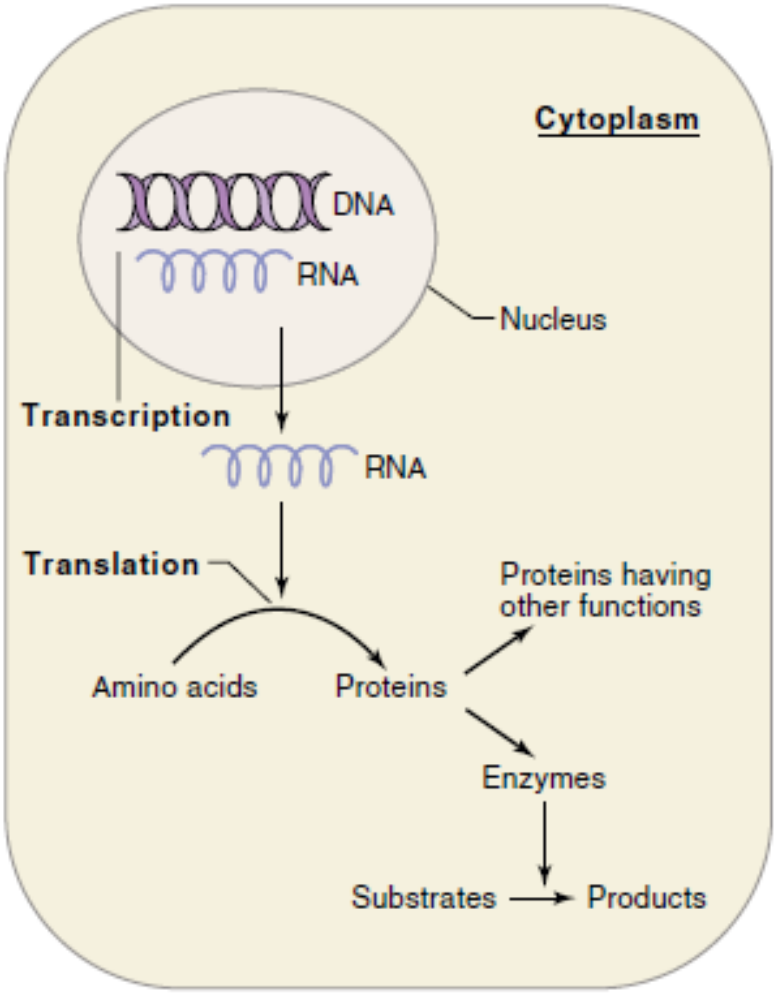


	DNA	RNA
Nucleotide sugar	Deoxyribose	Ribose
Nucleotide bases		
Purines	Adenine	Adenine
	Guanine	Guanine
Pyrimidines	Cytosine	Cytosine
	Thymine	Uracil
Number of chains	Two	One

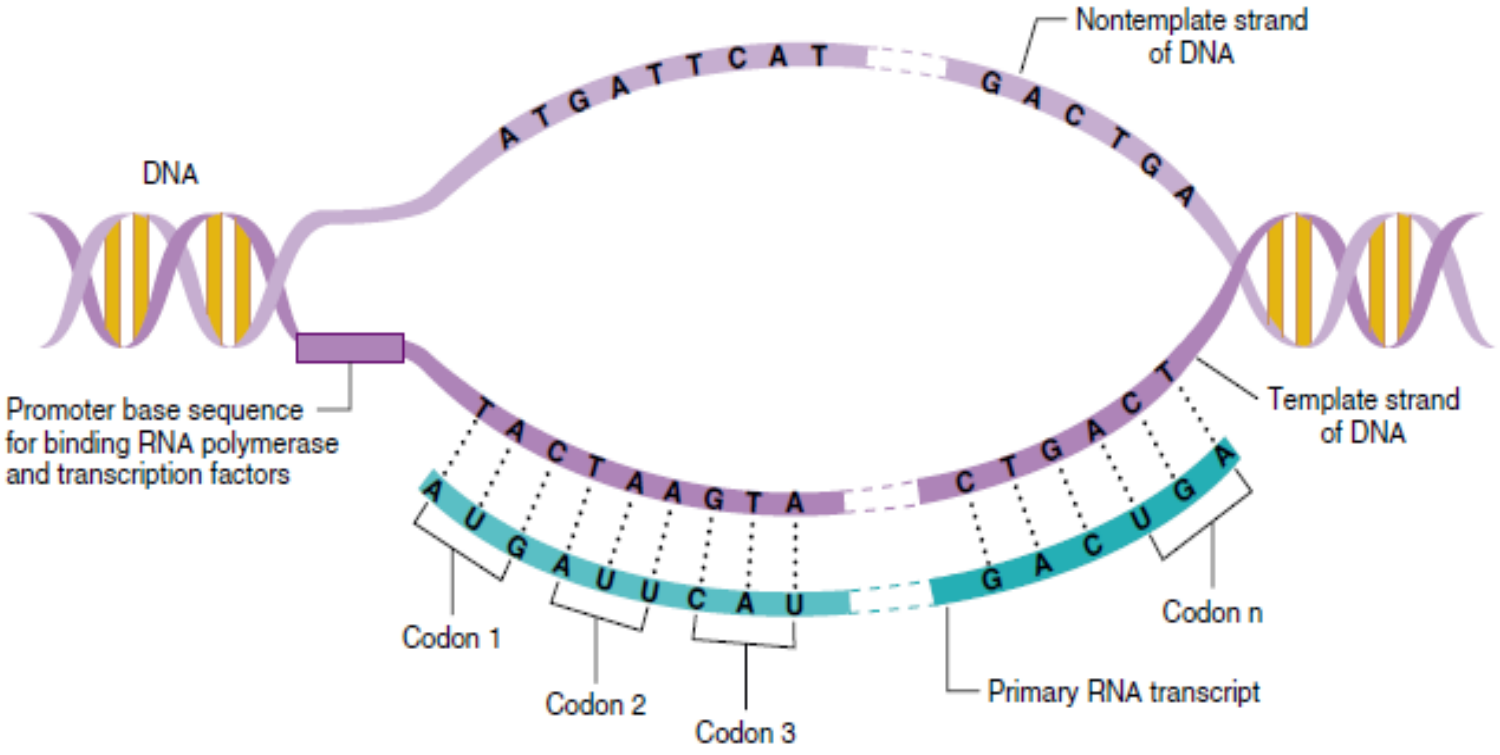

Portion of a gene in one strand of DNA
T—A—C
A—A—A
C—C—A
A—G—G
C—C—A
A—C—C
G—T—A
A—A—G
Amino acid sequence coded by gene
Met
Phe
Gly
Ser
Gly
Trp
His
Phe

DNA replication

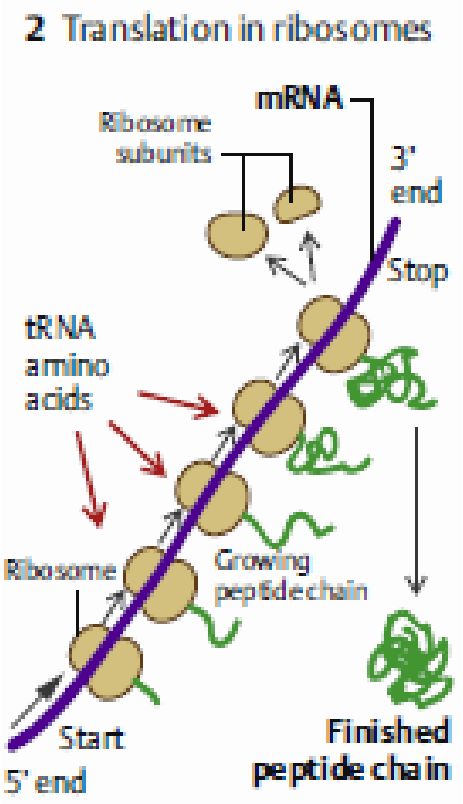


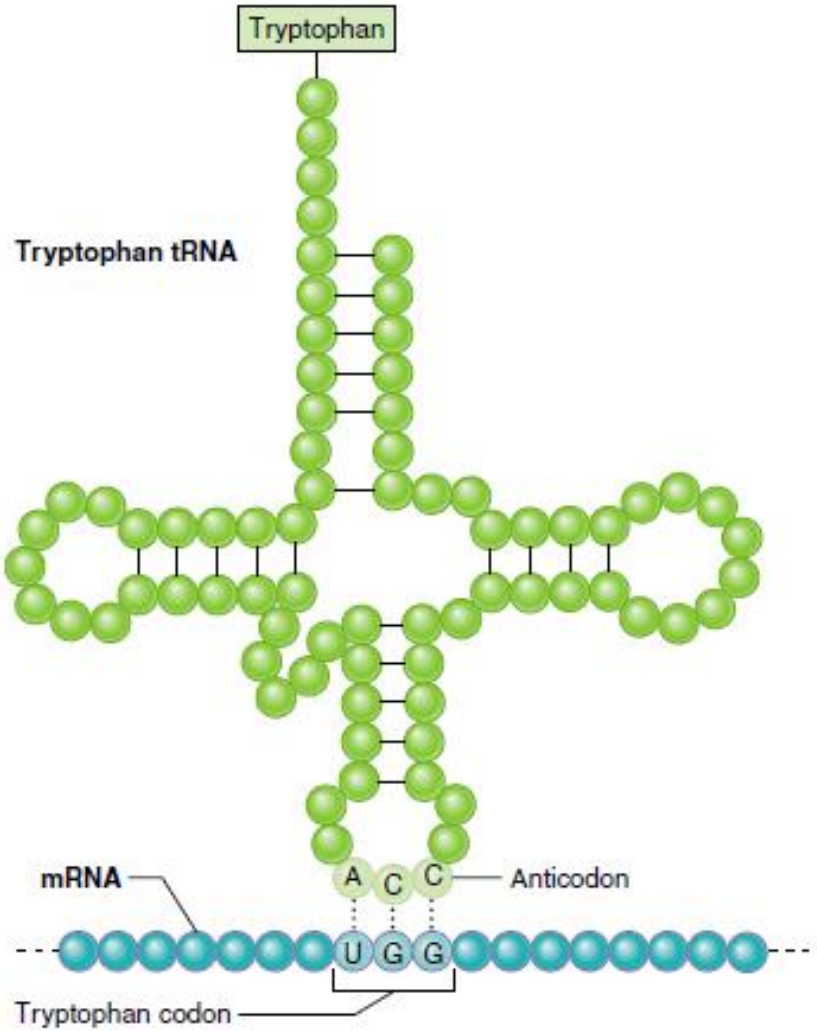

Cytoplasm
DNA
RNA
Nucleus
Transcription
RNA
Translation
Proteins having other functions
Amino acids
Proteins
Enzymes
Substrates
Products

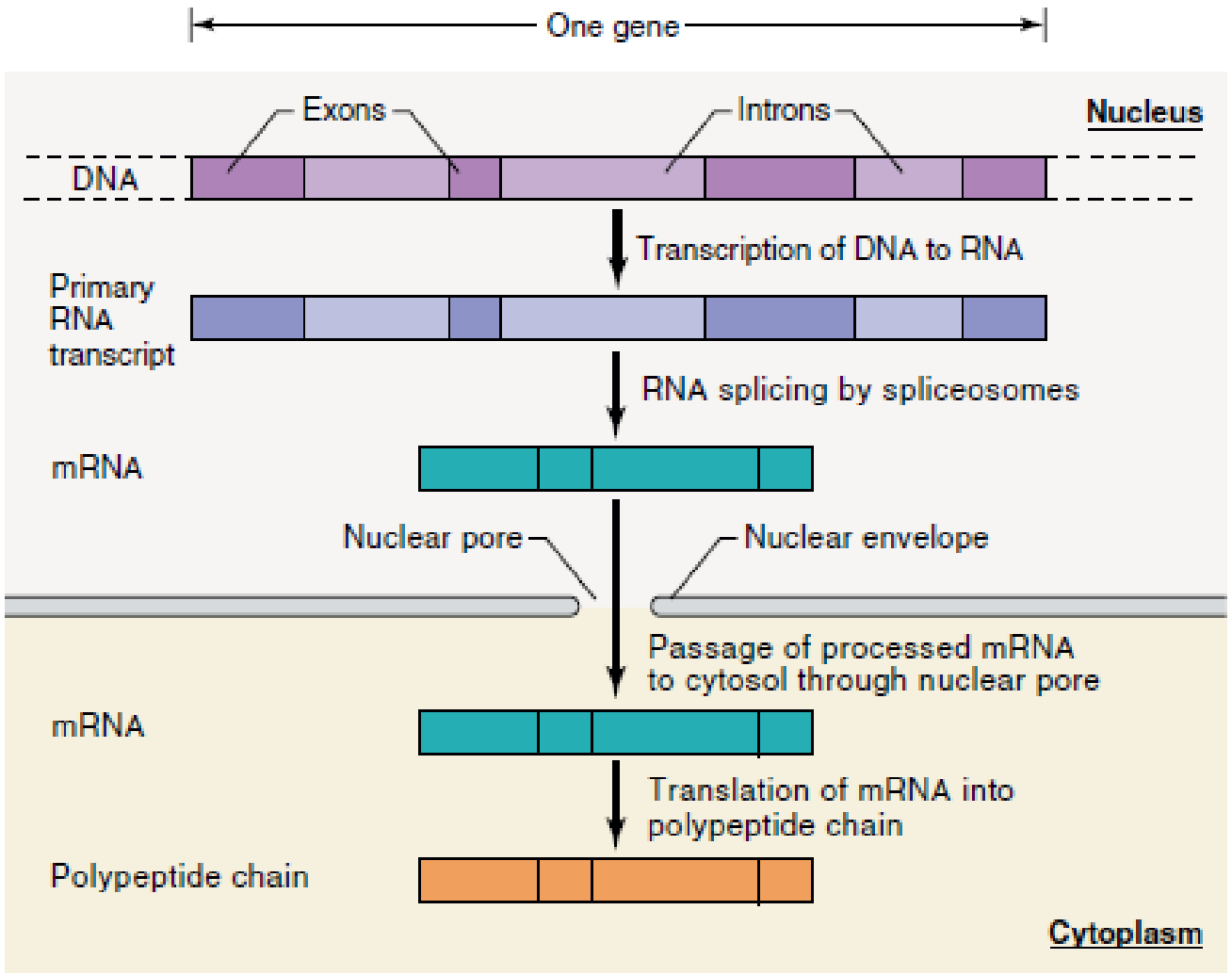
Transcription

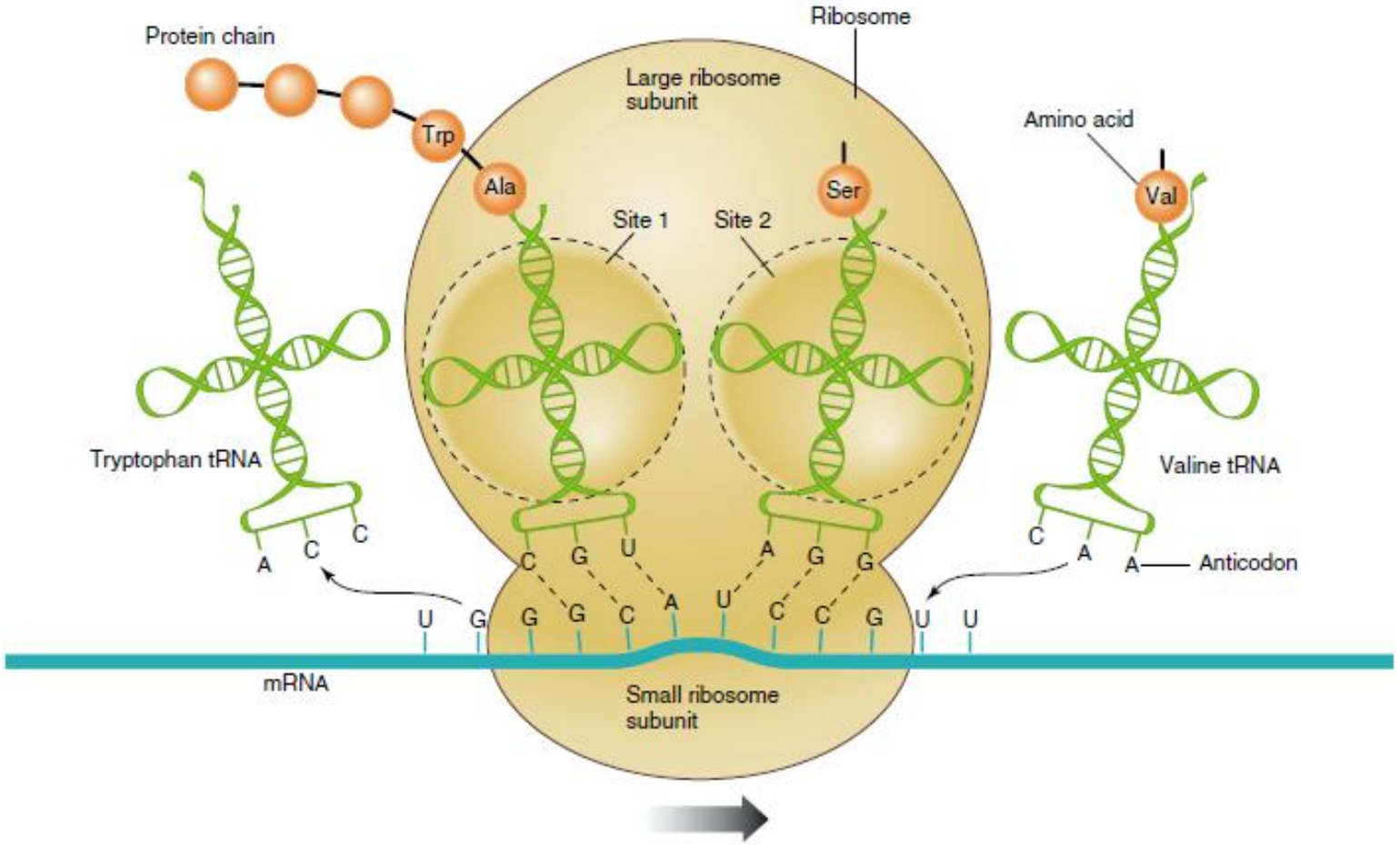


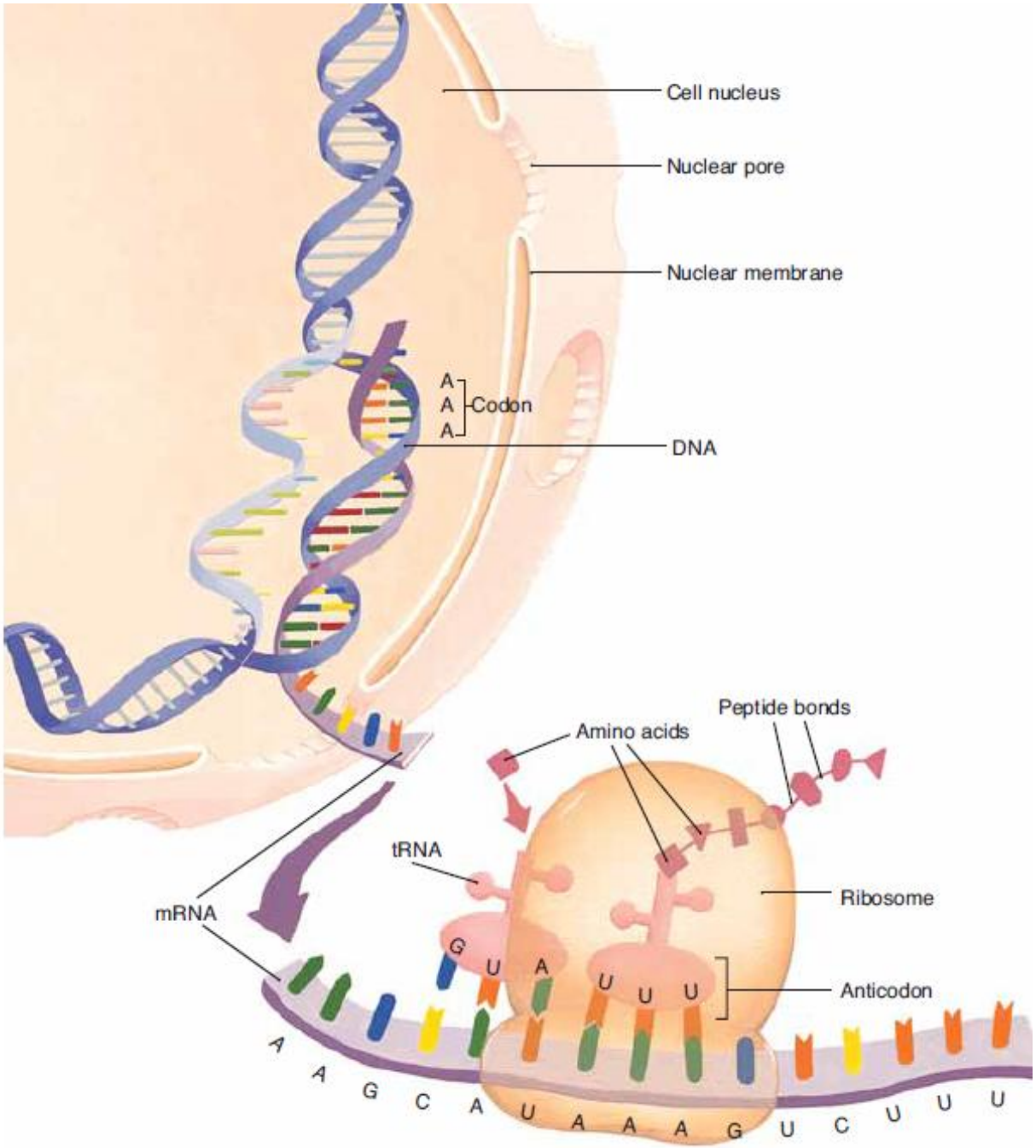
Translation

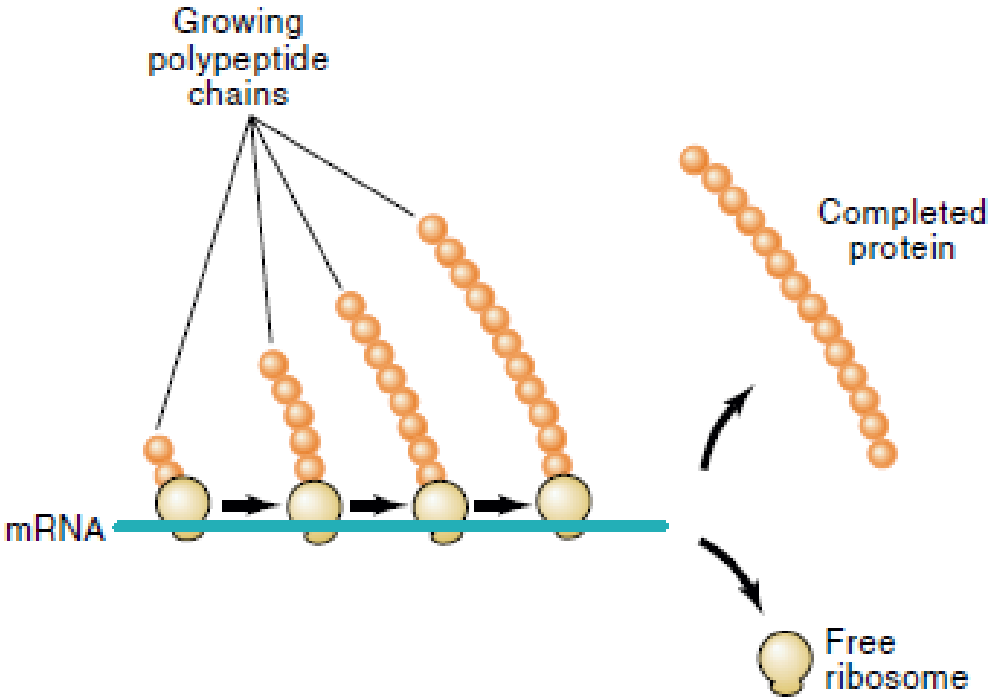



Tryptophan
Tryptophan tRNA
mRNA
A
C
C
Anticodon
U
G
G
Tryptophan codon

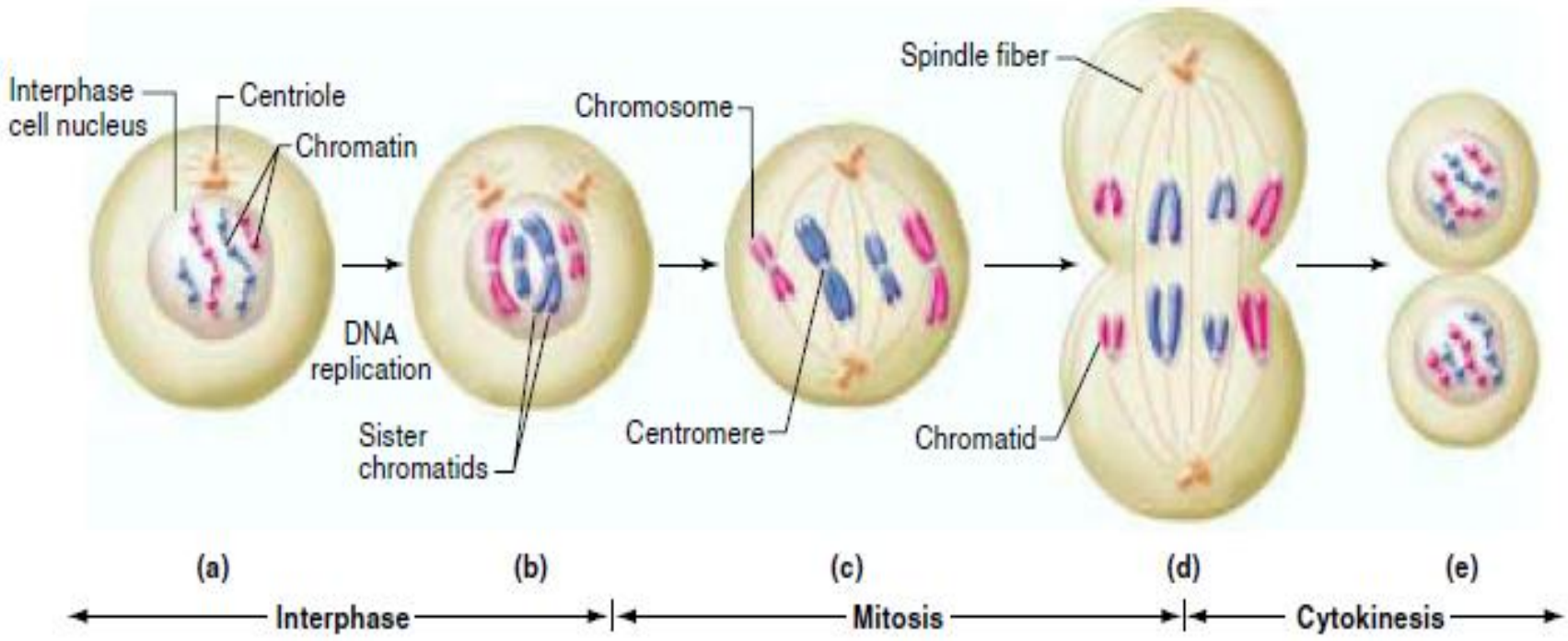

One gene
Exons
Introns
Nucleus
DNA
Transcription of DNA to RNA
Primary RNA transcript
RNA splicing by spliceosomes
mRNA
Nuclear pore
Nuclear envelope
Passage of processed mRNA to cytosol through nuclear pore
mRNA
Translation of mRNA into polypeptide chain
Polypeptide chain
Cytoplasm


Protein chain
Ribosome
Large ribosome subunit
Trp
Ala
Ser
Site 1
Site 2
Amino acid
Val
Tryptophan tRNA
Valine tRNA
Anticodon
mRNA
Small ribosome subunit


Cell nucleus
Nuclear pore
Nuclear membrane
A
A
A
Codon
DNA
Peptide bonds
Amino acids
tRNA
Ribosome
mRNA
G
U
A
U
U
U
Anticodon
A
A
G
C
A
U
A
A
A
G
U
C
U
U
U


Growing
polypeptide
chains
Completed
protein
mRNA
Free
ribosome

Cell division



Stage	Events
Prophase	1. The chromosomes coil up and become visible as short rods. Each chromosome is really two chromatids (original DNA plus its copy) still attached at a region called the centromere. 2. The nuclear membrane disappears. 3. The centrioles move toward opposite poles of the cell and organize the spindle fibers, which extend across the equator of the cell.
Metaphase	1. The pairs of chromatids line up along the equator of the cell. The centromere of each pair is attached to a spindle fiber. 2. The centromeres now divide.
Anaphase	1. Each chromatid is now considered a separate chromosome; there are two complete and separate sets. 2. The spindle fibers contract and pull the chromosomes, one set toward each pole of the cell.
Telophase	1. The sets of chromosomes reach the poles of the cell and become indistinct as their DNA uncoils to form chromatin. 2. A nuclear membrane re-forms around each set of chromosomes.
Cytokinesis	1. The cytoplasm divides; new cell membrane is formed.

Mutations & Cancer