GENERAL BIOLOGY · STUDY GUIDE

Final Exam Study Guide

The final covers all fourteen chapters. Each chapter here is shorter than in the exam guides: five paragraphs of what to know, the points to lock in, one table, two worked cases, the traps and six new self-test items. If a chapter feels shaky, go back to its exam guide for the full treatment. The long cram sheet at the end pulls the whole course into one place. Work two chapters a day and the course fits into a week.

WHAT THIS GUIDE COVERS

- Chemistry and cells: chapters 1 and 2 (bonds, water, macromolecules; organelles, membranes and transport).
- Energy and division: chapters 3 and 4 (enzymes, respiration, photosynthesis; signaling, the cell cycle, cancer and meiosis).
- Genes: chapters 5, 6 and 7 (Mendel and probability; DNA, replication and expression; regulation and biotechnology).
- Evolution and diversity: chapters 8, 9 and 10 (selection and Hardy-Weinberg; speciation, trees and history; microbes).
- Plants and animals: chapters 11, 12 and 13 (plant form and function; animal diversity; animal physiology and development).
- Ecology: chapter 14 (climate, populations, communities, ecosystems and conservation).
- Every chapter carries what to know, a table, two worked cases, the traps and a six-item self-test, and the cram sheet holds all the numbers.

CHAPTER 1

The Chemistry of Life and Biological Macromolecules

Read it in full: **Chapter 1 in the textbook**. See it in motion: **Chemistry of Life Lab** and **Macromolecules Lab**.

What to know

O, C, H and N make up about 96 percent of body mass. Atomic number (protons) defines an element; isotopes differ in neutrons and react alike. Valence electrons set bonding: HONC 1234.

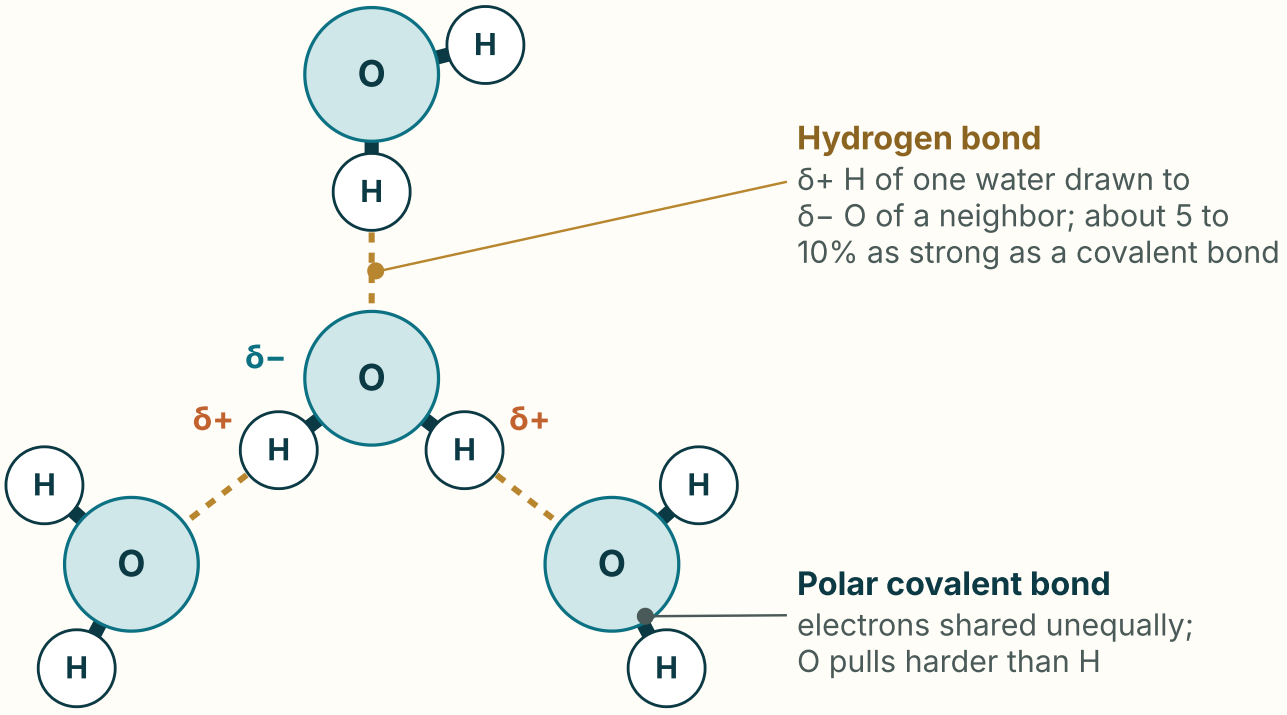
Covalent bonds share electrons (polar when O or N pulls harder); ionic bonds are weak in water; hydrogen bonds are about 5 to 10 percent as strong as covalent; the hydrophobic effect is not a true bond.

Water is polar, so it shows cohesion, a high specific heat (1 cal per g per °C), evaporative cooling, floating ice and strong solvent power. $pH = -\log[H^+]$, tenfold per unit; blood is 7.35 to 7.45, held by the bicarbonate buffer. A mole is 6.02×10^{23}; glucose is 180 g per mole.

Carbon makes four bonds. Isomers can be structural, cis trans or enantiomers. Seven functional groups (hydroxyl, carbonyl, carboxyl, amino, sulfhydryl, phosphate, methyl) set chemistry. Dehydration builds polymers and releases water; hydrolysis breaks them. Starch and glycogen (alpha glucose) store energy; cellulose and chitin (beta linkages) build structure. Fats are glycerol plus three fatty acids; phospholipids form bilayers; steroids have four rings.

Proteins: 20 amino acids joined by peptide bonds; primary (sequence), secondary (backbone hydrogen bonds), tertiary (R groups, disulfides), quaternary (subunits). Denaturation spares peptide bonds. Nucleic acids: nucleotides (sugar, base, phosphate); DNA is an antiparallel double helix with A to T (2 bonds) and G to C (3 bonds); RNA uses ribose and uracil. Information flows DNA to RNA to protein.

Shape follows bonding: carbon with four single bonds is tetrahedral and water is bent, and molecules recognize each other by fit, which is why morphine and endorphins bind the same receptors. The carbonic acid and bicarbonate buffer gives the lungs and kidneys two levers on blood pH. ATP releases energy when its end phosphate is removed by hydrolysis, and the cell recycles ADP back to ATP continuously.



Every water can hydrogen-bond to up to four neighbors. Together these weak bonds give cohesion, a high specific heat, evaporative cooling and floating ice.

Water and its hydrogen bonds. Each O to H bond is polar, so every water molecule has a slightly negative end and two slightly positive ends. The weak pull between neighbors is the hydrogen bond.

LOCK THESE IN

- HONC 1234.
- One pH unit = tenfold H^+.
- n monomers release n − 1 waters.
- Alpha stores; beta builds.
- Secondary = backbone; tertiary = R groups.
- Chargaff: A = T, G = C.

Key terms and comparisons

Item	Rule or value
Hydrogen bond	About 5 to 10% of a covalent bond
Specific heat of water	1 cal/g/°C
pH	$-\log[H^+]$; blood 7.35 to 7.45
Carbon-14	Half-life about 5,730 years
Fat versus carbohydrate	About 9 versus 4 kcal/g
Purines; pyrimidines	A, G; C, T, U
Helix	2 nm wide; about 10 bp per turn
Essential amino acids	9 of the 20

Worked cases

CASE 1.1 · PH AND CONCENTRATION

How many times more H^+ is in a pH 3 solution than in a pH 7 solution? What is $[H^+]$ at pH 3?

STEP 1 · SUBTRACT

$7 - 3 = 4$ units.

STEP 2 · RAISE 10

$10^4 =$ **10,000 times**.

STEP 3 · CONCENTRATION

$[H^+] = 10^{-3}$ M = **0.001 M**.

CASE 1.2 · BASE COMPOSITION

A DNA sample is 32 percent cytosine. Give the other bases. Then write the partner of 5′-GACT-3′ in the 5′ to 3′ direction.

STEP 1 · PAIR

G = C = 32%, so G plus C = 64%.

STEP 2 · SPLIT THE REST

36% left: A = T = **18%**.

STEP 3 · COMPLEMENT AND FLIP

Pairing gives 3′-CTGA-5′, written **5′-AGTC-3′**.

TRAPS PEOPLE FALL INTO

- **Isotopes reacting differently.** Chemistry depends on electrons, not neutrons.
- **Lipids as polymers.** They have no repeating monomer.
- **R groups in secondary structure.** Secondary is backbone only.
- **Writing a complement without flipping.** Reverse it to read 5′ to 3′.

Chapter 1 self-test · six items

1. Which property of water lets sweat cool the body?

A. Low density of solid ice
B. High heat of vaporization
C. Strong adhesion to skin
D. High surface tension

B. High heat of vaporization Evaporating water carries away a lot of heat as the fastest molecules leave.

2. Which group ionizes to $-NH_3^+$ at cell pH?

A. Amino
B. Hydroxyl
C. Methyl
D. Carboxyl

A. Amino Amino groups accept H^+ and act as bases.

3. How many waters are released when 20 glucose units are joined into one unbranched chain?

A. 21
B. 20
C. 19
D. 10

C. 19 Each linkage releases one water: 20 units have 19 bonds.

4. What makes olive oil liquid at room temperature?

A. It is a steroid with fused rings
B. Its fatty acids are fully saturated
C. It has more glycerol per molecule
D. Cis double bonds kink its chains

D. Cis double bonds kink its chains Kinked unsaturated chains cannot pack tightly.

5. A disulfide bridge is broken. Which level of structure is hit first?

A. Tertiary
B. Primary
C. Secondary
D. Quaternary only

A. Tertiary Disulfides link R groups of cysteines within one chain.

6. Which pair of bases is joined by three hydrogen bonds?

A. T and U
B. G and C
C. A and U
D. A and T

B. G and C G-C pairs have three hydrogen bonds; A-T and A-U have two.

CHAPTER 2

Cell Structure, Membranes and Transport

Read it in full: **Chapter 2 in the textbook**. See it in motion: **Cell Structure Lab** and **Membranes Lab**.

What to know

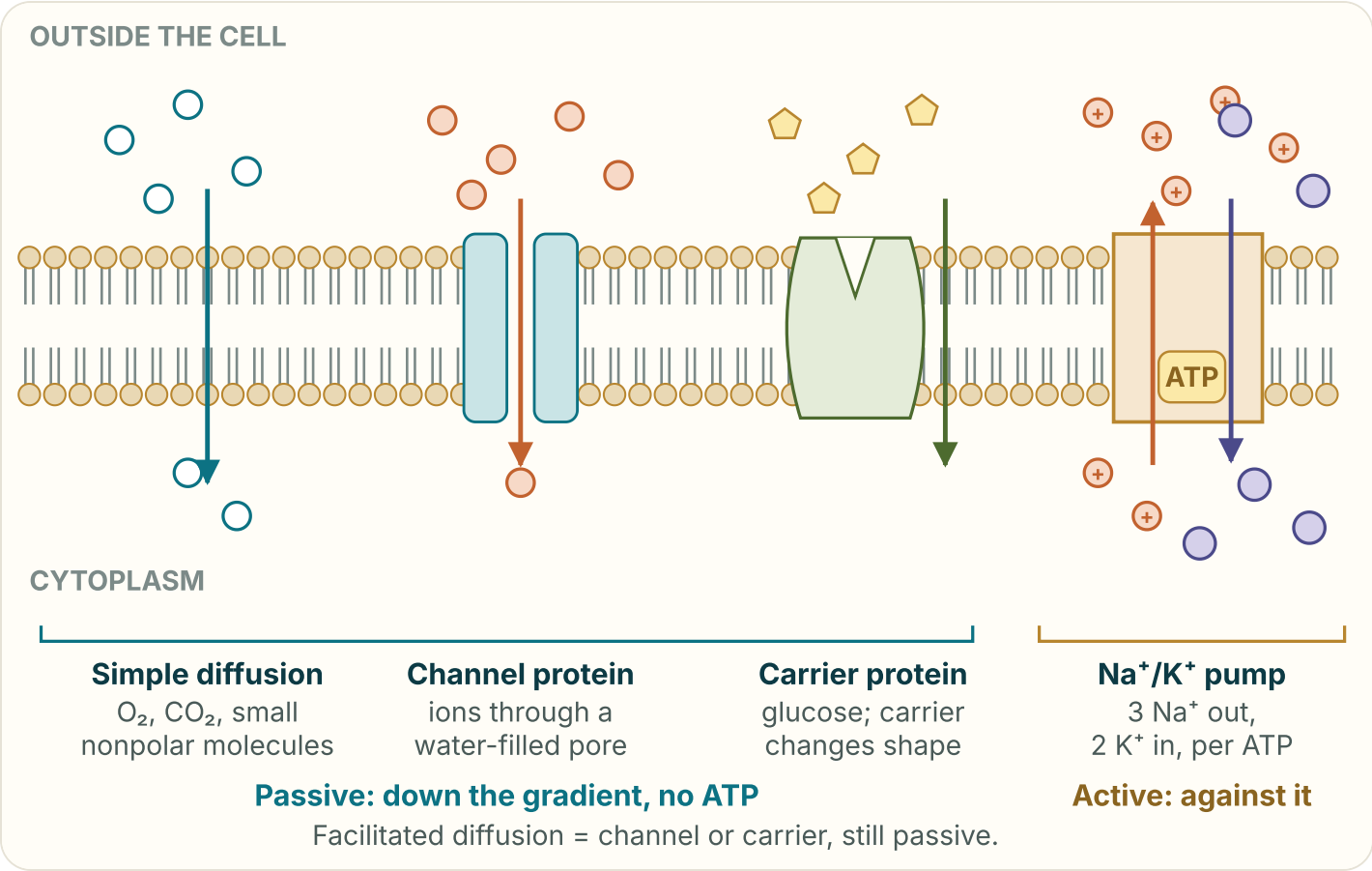
Light microscopes resolve about 200 nm and show living cells; electron microscopes resolve a few nm (SEM surfaces, TEM interiors) but need dead samples. The cell theory: all life is cells, the cell is the basic unit, and cells come from cells. A cube cell's surface area to volume ratio is 6/s, so cells stay small.

Prokaryotes (bacteria, archaea) have a nucleoid, 70S ribosomes, usually a wall and no membrane-enclosed organelles. Eukaryotes have a nucleus and organelles. Plants add a cellulose wall, chloroplasts, a central vacuole and plasmodesmata; animals have lysosomes, centrioles and an extracellular matrix.

Secreted proteins go rough ER, vesicle, Golgi (cis to trans), vesicle, plasma membrane. Smooth ER makes lipids and detoxifies; lysosomes digest at pH 5; peroxisomes break down H_2O_2. Mitochondria and chloroplasts have two membranes, circular DNA and 70S ribosomes: evidence of endosymbiosis. Microtubules (25 nm, tubulin), microfilaments (7 nm, actin) and intermediate filaments (8 to 12 nm) form the cytoskeleton. Tight junctions seal, desmosomes anchor, gap junctions connect.

Membranes are fluid mosaics. Water follows nonpenetrating solute by osmosis; tonicity describes the outside solution. Passive transport runs down gradients (simple diffusion, osmosis, facilitated diffusion, which saturates). Active transport runs up them: the Na^+/K^+ pump moves 3 Na^+ out and 2 K^+ in per ATP; cotransport uses a gradient. Bulk transport uses exocytosis and endocytosis.

Cell fractionation spins broken cells at rising speeds to separate nuclei, then mitochondria, then ribosomes and membranes, which is how the job of each organelle was tested. Cilia and flagella share a 9 + 2 microtubule core bent by dynein, anchored by a basal body built like a centriole. The extracellular matrix links to the cytoskeleton through integrins, so changes outside the cell can change gene expression inside it.



Four ways across the membrane. Diffusion, channels and carriers all run downhill and need no ATP. Only the pump spends ATP to move ions uphill.

LOCK THESE IN

- Resolution, not magnification, gives detail.
- SA:V = 6/s.
- Prokaryotes lack membrane-enclosed organelles, not ribosomes.
- Rough ER to Golgi to membrane.
- Hypertonic outside: cell shrinks.
- 3 Na^+ out, 2 K^+ in, 1 ATP.

Key terms and comparisons

Item	Rule or value
Light vs electron microscope	About 200 nm, living; a few nm, dead
Prokaryote vs eukaryote size	1 to 5 µm vs 10 to 100 µm
Ribosomes	70S prokaryotes; 80S eukaryotic cytosol
Isotonic saline	0.9% NaCl
Membrane potential	About −50 to −70 mV
Facilitated diffusion	Down gradient; carrier saturates
Cotransport	Gradient drives a second solute uphill

Worked cases

CASE 2.1 · SURFACE AREA TO VOLUME

Compare cube cells 3 µm and 30 µm on a side.

STEP 1 · SMALL

6 ÷ 3 = **2.0**.

STEP 2 · LARGE

6 ÷ 30 = **0.2**.

MEANING

The large cell has a tenth the membrane per unit volume.

CASE 2.2 · TONICITY

Plant and animal cells go into a solution with more nonpenetrating solute than their cytoplasm. Predict both.

STEP 1 · NAME IT

More solute outside: **hypertonic**.

STEP 2 · ANIMAL CELL

Water leaves; the cell shrivels (crenates).

STEP 3 · PLANT CELL

The membrane pulls from the wall: **plasmolysis**.

TRAPS PEOPLE FALL INTO

- **Plant cells without mitochondria.** They have both chloroplasts and mitochondria.
- **Calling a shrinking cell hypertonic.** Tonicity describes the outside solution.
- **Cotransporters using ATP.** They use a gradient the pump built.
- **Mitochondria in the endomembrane system.** They are separate, with their own DNA.

Chapter 2 self-test · six items

1. A protein made on free ribosomes most likely ends up where?

A. In the cytosol
B. In the plasma membrane
C. In the lysosome
D. Outside the cell

A. In the cytosol Free ribosomes make proteins for the cytosol and some organelles; bound ribosomes make secreted, lysosomal and membrane proteins.

2. Which fiber is hollow and built of tubulin?

A. Microfilament
B. Microtubule
C. Keratin filament
D. Collagen fiber

B. Microtubule Microtubules are about 25 nm hollow tubes of tubulin dimers.

3. Which junction is the plant version of a gap junction?

A. Middle lamella
B. Desmosome
C. Plasmodesma
D. Tight junction

C. Plasmodesma Plasmodesmata join the cytosol of neighboring plant cells.

4. Red cells in distilled water swell and burst. What is distilled water to them?

A. Amphipathic
B. Hypertonic
C. Isotonic
D. Hypotonic

D. Hypotonic Less solute outside means water rushes in.

5. What keeps animal membranes fluid across temperatures?

A. Chitin under the membrane
B. Peptidoglycan in the wall
C. Cholesterol in the bilayer
D. Glycogen in the cytosol

C. Cholesterol in the bilayer Cholesterol restrains movement when warm and prevents tight packing when cold.

6. A cell takes up LDL bound to specific receptors in coated pits. What is this?

A. Pinocytosis of extracellular fluid
B. Receptor-mediated endocytosis
C. Exocytosis from Golgi vesicles
D. Facilitated diffusion by GLUT

B. Receptor-mediated endocytosis Clathrin-coated pits with LDL receptors pinch off as vesicles.

CHAPTER 3

Energy, Enzymes, Cellular Respiration and Photosynthesis

Read it in full: **Chapter 3 in the textbook**. See it in motion: **Energy and Enzymes Lab** and **Cellular Respiration Lab** and **Photosynthesis Lab**.

What to know

Energy is conserved (first law) and every transfer raises entropy (second law). $\Delta G = \Delta H - T\Delta S$; negative is exergonic, positive endergonic, zero equilibrium. ATP hydrolysis releases about 7.3 kcal/mol and drives uphill reactions by phosphorylation; coupled ΔG values add.

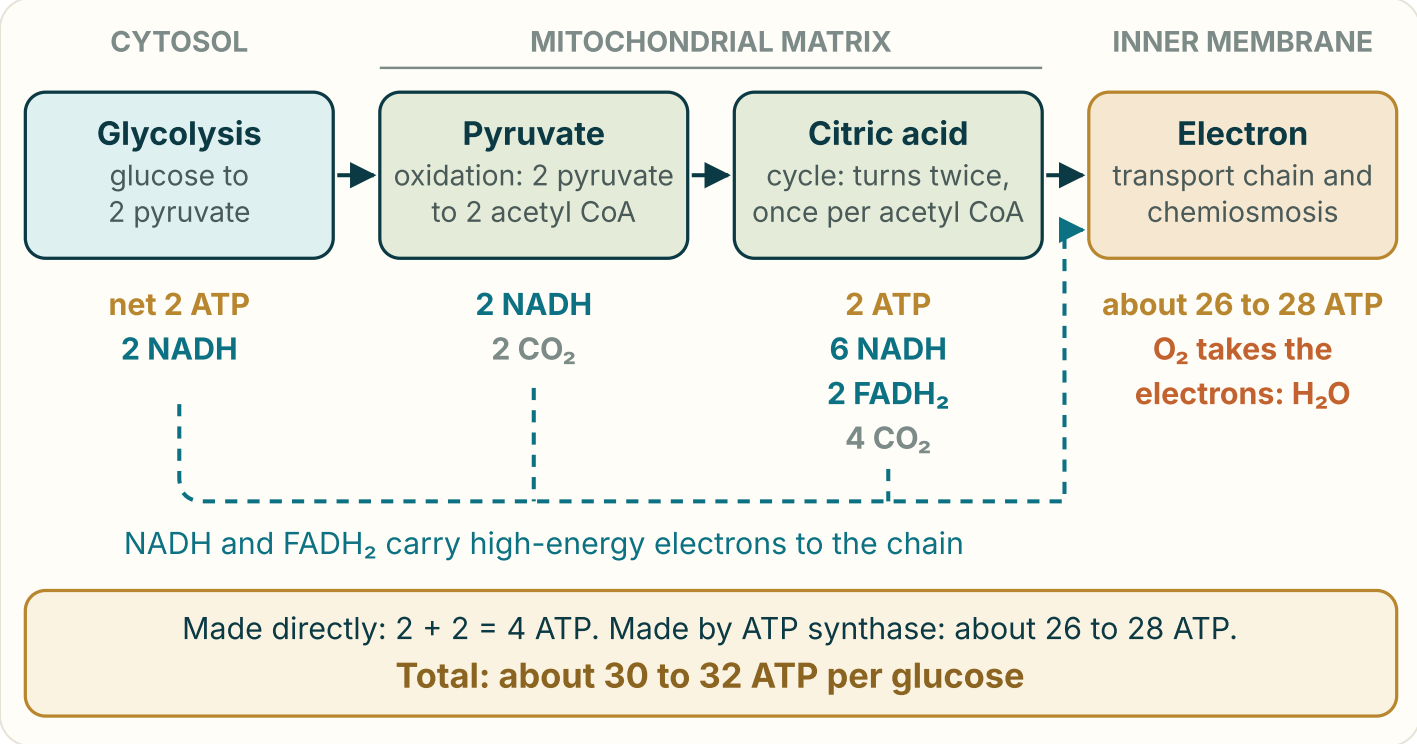
Enzymes lower activation energy and change only the rate. Competitive inhibitors use the active site (Vmax unchanged, beaten by substrate); noncompetitive inhibitors bind elsewhere (Vmax

lower). Allosteric regulation and feedback inhibition tune pathways; PFK is inhibited by ATP and citrate and activated by AMP.

Per glucose: glycolysis (cytosol) gives net 2 ATP and 2 NADH; pyruvate oxidation gives 2 NADH and 2 CO_2; the citric acid cycle gives 6 NADH, 2 $FADH_2$, 2 ATP and 4 CO_2. The electron transport chain pumps protons; ATP synthase makes ATP by chemiosmosis; O_2 is the final acceptor. Total about 30 to 32 ATP. Fermentation recycles NAD^+ and yields 2 ATP.

Light reactions in thylakoids split water at PS II (P680), pass electrons to PS I (P700) and $NADP^+$, and make ATP by chemiosmosis. The Calvin cycle in the stroma uses 9 ATP and 6 NADPH per G3P (3 CO_2). Rubisco's oxygen reaction causes photorespiration; C4 plants separate steps in space and CAM plants in time.

Redox reactions move energy: oxidation is loss of electrons and reduction is gain, and electrons fall step by step to oxygen instead of all at once. Fats enter respiration as acetyl CoA by beta oxidation and, being rich in C to H bonds, yield more than twice the ATP per gram of carbohydrate. Uncouplers let protons leak past ATP synthase, so fuel burns and heat rises but little ATP is made; brown fat does this on purpose.



Where the ATP comes from. The first three stages make only 4 ATP directly. Their real product is loaded electron carriers, which the chain cashes in for most of the ATP.

LOCK THESE IN

- Enzymes change rate only.
- 10 NADH × 2.5 + 2 $FADH_2$ × 1.5 + 4 = 32.
- Six CO_2 per glucose; none from glycolysis.
- Fermentation: 2 ATP.
- O_2 from photosynthesis comes from water.
- Calvin cycle per G3P: 9 ATP, 6 NADPH.

Key terms and comparisons

Item	Rule or value
Glucose oxidation	ΔG about −686 kcal/mol
ATP hydrolysis	About −7.3 kcal/mol
NADH; $FADH_2$	About 2.5 and 1.5 ATP
Total ATP	About 30 to 32 per glucose; about 34% efficiency
Proton pumps	Complexes I, III, IV
PS II; PS I	P680; P700
C4; CAM	Space; time

Worked cases

CASE 3.1 · ATP FOR TWO GLUCOSE

How many NADH, $FADH_2$ and ATP (at 2.5 and 1.5) come from two glucose molecules?

STEP 1 · CARRIERS

2 × 10 = **20 NADH**; 2 × 2 = **4 $FADH_2$**.

STEP 2 · OXIDATIVE

20 × 2.5 + 4 × 1.5 = 50 + 6 = 56.

STEP 3 · SUBSTRATE LEVEL

2 × 4 = 8. Total **64 ATP**.

CASE 3.2 · CALVIN CYCLE FOR GLUCOSE

How many CO_2, ATP and NADPH make one glucose?

STEP 1 · G3P NEEDED

Glucose is two G3P.

STEP 2 · MULTIPLY

2 × 3 CO_2 = **6**; 2 × 9 ATP = **18**; 2 × 6 NADPH = **12**.

TRAPS PEOPLE FALL INTO

- **Enzymes making reactions more exergonic.** ΔG is unchanged.
- **Fermentation making extra ATP.** It only recycles NAD^+.
- **The citric acid cycle using O_2.** It stops without O_2 only because NADH backs up.
- **"Dark reactions" running in the dark.** The Calvin cycle needs ATP and NADPH from light.

Chapter 3 self-test · six items

1. Coupling a +4.0 kcal/mol reaction to ATP hydrolysis gives what overall ΔG?

A. −3.3 kcal/mol

B. +3.3 kcal/mol

C. −11.3 kcal/mol

D. +11.3 kcal/mol

A. −3.3 kcal/mol +4.0 + (−7.3) = −3.3, so the pair proceeds.

2. Adding much more substrate restores full speed with a drug present. What kind of drug is it?

A. An irreversible inhibitor
B. A noncompetitive inhibitor
C. An allosteric activator
D. A competitive inhibitor

D. A competitive inhibitor Only competitive inhibition can be outcompeted, leaving Vmax unchanged.

3. Where does ATP synthase sit in a mitochondrion?

A. The intermembrane space
B. The outer membrane
C. The inner membrane
D. The cytosol

C. The inner membrane It spans the inner membrane, using protons flowing back into the matrix.

4. Which molecule is the final electron acceptor in aerobic respiration?

A. Carbon dioxide
B. Oxygen
C. Pyruvate
D. NAD^+

B. Oxygen O_2 accepts electrons at complex IV and becomes water.

5. Which enzyme fixes CO_2 in C4 mesophyll cells?

A. Rubisco
B. Phosphofructokinase
C. ATP synthase
D. PEP carboxylase

D. PEP carboxylase PEP carboxylase has no affinity for O_2, so it keeps fixing in hot conditions.

6. What does photosystem II supply that photosystem I does not?

A. Carbon fixed into a G3P
B. Electrons pulled from water
C. NADPH made in the stroma
D. Cyclic ATP with no O_2

B. Electrons pulled from water Water is split at PS II, releasing O_2 and refilling P680.

CHAPTER 4

Cell Communication and Cell Division

Read it in full: **Chapter 4 in the textbook**. See it in motion: **Cell Communication Lab** and **Cell Cycle Lab** and **Meiosis Lab**.

What to know

Signals act by contact, paracrine, synaptic, autocrine or endocrine routes. Signaling runs reception, transduction and response. GPCRs act through G proteins and GTP; RTKs dimerize and autophosphorylate; ligand-gated channels open for ions; steroids bind intracellular receptors. Kinase cascades and second messengers (cAMP, Ca^{2+}, IP_3, DAG) relay and amplify signals.

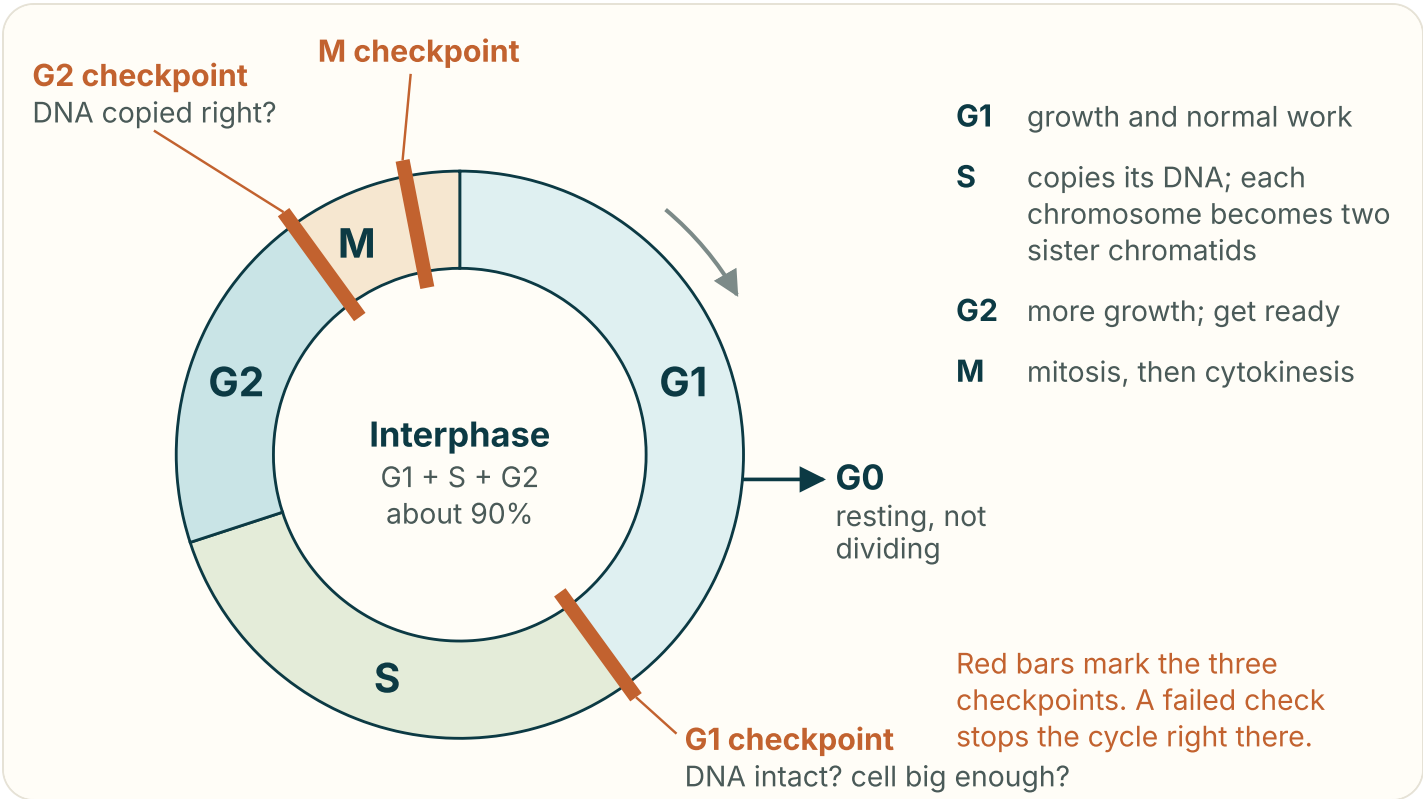
Apoptosis is orderly caspase-driven death with no inflammation; the intrinsic path releases cytochrome c (Bcl-2 blocks it) and the extrinsic path uses death receptors. Necrosis swells, bursts

and inflames.

The cell cycle is G1, S, G2 and M. Mitosis runs prophase, prometaphase, metaphase, anaphase and telophase; cytokinesis uses a cleavage furrow (animals) or a cell plate (plants). Cyclins and Cdks (MPF) drive it, with checkpoints at G1, G2 and M. Cancer comes from several mutations: oncogenes (gain of function, one copy) and tumor suppressors (loss of function, both copies).

Meiosis makes four unique haploid cells: meiosis I separates homologs after synapsis and crossing over; meiosis II separates sisters. Variation comes from independent assortment (2^n), crossing over and random fertilization. Nondisjunction causes aneuploidy.

Checkpoints exist because errors are costly: the M checkpoint holds anaphase until every kinetochore is attached to both poles, then the anaphase promoting complex lets separase cut cohesins. Normal cells stop dividing when crowded and need an anchor; cancer cells ignore both rules, make their own growth signals and often turn on telomerase. Nondisjunction risk for trisomy 21 rises with maternal age.



The cell cycle and its checkpoints. Most of a cell's life is interphase. The three checkpoints are the brakes that cancer cells lose.

LOCK THESE IN

- Reception, transduction, response.
- Count centromeres for chromosomes.
- Cyclin levels swing; Cdk levels stay.
- Gas pedal = oncogene; brakes = tumor suppressor.
- Meiosis I: homologs. Meiosis II: sisters.
- Humans: $2^{23} \approx 8.4$ million assortments.

Counting in a human cell

Stage	Chromosomes	Chromatids
G1	46	46
G2 to metaphase	46	92
Anaphase (mitosis)	92	92
After meiosis I	23	46
After meiosis II	23	23

Worked cases

CASE 4.1 · ASSORTMENT AND COUNTS

An organism has 2n = 10. How many chromosomes does each cell have after meiosis II, and how many gamete combinations can assortment give?

STEP 1 · HAPLOID

n = **5** chromosomes per cell.

STEP 2 · COMBINATIONS

$2^5 = \mathbf{32}$.

CASE 4.2 · SIGNAL AMPLIFICATION

One hormone activates 10 G proteins, each leads to 100 kinase activations, and each of those switches on 100 enzymes. How many enzymes end up active?

STEP 1 · MULTIPLY

10 × 100 × 100 = **100,000**.

WHY IT MATTERS

Tiny hormone doses have large effects because each step multiplies.

TRAPS PEOPLE FALL INTO

- **Steroids needing second messengers.** They bind intracellular receptors.
- **Separating sisters in meiosis I.** Meiosis I separates homologs.
- **One tumor suppressor hit causing cancer.** Usually both copies and several genes.
- **Apoptosis causing inflammation.** Contents never spill.

Chapter 4 self-test · six items

1. Insulin binds a receptor that pairs up and phosphorylates tyrosines. Which receptor class is this?

A. Receptor tyrosine kinase
B. Ligand-gated ion channel
C. Intracellular steroid receptor
D. G protein-coupled receptor

A. Receptor tyrosine kinase RTKs dimerize and autophosphorylate.

2. Which enzyme makes cAMP from ATP?

A. Phospholipase C
B. Phosphodiesterase
C. Adenylyl cyclase
D. Protein kinase A

C. Adenylyl cyclase G proteins activate adenylyl cyclase; phosphodiesterase breaks cAMP down.

3. At which stage are chromosomes lined up on the plate?

A. Telophase
B. Prophase
C. Anaphase
D. Metaphase

D. Metaphase Chromosomes align midway between the poles in metaphase.

4. Which protein is called the guardian of the genome?

A. Ras
B. p53
C. Separase
D. Cyclin B

B. p53 p53 halts the cycle, starts repair or triggers apoptosis after DNA damage.

5. A plant's haploid gametophyte makes gametes. Which division does it use?

A. Mitosis only
B. Meiosis II
C. Fission
D. Meiosis I

A. Mitosis only Haploid cells cannot do meiosis; gametophytes make gametes by mitosis.

6. Which event happens in prophase I only?

A. DNA is replicated again
B. The nuclear envelope reforms
C. Synapsis and crossing over
D. Sister chromatids separate

C. Synapsis and crossing over Homologs pair and exchange segments only in prophase I.

CHAPTER 5

Mendelian Genetics and the Chromosomal Basis of Inheritance

Read it in full: **Chapter 5 in the textbook**. See it in motion: **Mendelian Genetics Lab** and **Chromosomes and Inheritance Lab**.

What to know

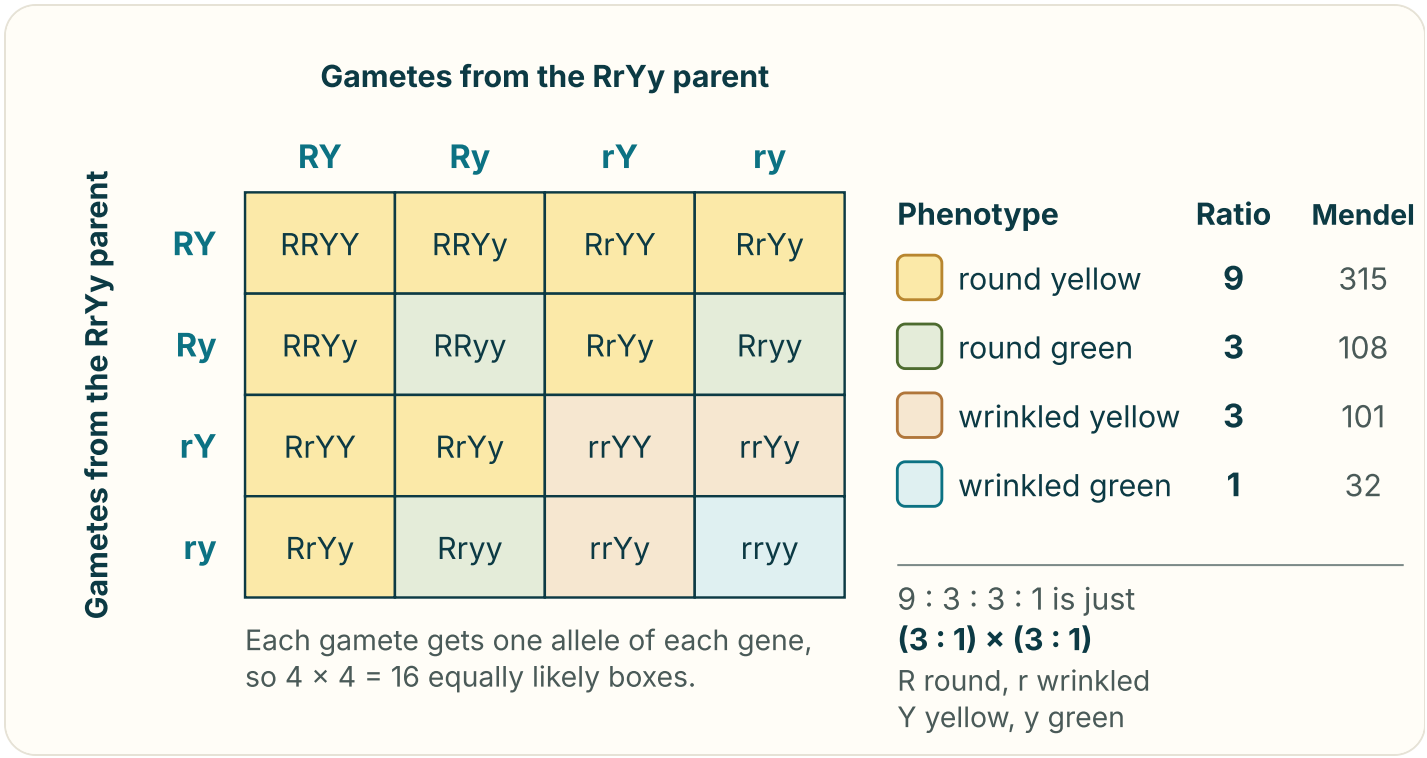
Inheritance is particulate. Alleles segregate into gametes (anaphase I), and genes on different chromosomes assort independently (metaphase I). Monohybrid F_2: 3:1 (1:2:1 genotypes). Dihybrid F_2: 9:3:3:1. A testcross to a homozygous recessive reveals an unknown genotype.

Multiply for "and," add for "or," solve one gene at a time. "Exactly k of n" uses the binomial; "at least one" is 1 minus none. An unaffected sibling of an affected child of carriers is a carrier with probability 2/3. Chi square = $\Sigma(O - E)^2/E$ with classes minus 1 df; critical values 3.84, 5.99, 7.81.

Incomplete dominance (1:2:1 phenotypes), codominance (AB, MN), multiple alleles (ABO), pleiotropy (sickle cell), lethal alleles (2:1), epistasis (9:3:4, 12:3:1, 9:7, 15:1), polygenic traits (bell curves), penetrance and expressivity.

X linked recessive traits mostly affect hemizygous males and never pass father to son; X inactivation makes females mosaics. Linked genes recombine by crossing over; 1 percent recombination = 1 map unit, maximum 50 percent. Nondisjunction causes trisomy 21, 47,XXY and 45,X; structural changes include deletions, duplications, inversions and translocations; imprinting and mitochondrial inheritance depend on the parent.

Pedigrees reward a few decisive clues: affected children of unaffected parents point to recessive inheritance, and an affected father with an affected son rules out X linkage. Morgan's white-eyed flies tied a gene to the X, and Sturtevant turned recombination frequencies into the first map. Polyploidy is common in plants, and triploids are sterile, which is how seedless bananas and watermelons are made.



The dihybrid cross, box by box. Two genes on different chromosomes sort independently, so the 16 boxes give 9 : 3 : 3 : 1.

LOCK THESE IN

- "And" multiply; "or" add.
- 2/3 for an unaffected sibling.
- 1% = 1 map unit; max 50%.
- X linked: never father to son.
- Modified ratios over 16 mean two genes.
- Meiosis I nondisjunction ruins all four gametes.

Ratios and rules

Situation	Answer
Aa × Aa	3:1; 1:2:1
Aa × aa	1:1
AaBb × AaBb	9:3:3:1
Gametes from n heterozygous genes	2^n
Recessive lethal	2:1
Recessive epistasis	9:3:4
Complementary genes	9:7
Chi square, 1 df	Critical 3.84

Worked cases

CASE 5.1 · A TRIHYBRID SHORTCUT

In AaBbCc × AaBbCc, what fraction is aaB_Cc?

STEP 1 · GENE A

aa: 1/4.

STEP 2 · GENE B

B_: 3/4.

STEP 3 · GENE C

Cc: 1/2.

STEP 4 · MULTIPLY

1/4 × 3/4 × 1/2 = **3/32**.

CASE 5.2 · CHI SQUARE ON A TESTCROSS

A dihybrid testcross gives 130, 120, 128 and 122 (500 total). Does it fit 1:1:1:1?

STEP 1 · EXPECTED

125 each.

STEP 2 · TERMS

25/125 + 25/125 + 9/125 + 9/125 = 0.20 + 0.20 + 0.072 + 0.072.

STEP 3 · TOTAL

χ^2 = **0.544**, below 7.81 (3 df): the genes assort independently.

TRAPS PEOPLE FALL INTO

- **Dominant meaning common.** Dominance is about one heterozygote.
- **Forgetting the 2/3.** The unaffected sibling cannot be aa.
- **Recombination above 50%.** It caps at 50%.
- **Linked meaning sex linked.** Linked means the same chromosome.

Chapter 5 self-test · six items

1. A color-blind man has children with a woman who is not a carrier. What fraction of daughters are carriers?

A. All of them

B. Half of them

C. One quarter

D. None of them

A. All of them Every daughter receives his X with the allele.

2. Three children are born to two carriers of a recessive trait. What is the chance exactly two are affected?

A. 27/64
B. 3/64
C. 1/16
D. 9/64

D. 9/64 Three orders × (1/4)(1/4)(3/4) = 3 × 3/64 = 9/64.

3. A heterozygous red-white snapdragon is pink. Selfing pink plants gives which phenotype ratio?

A. 3 red : 1 white only
B. 2 pink : 1 red : 0 white
C. 1 red : 2 pink : 1 white
D. 9 : 3 : 3 : 1 ratio

C. 1 red : 2 pink : 1 white With incomplete dominance each genotype shows its own phenotype.

4. Two genes are 8 map units apart. What percent of testcross offspring are recombinant?

A. 92 percent
B. 8 percent
C. 4 percent
D. 16 percent

B. 8 percent One map unit equals 1 percent recombination.

5. Which karyotype is the only viable human monosomy?

A. 45,X
B. 47,+21
C. 47,XXY
D. 47,XYY

A. 45,X Turner syndrome is 45,X.

6. A paternal 15q deletion causes which syndrome?

A. Turner syndrome
B. Klinefelter syndrome
C. Prader-Willi syndrome
D. Angelman syndrome

C. Prader-Willi syndrome Imprinting: losing the active paternal genes gives Prader-Willi.

CHAPTER 6

DNA Structure, Replication and Gene Expression

Read it in full: **Chapter 6 in the textbook**. See it in motion: **DNA Structure and Replication Lab** and **Gene Expression Lab**.

What to know

Griffith (transformation), Avery and colleagues (DNase stops it) and Hershey and Chase (^{32}P went in) proved DNA is the gene. DNA is an antiparallel double helix, 2 nm wide, about 10 bp per turn, wrapped on histone octamers (about 147 bp) into nucleosomes.

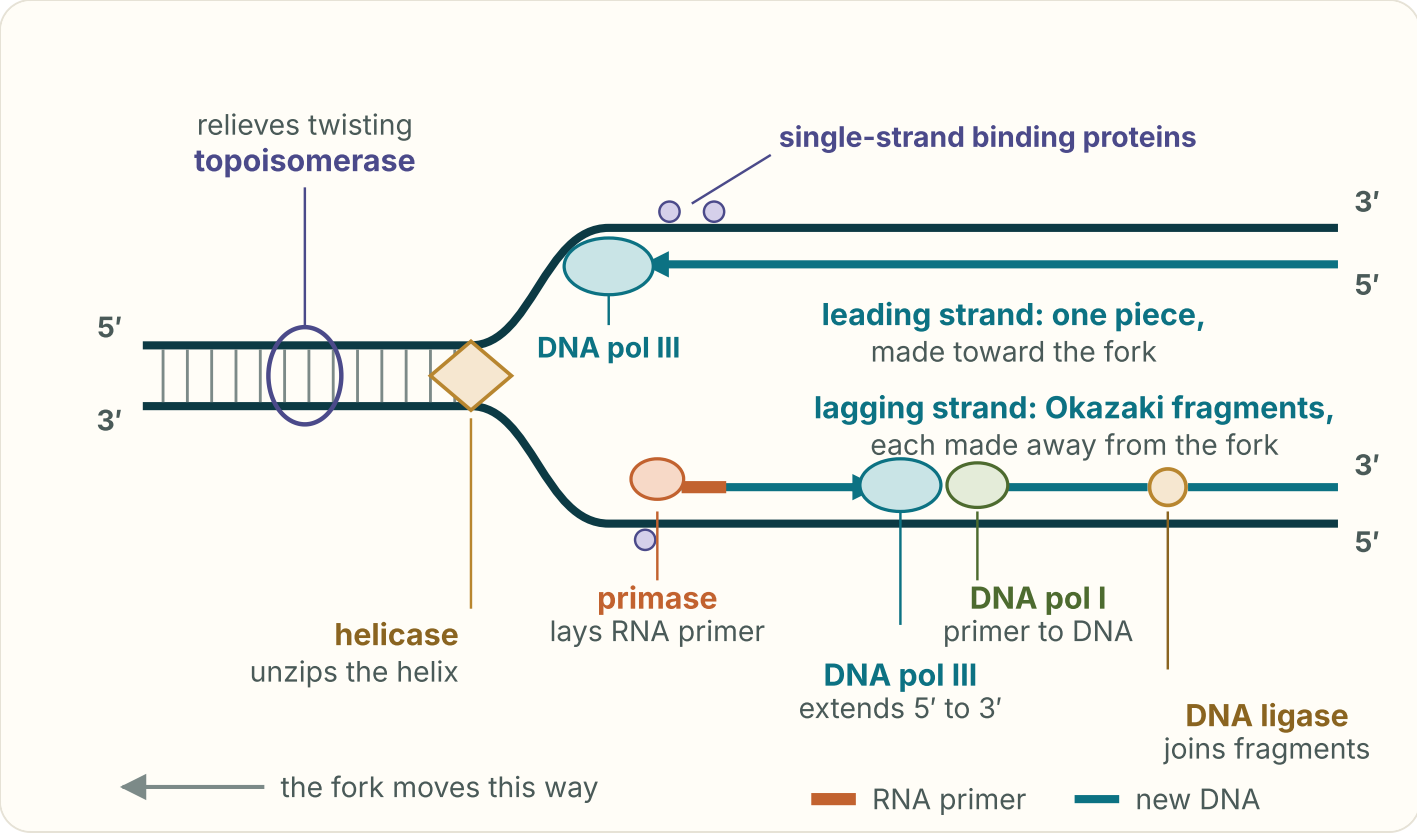
Replication is semiconservative (Meselson and Stahl). Helicase unwinds, topoisomerase relieves strain, primase lays RNA primers, polymerase adds 5′ to 3′ and proofreads, ligase seals. The leading strand is continuous; the lagging strand forms Okazaki fragments. Telomerase extends

chromosome ends. Repair includes mismatch, base excision, nucleotide excision (thymine dimers) and double-strand break repair.

RNA polymerase reads the template strand 3′ to 5′, needs no primer, and makes RNA matching the coding strand (U for T). Eukaryotic pre-mRNA gets a 5′ cap, poly-A tail and splicing (GU to AG introns); alternative splicing yields several proteins per gene.

The code: 64 codons, AUG start, UAA, UAG, UGA stop, redundant but unambiguous, nearly universal. tRNA synthetases load amino acids; ribosomes (A, P, E sites) make peptide bonds with rRNA. Mutations: silent, missense, nonsense, frameshift; repeat expansions; mutagens screened by the Ames test.

Proofreading and mismatch repair keep replication errors near one per human cell division. Germline mutations can be inherited; somatic ones affect only one cell line but can contribute to cancer. Most new mutations are neutral, many are harmful and a few help in a particular environment, which makes them the raw material of evolution.



The replication fork. Polymerase only adds to a 3′ end, so one new strand is made smoothly toward the fork and the other in pieces away from it.

LOCK THESE IN

- ^{32}P went in.
- Primer needed; build 5′ to 3′.
- mRNA = coding strand with U.
- Cap, tail, splice.
- AUG start; three stops.
- Frame first, then codon.

Key terms and comparisons

Item	Rule
Leading vs lagging	Continuous; Okazaki fragments
Template vs coding	Read; matches mRNA
Intron vs exon	Removed; kept
Ribosome sites	A next tRNA; P chain; E exit
Silent; missense; nonsense	Same amino acid; different; stop
Frameshift	Indel not a multiple of 3

Worked cases

CASE 6.1 · READING A CODING STRAND

A coding strand reads 5′-ATGTGGCATTGA-3′. Give the mRNA and the peptide.

STEP 1 · MRNA

Swap T for U: **5′-AUGUGGCAUUGA-3′**.

STEP 2 · CODONS

AUG Met, UGG Trp, CAU His, UGA stop.

STEP 3 · PEPTIDE

Met-Trp-His.

CASE 6.2 · OKAZAKI FRAGMENTS

A eukaryotic lagging strand of 9,000 nucleotides is made in fragments of about 150. About how many fragments and primers are needed?

STEP 1 · DIVIDE

9,000 ÷ 150 = **60 fragments**.

STEP 2 · PRIMERS

One per fragment: about **60 RNA primers**, each later replaced and sealed by ligase.

TRAPS PEOPLE FALL INTO

- **mRNA matching the template.** It matches the coding strand.
- **Any indel causing a frameshift.** Multiples of three keep the frame.
- **Forgetting to reverse anticodons.** They are antiparallel to codons.
- **Bacteria splicing introns.** They cannot; use cDNA.

Chapter 6 self-test · six items

1. Which enzyme relieves overwinding ahead of the fork?

A. DNA helicase

B. DNA ligase

C. Topoisomerase

D. RNA primase

C. Topoisomerase Topoisomerase cuts, swivels and rejoins DNA ahead of the fork.

2. A tRNA anticodon is 3′-UAC-5′. Which codon does it read?

A. 5′-AUG-3′
B. 5′-CAU-3′
C. 5′-UAC-3′
D. 5′-GUA-3′

A. 5′-AUG-3′ Pair U with A, A with U, C with G, keeping the strands antiparallel.

3. What signals the end of most eukaryotic introns?

A. AAUAAA at the tail
B. AG at the 3′ end
C. AUG at the 5′ end
D. TATA at the start

B. AG at the 3′ end Introns begin with GU and end with AG.

4. Which change keeps the reading frame?

A. Deleting one single base
B. Inserting two extra bases
C. Inserting four extra bases
D. Deleting three bases together

D. Deleting three bases together Only multiples of three preserve the frame.

5. In Huntington disease, which repeat expands?

A. CAG
B. TTAGGG
C. CGG
D. GAATTC

A. CAG A CAG repeat adds a long glutamine stretch to huntingtin.

6. What does the Ames test detect?

A. The sequence of a short DNA
B. Whether a gene has introns
C. Which bacteria carry plasmids
D. Whether a chemical is mutagenic

D. Whether a chemical is mutagenic His^- Salmonella that revert to His^+ reveal mutagens.

CHAPTER 7

Gene Regulation and Biotechnology

Read it in full: **Chapter 7 in the textbook**. See it in motion: **Gene Regulation Lab** and **Biotechnology Lab**.

What to know

Operons have a promoter, an operator and structural genes. The lac operon is inducible (allolactose releases the repressor; cAMP-CAP activates when glucose is low). The trp operon is repressible (tryptophan activates the repressor) and uses attenuation. Operators are cis-acting; repressors are trans-acting.

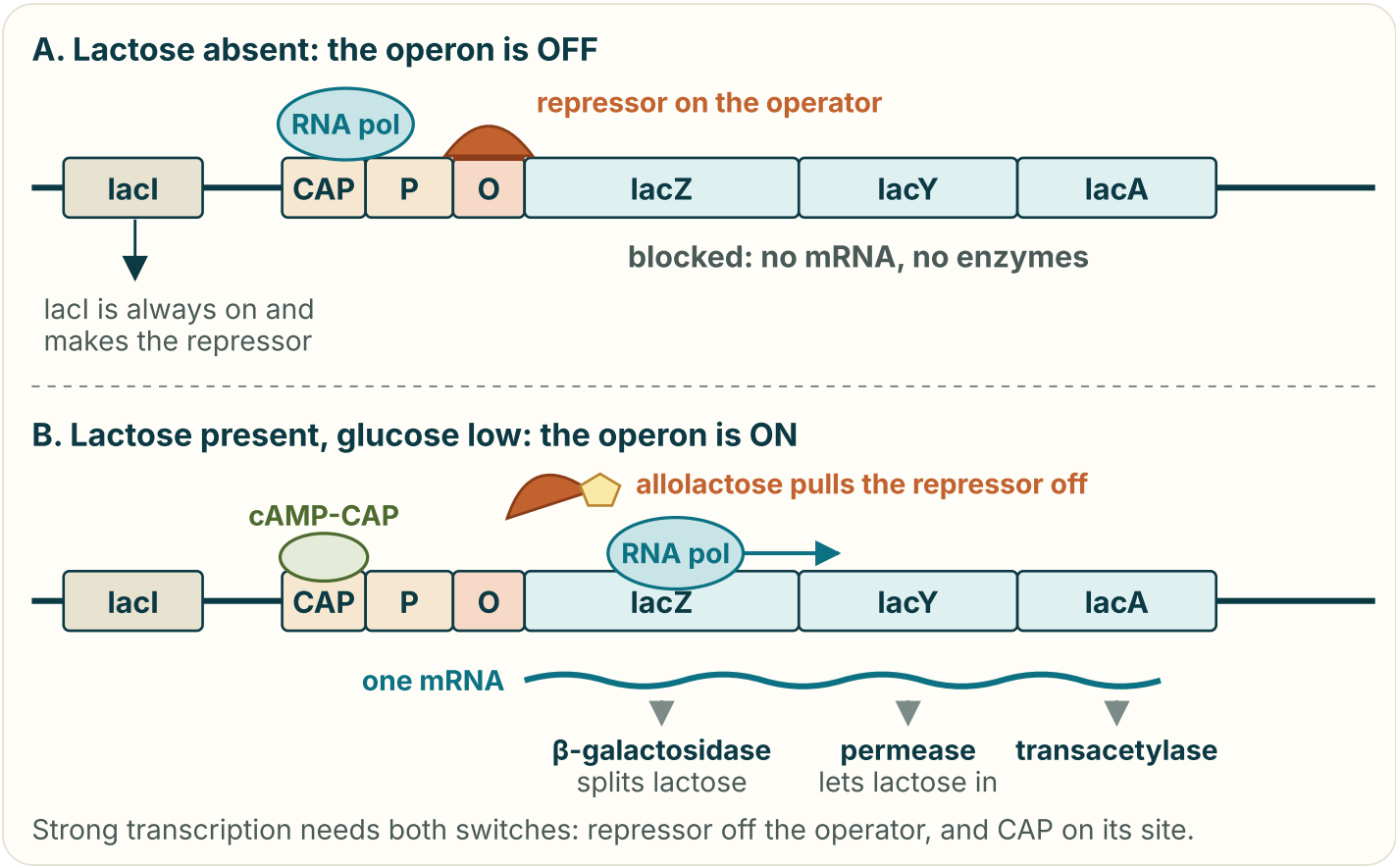
Eukaryotes regulate at chromatin (acetylation opens; DNA methylation silences), transcription (enhancers, activators, mediator, combinatorial control), RNA processing, mRNA stability and

microRNAs, translation and protein breakdown. Epigenetic marks pass through cell divisions without sequence change.

Development uses differential gene expression: cytoplasmic determinants, induction, morphogens (Bicoid), and a fly cascade from gap to pair-rule to segment polarity to Hox genes. Stem cells are totipotent, pluripotent or multipotent; four factors make iPS cells.

Tools: restriction enzymes and ligase, plasmid vectors, cDNA, gel electrophoresis (short runs farthest), PCR (2^n copies), Sanger sequencing (ddNTPs), CRISPR-Cas9 (20 nt guide, NGG PAM; NHEJ knockouts, HDR edits). Uses include insulin, gene therapy, STR forensics and Bt crops; ethics asks safe, effective and right.

Combinatorial control lets a few thousand transcription factors run about 20,000 genes: each enhancer needs a particular mix of activators. MicroRNAs pair with target mRNAs to block translation or trigger cutting, and one microRNA can regulate hundreds of targets. iPS cells avoid immune rejection because they come from the patient, and the 2023 CRISPR therapy for sickle cell disease restarts fetal hemoglobin production.



The lac operon, off and on. The repressor is the lactose switch and CAP is the glucose switch. Both must be in the right place for strong transcription.

LOCK THESE IN

- lac: lactose present, glucose absent.
- Inducible catabolic; repressible anabolic.
- Acetylation opens; methylation silences.
- Bicoid, gap, pair-rule, segment polarity, Hox.
- PCR: 2^n.
- CRISPR needs NGG.

Key terms and comparisons

Item	Rule
Inducer vs corepressor	Turns repressor off; turns it on
Cis vs trans	DNA site; diffusible product
Totipotent vs pluripotent	Whole organism; all body cells
PCR steps	94 to 98, 50 to 65, about 72 °C
Gel	DNA runs to + pole; short farthest
NHEJ vs HDR	Knockout; precise edit

Worked cases

CASE 7.1 · PCR COPIES

How many copies does PCR give after 20 cycles from one molecule?

STEP 1 · 2^N

2^{20} = **1,048,576**, about a million.

CASE 7.2 · A LAC MUTANT

A lacI$^-$ cell grows on lactose with no glucose. Then a second strain has a super repressor that cannot bind allolactose. Predict each.

STEP 1 · LACI$^-$

No working repressor; CAP bound: **high** expression.

STEP 2 · SUPER REPRESSOR

Repressor stays on the operator even with lactose: **off**.

TRAPS PEOPLE FALL INTO

- **Lactose alone giving full lac output.** Glucose must also be low.
- **Plasmid operators rescuing lacO^c.** Operators act only in cis.

- **Long DNA running farthest.** Short fragments run farthest.
- **Somatic edits being inherited.** Only germline edits pass on.

Chapter 7 self-test · six items

1. With glucose and lactose both present, lac transcription is what?

A. Constitutive
B. Low (basal)
C. Fully off
D. High

B. Low (basal) The repressor is off, but low cAMP keeps CAP off the DNA.

2. What does attenuation in the trp operon depend on?

A. Ribosome speed in the leader
B. cAMP bound to the CAP protein
C. Methylation of the operator
D. Splicing of the leader RNA

A. Ribosome speed in the leader Coupled translation of the leader decides whether a terminator forms.

3. About how long is a microRNA?

A. About 5 nucleotides
B. About 2,000 nucleotides
C. About 180 nucleotides
D. About 22 nucleotides

D. About 22 nucleotides Dicer trims the hairpin to about 22 nucleotides.

4. A fly has legs where antennae should be. Which gene class is involved?

A. A gap gene
B. A segment polarity gene
C. A Hox (homeotic) gene
D. A pair-rule gene

C. A Hox (homeotic) gene Antennapedia is a Hox mutation that swaps body part identity.

5. Which enzyme cuts at GAATTC and leaves sticky ends?

A. Reverse transcriptase
B. Taq polymerase
C. DNA ligase
D. EcoRI enzyme

D. EcoRI enzyme EcoRI is a restriction enzyme with a palindromic site.

6. A forensic profile compares what kind of site?

A. Mitochondrial ribosomes
B. Single exons of one gene
C. Short tandem repeats
D. Telomere repeats only

C. Short tandem repeats STR repeat numbers vary widely among people.

CHAPTER 8

Evolution, Natural Selection and Population Genetics

Read it in full: **Chapter 8 in the textbook**. See it in motion: **Evolution and Natural Selection Lab** and **Population Genetics Lab**.

What to know

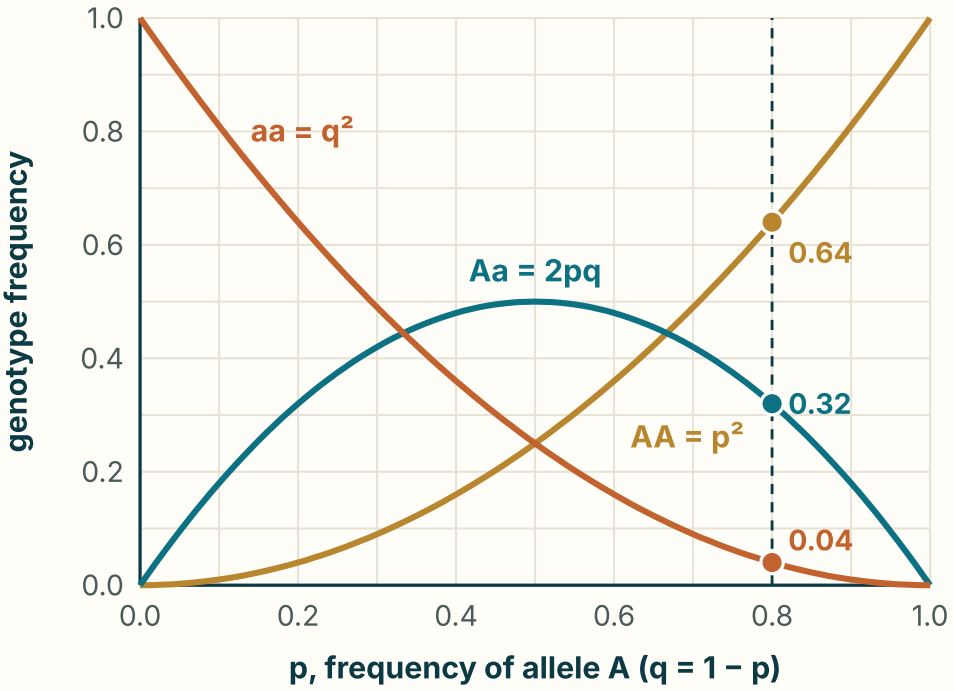
Evolution is descent with modification, measured as allele frequency change. Darwin (and Wallace) drew on Lyell, Cuvier, Malthus and breeders. Natural selection follows from heritable variation, overproduction and limited resources; individuals are selected, populations evolve, and only heritable traits count.

Evidence: direct observation (finches, soapberry bugs, MRSA), homology (forelimbs, embryos, the genetic code), vestigial structures and pseudogenes (GULO), convergent evolution, transitional fossils (Tiktaalik, whale series) and biogeography.

Hardy-Weinberg: $p + q = 1$ and $p^2 + 2pq + q^2 = 1$, holding with no mutation, random mating, no selection, a huge population and no gene flow. Start from q^2. CF (1 in 2,500) gives about 1 in 25 carriers.

Selection is the only consistently adaptive force; drift (founder, bottleneck) is random and strongest in small populations; gene flow homogenizes. Modes: directional, stabilizing, disruptive; plus sexual and balancing selection (heterozygote advantage, frequency dependence). Selection cannot make perfect organisms because of limited variation, history, trade-offs and chance.

Mutation is the source of all new alleles but acts slowly; recombination reshuffles alleles every generation. Small populations lose variation by drift and can fall into an extinction vortex, as Illinois prairie chickens nearly did until gene flow from other states restored their hatching rates. Coevolution, such as newts and garter snakes or pathogens and immune systems, keeps the target moving.



Wildflower example

p = 0.8 red, q = 0.2 white

AA red $0.8^2 = 0.64$

Aa pink $2(0.8)(0.2) = 0.32$

aa white $0.2^2 = 0.04$

Sum: 0.64 + 0.32 + 0.04 = 1

Of 500 plants: 320, 160, 20

Heterozygotes peak at 0.5 when p = q = 0.5. When a recessive allele is rare, most copies hide in carriers.

Hardy-Weinberg, drawn to scale. Pick any allele frequency p, read up, and the three curves give the genotype frequencies. They always add to 1.

LOCK THESE IN

- Populations evolve.
- Homology = ancestry; analogy = convergence.
- Start from q^2.
- Five Hardy-Weinberg conditions.
- Drift strongest in small populations.
- Fitness = reproductive success.

Formulas and forces

Item	Rule
Allele frequency	p = (2 AA + Aa) ÷ 2N
Genotypes	p^2, 2pq, q^2
Selection	Adaptive; changes allele frequencies
Drift	Random; erodes variation
Gene flow	Makes populations alike
Nonrandom mating	Changes genotypes, not alleles

Worked cases

CASE 8.1 · ALLELE COUNTS

A population has 360 AA, 480 Aa and 160 aa. Find p and q and test for equilibrium.

STEP 1 · COUNT A

2(360) + 480 = 1,200 of 2,000: p = **0.6**, q = **0.4**.

STEP 2 · EXPECTED

0.36, 0.48, 0.16 of 1,000: 360, 480, 160.

STEP 3 · RESULT

Observed matches expected: **in equilibrium**.

CASE 8.2 · CARRIER FREQUENCY

A recessive trait shows in 1 in 400 people. Estimate the carrier frequency.

STEP 1 · Q^2

1/400 = 0.0025, so q = **0.05**.

STEP 2 · P

0.95.

STEP 3 · CARRIERS

$2pq = 2 \times 0.95 \times 0.05 =$ **0.095**, about 1 in 10.5.

TRAPS PEOPLE FALL INTO

- **"Needed to" explanations.** Variants already existed; others died.
- **Square-rooting the dominant fraction.** It is $p^2 + 2pq$.
- **Drift as adaptive.** It is chance.
- **Fitness as strength.** It is reproductive success.

Chapter 8 self-test · six items

1. Who argued that slow geological processes act at the same rates now as in the past?

A. Malthus
B. Lamarck
C. Cuvier
D. Lyell

D. Lyell Lyell's uniformitarianism implied an old Earth.

2. Whale pelvic bones are an example of what?

A. A new adaptation
B. A vestigial structure
C. A byproduct of drift
D. An analogous structure

B. A vestigial structure They are reduced remnants of structures that worked in ancestors.

3. If q = 0.1, what share of people are heterozygous?

A. 0.18
B. 0.01
C. 0.81
D. 0.10

A. 0.18 2pq = 2 × 0.9 × 0.1 = 0.18.

4. Which mechanism makes two neighboring populations more alike?

A. Divergent selection
B. A small founder event
C. Gene flow by migration
D. Genetic drift by chance

C. Gene flow by migration Migration moves alleles and evens out differences.

5. Where malaria is common, why does the sickle cell allele persist?

A. Mutation constantly replaces it
B. Heterozygotes resist severe malaria
C. Homozygotes have the highest fitness
D. Drift keeps every allele forever

B. Heterozygotes resist severe malaria Heterozygote advantage is a form of balancing selection.

6. Why can't selection build a perfect organism?

A. It works only on existing variation
B. It always aims at more complex forms
C. It acts only on single genes
D. It creates the mutations it needs

A. It works only on existing variation Selection has no foresight and is bound by history and trade-offs.

CHAPTER 9

Speciation, Phylogeny and the History of Life

Read it in full: **Chapter 9 in the textbook**. See it in motion: **Speciation Lab** and **Phylogeny Lab**.

What to know

The biological species concept rests on interbreeding in nature with fertile offspring; morphological, ecological and phylogenetic concepts cover fossils and asexual organisms. Prezygotic barriers (habitat, temporal, behavioral, mechanical, gametic) and postzygotic barriers (hybrid viability, fertility, breakdown) keep species apart.

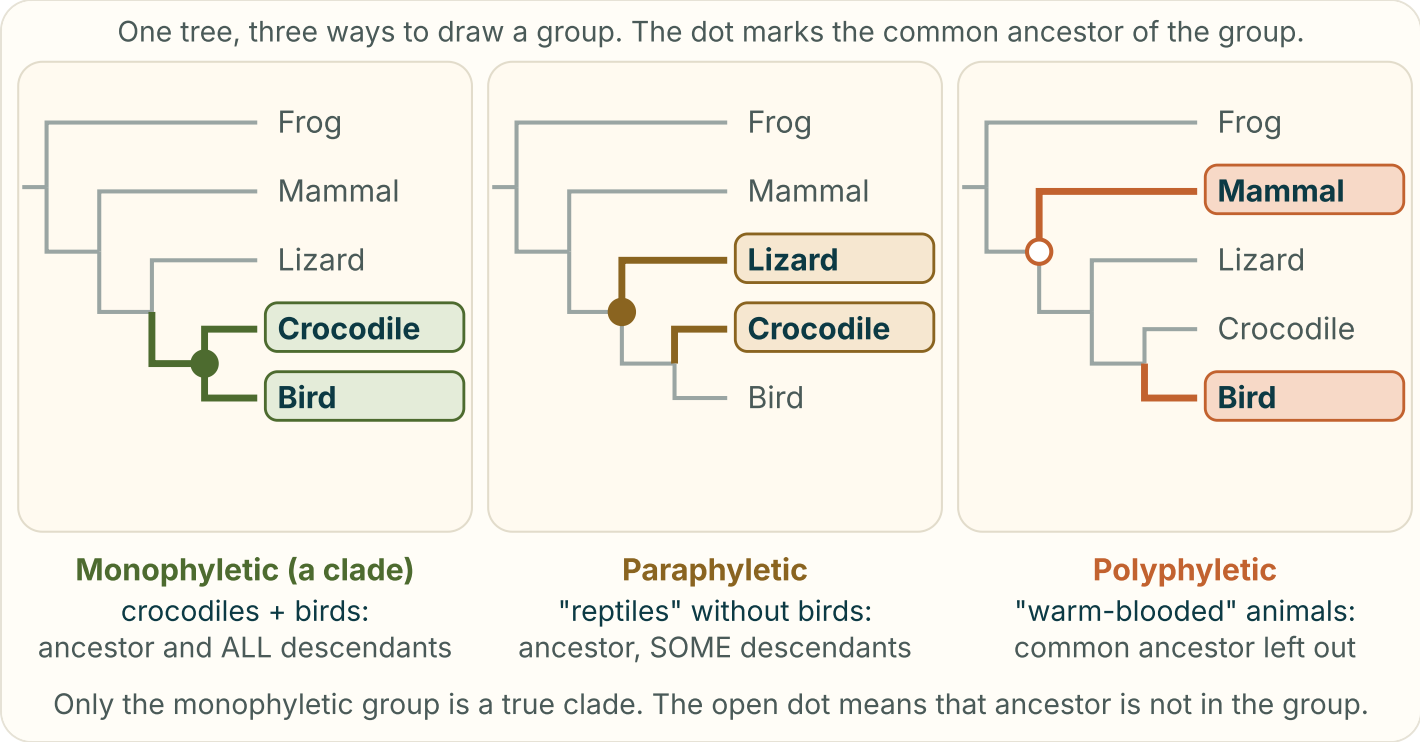
Allopatric speciation follows a geographic barrier; sympatric speciation happens by polyploidy (allopolyploids form in one generation), habitat differentiation or sexual selection. Hybrid zones show reinforcement, fusion or stability. Tempo can be punctuated or gradual.

Trees show descent: nodes are ancestors, sister taxa share the most recent ancestor, tips rotate freely. Clades (monophyletic) are defined by shared derived characters, found with an outgroup; paraphyletic and polyphyletic groups are rejected. Parsimony picks the fewest changes; molecular clocks date splits.

Earth about 4.6 billion years; life by 3.5 billion. Origin of life: monomers, polymers, protocells, RNA world. Dating: half-lives (C-14, 5,730 years). Events: oxygen 2.4 billion, eukaryotes 1.8

billion, Cambrian 535 to 525 million; five mass extinctions (end-Permian worst, end-Cretaceous 66 million) followed by adaptive radiations.

Speciation intervals vary from a few thousand years in young cichlid lakes to millions of years, and the average to full isolation is often a few million years. Molecular clocks work because some genes gain neutral changes at a fairly steady rate, calibrated against dated fossils. Mass extinctions removed lineages regardless of how well adapted they were, and recovery took 5 to 10 million years or more.



Good groups and bad groups. A clade keeps an ancestor and every one of its descendants. Leave one out and the group is paraphyletic; skip the ancestor and it is polyphyletic.

LOCK THESE IN

- Fertile offspring in nature.
- Pre before fertilization; post after.
- Allopolyploid = doubled hybrid.
- Clade = ancestor plus all descendants.
- Half-life halves what is left.
- Permian 252; Cretaceous 66.

Key terms and comparisons

Item	Rule or value
Allopatric vs sympatric	Barrier; same area
Reinforcement	Hybrids unfit; prezygotic barriers strengthen
Monophyletic	Ancestor and all descendants
Paraphyletic	Leaves out some descendants
Polyphyletic	Lacks the common ancestor
C-14; K-40; U-238	5,730 years; 1.3 billion; 4.5 billion

Worked cases

CASE 9.1 · AN ALLOPOLYPLOID

Parents with 2n = 12 and 2n = 20 form a sterile hybrid that later doubles. Give both counts.

STEP 1 · HYBRID

6 + 10 = **16**, unpaired, sterile.

STEP 2 · DOUBLED

16 × 2 = **32**, fertile.

CASE 9.2 · DATING A VOLCANIC LAYER

An ash layer keeps 1/8 of its original potassium-40 (half-life about 1.3 billion years). How old is it?

STEP 1 · HALF-LIVES

$1/8 = (1/2)^3$: three half-lives.

STEP 2 · MULTIPLY

3 × 1.3 billion = **about 3.9 billion years**.

WHY NOT CARBON

Carbon-14 is gone after about 50,000 to 75,000 years, so old layers need long half-life isotopes.

TRAPS PEOPLE FALL INTO

- **Any hybrid means one species.** The hybrid must be fertile.
- **Reading tip order.** Branches rotate.
- **Humans from chimps.** Cousins with a common ancestor.
- **Fossil gaps as proof of absence.** The record is biased.

Chapter 9 self-test · six items

1. Two sea urchin species release gametes together, but sperm cannot bind eggs of the other. Which barrier is this?

A. Gametic isolation
B. Temporal isolation
C. Hybrid breakdown
D. Mechanical isolation

A. Gametic isolation Bindin proteins must match egg receptors.

2. Apple maggot flies on apples versus hawthorns illustrate which mode?

A. Allopatric speciation by dispersal
B. Speciation by polyploidy
C. Sympatric speciation by habitat
D. Allopatric speciation by vicariance

C. Sympatric speciation by habitat They share a range but use different hosts with different timing.

3. What does a polytomy on a tree indicate?

A. The species are all extinct
B. The group is surely paraphyletic
C. Those taxa are ancestors of others
D. The branching order is unresolved

D. The branching order is unresolved More than two lineages from one node means the order is not yet known.

4. Which data best identify ancestral versus derived traits?

A. The number of living species
B. Comparison with an outgroup
C. The order of tips on a tree
D. The length of drawn branches

B. Comparison with an outgroup Traits shared with the outgroup are ancestral.

5. Which discovery supports the RNA world?

A. Proteins store all heredity
B. Lipids copy themselves exactly
C. DNA forms on hot clay
D. RNA can act as a catalyst

D. RNA can act as a catalyst Ribozymes, including the ribosome core, both store information and catalyze reactions.

6. What caused the end-Cretaceous extinction, according to the iridium layer?

A. Rising oxygen levels
B. An asteroid impact
C. Siberian volcanism alone
D. A long ice age

B. An asteroid impact Iridium and the Chicxulub crater point to an impact.

CHAPTER 10

Bacteria, Archaea, Viruses, Protists and Fungi

Read it in full: **Chapter 10 in the textbook**. See it in motion: **Prokaryotes Lab** and **Protists Lab** and **Fungi Lab**.

What to know

Prokaryotes have a nucleoid, plasmids and 70S ribosomes. Gram positive walls are thick peptidoglycan (purple); gram negative walls are thin with an LPS outer membrane (pink). Binary fission plus transformation, transduction and conjugation make them evolve fast. They show all four nutritional modes and alone fix nitrogen. Archaea lack peptidoglycan and include extremophiles and methanogens.

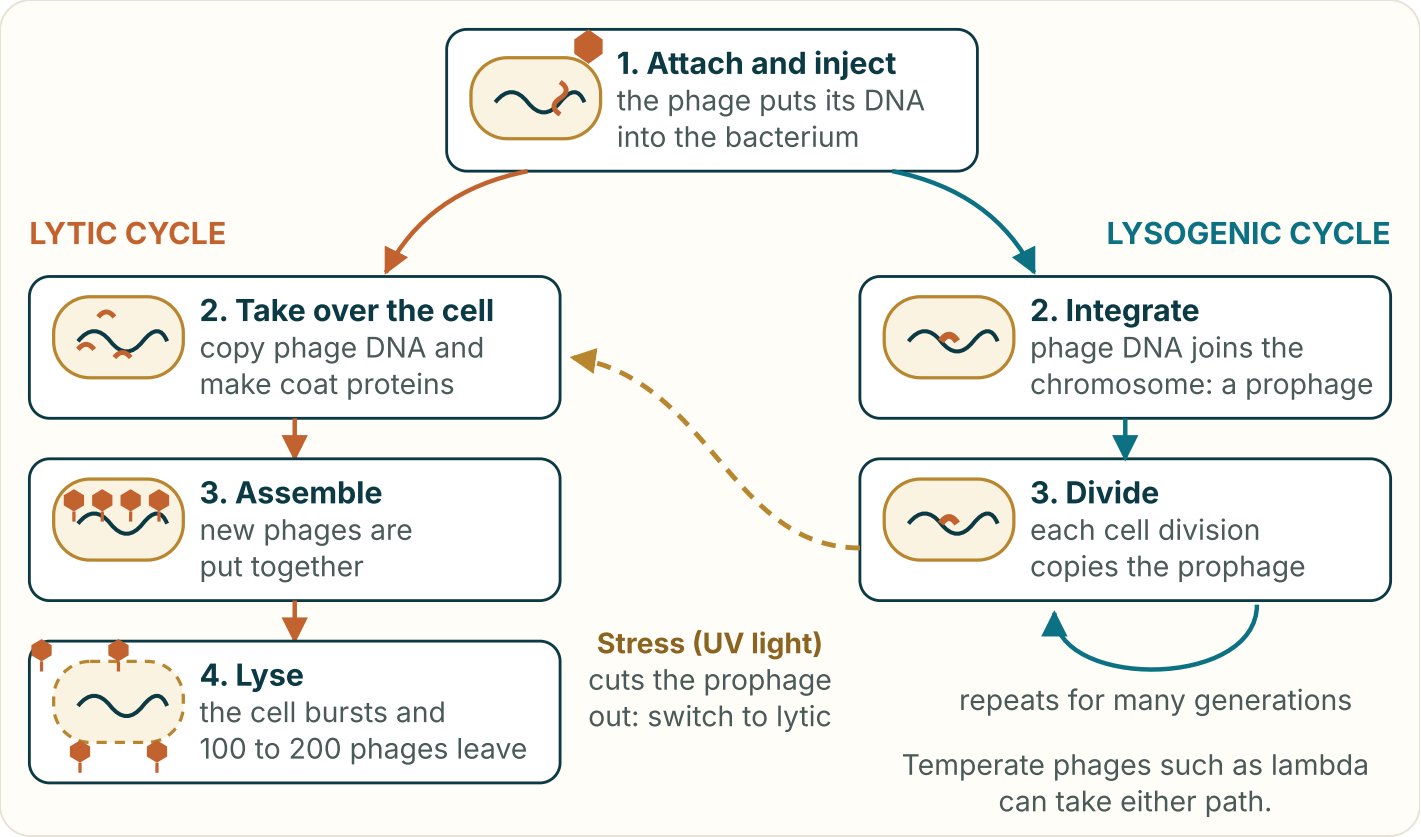
Viruses are nucleic acid in a capsid, sometimes enveloped; they replicate only in hosts. Phages are lytic or lysogenic (prophage). RNA viruses mutate fast. Retroviruses use reverse transcriptase and integrate as proviruses. Viroids are naked RNA; prions are misfolded protein.

Protists are paraphyletic eukaryotes. Mitochondria and plastids came from endosymbiosis; primary plastids have two membranes, secondary ones three or four. Supergroups: Excavata, SAR, Archaeplastida, Unikonta. Plasmodium cycles between mosquitoes and humans.

Fungi are absorptive heterotrophs with chitin walls, hyphae and mycelia; plasmogamy precedes karyogamy. Groups: chytrids, zygomycetes, glomeromycetes, ascomycetes, basidiomycetes. Microbes decompose, run the nitrogen cycle and form mutualisms. Koch's postulates link

microbes to disease; exotoxins are secreted proteins and endotoxins are LPS; resistance evolves by selection.

Microbes are essential partners: Rhizobium fixes nitrogen in legume nodules, mycorrhizal fungi supply phosphate, rumen and termite microbes digest cellulose, and gut bacteria make vitamin K and ferment fiber. Broad-spectrum antibiotics can disturb the gut community and let Clostridioides difficile overgrow. R plasmids move resistance genes between species, which is why resistance spreads quickly.



Two ways for a phage to live. The lytic cycle kills the host now. The lysogenic cycle rides along in the chromosome until stress flips it to lytic.

LOCK THESE IN

- Thick wall purple; thin wall pink.
- DNase stops transformation only.
- Lytic bursts; lysogenic hides.
- Provirus stays; prophage can leave.
- Count plastid membranes.
- Plasmogamy before karyogamy.

Key terms and comparisons

Item	Rule
Transformation; transduction; conjugation	Naked DNA; phage; pilus
Chemoautotroph	Inorganic energy; CO_2
Positive vs negative sense RNA	Acts as mRNA; copied first
Nitrification	NH_4^+ to NO_2^- to NO_3^-
Denitrification	NO_3^- to N_2
Exotoxin vs endotoxin	Secreted protein; LPS

Worked cases

CASE 10.1 · DOUBLING TIME

A bacterium divides every 30 minutes. How many cells from one after 4 hours?

STEP 1 · GENERATIONS

$240 \div 30 = 8$.

STEP 2 · CELLS

$2^8 = \mathbf{256}$.

CASE 10.2 · KOCH'S POSTULATES

A new bacterium is found in every patient, grown in pure culture, causes the disease in a healthy animal and is grown again from that animal. Which postulates are met?

STEP 1 · LIST

Found in every case (1), pure culture (2), causes disease (3), reisolated (4).

STEP 2 · RESULT

All four, so the case for causation is strong.

TRAPS PEOPLE FALL INTO

- **Antibiotics for viruses.** Viruses lack the bacterial targets.
- **Protists as a clade.** They are paraphyletic.
- **Fungi as plants.** Chitin, absorption, closer to animals.
- **Mushroom as the whole fungus.** The mycelium is the organism.

Chapter 10 self-test · six items

1. Why must canned foods be heated under pressure, above boiling?

A. Viruses form spores inside the cans
B. Endospores survive ordinary boiling
C. Archaea grow only at boiling point
D. Capsules block heat from reaching cells

B. Endospores survive ordinary boiling Endospores of bacteria such as the botulism agent survive boiling, so higher temperatures are needed.

2. Which archaea produce methane in cattle guts and swamps?

A. Methanogens
B. Extreme halophiles
C. Spirochetes
D. Cyanobacteria

A. Methanogens Methanogens are strict anaerobes that make methane.

3. Influenza vaccines are updated yearly mainly because the virus does what?

A. Forms endospores in the lungs
B. Carries R plasmids between hosts
C. Integrates as a permanent provirus
D. Mutates fast without proofreading

D. Mutates fast without proofreading RNA-dependent RNA polymerase lacks proofreading.

4. Diatoms belong to which supergroup?

A. Excavata
B. Unikonta
C. SAR clade
D. Archaeplastida

C. SAR clade Diatoms are stramenopiles in the SAR clade.

5. Which fungi are the only ones with flagellated spores?

A. Ascomycetes
B. Basidiomycetes
C. Zygomycetes
D. The chytrids

D. The chytrids Zoospores are a trait kept from the fungal ancestor.

6. Which partner in a lichen usually supplies sugars?

A. The fungus on its own
B. The alga or cyanobacterium
C. A nearby host plant root
D. Neither of the partners

B. The alga or cyanobacterium The photosynthetic partner makes carbon compounds; the fungus gives shelter, water and minerals.

CHAPTER 11

Plants: Diversity, Structure, Transport and Reproduction

Read it in full: **Chapter 11 in the textbook**. See it in motion: **Plant Diversity Lab** and **Plant Structure Lab** and **Plant Transport Lab** and **Plant Reproduction and Responses Lab**.

What to know

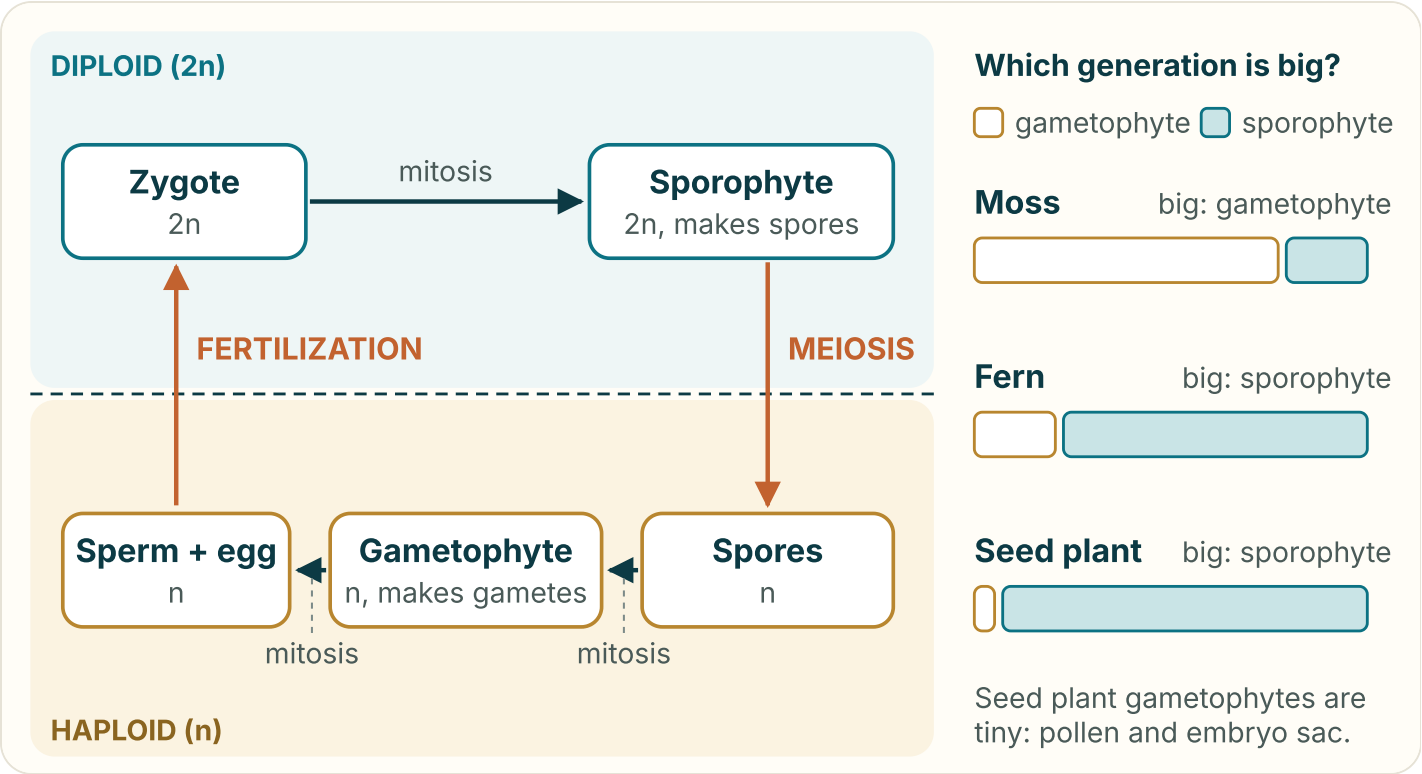
Land plants came from charophytes. Alternation of generations: sporophytes make spores by meiosis; gametophytes make gametes by mitosis. Bryophytes are gametophyte dominant; vascular plants add lignified xylem; seed plants add pollen and ovules; angiosperms add flowers, fruit and double fertilization.

Three tissue systems (dermal, vascular, ground) and cell types (parenchyma, collenchyma, sclerenchyma; dead xylem; living sieve tubes with companion cells). Apical meristems lengthen; vascular and cork cambia thicken. Monocots and eudicots differ in cotyledons, veins, bundles, roots and flower parts.

Water moves to lower Ψ ($= \Psi_S + \Psi_P$). The Casparian strip screens ions. Cohesion tension pulls xylem water with no ATP; guard cells open with K^+; ABA closes them. Phloem moves sugar by pressure flow from source to sink. Seventeen essential elements; mobile nutrients show in old leaves first.

Flowers: sepals, petals, stamens, carpels. Pollen is a two-cell male gametophyte; the embryo sac has seven cells and eight nuclei. Double fertilization: 2n zygote and 3n endosperm. Hormones: auxin, cytokinins, gibberellins, ABA, ethylene. Phytochrome (red to Pfr, far-red to Pr) times germination and flowering by night length.

Plants have no heart, yet they move water and sugar in opposite directions at the same time: water rises in dead xylem under tension, and sugar flows in living phloem under pressure. Roots get help from cation exchange in soil, nitrogen-fixing bacteria and mycorrhizae. Defense uses thorns, toxins, jasmonate signals that call in parasitoid wasps, and salicylic acid signals that set up systemic acquired resistance.



Alternation of generations. Meiosis makes spores, not gametes, in plants. Gametes come from the haploid gametophyte by mitosis.

LOCK THESE IN

- Spores by meiosis; gametes by mitosis.
- Xylem dead; phloem alive.
- Water to the more negative Ψ.
- Source to sink by pressure flow.
- Embryo 2n; endosperm 3n.
- Plants time night length.

Key terms and comparisons

Item	Rule
Monocot vs eudicot	1 vs 2 cotyledons; parallel vs net veins; scattered vs ring bundles
Mobile vs immobile nutrients	Old leaves first; young leaves first
Auxin; ABA; ethylene	Elongation; drought and dormancy; ripening
Short-day vs long-day	Long night needed; short night needed
Pr vs Pfr	Absorbs red; absorbs far-red, active

Worked cases

CASE 11.1 · WATER POTENTIAL

A cell has $\Psi_S = -0.9$ MPa and $\Psi_P = +0.4$ MPa. It sits in a solution of −0.7 MPa. Which way does water move?

STEP 1 · CELL

−0.9 + 0.4 = **−0.5 MPa**.

STEP 2 · COMPARE

−0.7 is lower, so water moves **out** of the cell.

CASE 11.2 · SEED PLOIDY

A monocot has 2n = 14. Give chromosome numbers in its endosperm, embryo and pericarp.

STEP 1 · ENDOSPERM

3n = **21**.

STEP 2 · EMBRYO

2n = **14**.

STEP 3 · PERICARP

Maternal ovary wall, 2n = **14**.

TRAPS PEOPLE FALL INTO

- **Gametes by meiosis in plants.** Meiosis makes spores.
- **Water moving away from negative Ψ.** It moves toward lower Ψ.
- **Palm wood.** Monocots lack a vascular cambium.
- **Plants measuring day length.** They measure darkness.

Chapter 11 self-test · six items

1. Which innovation do all vascular plants share but bryophytes lack?

A. Seeds in cones
B. Flowers and fruit
C. Pollen grains
D. Lignified xylem

D. Lignified xylem Lignin-reinforced xylem appears with vascular plants.

2. In a fern, which generation is the large leafy plant?

A. The gametophyte
B. The sporophyte
C. The prothallus
D. The protonema

B. The sporophyte Ferns are sporophyte dominant; the gametophyte is a small prothallus.

3. Which tissue makes wood?

A. The apical meristem
B. The cork cambium
C. The vascular cambium
D. The root pericycle

C. The vascular cambium It makes secondary xylem inward.

4. What drives xylem sap upward?

A. Transpiration from the leaves
B. ATP pumps in the vessels
C. Phloem loading in leaves
D. Root pressure acting alone

A. Transpiration from the leaves Evaporation creates tension, and cohesion carries the pull down the column.

5. A sprouting potato tuber is acting as what?

A. A sugar sink
B. A sugar source
C. A root system
D. A gametophyte

B. A sugar source It breaks down starch and exports sugar to growing shoots.

6. Which hormone makes a cereal seed's aleurone release amylase?

A. Ethylene
B. Abscisic acid
C. Gibberellin
D. Cytokinin

C. Gibberellin The embryo releases gibberellin, which signals amylase secretion.

CHAPTER 12

Animal Diversity

Read it in full: **Chapter 12 in the textbook**. See it in motion: **Animal Diversity Lab**.

What to know

Animals are multicellular ingestive heterotrophs without walls; development runs cleavage, blastula and gastrulation; Hox genes set the axis. Body plans vary in tissues, symmetry, germ layers (diploblastic or triploblastic) and body cavity (acoelomate, pseudocoelomate, coelomate).

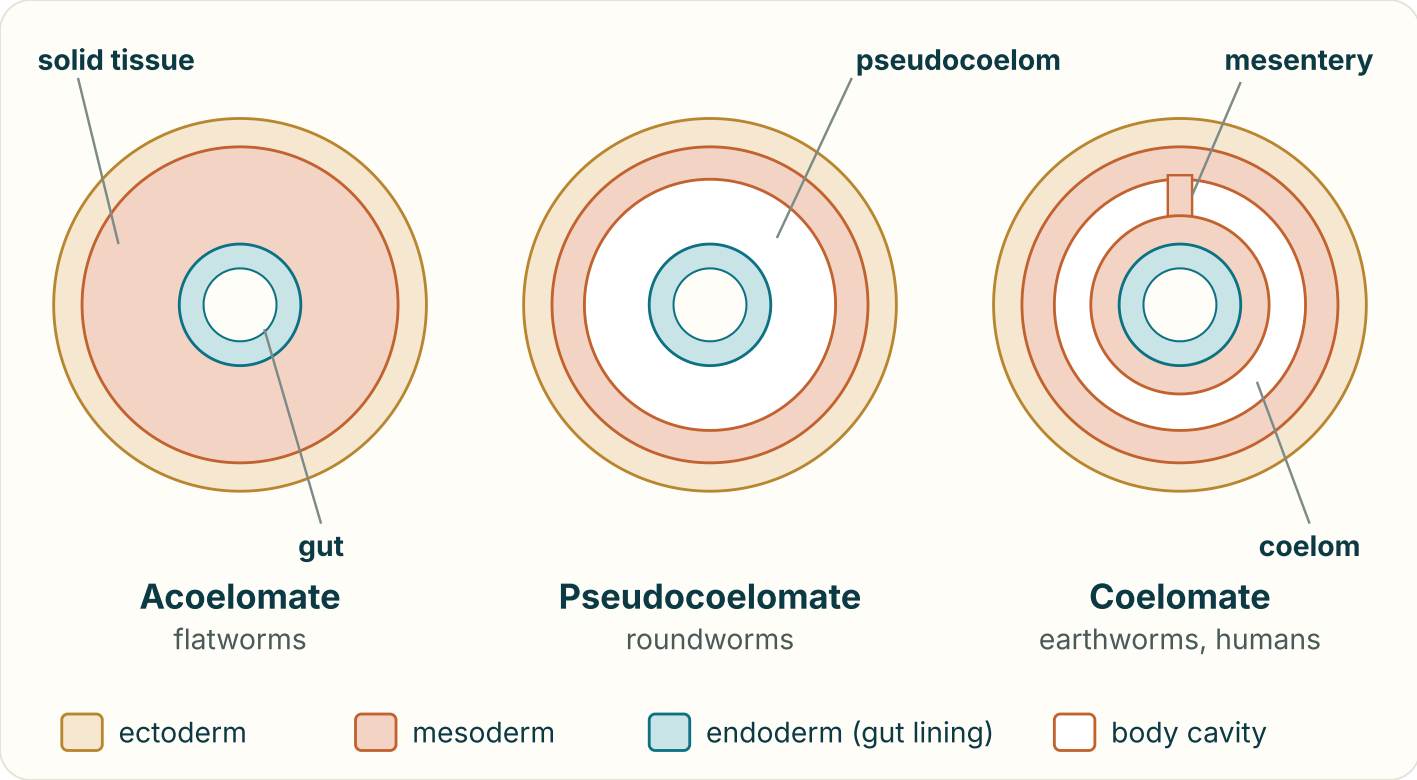
Protostomes: spiral, determinate cleavage; blastopore becomes the mouth. Deuterostomes: radial, indeterminate cleavage; blastopore becomes the anus. The tree: sponges and comb jellies, cnidarians, then Lophotrochozoa (flatworms, molluscs, annelids), Ecdysozoa (nematodes, arthropods) and Deuterostomia (echinoderms, chordates).

Sponges use choanocytes; cnidarians have cnidocytes and polyp or medusa forms; flatworms rely on diffusion; molluscs have foot, visceral mass and mantle; annelids are segmented; nematodes molt a cuticle; arthropods have chitin exoskeletons, jointed appendages and open circulation; echinoderms use a water vascular system.

Chordates have a notochord, dorsal hollow nerve cord, pharyngeal slits and post-anal tail. Innovations: skull and neural crest, backbone, jaws, bone and lungs, lobed fins and limbs, the

amniotic egg, feathers. Birds are reptiles. Mammals have milk, hair and three ear bones. Hominins walked upright long before brains grew; Homo sapiens arose in Africa about 300,000 years ago.

Arthropods are the most diverse animals, with over a million described species, and insects owe much of that to flight and complete metamorphosis, where larva and adult eat different foods. Amniotes split about 310 million years ago into synapsids (toward mammals) and sauropsids (reptiles, including birds). Hominin species often overlapped in time rather than forming a single line.



Where the mesoderm sits. Count the sides of the cavity lined by mesoderm: none, one or both.

LOCK THESE IN

- Protostome mouth first; deuterostome anus first.
- Coelom fully mesoderm lined.
- Ecdysozoa molt.
- Spider 8 legs, 0 antennae; insect 6 legs, 2 antennae.
- Four chordate traits.
- Bipedalism before big brains.

Key terms and comparisons

Group	Signature
Porifera	Choanocytes; no true tissues
Cnidaria	Cnidocytes; radial; two layers
Mollusca	Foot, visceral mass, mantle
Arthropoda	Chitin, jointed legs, molting
Echinodermata	Water vascular system; pentaradial adults
Chordata	Notochord, nerve cord, slits, tail
Amniotes	Amnion, chorion, yolk sac, allantois

Worked cases

CASE 12.1 · PLACING AN ANIMAL

An animal is pentaradial as an adult, bilateral as a larva, has tube feet and an ossicle skeleton. Where does it go?

STEP 1 · TUBE FEET

A water vascular system marks an **echinoderm**.

STEP 2 · DEVELOPMENT

Bilateral larvae show bilateral ancestry; echinoderms are **deuterostomes**.

CASE 12.2 · BRAIN GROWTH

Brain size rose from about 450 cm^3 (Australopithecus) to about 1,350 cm^3 (Homo sapiens). By how much, and by what factor?

STEP 1 · DIFFERENCE

1,350 − 450 = **900 cm^3**.

STEP 2 · FACTOR

1,350 ÷ 450 = **3 times**.

TRAPS PEOPLE FALL INTO

- **Deuterostomes as more advanced.** They are sister lineages.
- **Ticks as insects.** They are arachnids.
- **Chordate meaning vertebrate.** Lancelets and tunicates lack backbones.
- **Birds as not reptiles.** A clade must include birds.

Chapter 12 self-test · six items

1. Which animals are diploblastic?

A. Annelids
B. Cnidarians
C. Flatworms
D. Echinoderms

B. Cnidarians Cnidarians have only ectoderm and endoderm.

2. Which mollusc class undergoes torsion?

A. Bivalves
B. Cephalopods
C. Gastropods
D. No mollusc class

C. Gastropods Snails twist 180 degrees during development.

3. Insects breathe mainly through what?

A. Lungs with alveoli
B. Gills under a mantle
C. Book lungs
D. Tracheal tubes

D. Tracheal tubes Tracheae carry air directly to cells.

4. Vertebrate jaws evolved from what?

A. Pharyngeal arches
B. Vertebrae in the neck
C. Neural crest pigment
D. Lateral line organs

A. Pharyngeal arches Arches that supported anterior gill slits became jaws.

5. Which fish group is the closest living relative of tetrapods?

A. Lampreys
B. Lungfishes
C. Ray-finned fishes
D. Sharks and rays

B. Lungfishes Lobe-finned lungfishes are closest to tetrapods.

6. People of non-African ancestry carry about how much Neanderthal DNA?

A. None that is detectable
B. About 25 percent
C. About 50 percent
D. About 1 to 2 percent

D. About 1 to 2 percent Ancient DNA shows limited interbreeding.

CHAPTER 13

Animal Form, Function, Homeostasis, Reproduction and Development

Read it in full: **Chapter 13 in the textbook**. See it in motion: **Animal Form and Function Lab** and **Reproduction and Development Lab**.

What to know

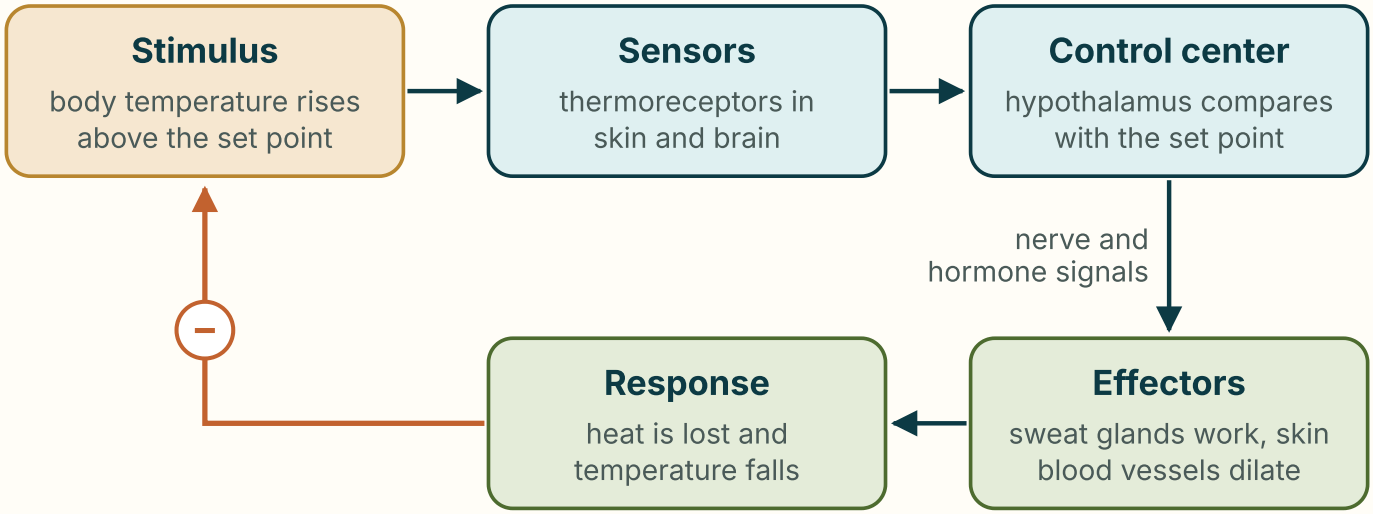
Four tissues: epithelial, connective, muscle, nervous. Large animals beat falling SA:V with folded surfaces and circulation. Homeostasis uses negative feedback; positive feedback finishes events such as birth. Endotherms make heat; ectotherms borrow it; heat moves by radiation, conduction, convection and evaporation.

Digestion: ingestion, hydrolysis, absorption, elimination; most happens in the small intestine. Closed circulation and double circulation with a four-chambered heart serve birds and mammals; cardiac output = rate × stroke volume. Gas exchange uses thin, moist surfaces, countercurrent gills and cooperative hemoglobin with a Bohr shift.

Innate immunity is fast and broad; adaptive immunity uses B and T cells, MHC presentation, clonal selection and memory. Kidneys filter, reabsorb about 99 percent and secrete; ADH concentrates urine. Water-soluble hormones act fast at the surface; lipid-soluble hormones change genes.

Neurons rest at −70 mV and fire all or none at threshold; synapses release transmitter when Ca^{2+} enters; muscle contracts by sliding filaments when Ca^{2+} binds troponin. Gametogenesis gives four sperm or one egg; the LH surge causes ovulation. Development: cleavage, blastula, gastrulation into three germ layers, then organogenesis.

Hormones coordinate slow, body-wide responses while nerves give fast, targeted ones, and the hypothalamus links the two. Insulin and glucagon act as an antagonistic pair on blood glucose; type 1 diabetes is autoimmune loss of beta cells and type 2 is poor response to insulin. In development, the notochord induces the neural tube, somites form vertebrae and muscle, and apoptosis separates fingers.



Negative feedback keeps you near 37 °C. The loop runs until the response removes the stimulus, then it stops.

LOCK THESE IN

- Negative stabilizes; positive amplifies.
- Vessels named by direction.
- Bohr shift unloads O_2.
- CD8 with class I; CD4 with class II.
- About 99% of filtrate reabsorbed.
- Nervous system from ectoderm.

Numbers to know

Item	Value
Cardiac output	About 5 L/min at rest
Blood pressure	About 120/80 mm Hg
PO_2	About 160 mm Hg
Kidney	180 L filtered; 1.5 L urine
Neuron	−70 rest; −55 threshold; +30 to +40 peak
Primary response	Peaks about 10 to 17 days
Cycle	About 28 days; ovulation about day 14

Worked cases

CASE 13.1 · CARDIAC OUTPUT

Heart rate 60 beats per minute, stroke volume 80 mL. Find cardiac output.

STEP 1 · MULTIPLY

60 × 80 = 4,800 mL = **4.8 L/min**.

CASE 13.2 · WHICH WASTE?

Match each animal to its main nitrogenous waste: a trout, a dog, a sparrow.

STEP 1 · TROUT

Aquatic: **ammonia**.

STEP 2 · DOG

Mammal: **urea**.

STEP 3 · SPARROW

Bird, saves water: **uric acid**.

TRAPS PEOPLE FALL INTO

- **Bile digesting fat.** It emulsifies only.
- **Low O_2 driving breathing.** Rising CO_2 drives it.
- **Bigger stimuli making bigger spikes.** All or none; frequency codes strength.
- **Filaments shortening.** They slide.

Chapter 13 self-test · six items

1. Countercurrent heat exchange in a goose's legs mainly does what?

A. Cools the core to save energy
B. Speeds blood flow out to the feet
C. Keeps core heat out of the feet
D. Warms the feet to core temperature

C. Keeps core heat out of the feet Arterial heat passes to returning veins before reaching the feet.

2. Where are most nutrients absorbed?

A. The small intestine
B. The stomach lining
C. The large intestine
D. The esophagus wall

A. The small intestine Villi and microvilli give a huge absorptive surface.

3. Which chamber of the mammalian heart has the thickest wall?

A. Left atrium
B. Left ventricle
C. Right atrium
D. Right ventricle

B. Left ventricle It pumps blood through the whole systemic circuit.

4. A newborn gets antibodies from breast milk. What kind of immunity is this?

A. Cell-mediated immunity
B. Active immunity
C. Innate barrier immunity
D. Passive immunity

D. Passive immunity Ready-made antibodies give temporary protection with no memory.

5. Which ion's entry triggers transmitter release at a synapse?

A. Potassium
B. Sodium
C. Calcium
D. Chloride

C. Calcium Voltage-gated Ca^{2+} channels open and vesicles fuse.

6. Which hormone do pregnancy tests detect?

A. LH
B. FSH
C. Progesterone
D. hCG

D. hCG The embryo secretes hCG, which keeps the corpus luteum alive.

CHAPTER 14

Ecology: Populations, Communities, Ecosystems and Conservation

Read it in full: **Chapter 14 in the textbook**. See it in motion: **Populations and Communities Lab** and **Ecosystems Lab**.

What to know

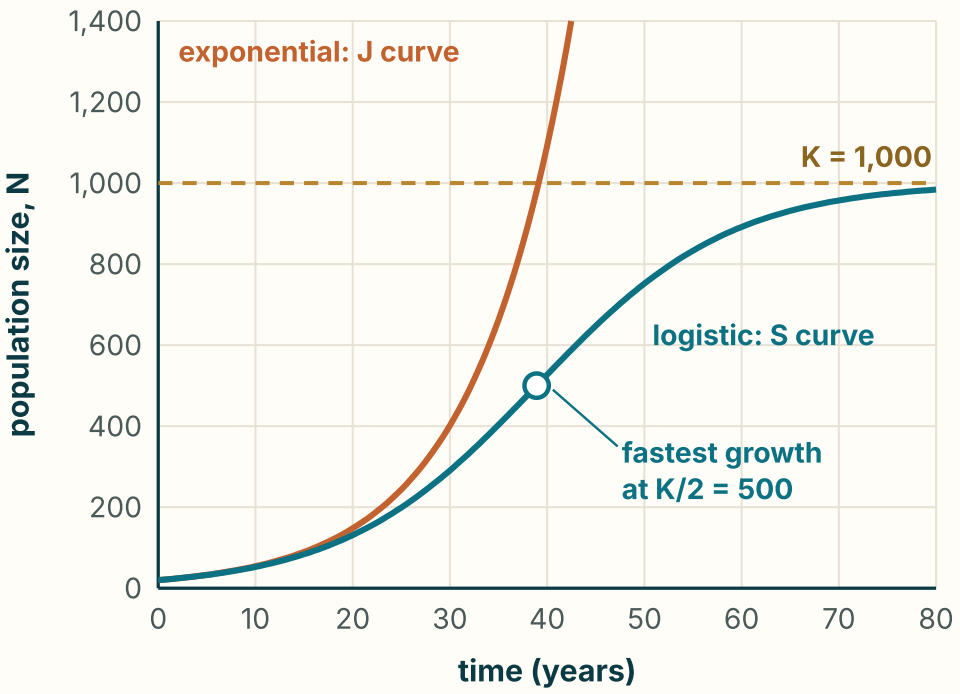
Uneven solar heating drives circulation: rain at the equator, deserts near 30 degrees; seasons come from the 23.5 degree tilt; mountains cast rain shadows. Biomes depend on temperature and precipitation on land and on light, depth, salinity and nutrients in water.

Mark recapture: $N = s \times n \div x$. Exponential growth $dN/dt = r_{max}N$; logistic growth multiplies by $(K - N)/K$, fastest at $K/2$. Survivorship types I to III; r and K selection. Only density-dependent factors regulate.

Interactions: competition, predation, herbivory, parasitism, mutualism, commensalism. Realized niches are smaller than fundamental ones; competitive exclusion drives resource partitioning. Keystone species and trophic cascades show top-down control; primary and secondary succession follow disturbance.

$NPP = GPP - R$; about 10 percent passes up each level; energy flows and matter cycles (water, carbon, nitrogen, phosphorus). Threats: habitat loss, invasives, pollution with biological magnification, population growth, overharvesting. Climate change from greenhouse gases shifts ranges and phenology; mitigation and adaptation respond.

Ecology is quantitative: ecologists test hypotheses with field experiments, natural experiments and models. Island biogeography predicts that large islands near a mainland hold the most species, which guides reserve design and corridors. Cultural eutrophication from excess phosphorus and nitrogen causes algal blooms and dead zones, and coordinated action, as with the ozone layer, shows that global problems can be reversed.



Same start, same rate

N_o = 20, r_{max} = 0.1 per year

Exponential

$dN/dt = r_{max}N$

no limit, keeps speeding up

Logistic

$dN/dt = r_{max}N(K - N)/K$

slows as N nears K

At N = 900: $(K - N)/K = 0.1$, so growth is 10% of the exponential rate.

K is the carrying capacity, the most the habitat holds.

Exponential against logistic growth. Both curves come from the same numbers. Only the logistic one feels the limit of K.

LOCK THESE IN

- Rising air wet; sinking air dry.
- N = s × n ÷ x.
- Fastest growth at K/2.
- Only density-dependent factors regulate.
- Multiply by 0.1 per level.
- Energy flows; matter cycles.

Formulas and values

Item	Rule or value
Logistic	$dN/dt = r_{max}N(K - N)/K$
NPP	GPP − R
Trophic efficiency	About 10%
Elevation	About 6 °C cooler per 1,000 m
CO_2	About 280 to over 420 ppm
Warming	About 1.1 to 1.3 °C
Greenhouse effect	About 15 °C versus about −18 °C

Worked cases

CASE 14.1 · MARK RECAPTURE

120 snails are marked. A later sample of 90 has 27 marked. Estimate N.

STEP 1 · FORMULA

$N = 120 \times 90 \div 27$.

STEP 2 · COMPUTE

$10{,}800 \div 27 =$ **400 snails**.

CASE 14.2 · LOGISTIC GROWTH

$K = 2{,}000$ and $r_{max} = 0.3$ per year. Find dN/dt at N = 1,000 and N = 1,800.

STEP 1 · N = 1,000

$0.3 \times 1{,}000 \times 0.5 =$ **150 per year**.

STEP 2 · N = 1,800

$0.3 \times 1{,}800 \times 0.1 =$ **54 per year**.

TRAPS PEOPLE FALL INTO

- **Seasons from distance.** Tilt causes seasons.
- **Frost regulating populations.** It is density independent.
- **Energy cycling.** Energy leaves as heat.
- **Upright biomass pyramids always.** Some aquatic ones invert.

Chapter 14 self-test · six items

1. Which biome has nutrient-poor soils because nutrients are held in living biomass?

A. Arctic tundra
B. Northern coniferous taiga
C. Temperate grassland
D. Tropical rain forest

D. Tropical rain forest Rapid uptake and decay keep nutrients in plants, not soil.

2. Humans have which survivorship curve?

A. Type I
B. Type III
C. Type IV
D. Type II

A. Type I Most people survive to old age, then mortality rises steeply.

3. A harmless and a stinging insect share yellow and black bands. Which is Batesian?

A. Two stinging species sharing colors
B. A frog with bright warning colors
C. The harmless one copying the stinger
D. A plant hiding with green colors

C. The harmless one copying the stinger Batesian mimicry is a harmless mimic of a harmful model.

4. A farm field is abandoned and forest returns in decades. What is this?

A. Adaptive radiation
B. Secondary succession
C. Primary succession
D. Competitive exclusion

B. Secondary succession Soil remained, so recovery is fast.

5. Which nutrient most often limits production in lakes?

A. Phosphorus
B. Iron ions
C. Carbon
D. Oxygen gas

A. Phosphorus Phosphate weathers slowly from rock and often limits freshwater production.

6. Why is mercury highest in top predators?

A. Trophic efficiency gains
B. Biological magnification
C. Primary succession
D. Nitrogen fixation in tuna

B. Biological magnification Persistent toxins concentrate at each step up a food chain.

ONE PAGE

Cram sheet

The whole course on one sheet. Cover the right column and rebuild each row. If a row is shaky, go back to that chapter's exam guide.

Numbers to know

Item	Value	Chapter
O, C, H, N	About 96% of body mass	1
Hydrogen bond	About 5 to 10% of covalent	1
Blood pH	7.35 to 7.45	1
Mole	6.02×10^{23}; glucose 180 g	1
Resolution	Light about 200 nm; EM a few nm	2
Cell sizes	1 to 5 µm; 10 to 100 µm	2
Pump	3 Na^+ out, 2 K^+ in, 1 ATP	2
Glucose oxidation	ΔG about −686 kcal/mol	3
ATP hydrolysis	About −7.3 kcal/mol	3
ATP per glucose	About 30 to 32	3
Calvin cycle	9 ATP, 6 NADPH per G3P	3
Human chromosomes	2n = 46; n = 23	4
Assortment	$2^{23} \approx 8.4$ million	4
Chi square critical	3.84, 5.99, 7.81	5
Map unit	1% recombination	5
Helix	2 nm; about 10 bp per turn	6
Codons	64; 61 sense; 3 stop	6
Error rate	About 1 in 10^9 to 10^{10}	6
PCR	2^n copies; 30 cycles about a billion	7
CRISPR	20 nt guide; NGG PAM	7

Item	Value	Chapter
CF carriers	About 1 in 25	8
Carbon-14	5,730 years	9
Earth; first life	4.6; 3.5 billion years	9
Mass extinctions	444, 372, 252, 201, 66 million years ago	9
Prokaryote; virus size	0.5 to 5 µm; 20 to 300 nm	10
Angiosperms	About 300,000 species	11
Essential plant elements	17	11
Human-chimp split	6 to 7 million years ago	12
Homo sapiens	About 300,000 years ago	12
Cardiac output	About 5 L/min	13
Kidney	180 L filtered, 1.5 L urine	13
Neuron	−70, −55, +30 to +40 mV	13
Trophic efficiency	About 10%	14
CO_2	About 280 to over 420 ppm	14

Equations

Name	Equation	Chapter
pH	$pH = -\log[H^+]$	1
Surface area to volume (cube)	$6/s$	2
Free energy	$\Delta G = \Delta H - T\Delta S$	3
Coupled reactions	ΔG_{total} = sum of ΔG	3
Exactly k of n	$[n! \div (k!(n-k)!)]\ p^k q^{n-k}$	5
Chi square	$\Sigma(O-E)^2/E$	5
Recombination frequency	Recombinants ÷ total	5
PCR copies	2^n	7
Hardy-Weinberg	$p + q = 1;\ p^2 + 2pq + q^2 = 1$	8
Radiometric age	Half-lives × half-life	9
Water potential	$\Psi = \Psi_S + \Psi_P$	11
Cardiac output	Heart rate × stroke volume	13
Mark recapture	$N = s \times n \div x$	14
Logistic growth	$dN/dt = r_{max}N(K-N)/K$	14
Net primary production	$NPP = GPP - R$	14

Key terms and comparisons

Pair	How to tell them apart
Dehydration vs hydrolysis	Builds and releases water; breaks and adds water.
Prokaryote vs eukaryote	Nucleoid, 70S; nucleus, organelles, 80S.
Passive vs active transport	Down a gradient, no energy; up a gradient, ATP or a gradient.
Exergonic vs endergonic	ΔG negative; positive.
Competitive vs noncompetitive	Active site; other site.
Mitosis vs meiosis	Two identical; four unique haploid.
Oncogene vs tumor suppressor	Gain, one copy; loss, both copies.
Incomplete vs codominance	Intermediate; both shown.
Leading vs lagging strand	Continuous; Okazaki fragments.
Template vs coding strand	Read; matches mRNA.
Inducible vs repressible	Default off, catabolic; default on, anabolic.
Homology vs analogy	Ancestry; convergence.
Drift vs selection	Random; adaptive.
Allopatric vs sympatric	Barrier; same area.
Monophyletic vs paraphyletic	All descendants; some.
Gram positive vs negative	Thick, purple; thin plus outer membrane, pink.
Lytic vs lysogenic	Burst; hide as a prophage.
Sporophyte vs gametophyte	2n, spores by meiosis; n, gametes by mitosis.
Xylem vs phloem	Dead, water up; living, sugar both ways.
Protostome vs deuterostome	Mouth first; anus first.
Innate vs adaptive	Fast, broad; specific, memory.

Pair	**How to tell them apart**
Exponential vs logistic	J; S at K.
GPP vs NPP	Total; minus producer respiration.

Rules that win points

Topic	The rule
pH	Subtract, then raise 10 to that power.
Complement strand	Pair, then flip to 5′ to 3′.
Osmosis	Water follows nonpenetrating solute.
Enzymes	Only the rate changes.
ATP count	Count carriers, then convert.
Chromosome count	Count centromeres.
Probability	"And" multiply; "or" add.
Sibling carrier	2/3.
Mutations	Frame first, then codon.
lac operon	Lactose first, then glucose.
Hardy-Weinberg	Start from q^2.
Trees	Read nodes, not tips.
Half-lives	Each halves what is left.
Plant life cycle	Spores by meiosis; gametes by mitosis.
Water potential	Toward the more negative value.
Vessels	Named by direction.
Rainfall	Rising air wet; sinking air dry.
Food chains	About 10% per step.

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