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— STUDY NOTES

Cellular Homeostasis: How Animal Cells Maintain Balance

Cellular homeostasis is how every animal cell holds a stable internal environment against a constantly changing world. It runs on three tools — a selective membrane that controls what crosses, electrochemical gradients built by ATP-driven pumps, and chemical signalling that links cells together. Every disease in veterinary medicine is, at its root, a failure of one of them.

INSIDE THESE NOTES

LEVEL
Vets & veterinary students

EDITION
2026-06-27

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Cellular Homeostasis: How Animal Cells Maintain Balance

STUDY NOTES · BASIC SCIENCES · PHYSIOLOGY · UPDATED 2026-06-27

CONTENTS

LEARNING OBJECTIVES

After working through these notes you will be able to:

- ✓ Define cellular homeostasis and explain why it underlies every physiological process and disease.
- ✓ Describe the structure of the cell membrane and how its selective permeability controls what crosses.
- ✓ Compare passive and active membrane transport, and explain how the Na+/K+ ATPase builds electrochemical gradients.
- ✓ Explain the origin of the resting membrane potential and its role in every excitable tissue.
- ✓ Outline the five modes of cell signalling and how negative feedback keeps the internal environment stable.

TL;DR

Cellular homeostasis is how every animal cell holds a stable internal environment against a constantly changing world. It runs on three tools — a selective membrane that controls what crosses, electrochemical gradients built by ATP-driven pumps, and chemical signalling that links cells together. Every disease in veterinary medicine is, at its root, a failure of one of them.

AT A GLANCE

DEFINITION	Active maintenance of a stable internal milieu
SENSORS	Hypothalamic neurons · baroreceptors · chemoreceptors · ion-sensitive cells
EFFECTORS	Sweat glands · panting · vasomotion · endocrine cells · kidney
CURRENCY	Electrochemical gradient across the cell membrane
MAIN PUMP	Na+/K+ ATPase — 3 Na+ out, 2 K+ in, per ATP
RESTING POTENTIAL	Inside negative; –70 mV neuron · –85 mV cardiac · –90 mV skeletal muscle
SIGNALLING MODES	Autocrine · paracrine · endocrine · juxtacrine · neurotransmission
RECEPTOR CLASSES	Ion-channel · GPCR · enzyme-linked · nuclear/intracellular
FEEDBACK RULE	Negative is the default; positive is the exception

01 What is homeostasis — and why it matters

- **Homeostasis** = the active, ongoing maintenance of a stable internal environment against constant external change — a process of constant correction, *not* a static state.
- **Control loop (3 parts): Sensor** detects deviation → **Integrator** compares to setpoint → **Effector** restores it. **Negative feedback** closes the loop.
- **Every disease = a homeostatic failure:**
  - Dehydration → ECF tonicity · Fever → thermoregulation overshoot
  - DKA → glucose + acid-base collapse · Hypovolaemic shock → BP loop exhausted

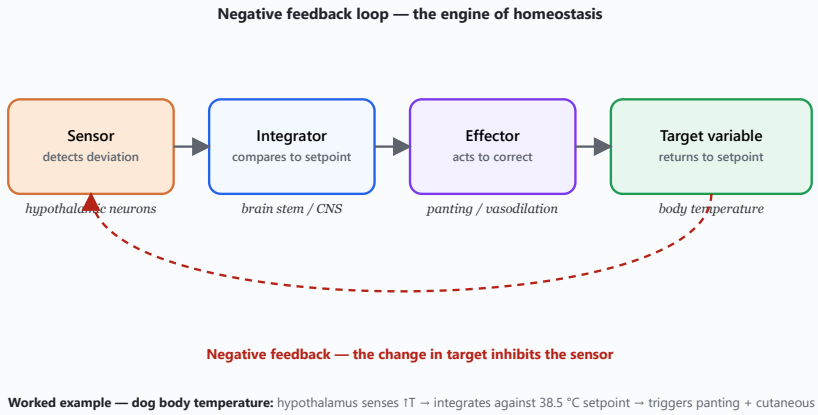


Fig 1 — The sensor → integrator → effector loop (worked example: dog body temperature).

100 T Cells kept alive inside a <1% variation window — all on the same membrane-and-pump machinery.

02 The cell membrane

- **Why it matters:** the boundary that lets a cell hold gradients, receive signals and stay excitable — no membrane, no homeostasis.
- **Structure:** phospholipid bilayer (water-loving heads out, tails in); cholesterol tunes fluidity; glycolipids on the outer face.
- **Proteins: integral** (channels, pumps, receptors, enzymes) span the bilayer; **peripheral** sit on one face → the **fluid mosaic model**.

SELECTIVE PERMEABILITY

Impermeable enough to hold gradients, yet selective enough to let specific molecules cross via specific proteins. Lose it and the cell dies within minutes.

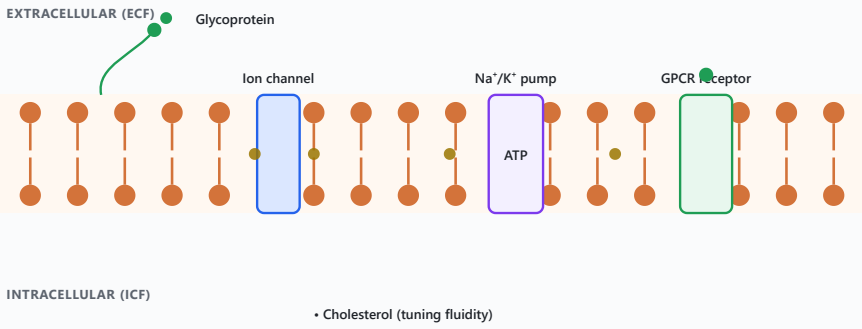
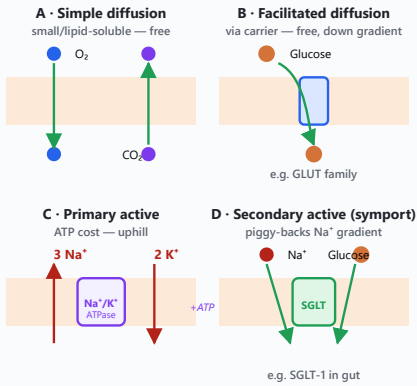


Fig 2 — Fluid mosaic membrane: bilayer with channel, pump and receptor proteins.

03 Membrane transport

- **Two strategies: passive** = down the gradient, no ATP · **active** = against the gradient, costs ATP.
- **Passive:** simple diffusion (O_2, CO_2, steroids) · facilitated (glucose/GLUT, ions/channels) · osmosis (water/aquaporins).
- **Active — primary** (ATP directly): **Na^+/K^+ ATPase** (3 Na^+ out / 2 K^+ in per ATP), Ca^{2+} ATPase, H^+/K^+ ATPase.
- **Active — secondary** (rides the Na^+ gradient): symport (SGLT: Na^++glucose) · antiport (Na^+/Ca^{2+} exchanger).

MECHANISM	DRIVER	EXAMPLE	ATP
Simple diffusion	Gradient	O_2, CO_2, steroids	None
Facilitated diffusion	Gradient + carrier	Glucose via GLUT	None
Osmosis	Water potential	Water via aquaporins	None
Primary active	Direct ATP	Na^+/K^+ ATPase	1 / cycle
Secondary active	Ion gradient	SGLT-1 (Na^+/glucose)	Indirect
Endo / exocytosis	Cytoskeleton	LDL uptake; hormone release	ATP



Key rule

Passive = free.
Active = costs ATP.

→ Move **down** the gradient → passive.

→ Move **against** the gradient → active.

Primary active burns ATP directly — e.g. Na^+/K^+ ATPase.

Secondary active rides the Na^+ gradient — e.g. glucose uptake in intestinal villi.

~30 % of total cellular ATP goes to the Na^+/K^+ pump.

Fig 3 — Four key transport modes. Rule: against a gradient always costs ATP.

EXAM HOOK

The Na^+/K^+ ATPase burns ~30% of every cell's ATP — why brain and heart need a relentless O_2 supply.

04 The resting membrane potential

- **Fact:** every cell is negative inside — neuron ≈ **−70 mV**, cardiac ≈ −85, skeletal ≈ −90.
- **Origin:** (1) Na^+/K^+ ATPase builds the gradients; (2) **K^+ leak channels** let K^+ flow out until electrical pull = chemical push (≈ K^+ equilibrium — Nernst).
- **Why it matters:** basis of nerve firing, cardiac contraction, secretion, muscle. **Hyperkalaemia** (K^+ >7) collapses the gradient → cardiac arrest.

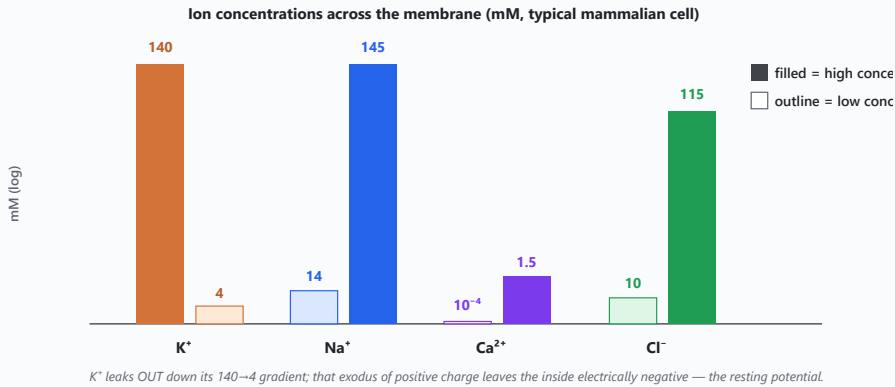


Fig 4 — Intra- vs extracellular ions. The 140:4 mM K^+ ratio is the source of the resting potential.

140 : 4 Intra:extra K^+ (mM) — holds every excitable cell ready to fire; why hyperkalaemia is an emergency.

05 Five modes of cell signalling

- **Autocrine** — cell signals itself (T-cell IL-2).
- **Paracrine** — local neighbours (mast-cell histamine); never reaches blood.
- **Endocrine** — body-wide via the bloodstream (insulin).
- **Juxtacrine** — direct contact / gap junctions (Notch).
- **Neurotransmission** — across the synapse; fast, local, precise.

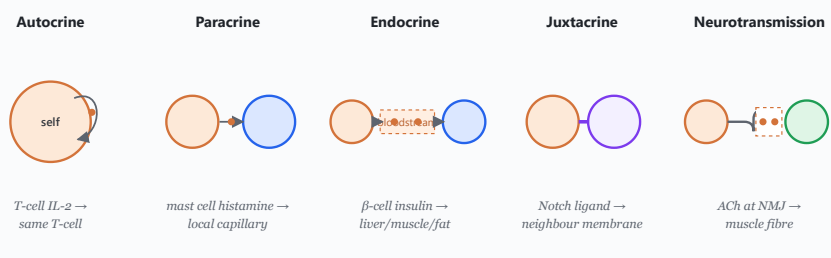


Fig 5 — Reach defines the mode: from self → neighbour → bloodstream-wide.

CLINICAL LINK

Injected insulin piggybacks the endocrine pathway. Most vet drugs exploit or block one of these five modes.

06 Receptors and second messengers

- **4 receptor classes (by speed):** ion-channel (ms — ACh/nicotinic) · GPCR (s — 7-TM → G-protein → 2nd messenger) · enzyme-linked kinase (min–h — insulin) · nuclear/intracellular (h–days — steroids → transcription).
- **Second messengers** amplify one binding event into thousands of effects: **cAMP, cGMP, IP_3/DAG, Ca^{2+}, NO**.

RECEPTOR CLASS	SPEED	EXAMPLE	VET DRUG
Ion-channel	ms	ACh (nicotinic)	Atracurium
GPCR	seconds	Epinephrine (β_2), histamine	Propranolol, antihistamines
Enzyme-linked	min–h	Insulin, growth factors	Insulin therapy
Nuclear	h–days	Cortisol, thyroxine	Prednisolone, dexamethasone

07 Negative feedback — the engine

- **Rule:** a variable drifts → the response opposes it; the bigger the deviation, the bigger the correction.
- **4 loops to memorise:** temperature, blood glucose, blood pressure, blood pH (table below).
- **Positive feedback** (rare, self-limiting): parturition (oxytocin), clotting (thrombin).

VARIABLE	SENSOR	EFFECTOR	RANGE (DOG)
Temperature	Hypothalamic neurons	Panting, vasomotion, shivering	38.3–39.2 °C
Blood glucose	Pancreatic α/β-cells	Insulin / glucagon	3.3–6.7 mmol/L
Blood pressure	Baroreceptors	ANS tone, RAAS	~120/80 mmHg
Blood pH	Chemoreceptors	Ventilation, renal HCO_3^-	7.35–7.45

EXAM HOOK

Any "compensation" on a path-phys exam is feedback in action (e.g. the acidotic dog hyperventilating to blow off CO_2).

08 When homeostasis fails — the clinic

- Vet medicine = managing homeostatic failure; every emergency is a feedback loop losing the fight.
- **Examples:** acidosis/alkalosis (resp-renal loop) · hypovolaemic shock (BP loop) · heat stroke (thermo loop; brachycephalics) · diabetes (glucose loop) · Cushing's / Addison's (cortisol loop).

COMPENSATION ≠ STABLE

A rising heart rate with normal mucous membranes is one step from collapse — the effector is at full deflection. Treat early, before the loop exhausts.

> *Understand homeostasis and every other organ system is the same story told with different proteins.*
>
> — after the Cunningham 6e preface.

KEY TERMS — QUICK GLOSSARY

Homeostasis	Active, ongoing maintenance of a stable internal environment against constant external change.
Selective permeability	The membrane's ability to let some substances cross while blocking others.
Passive transport	Movement of a substance down its electrochemical gradient — no ATP required.
Active transport	Movement against a gradient, powered by ATP (e.g. the Na+/K+ ATPase).
Electrochemical gradient	The combined concentration and electrical difference of an ion across the membrane.
Resting membrane potential	The voltage (~-70 mV) across a resting cell, set mainly by K+ leaking out.
Second messenger	An intracellular signal (cAMP, Ca2+, IP3) that relays a message from a surface receptor.
Negative feedback	A control loop whose response opposes the original change, restoring the set point.

QUICK REVISION — REMEMBER THESE

1. Homeostasis is a continuous process, not a state — every animal cell defends a narrow internal range against constant external load.
2. The cell membrane's selective permeability is the foundation of every transport, signal, and excitable event in the body.
3. Primary active transport (especially the Na+/K+ ATPase) sets up the electrochemical gradients that all other physiology exploits.
4. Every excitable tissue — nerve, cardiac muscle, skeletal muscle, secretory cells — runs on the same K+-leak resting potential.
5. Cells communicate by five modes (autocrine, paracrine, endocrine, juxtacrine, neurotransmission) converging on four receptor classes.
6. Negative feedback is the engine of homeostasis; positive feedback is the rare exception (parturition, clotting).
7. Every emergency case in clinical practice is, at root, a homeostatic loop losing the fight against an external or internal load.

MEMORY AIDS

Five signalling modes — **A**utocrine, **P**aracrine, **E**ndocrine, **J**uxtacrine, **N**eurotransmission — *"A Penguin Eats Jelly Nightly"*.

Na+/K+ ATPase stoichiometry — **3 Na+ out, 2 K+ in** per ATP — "three out, two in, net positive out" (so the inside stays negative).

Four receptor classes — **I-G-E-N**: **I**on-channel, **G**PCR, **E**nzyme-linked, **N**uclear.

TEST YOURSELF — ACTIVE RECALL

Cover the answers and try to retrieve each one from memory first — self-testing beats re-reading.

1. **Define homeostasis in one sentence.**
2. **Name the three tools a cell uses to defend its internal environment.**
3. **What is the difference between passive and active transport?**
4. **Which ion, moving which way, sets the resting membrane potential — and its typical neuron value?**
5. **List the five modes of cell signalling.**
6. **Name the four receptor classes.**
7. **Which type of feedback maintains homeostasis, and name one exception.**
8. **Why is every emergency case ultimately a homeostatic problem?**

ANSWERS

1. The active, ongoing maintenance of a stable internal environment against constant external change.
2. A selectively permeable membrane, ATP-driven electrochemical gradients (Na+/K+ ATPase), and chemical signalling.
3. Passive moves a substance down its electrochemical gradient (no ATP); active moves it against the gradient and costs ATP.
4. K+ leaking out of the cell; about -70 mV.
5. Autocrine, paracrine, endocrine, juxtacrine, neurotransmission.
6. Ligand-gated ion channel, GPCR, enzyme-linked, and nuclear/intracellular.
7. Negative feedback maintains it; positive feedback is the exception (e.g. parturition, blood clotting).
8. Because disease is a control loop losing the fight against an internal or external load.

WHEN TO REFER OR ESCALATE

- A patient looks 'compensated' but the heart rate keeps climbing — escalate fluid + monitor before the loop exhausts.
- Serum K^+ > 6.5 mmol/L with ECG changes — emergency; the resting-potential gradient is collapsing.
- Acid-base derangement that does not correct with predicted compensation — refer for blood gas + lactate workup.
- Suspected endocrine homeostatic failure (Cushing's, Addison's, DKA) — refer for confirmatory diagnostics + ICU support.

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