Neural Signaling & Homeostasis

IB HL Study Guide

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Mixed Practice — Exam Style

May 2026 Prediction Questions

Complete Study Guide

Topics Covered

1. Neural Signaling (C2.2)
2. Homeostasis (D3.3)
3. Chemical Signaling (C2.1)
4. Integration of Body Systems (C3.1) HL
5. Mixed Practice — Exam Style

Aligned to IB Biology HL 2025 syllabus — C2.2, D3.3, C2.1, C3.1

Section 1: Neural Signaling (C2.2)

The nervous system enables rapid communication between different parts of the body. Signals travel as **electrical impulses** along neurons and are transmitted between neurons via **chemical messengers** (neurotransmitters) at synapses. Understanding the structure of neurons, the ionic basis of nerve impulses, and synaptic transmission is essential for IB Biology HL.

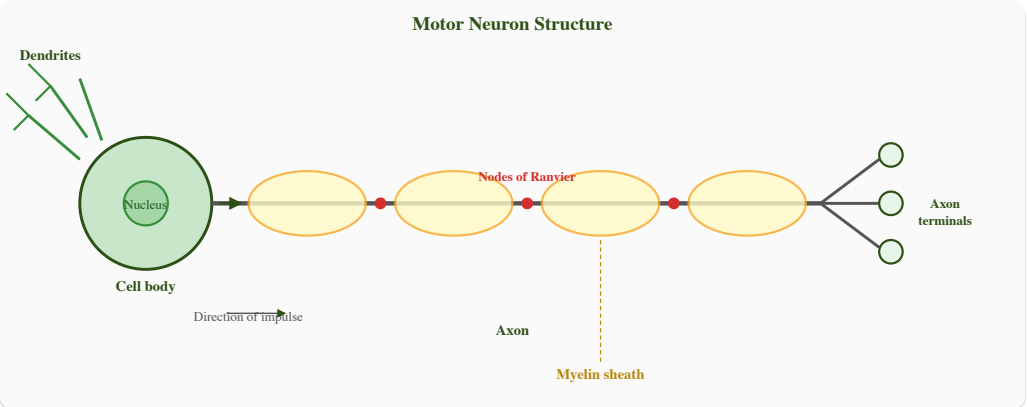
1.1 Neuron Structure

Neurons are specialised cells that transmit electrical signals. Although neurons vary in shape, most share a common set of structural features.

MEMORISE THIS

Core definitions to memorise:

Term	Definition
Neuron	Nerve cell specialised for transmitting electrical impulses
Cell body (soma)	Contains the nucleus and most organelles; integrates incoming signals
Dendrites	Short, branched extensions that receive signals from other neurons
Axon	Long, thin fibre that conducts the action potential away from the cell body
Myelin sheath	Insulating layer of lipid-rich membrane formed by Schwann cells (PNS) or oligodendrocytes (CNS)
Nodes of Ranvier	Gaps in the myelin sheath where ion channels are concentrated
Axon terminal (synaptic knob)	Swollen end of the axon that releases neurotransmitters into the synapse
Schwann cell	Glial cell that wraps around the axon to form the myelin sheath in the peripheral nervous system



There are three main types of neuron: **sensory neurons** (carry impulses from receptors to the CNS), **motor neurons** (carry impulses from the CNS to effectors), and **relay neurons** (interneurons; connect sensory and motor neurons within the CNS).

1.2 Resting Potential

When a neuron is not transmitting a signal, it maintains a **resting potential** of approximately $-70\ \text{mV}$ across its membrane. The inside of the axon is negatively charged relative to the outside. This charge difference is called the **membrane potential**.

The resting potential is established and maintained by:

1. **The Na^+/K^+ ATPase pump** — actively transports **3 Na^+ out** and **2 K^+ in** per cycle, using one molecule of ATP. This creates a net outward movement of positive charge.
2. **Potassium leak channels** — the membrane is more permeable to K^+ than to Na^+ at rest. K^+ diffuses out through leak channels, making the inside more negative.
3. **Large intracellular anions** — negatively charged proteins and organic molecules inside the cell cannot cross the membrane.

EXAM ALERT

Exam trap: The resting potential is NOT simply caused by the pump. The pump establishes the ion gradients, but the resting potential itself is mostly due to K^+ diffusing out through leak channels. Students who write "the pump causes the $-70\ \text{mV}$" miss the mark — the pump contributes only about $-10\ \text{mV}$ directly. The remaining $-60\ \text{mV}$ comes from K^+ leakage.

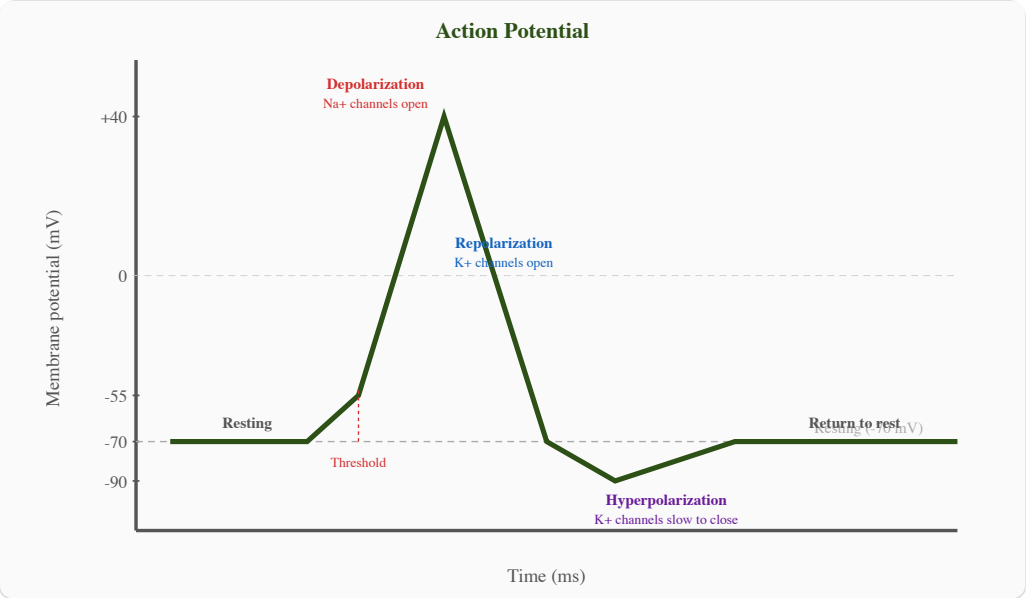
MEMORISE THIS

Ion concentrations at rest (approximate):

Ion	Intracellular	Extracellular	Direction of gradient
Na^+	Low (~15 mM)	High (~150 mM)	Into cell
K^+	High (~150 mM)	Low (~5 mM)	Out of cell
Cl^-	Low (~10 mM)	High (~120 mM)	Into cell

1.3 Action Potential

An **action potential** is a rapid, temporary reversal of the membrane potential that travels along the axon as a nerve impulse. It follows an all-or-nothing principle: if the stimulus reaches the **threshold** (approximately $-55\ \text{mV}$), a full action potential is generated; if not, nothing happens.



Phases of the action potential:

1. **Resting state** — membrane at $-70\ \text{mV}$; voltage-gated Na^+ and K^+ channels are closed.
2. **Depolarization** — a stimulus causes voltage-gated Na^+ channels to open; Na^+ rushes in (down its electrochemical gradient); the membrane potential rises rapidly toward $+40\ \text{mV}$.
3. **Repolarization** — Na^+ channels inactivate (close); voltage-gated K^+ channels open; K^+ rushes out; the membrane potential returns toward resting level.
4. **Hyperpolarization** — K^+ channels are slow to close, so K^+ continues to leave the cell, briefly driving the potential below $-70\ \text{mV}$ (to about $-90\ \text{mV}$).
5. **Return to resting potential** — K^+ channels close; the Na^+/K^+ ATPase pump restores the original ion distribution.

> **IB TIP**
>
> **IB key concept — Refractory period:** After an action potential, there is a brief period during which the neuron cannot fire again. The **absolute refractory period** (during depolarization and most of repolarization) prevents a new action potential entirely. The **relative refractory period** (during hyperpolarization) requires a stronger-than-normal stimulus. The refractory period ensures that action potentials travel in one direction along the axon and limits the maximum firing frequency.

1.4 Myelination and Saltatory Conduction (HL)

HL

In myelinated neurons, the myelin sheath acts as an **electrical insulator**, preventing ion exchange across the membrane where it is present. Ion channels are concentrated at the **nodes of Ranvier** — the small gaps between adjacent Schwann cells.

The action potential "jumps" from node to node. This is called **saltatory conduction** (from the Latin *saltare*, to jump). Saltatory conduction dramatically increases the speed of impulse transmission:

- **Unmyelinated axon:** ~1—2 m/s (continuous conduction)
- **Myelinated axon:** ~100—120 m/s (saltatory conduction)

⚠ EXAM ALERT

HL exam point: You must be able to explain *why* saltatory conduction is faster. The key points are: (1) depolarization occurs only at nodes, so fewer ion channels need to open and close; (2) the electrical signal passes rapidly through the myelinated internodal region as a local current; (3) less ATP is required because fewer Na^+/K^+ pumps are needed to restore ion gradients. Diseases like multiple sclerosis (MS) damage the myelin sheath, slowing or blocking impulse transmission.

1.5 Synaptic Transmission

Neurons communicate at junctions called **synapses**. Most synapses are **chemical synapses**, where the signal is carried across the synaptic cleft by neurotransmitters.

Steps of synaptic transmission:

1. An action potential arrives at the **presynaptic axon terminal**.
2. Voltage-gated Ca^{2+} channels open; Ca^{2+} enters the terminal.
3. Ca^{2+} triggers **synaptic vesicles** to fuse with the presynaptic membrane (**exocytosis**).
4. **Neurotransmitter** is released into the **synaptic cleft** (~20 nm wide).
5. Neurotransmitter binds to specific **receptors** on the **postsynaptic membrane**.
6. This binding opens (or closes) **ligand-gated ion channels**, generating a postsynaptic potential.
7. The signal is terminated by: (a) enzymatic breakdown of the neurotransmitter, (b) reuptake into the presynaptic neuron, or (c) diffusion away from the cleft.

IB TIP

IB key concept — Calcium is the trigger: The entry of Ca^{2+} is what causes vesicle fusion and neurotransmitter release. Without Ca^{2+} influx, no neurotransmitter is released even if the action potential arrives. This is a very commonly tested point.

1.6 Neurotransmitters: Excitatory vs Inhibitory

Neurotransmitters can be classified by their effect on the postsynaptic neuron:

MEMORISE THIS

Key neurotransmitters:

Neurotransmitter	Type	Effect on postsynaptic membrane	Notes
Acetylcholine (ACh)	Excitatory (usually)	Opens Na^+ channels; depolarization	Neuromuscular junctions; broken down by acetylcholinesterase
Dopamine	Excitatory or modulatory	Complex; involved in reward and motor control	Deficiency linked to Parkinson's disease
Serotonin	Modulatory	Mood regulation, sleep, appetite	Target of many antidepressant drugs (SSRIs)
GABA	Inhibitory	Opens Cl^- channels; hyperpolarization	Main inhibitory neurotransmitter in the brain
Glutamate	Excitatory	Opens Na^+ channels; depolarization	Main excitatory neurotransmitter in the brain
Norepinephrine	Excitatory	Increases heart rate, alertness	Fight-or-flight response

- An **excitatory postsynaptic potential (EPSP)** depolarizes the membrane, making it more likely to reach threshold and fire an action potential.
- An **inhibitory postsynaptic potential (IPSP)** hyperpolarizes the membrane, making it less likely to fire.
- **Summation** — a postsynaptic neuron integrates multiple EPSPs and IPSPs. If the sum exceeds the threshold, an action potential is triggered. Summation can be **temporal** (rapid signals from one synapse) or **spatial** (simultaneous signals from multiple synapses).

⚠ EXAM ALERT

Common mistake: Do not say GABA "stops" the neuron from firing. GABA makes firing *less likely* by hyperpolarizing the membrane. The neuron can still fire if excitatory inputs are strong enough to overcome the inhibition through summation.

Section 2: Homeostasis (D3.3)

Homeostasis is the maintenance of a relatively constant internal environment despite changes in external conditions. It is essential for enzyme function, cell integrity, and survival.

MEMORISE THIS

Core definitions to memorise:

Term	Definition
Homeostasis	Maintenance of relatively stable internal conditions (e.g. temperature, pH, blood glucose)
Negative feedback	A response that counteracts (reverses) a deviation from the set point
Positive feedback	A response that amplifies the deviation from the set point (rare; e.g. labour contractions, blood clotting)
Set point	The normal/target value of a physiological variable
Receptor	Detects changes (stimuli) in the internal environment
Coordinator / Control centre	Processes information and coordinates a response (e.g. hypothalamus)
Effector	Carries out the response to restore the set point (e.g. muscles, glands)

2.1 Negative Feedback Loops

Most homeostatic mechanisms use **negative feedback**: the response opposes the change, returning the variable to its set point. This produces oscillations around the set point rather than a perfectly stable value.

The negative feedback model:

Stimulus (deviation from set point) → Receptor (detects change) → Coordinator (processes signal) → Effector (produces response) → Variable returns toward set point → Receptor detects return → Response diminishes

> **IB TIP**
>
> **IB key concept:** You must be able to distinguish negative feedback from positive feedback. Negative feedback **reduces** the deviation; positive feedback **increases** it. Almost all homeostatic mechanisms are negative feedback. The only common examples of positive feedback in IB Biology are oxytocin during labour and the cascade of blood clotting.

2.2 Thermoregulation

Humans are **endotherms** — we maintain a core body temperature of approximately **37 degrees C** regardless of the external temperature. The **hypothalamus** acts as the thermostat, receiving input from thermoreceptors in the skin and blood.

Response to overheating (above 37 degrees C):

Mechanism	How it works
Vasodilation	Arterioles near the skin surface dilate; more blood flows near the surface; more heat is lost by radiation
Sweating	Sweat glands secrete sweat; evaporation of water from the skin removes heat (latent heat of vaporization)
Behavioural responses	Seeking shade, removing clothing, reducing activity
Reduced metabolic heat production	Less cellular respiration generates less heat

Response to cooling (below 37 degrees C):

Mechanism	How it works
Vasoconstriction	Arterioles near the skin surface constrict; less blood flows near the surface; less heat is lost
Shivering	Involuntary rapid muscle contractions generate heat from increased cellular respiration
Piloerection	Erector pili muscles contract, raising body hairs; traps an insulating layer of air (minimal effect in humans)
Behavioural responses	Adding clothing, curling up, seeking warmth
Increased metabolic rate	Thyroxine and adrenaline increase basal metabolic rate over time

⚠ EXAM ALERT

Exam precision: Vasodilation and vasoconstriction refer to the **arterioles**, not the capillaries. Capillaries do not have smooth muscle and cannot dilate or constrict. Also, say "more/less blood flows *near the skin surface*" — not "to the skin". Blood always flows to the skin; the question is whether it flows through superficial or deeper vessels.

2.3 Blood Glucose Regulation

Blood glucose concentration is maintained at approximately **4—6 mmol/L** (fasting) by the hormones **insulin** and **glucagon**, both produced by the **islets of Langerhans** in the pancreas.

MEMORISE THIS

Insulin vs Glucagon:

Feature	Insulin	Glucagon
Source	Beta (β) cells of islets of Langerhans	Alpha (α) cells of islets of Langerhans
Stimulus	High blood glucose	Low blood glucose
Target cells	Liver cells, muscle cells, adipose tissue	Liver cells (primarily)
Main actions	Stimulates glucose uptake; promotes glycogenesis (glucose → glycogen); promotes lipogenesis	Promotes glycogenolysis (glycogen → glucose); promotes gluconeogenesis (amino acids/glycerol → glucose)
Effect on blood glucose	Decreases (lowers)	Increases (raises)

Key terms:

- **Glycogenesis** — synthesis of glycogen from glucose (stimulated by insulin)
- **Glycogenolysis** — breakdown of glycogen to glucose (stimulated by glucagon)
- **Gluconeogenesis** — synthesis of new glucose from non-carbohydrate sources such as amino acids, glycerol, and lactate (stimulated by glucagon)

WORKED EXAMPLE

Worked Example: Blood glucose regulation after a meal

After eating a carbohydrate-rich meal, blood glucose rises above the set point.

1. **Receptor:** Beta cells in the islets of Langerhans detect the rise in blood glucose.
2. **Coordinator/Effector:** Beta cells secrete **insulin** into the blood.
3. **Response:** Insulin binds to receptors on target cells (liver, muscle, adipose). This causes:
    - Increased uptake of glucose via GLUT4 transporters (in muscle and adipose)
    - Increased **glycogenesis** in the liver and muscle (glucose → glycogen)
    - Increased conversion of glucose to fat (lipogenesis) in adipose tissue
4. **Result:** Blood glucose falls back toward the set point (~5 mmol/L).
5. **Feedback:** As glucose returns to normal, the stimulus for insulin secretion diminishes (negative feedback).

WORKED EXAMPLE

Worked Example: Blood glucose regulation during fasting

Between meals or during exercise, blood glucose falls below the set point.

1. **Receptor:** Alpha cells in the islets of Langerhans detect the fall in blood glucose.
2. **Coordinator/Effector:** Alpha cells secrete **glucagon** into the blood.
3. **Response:** Glucagon binds to receptors on liver cells. This causes:
    - **Glycogenolysis** — breakdown of stored glycogen to glucose
    - **Gluconeogenesis** — production of new glucose from amino acids and glycerol
4. **Result:** Blood glucose rises back toward the set point.
5. **Feedback:** As glucose returns to normal, the stimulus for glucagon secretion diminishes (negative feedback).

EXAM ALERT

Type 1 vs Type 2 Diabetes:

- **Type 1** — autoimmune destruction of beta cells; no insulin produced; requires insulin injections
- **Type 2** — target cells become resistant to insulin (insulin receptors less responsive); often linked to obesity and lifestyle; managed with diet, exercise, and medication
- IB examiners expect you to distinguish these clearly. Type 1 is "insulin-dependent"; Type 2 is "non-insulin-dependent" (though some Type 2 patients eventually need insulin).

2.4 Osmoregulation

Osmoregulation is the control of water potential (osmolarity) of the blood. The kidney is the primary organ responsible for this, under the control of **antidiuretic hormone (ADH)**.

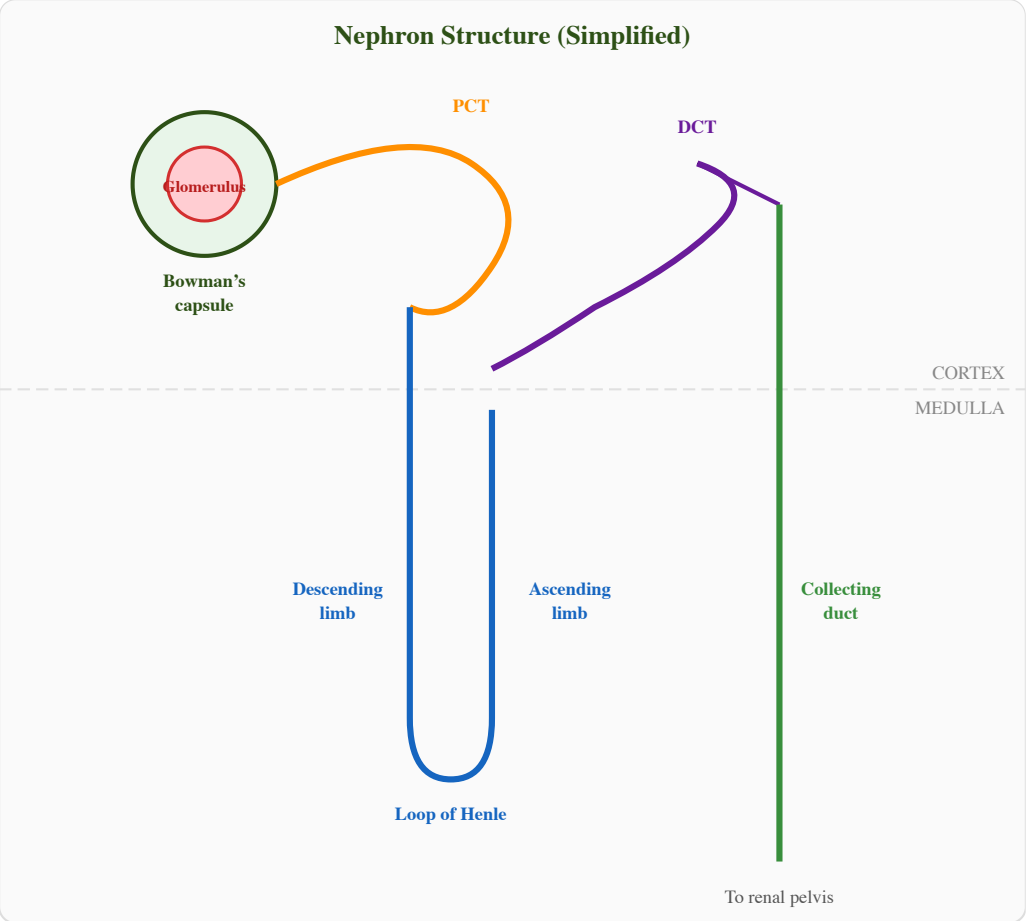
Kidney structure — the nephron:

The functional unit of the kidney is the **nephron**. Each kidney contains approximately 1 million nephrons. Key structures:

MEMORISE THIS

Nephron regions and their functions:

Region	Function
Bowman's capsule	Receives filtrate from the glomerulus by ultrafiltration
Proximal convoluted tubule (PCT)	Reabsorbs ~65% of water, all glucose, amino acids, and most ions (active transport and osmosis)
Loop of Henle	Establishes an osmotic gradient in the medulla (countercurrent multiplier)
Distal convoluted tubule (DCT)	Fine-tuning of ion reabsorption and secretion; regulated by aldosterone
Collecting duct	Water reabsorption regulated by ADH; determines final urine concentration



The Loop of Henle — Countercurrent Multiplier:

The loop of Henle creates a concentration gradient in the kidney medulla that allows the collecting duct to produce concentrated urine. This is the **countercurrent multiplier** mechanism:

1. **Descending limb** — permeable to water, impermeable to ions. Water leaves by osmosis as the filtrate passes into the increasingly concentrated medulla. The filtrate becomes more concentrated as it descends.
2. **Ascending limb** — impermeable to water, actively pumps Na^+ and Cl^- out into the medulla. The filtrate becomes more dilute as it ascends, while the medullary interstitial fluid becomes more concentrated.
3. The **countercurrent flow** (descending and ascending limbs running in opposite directions) multiplies the osmotic gradient, creating a very high solute

concentration deep in the medulla.

> **IB TIP**
>
> **IB key concept:** The longer the loop of Henle, the greater the concentration gradient that can be established, and the more concentrated the urine can be. Desert mammals like the kangaroo rat have very long loops of Henle, enabling them to produce extremely concentrated urine and conserve water.

ADH and Water Reabsorption:

Antidiuretic hormone (ADH), also called **vasopressin**, is produced by the hypothalamus and released from the posterior pituitary gland.

- **When blood is too concentrated** (high osmolarity, e.g. after sweating or low water intake):
    - Osmoreceptors in the hypothalamus detect the change
    - More ADH is released
    - ADH makes the collecting duct walls more permeable to water (by inserting aquaporin channels)
    - More water is reabsorbed from the collecting duct back into the blood
    - Small volume of concentrated urine is produced
- **When blood is too dilute** (low osmolarity, e.g. after drinking a large volume of water):
    - Less ADH is released
    - Collecting duct walls become less permeable to water
    - Less water is reabsorbed
    - Large volume of dilute urine is produced

> **EXAM ALERT**
>
> **Exam trap:** ADH does NOT affect the loop of Henle. ADH acts on the **collecting duct** (and to a lesser extent the DCT). The loop of Henle establishes the gradient; ADH determines how much water the collecting duct reabsorbs using that gradient. Also, alcohol inhibits ADH release — this is why alcohol consumption leads to increased urine production (diuresis).

Section 3: Chemical Signaling (C2.1)

3.1 Hormones and Glands

Hormones are chemical messengers secreted by **endocrine glands** directly into the blood. They travel to target cells with specific receptors and produce a response.

> **MEMORISE THIS**

Endocrine vs Exocrine glands:

Feature	Endocrine glands	Exocrine glands
Duct	Ductless — secrete into blood	Have ducts — secrete into body cavities or skin surface
Secretion	Hormones	Enzymes, sweat, mucus, etc.
Transport	Via bloodstream	Via ducts
Speed of effect	Slower (seconds to hours)	Immediate at site
Examples	Pituitary, thyroid, adrenal, pancreas (islets)	Salivary glands, sweat glands, pancreas (acinar cells)

IB TIP

IB key concept: The pancreas is both an endocrine and an exocrine gland. The **islets of Langerhans** (endocrine) secrete insulin and glucagon into the blood. The **acinar cells** (exocrine) secrete digestive enzymes (e.g. lipase, amylase, trypsinogen) through the pancreatic duct into the duodenum.

3.2 Signal Transduction: First and Second Messengers

Many hormones are **hydrophilic** (e.g. peptide hormones like insulin, glucagon, ADH) and cannot cross the cell membrane. They bind to **receptors on the cell surface** and trigger an intracellular signaling cascade.

First messenger: The hormone itself (e.g. adrenaline binding to a receptor on a liver cell).

Second messenger: An intracellular molecule produced in response to the first messenger that amplifies the signal inside the cell. The most common second messenger is **cyclic AMP (cAMP)**.

Signal transduction pathway (cAMP example):

1. Hormone (first messenger) binds to a **G-protein-coupled receptor** on the cell surface.
2. The receptor activates a **G-protein** on the inner surface of the membrane.
3. The activated G-protein activates the enzyme **adenylyl cyclase**.
4. Adenylyl cyclase converts **ATP** → **cAMP** (the second messenger).
5. cAMP activates **protein kinases** (enzymes that phosphorylate other proteins).
6. A cascade of protein phosphorylation amplifies the signal and produces the cellular response.

EXAM ALERT

Why second messengers matter: One hormone molecule binding to one receptor can trigger the production of many cAMP molecules, each of which activates many protein kinases. This is **signal amplification** — a small external signal produces a large intracellular response. IB examiners love to test this concept.

Steroid hormones (e.g. estrogen, testosterone, cortisol) are **hydrophobic** and can cross the cell membrane directly. They bind to **intracellular receptors** (often in the nucleus) and act as transcription factors, directly activating or repressing gene expression. No second messenger is needed.

3.3 Neural vs Hormonal Signaling

MEMORISE THIS

Comparison: Neural vs Hormonal signaling:

Feature	Neural signaling	Hormonal signaling
Speed	Very fast (milliseconds)	Slower (seconds to hours)
Duration	Short-lived	Longer-lasting
Transmission	Electrical impulses along neurons, chemical at synapses	Chemical (hormones) via blood
Specificity	Highly targeted — specific neurons to specific targets	Widespread — hormones travel in blood but only affect cells with correct receptors
Distance	Can be very long (e.g. spinal cord to toe)	Systemic via blood circulation
Response type	Precise, localised	Often widespread, generalised
Examples	Withdrawal reflex, voluntary movement	Growth, metabolism, blood glucose regulation

IB TIP

Integration of neural and hormonal signaling: Many physiological processes use both systems. For example, the **fight-or-flight response**: the sympathetic nervous system rapidly activates target organs (neural), while the adrenal medulla releases adrenaline into the blood (hormonal) for a sustained response. The hypothalamus links the two systems — it is both a neural structure and a controller of the pituitary gland (the “master” endocrine gland).

Section 4: Integration of Body Systems (C3.1) HL

The nervous system and endocrine system do not operate in isolation. In a living organism, coordinated responses require **integration** — multiple organ systems communicating through both neural and hormonal pathways. C3.1 focuses on how the body achieves this integration, with the **hypothalamus** as the central link between the two systems.

4.1 The Hypothalamus-Pituitary Axis

The **hypothalamus** is the key integration point between the nervous and endocrine systems. It is a brain structure (part of the CNS) that also functions as an endocrine

organ, controlling the **pituitary gland** — often called the "master gland" because its hormones regulate many other endocrine glands.

MEMORISE THIS

The two lobes of the pituitary gland:

Feature	Anterior pituitary	Posterior pituitary
Connection to hypothalamus	Portal blood vessels (hypothalamic-hypophyseal portal system)	Direct neural connection (axons from hypothalamic neurons)
Mechanism	Hypothalamus releases **releasing hormones** (e.g. GnRH, TRH, CRH) or **inhibiting hormones** into portal blood; these stimulate or inhibit hormone secretion by the anterior pituitary	Hypothalamic neurons synthesise hormones (ADH, oxytocin) and transport them down axons to the posterior pituitary for storage and release
Key hormones	TSH, ACTH, FSH, LH, GH, prolactin	ADH (vasopressin), oxytocin
Nature of control	Neuroendocrine — neural input converted to hormonal output via releasing factors	Neurosecretion — neurons directly release hormones into the blood

EXAM ALERT

Exam precision: The posterior pituitary does not *produce* ADH or oxytocin — it only *stores and releases* them. These hormones are **synthesised in the hypothalamus** and transported along axons to the posterior pituitary. This is a commonly tested distinction.

4.2 The Fight-or-Flight Response: Neuroendocrine Integration

The fight-or-flight response is a classic example of how the nervous and endocrine systems work together to produce a rapid, coordinated, whole-body response to a perceived threat.

Sequence of events:

1. A threat is perceived by the cerebral cortex and relayed to the **hypothalamus**.
2. The hypothalamus activates two parallel pathways:

Pathway 1 — Neural (fast, seconds):

- The hypothalamus stimulates the **sympathetic nervous system**.
- Sympathetic neurons directly innervate target organs: heart (increases rate and force), bronchioles (dilate), pupils (dilate), gut (decreases activity), blood vessels to skeletal muscle (dilate).
- Sympathetic neurons also stimulate the **adrenal medulla**.

Pathway 2 — Hormonal (sustained, minutes to hours):

- The adrenal medulla releases **adrenaline** (epinephrine) and **noradrenaline** (norepinephrine) into the blood.
- These hormones reinforce and prolong the neural effects: increased heart rate, increased blood glucose (via glycogenolysis in the liver), redirection of blood flow to muscles, bronchodilation.
- The hypothalamus also triggers the **HPA axis** (hypothalamus → CRH → anterior pituitary → ACTH → adrenal cortex → **cortisol**). Cortisol sustains the stress response over hours by maintaining blood glucose and suppressing non-essential functions (immune response, digestion).

MEMORISE THIS

Fight-or-flight effects on organ systems:

Organ/System	Effect	Mechanism
Heart	Increased rate and force of contraction	Sympathetic nerves + adrenaline acting on cardiac muscle
Bronchioles	Dilation	Adrenaline relaxes smooth muscle
Liver	Glycogenolysis — release of glucose into blood	Adrenaline activates glycogen phosphorylase via cAMP pathway
Skeletal muscle blood vessels	Vasodilation	Adrenaline acting on β_2 receptors
Digestive system	Reduced peristalsis and secretion	Sympathetic inhibition; blood redirected away
Pupils	Dilation (mydriasis)	Sympathetic stimulation of radial muscle of iris
Adrenal cortex	Cortisol release	ACTH from anterior pituitary (HPA axis)

IB TIP

IB key concept: The fight-or-flight response demonstrates **dual-speed integration**. The neural pathway gives an immediate response (within seconds), while the hormonal pathway sustains the response (minutes to hours). This is why you feel a surge of energy instantly when startled (neural), but your hands may still be shaking minutes later (adrenaline circulating in the blood).

4.3 Osmoregulation: Integration of Nervous, Endocrine, and Renal Systems

Osmoregulation is an excellent example of three organ systems working together through negative feedback. The kidney's ability to concentrate or dilute urine depends on signals from the nervous and endocrine systems.

Integrated pathway — response to dehydration:

1. **Detection (nervous):** Osmoreceptors in the **hypothalamus** detect increased blood osmolarity (more concentrated blood).

2. **Neural signaling:** The hypothalamus sends nerve impulses that trigger two responses:
    - Stimulates the **thirst centre** in the cerebral cortex (behavioural response — drink water)
    - Stimulates neurosecretory cells in the hypothalamus to increase ADH synthesis
3. **Hormonal signaling (endocrine):** More **ADH** is released from the **posterior pituitary** into the blood.
4. **Target organ response (renal):** ADH travels via the blood to the **kidneys**. ADH binds to receptors on collecting duct cells, triggering insertion of **aquaporin** water channels into the apical membrane.
5. **Effect:** More water is reabsorbed from the collecting duct into the medullary interstitial fluid and then into the blood. A small volume of **concentrated urine** is produced.
6. **Negative feedback:** As blood osmolarity returns to normal, osmoreceptors detect the change, ADH release decreases, and fewer aquaporins are present — restoring the balance.

⚠ EXAM ALERT

HL exam point: You must be able to trace the complete pathway from stimulus to response, naming all three systems involved (nervous, endocrine, renal). A common error is to describe only the ADH-kidney part without mentioning the osmoreceptors and hypothalamic integration that initiate the response.

4.4 The Medulla Oblongata: Autonomic Integration Centre

The **medulla oblongata** (in the brainstem) is the primary integration centre for **autonomic** (involuntary) functions. It continuously monitors and adjusts vital processes without conscious input.

MEMORISE THIS

Functions integrated by the medulla oblongata:

Function	Receptors	Effectors	Mechanism
Heart rate	Baroreceptors (aortic arch, carotid sinus) detect blood pressure; chemoreceptors detect CO_2/O_2/pH	Cardiac muscle via sympathetic (accelerator) and parasympathetic (vagus) nerves	High BP → vagus nerve slows heart; low BP → sympathetic nerves increase rate
Breathing rate	Central chemoreceptors in medulla detect CO_2 (via pH of cerebrospinal fluid); peripheral chemoreceptors in aortic/carotid bodies	Intercostal muscles and diaphragm	High CO_2 → decreased pH → medulla increases breathing rate and depth
Blood pressure	Baroreceptors in aortic arch and carotid sinus	Arteriole smooth muscle; heart	High BP → vasodilation + decreased heart rate; low BP → vasoconstriction + increased heart rate

IB TIP

IB key concept — CO_2 drives breathing, not O_2: The primary stimulus for increasing breathing rate is a rise in blood CO_2, which lowers the pH of cerebrospinal fluid. The medulla's chemoreceptors are far more sensitive to CO_2/pH changes than to O_2 levels. This is a very commonly tested point.

4.5 Negative Feedback Across Multiple Organ Systems

C3.1 requires you to understand how negative feedback loops connect the nervous, endocrine, and other organ systems in an integrated network. Here are the key multi-system feedback loops you need to know:

1. Thyroid regulation (HPT axis):

Hypothalamus → TRH → Anterior pituitary → TSH → Thyroid gland → Thyroxine (T_4)

Thyroxine increases metabolic rate. When thyroxine levels are sufficient, it inhibits both the hypothalamus (less TRH) and the anterior pituitary (less TSH) — **negative feedback at two levels**.

2. Stress response (HPA axis):

Hypothalamus → CRH → Anterior pituitary → ACTH → Adrenal cortex → Cortisol

Cortisol inhibits both CRH release from the hypothalamus and ACTH release from the anterior pituitary. This prevents the stress response from escalating indefinitely.

3. Blood calcium regulation:

- Low blood Ca^{2+} → parathyroid glands release **PTH** → increased Ca^{2+} reabsorption in kidneys, increased Ca^{2+} release from bone, increased vitamin D

activation (which increases Ca^{2+} absorption from gut)
- High blood Ca^{2+} → thyroid C-cells release **calcitonin** → decreased bone resorption, increased Ca^{2+} excretion

⚠ EXAM ALERT

Exam strategy for integration questions: When asked to "explain how body systems are integrated" or "describe the role of the hypothalamus in coordination," structure your answer as a **pathway**: stimulus → receptor → integration centre → effector pathway (neural and/or hormonal) → target organ → response → feedback. Always name the specific hormones, nerves, and organs involved. Vague answers like "the nervous and endocrine systems work together" will not score marks without specific examples.

WORKED EXAMPLE

Worked Example: Explain how the body integrates multiple systems to respond to a sudden drop in blood pressure (e.g. after blood loss). (6 marks)

1. **Detection:** Baroreceptors in the **aortic arch and carotid sinus** detect the fall in blood pressure and send fewer nerve impulses to the **medulla oblongata**. [1]
2. **Neural response (immediate):** The medulla increases **sympathetic** nerve activity and decreases **parasympathetic** (vagus nerve) activity. This causes: increased heart rate and force of contraction, vasoconstriction of arterioles (raising peripheral resistance), and stimulation of the adrenal medulla. [1]
3. **Short-term hormonal response:** The **adrenal medulla** releases **adrenaline** into the blood, reinforcing the sympathetic effects — increased cardiac output and vasoconstriction. [1]
4. **Medium-term hormonal response:** The **hypothalamus** stimulates ADH release from the posterior pituitary. ADH increases water reabsorption in the collecting ducts of the kidneys, conserving blood volume. ADH also causes vasoconstriction at high concentrations. [1]
5. **Longer-term hormonal response:** The kidneys release **renin**, triggering the **renin-angiotensin-aldosterone system (RAAS)**. Angiotensin II causes vasoconstriction; **aldosterone** from the adrenal cortex increases Na^+ reabsorption in the kidneys, which draws water back into the blood by osmosis. [1]
6. **Negative feedback:** As blood pressure returns toward normal, baroreceptors detect the increase and the medulla reduces sympathetic output. ADH and aldosterone secretion decrease as blood volume and osmolarity normalise. [1]

IB Exam-Style Questions

Question 1 *(3 marks)*

Explain how the resting potential of $-70\ \text{mV}$ is maintained across the axon membrane.

▶ Markscheme

Question 2 *(4 marks)*

Describe the events occurring during an action potential from threshold to return to resting potential.

▶ Markscheme

Question 3 *(3 marks)*

Explain the role of calcium ions in synaptic transmission.

▶ Markscheme

Question 4 *(4 marks)*

Outline the role of the loop of Henle in the production of concentrated urine.

▶ Markscheme

Question 5 *(3 marks)*

Compare and contrast insulin and glucagon in blood glucose regulation.

▶ Markscheme

Mixed Practice — Exam Style

> **IB TIP**
>
> **How to use this section:** These questions mix all topics from this guide in random order. Before answering, identify *which concept or topic area* the question is testing. This is exactly the skill you need on Paper 1 and Paper 2, where you don't know in advance which topic each question covers.

1. **[Resting Potential]** The resting potential of a neuron is approximately $-70\ \text{mV}$. Which of the following contributes most directly to maintaining this resting potential?

   A. Voltage-gated Na^+ channels being open at rest

   B. Equal concentrations of Na^+ and K^+ on both sides of the membrane

   C. K^+ diffusing out of the cell through leak channels, making the inside more negative relative to the outside

   D. Active transport of Ca^{2+} out of the axon

2. **[Synaptic Transmission]** A drug blocks the reuptake of serotonin from the synaptic cleft. The most likely effect is:

A. Serotonin is broken down faster in the synapse

B. Serotonin remains in the synaptic cleft longer, prolonging its effect on the postsynaptic neuron

C. The presynaptic neuron stops releasing serotonin

D. The postsynaptic neuron becomes permanently depolarized

3. **[Thermoregulation]** On a hot day, the hypothalamus detects a rise in core body temperature. Which response would help cool the body?

   A. Vasoconstriction of arterioles near the skin surface

   B. Increased shivering thermogenesis

   C. Vasodilation of arterioles near the skin surface and increased sweating

   D. Piloerection to trap a layer of warm air

4. **[Blood Glucose]** After a 24-hour fast, blood glucose is maintained primarily by:

   A. Continued absorption of glucose from the small intestine

   B. Insulin stimulating glucose uptake by muscle cells

   C. Glucagon stimulating glycogenolysis and gluconeogenesis in the liver

   D. ADH increasing water reabsorption to concentrate glucose in the blood

5. **[Action Potential]** During the absolute refractory period of an action potential, the neuron cannot fire again because:

   A. All K^+ channels are closed and cannot open

   B. The $\mathrm{Na}^+/\mathrm{K}^+$ pump is temporarily inactive

   C. Voltage-gated Na^+ channels are inactivated and cannot reopen until the membrane repolarizes

   D. The threshold has permanently increased to $+40\ \mathrm{mV}$

6. **[Osmoregulation]** A person drinks 2 litres of water in a short period. Which sequence correctly describes the homeostatic response?

   A. Blood osmolarity rises $\rightarrow$ more ADH released $\rightarrow$ more water reabsorbed $\rightarrow$ concentrated urine

   B. Blood osmolarity falls $\rightarrow$ less ADH released $\rightarrow$ collecting duct less permeable to water $\rightarrow$ large volume of dilute urine

   C. Blood osmolarity falls $\rightarrow$ more ADH released $\rightarrow$ more water reabsorbed $\rightarrow$ concentrated urine

D. Blood osmolarity rises → less ADH released → dilute urine produced

7. **[Myelination — HL]** Saltatory conduction in myelinated neurons is faster than continuous conduction because:

   A. Myelin increases the diameter of the axon, allowing more ions to flow

   B. The action potential jumps between nodes of Ranvier, skipping the insulated myelinated regions

   C. Myelination increases the number of ion channels along the entire axon

   D. Schwann cells actively pump Na^+ along the axon

8. **[Signal Transduction]** Adrenaline binds to a receptor on a liver cell, activating adenylyl cyclase. What is the role of cAMP in this pathway?

   A. cAMP is the first messenger that travels through the blood to the liver

   B. cAMP acts as a second messenger inside the cell, amplifying the signal by activating protein kinases

   C. cAMP directly breaks down glycogen into glucose

   D. cAMP binds to DNA to activate gene transcription

9. **[Neurotransmitters]** GABA is the main inhibitory neurotransmitter in the brain. When GABA binds to receptors on the postsynaptic membrane, the most likely effect is:

   A. Na^+ channels open, causing depolarization

   B. Cl^- channels open, causing hyperpolarization (IPSP), making the postsynaptic neuron less likely to fire

   C. Ca^{2+} channels open, triggering neurotransmitter release

   D. K^+ leak channels close, causing depolarization

10. **[Negative Feedback — Integration]** A student claims that "negative feedback always returns a variable to exactly its set point." Evaluate this claim:

    A. Correct — negative feedback mechanisms are perfectly precise and always restore the exact set point

    B. Incorrect — negative feedback produces oscillations around the set point; the variable is maintained within a narrow range but is never held at a single exact value

    C. Correct — the hypothalamus acts as a perfect thermostat with zero error

D. Incorrect — negative feedback amplifies deviations, so the variable moves further from the set point over time

▶ Show Answers

May 2026 Prediction Questions

> ⚠ **EXAM ALERT**
>
> **These are NOT official IB questions.** These are trend-based practice questions written to reflect the topic areas and question styles most likely to appear on the May 2026 IB Biology HL Paper 2. Based on recent exam patterns (2022—2025), expect heavy weighting on: the mechanism of synaptic transmission and drugs that modify it, hormonal vs. neural control in homeostasis (especially blood glucose and osmoregulation), and the distinction between excitatory and inhibitory postsynaptic potentials.

▶ **Question 1 — Synaptic Transmission and Pharmacology [8 marks]**

▶ **Question 2 — Blood Glucose Regulation and Diabetes [7 marks]**

▶ **Question 3 — Osmoregulation and ADH [6 marks]**

IB Biology HL — Neural Signaling & Homeostasis — Complete Study Guide — 2025 Syllabus — Good luck!