



Chemical signalling

Revision notes • IB Biology HL chemical signalling: ligands, receptors, quorum sensing, G proteins and cAMP, the insulin receptor, steroid hormones and feedback.

For IB Diploma Biology, Standard Level and Higher Level (first assessment 2025). **HL only** is additional higher level content, for HL students only.

Chemical signalling

Spec C2.1

HL only

Receptors, ligands and quorum sensing

Spec C2.1.1, C2.1.2

Cells receive many different chemical signals. Each signal is detected by a **receptor**: a protein with a binding site for one specific signalling chemical. The IB term for the signalling chemical is the **ligand**.

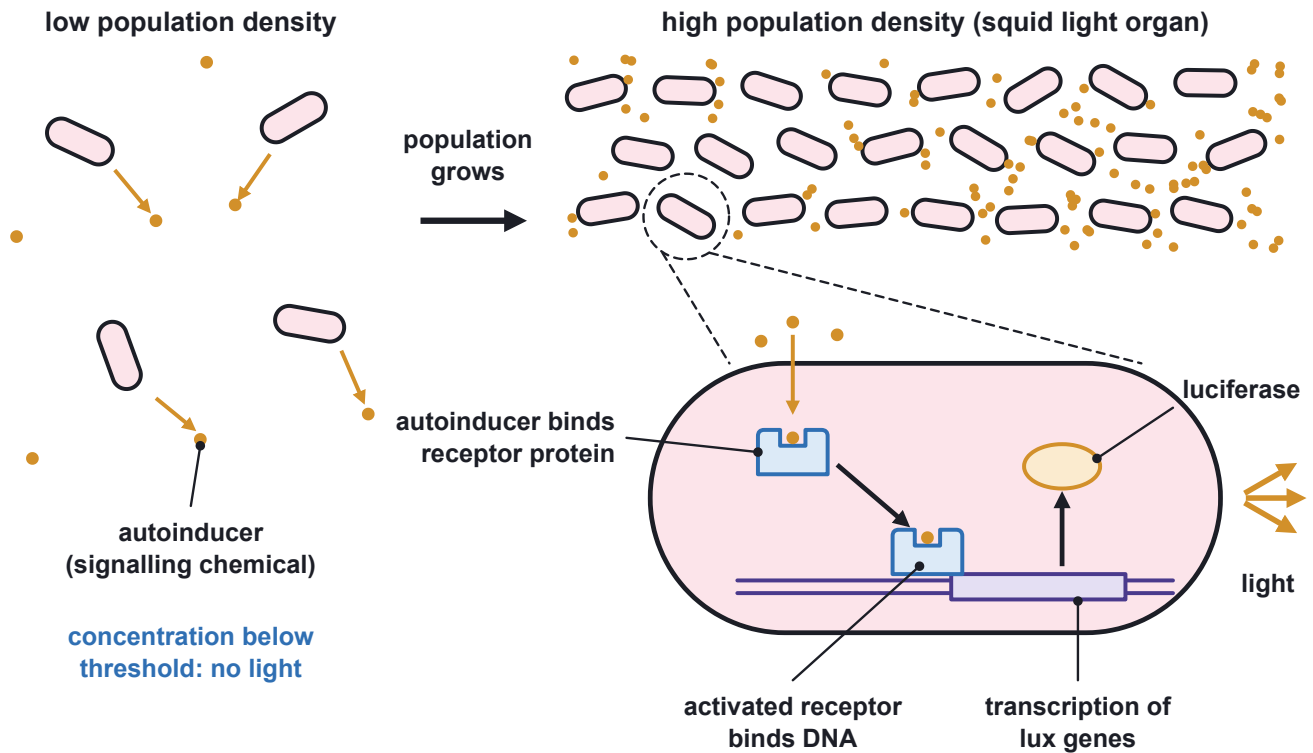
- The binding site has a shape and chemical properties (charge, polarity) that are complementary to the ligand, so only that ligand binds.
- Binding is reversible: the ligand binds, causes a change in the receptor, then leaves.
- When the ligand binds, the receptor changes conformation (shape). This change is what passes the signal on.
- A cell responds only to the ligands it has receptors for. This is how cells distinguish between the many signals they receive.

Quorum sensing in *Vibrio fischeri*

Bacteria also signal to each other. **Quorum sensing** is cell signalling in which bacteria detect the density of their own population and respond only when it is high. The marine bacterium *Vibrio fischeri* lives freely in sea water and also at very high density in the light organ of some squid and fish. It produces light (**bioluminescence**) only at high density.

1. Each *V. fischeri* cell makes a small signalling chemical (an autoinducer) and releases it. It diffuses freely across the bacterial membranes.
2. At low population density the autoinducer diffuses away, so its concentration stays low.
3. At high density, as in a light organ, the autoinducer accumulates and binds to receptor proteins inside the cells.
4. The activated receptor promotes transcription of the genes for bioluminescence, including the enzyme luciferase, so the whole population glows together.
5. The same genes include one for making more autoinducer, so the response reinforces itself (positive feedback).

Light production uses a lot of energy. A single cell's light would be useless, so it only pays when many cells glow together. The squid host benefits from the light; the bacteria gain nutrients and a place to live.



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Quorum sensing in *Vibrio fischeri*: light is produced only when the **autoinducer** concentration is high enough.

Exam tip: Always call the signalling chemical a ligand and say it binds to a specific binding site on the receptor. Avoid 'active site', which is for enzymes and substrates.

Types of signalling chemicals Spec C2.1.3, C2.1.4, C2.1.5

Functional categories of signalling chemicals in animals			
Category	Released by	How it reaches target cells	Effect
Hormones	Endocrine glands, secreted into the blood	Transported by the blood around the whole body	Distant, widespread, slower and longer lasting
Neurotransmitters	Neurons, at a presynaptic membrane	Diffuse across a synaptic gap (about 20 nm)	Localized to one postsynaptic cell, rapid and brief
Cytokines	Many cell types, especially cells of the immune system	Diffuse to nearby cells in tissue fluid	Mainly local, e.g. regulate immune responses and inflammation
Calcium ions (Ca²⁺)	Released inside a cell from stores or entering through channels	Act inside the cell that receives the first signal	Trigger responses such as exocytosis of neurotransmitter or muscle contraction

The difference between **localized and distant effects** is clearest when hormones are compared with neurotransmitters. A hormone reaches every cell the blood supplies, but only cells with the matching receptor respond. A neurotransmitter only crosses the narrow gap at one synapse and is removed within milliseconds.

Chemical diversity

Chemical groups of hormones and neurotransmitters	
Group	Examples
Amine hormones	Epinephrine (adrenaline), norepinephrine (noradrenaline)
Protein (peptide) hormones	Insulin, glucagon
Steroid hormones	Oestradiol, progesterone, testosterone
Amino acid neurotransmitters	Glutamate, glycine, GABA
Peptide neurotransmitters	Endorphins
Amine neurotransmitters	Dopamine, serotonin, norepinephrine (noradrenaline)
Gas	Nitric oxide (NO)

- **Many distinct signals are needed.** Each needs its own ligand and receptor, so cells can tell signals apart.
- **Different properties suit different routes.** Hydrophilic proteins and amines stay outside the cell and bind receptors on the plasma membrane. Hydrophobic steroids pass through the membrane to receptors inside.
- **Speed and duration vary.** Small molecules can be made and broken down quickly; a gas such as NO diffuses freely through membranes and acts briefly near where it is made.
- **One molecule can have more than one role.** Norepinephrine is a hormone when the adrenal gland secretes it into the blood and a neurotransmitter when a neuron releases it at a synapse.

Exam tip: The IB guide's list of neurotransmitters says 'nitrous oxide'. It means the gas that acts as a neurotransmitter, which chemists call nitric oxide (NO). Nitrous oxide (N₂O, 'laughing gas') is a different molecule. Write 'nitric oxide (NO)' in answers. If a question says 'nitrous oxide', it means this same gaseous neurotransmitter.

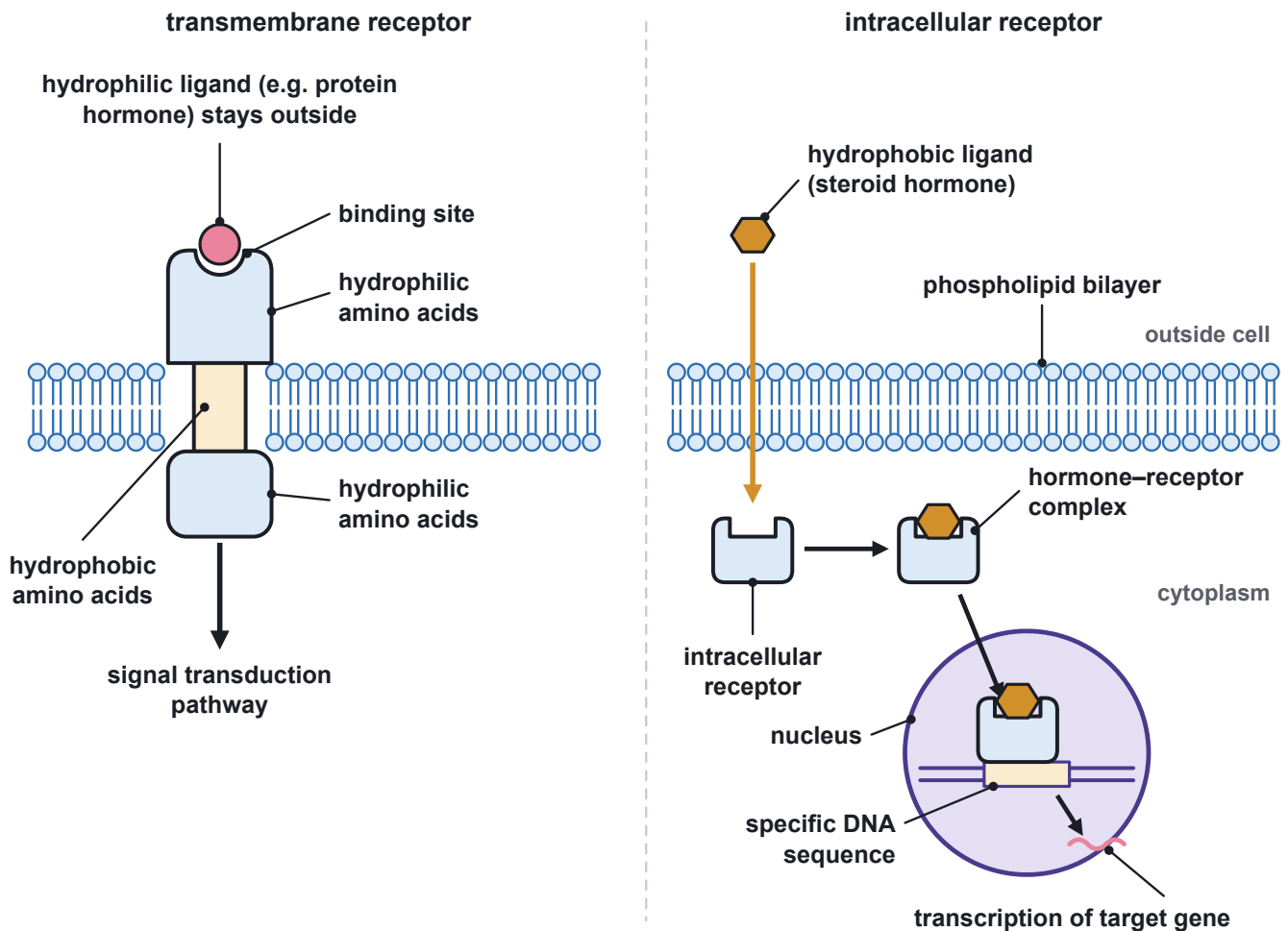
Transmembrane and intracellular receptors Spec C2.1.6, C2.1.7

Comparing the two types of receptor		
Feature	Transmembrane receptor	Intracellular receptor
Position	Spans the plasma membrane	In the cytoplasm or nucleus
Amino acids	Hydrophobic amino acids in the region within the phospholipid bilayer; hydrophilic amino acids in the parts facing the aqueous cytoplasm and extracellular fluid	A soluble protein with hydrophilic amino acids on its surface and no hydrophobic membrane-spanning region; hydrophobic amino acids line the binding site that holds the hydrophobic ligand
Ligand	Hydrophilic or large: proteins, peptides, amines, neurotransmitters	Hydrophobic: steroid hormones
Does the ligand enter the cell?	No, it binds on the outside and remains outside	Yes, it diffuses through the phospholipid bilayer
Typical response	Signal passed in by ion channels, G proteins or enzymes	Activated receptor binds DNA and changes gene expression

Signal transduction pathways

Binding of the ligand is only the start. It causes a conformational change in the receptor that sets off a **signal transduction pathway**: a sequence of responses within the cell that converts the outside signal into a change inside.

- The steps can involve ion movement, relay proteins, second messengers (such as cAMP) and enzymes that add phosphate groups to other proteins.
- Each activated molecule can activate many molecules in the next step, so a few ligand molecules can produce a large response (amplification).
- The final response may be a change in membrane potential, in enzyme activity, in the movement of vesicles or in gene expression.



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Transmembrane receptors bind ligands that stay outside; **intracellular receptors** bind hydrophobic ligands that enter the cell.

Exam tip: When asked to distinguish the receptor types, give paired contrasts: position, distribution of hydrophilic and hydrophobic amino acids, and whether the ligand enters the cell.

Ion channel receptors and G protein-coupled receptors Spec C2.1.8, C2.1.9, C2.1.10

Receptors for neurotransmitters: the acetylcholine receptor

1. Acetylcholine binds to binding sites on the acetylcholine receptor in the postsynaptic membrane.
2. The receptor changes shape and opens an **ion channel** within the receptor itself.
3. Positively charged ions, mainly Na^+ , diffuse into the cell down their concentration gradient.
4. The inside becomes less negative: the voltage across the plasma membrane (the membrane potential) changes. This depolarization may cause other changes, such as an action potential in a

neuron or contraction of a muscle fibre.

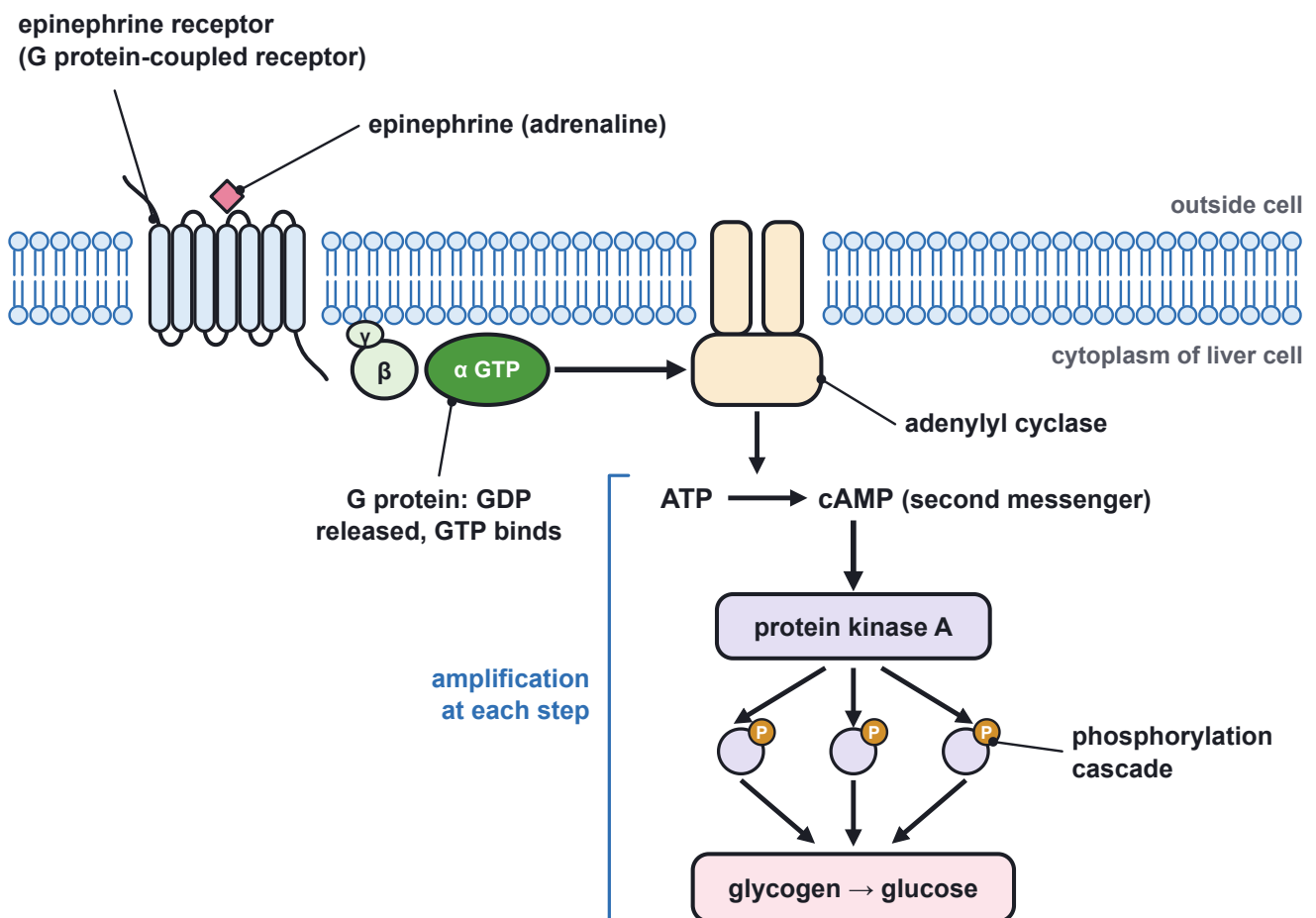
G protein-coupled receptors

A **G protein-coupled receptor** (GPCR) is a transmembrane receptor linked on the inside of the membrane to a G protein. Humans have many different GPCRs (hundreds of genes), detecting ligands such as hormones, neurotransmitters, odours and light.

1. The ligand binds to the receptor on the outside of the plasma membrane.
2. The receptor changes conformation and activates a G protein on the cytoplasmic side.
3. The G protein releases GDP and binds GTP. Part of it (the α subunit) separates and activates or inhibits a target protein, such as an enzyme or an ion channel.
4. The G protein switches itself off by hydrolysing GTP to GDP, so the signal stops when ligand binding stops.

Epinephrine (adrenaline) receptors

1. Epinephrine is carried in the blood and binds to its receptor (a GPCR) on a target cell such as a liver cell. It does not enter the cell.
2. The receptor activates a G protein, which binds GTP.
3. The activated G protein activates the enzyme adenylyl cyclase in the membrane.
4. Adenylyl cyclase converts ATP into **cyclic AMP (cAMP)**, the **second messenger**.
5. cAMP activates protein kinase A, which phosphorylates other enzymes in a cascade. In liver cells this activates glycogen breakdown, releasing glucose into the blood.



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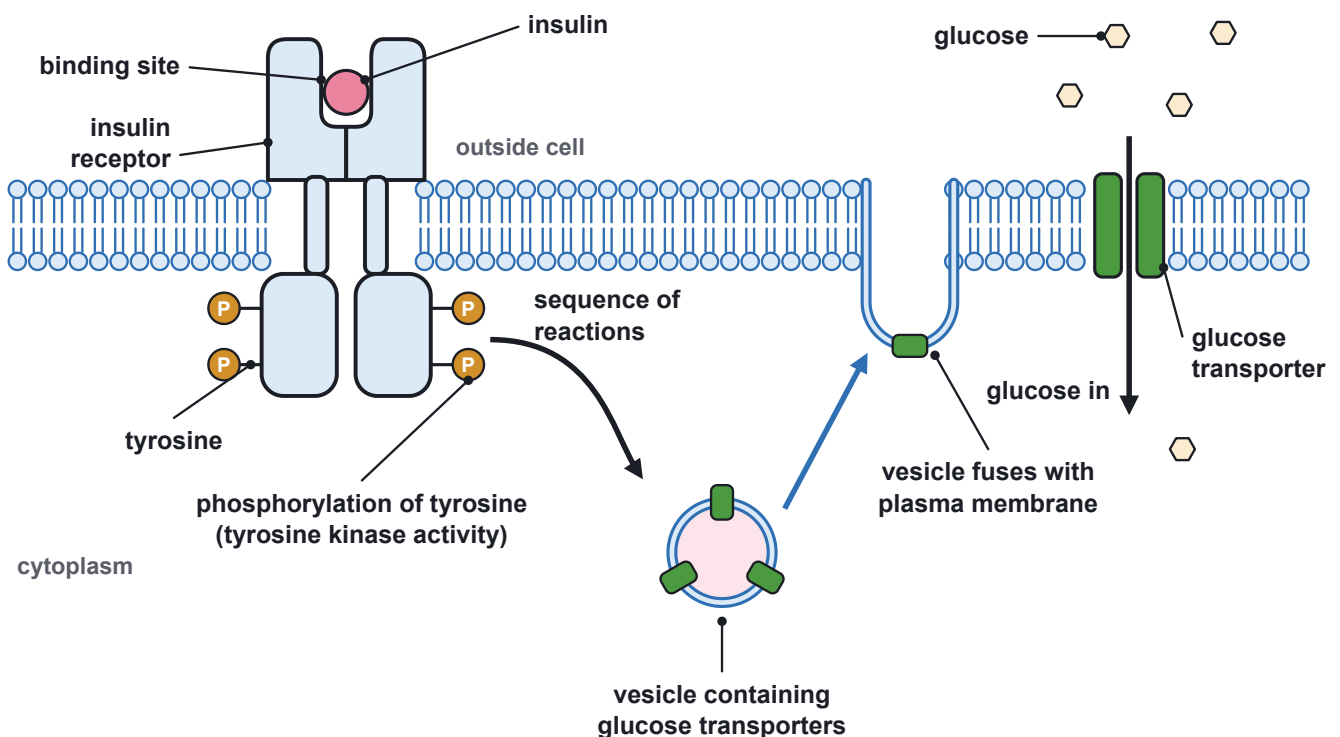
Epinephrine acts through a G protein and the second messenger **cAMP**; each step amplifies the signal.

Exam tip: Epinephrine and adrenaline are the same hormone. Both names come from its production by the adrenal gland, above the kidney; an example of naming conventions that persist side by side in international science.

Tyrosine kinase receptors: insulin Spec C2.1.11

Insulin is a protein hormone, so it cannot cross the plasma membrane. It binds to a transmembrane receptor whose cytoplasmic part acts as an enzyme: a **tyrosine kinase**, which adds phosphate groups to the amino acid tyrosine.

1. Insulin binds to the binding site of the insulin receptor on the outside of the plasma membrane.
2. The receptor changes conformation and its tyrosine kinase activity is switched on.
3. Phosphate groups (from ATP) are added to tyrosine residues on the part of the receptor inside the cell: **phosphorylation of tyrosine**.
4. Relay proteins recognise the phosphorylated tyrosines and start a sequence of reactions in the cytoplasm.
5. This ends with **vesicles containing glucose transporters** moving to the plasma membrane and fusing with it.
6. With more glucose transporters in the membrane, glucose enters the cell faster by facilitated diffusion, lowering blood glucose.



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Insulin binding causes **phosphorylation of tyrosine**, which leads to more glucose transporters in the plasma membrane.

Common mistake: Insulin does not enter the cell, and it does not carry glucose. It changes how many glucose transporters are in the plasma membrane.

Intracellular receptors and steroid hormones Spec C2.1.12, C2.1.13

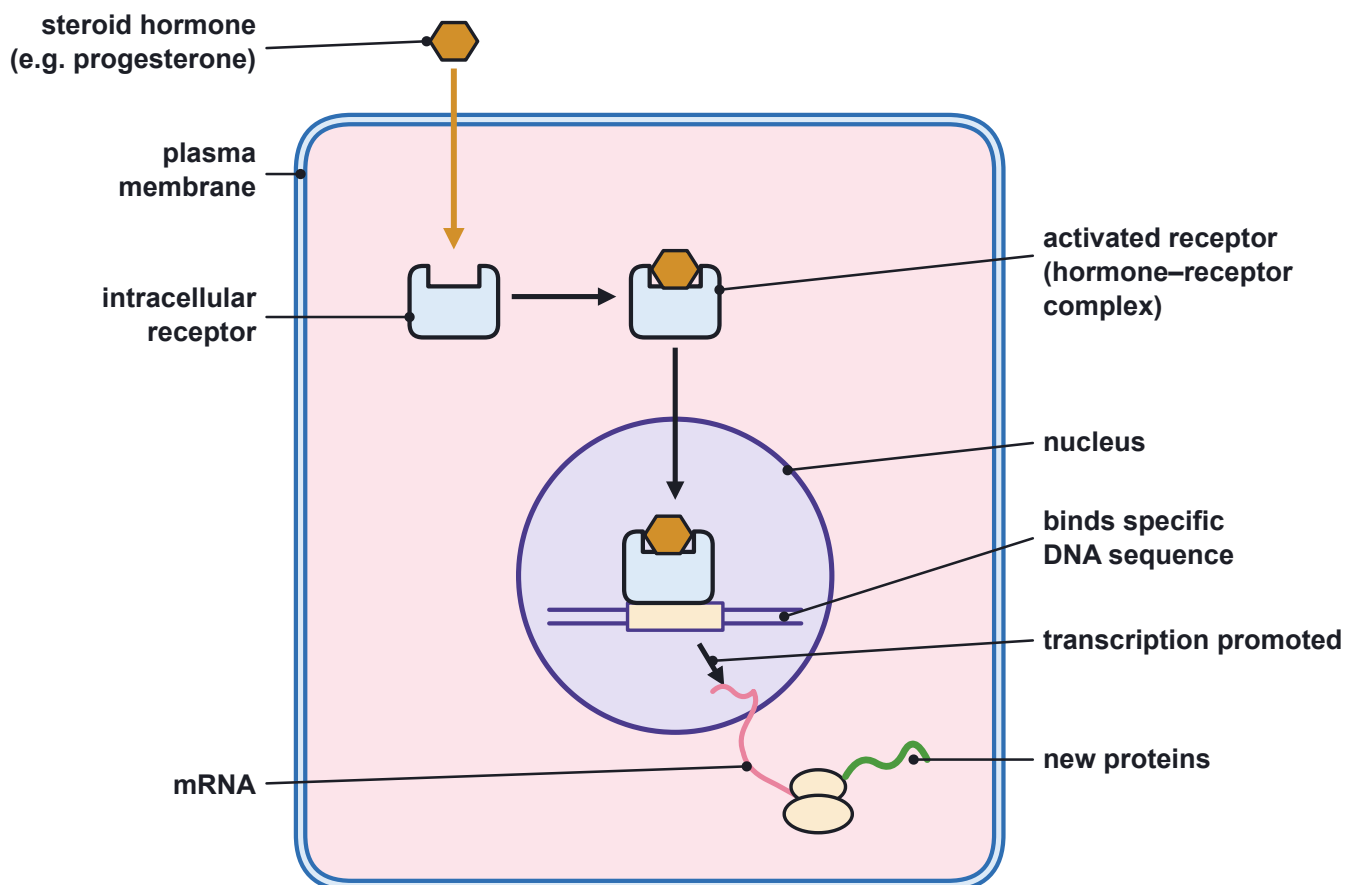
1. A steroid hormone diffuses through the phospholipid bilayer of the target cell.

2. It binds to a binding site on its specific receptor in the cytoplasm or nucleus, activating the receptor.
3. The activated hormone-receptor complex binds to **specific DNA sequences** next to target genes.
4. This **promotes transcription** of those genes, so new proteins are made and the cell's activity changes.

Examples are **oestradiol**, **progesterone** and **testosterone**. Because the response needs transcription and translation, steroid effects are slower to start but longer lasting than effects through membrane receptors.

Effects on target cells

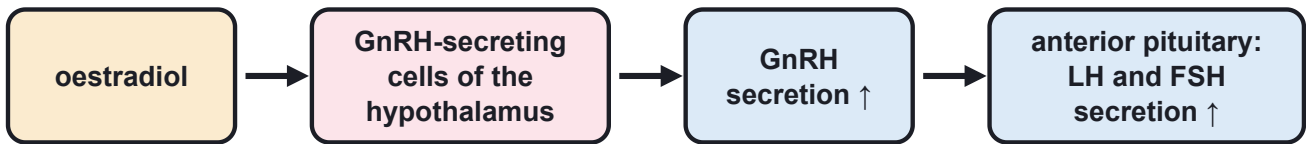
Two steroid hormones and their target cells		
Hormone	Target cells	Effect
Oestradiol	Cells in the hypothalamus that secrete gonadotropin-releasing hormone (GnRH)	Changes how much GnRH these cells secrete. At low or moderate concentrations, oestradiol inhibits GnRH secretion (negative feedback). When oestradiol stays high late in the follicular phase, it increases GnRH secretion (positive feedback). More GnRH raises LH and FSH secretion by the anterior pituitary, giving the LH surge that triggers ovulation.
Progesterone	Cells in the endometrium (uterus lining)	Maintains the thickened endometrium and promotes its further development, including glands and blood supply, ready for implantation. When progesterone falls, the endometrium breaks down (menstruation).



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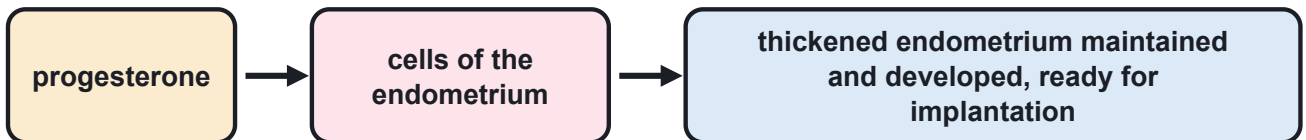
A steroid hormone binds an intracellular receptor, which then binds DNA and **promotes transcription**.

Oestradiol (high, late in the follicular phase)



At low or moderate concentrations, oestradiol inhibits GnRH secretion instead (negative feedback).

Progesterone



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Oestradiol acts on **GnRH-secreting cells of the hypothalamus**; progesterone acts on **cells of the endometrium**.

Exam tip: For C2.1.13 the guide limits you to two targets: oestradiol on GnRH-secreting hypothalamus cells and progesterone on endometrium cells. Answer about those, not the whole menstrual cycle, which is in D3.1.

Positive and negative feedback in cell signalling Spec C2.1.14

Two forms of regulation		
Feature	Negative feedback	Positive feedback
Effect of the response on the stimulus	Reduces it	Increases it
Result	Signal is damped; conditions return towards a set point	Signal is amplified; a rapid, large change
How it ends	Continuous, keeps things stable	Needs an outside event to stop the cycle

Negative feedback example: insulin

A rise in blood glucose stimulates insulin secretion. Insulin signalling makes cells take up glucose, so blood glucose falls. Lower glucose reduces insulin secretion, so the signal switches itself off.

Positive feedback example: oestradiol and GnRH

Late in the follicular phase, the growing follicle keeps oestradiol concentration high. Oestradiol now increases GnRH secretion by the hypothalamus, instead of inhibiting it as it does at lower concentrations. More GnRH raises FSH and LH, which stimulate the follicle to secrete even more oestradiol. The cycle builds to the LH surge and ends with ovulation.

Exam tip: Linking question: in what ways is negative feedback evident at all levels of biological organization? Here it acts on a signalling pathway; in C3.1 it controls heart rate and ventilation rate, and in D3.3 it keeps body temperature and blood glucose near their set points.

Quick check

1. **HL only** What term does the IB use for a signalling chemical that binds to a receptor?
2. **HL only** Which marine bacterium is the example of quorum sensing?
3. **HL only** What is the second messenger in the epinephrine pathway?
4. **HL only** Which amino acid in the insulin receptor is phosphorylated?
5. **HL only** Where are the receptors for steroid hormones?

Quick check answers

Chemical signalling

1. A ligand.
2. *Vibrio fischeri*, which becomes bioluminescent at high population density.
3. Cyclic AMP (cAMP).
4. Tyrosine.
5. Inside the cell, in the cytoplasm or nucleus.