



Overview
(/study/app)

C2.1 Teacher view

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Chemical signalling (HL)

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C2. Interaction and interdependence: Cells / C2.1 Chemical signalling (HL)

The big picture (HL)

Section

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Feedback



Print (/study/app/bio/sid-422-cid-755105/book/big-picture-hl-id-43540/print/)

Assign

Higher level (HL)

? Guiding question(s)

- How do cells distinguish between the many different signals that they receive?
- What interactions occur inside animal cells in response to chemical signals?

Keep the guiding questions in mind as you learn the science in this subtopic. You will be ready to answer them at the end of this subtopic. The guiding questions require you to pull together your knowledge and skills from different sections, to see the bigger picture and to build your conceptual understanding.

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In this subtopic you will learn how chemical signalling involves the transfer of information from one cell to another through the use of messenger molecules. These molecules bind to receptors on target cells and can have varying effects. These may range from regulating basic physiological processes such as metabolism, to guiding the development of an embryo.

Have you ever wondered how cells ‘talk’ to each other and coordinate complex functions like forming a blood clot without being in physical contact with each other (**Figure 1**)?

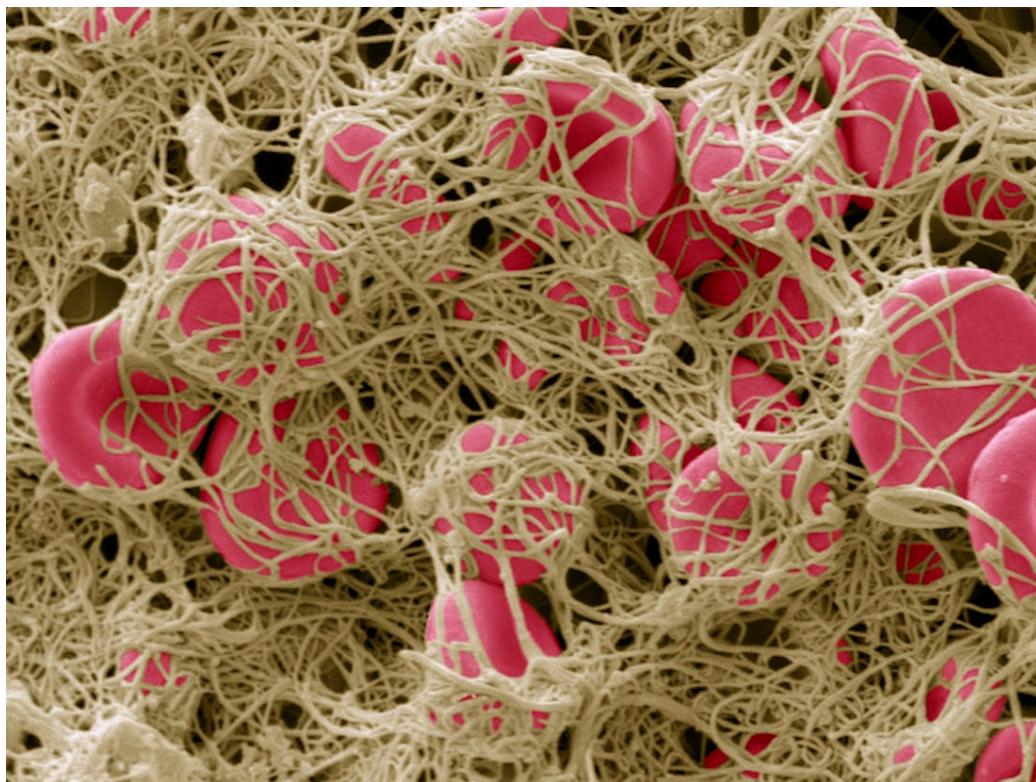


Figure 1. An electron micrograph of a blood clot.

Credit:Science Photo Library - Steve Gschmeissner, Getty Images



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Organisms, ranging from simple single-celled creatures to complex multicellular beings, have evolved ways to communicate with one another. While the ways of communicating vary depending on the organism, chemical signalling is one of the most prevalent and essential forms of communication. This system is ubiquitous in nature, and its role is to help organisms coordinate their actions and responses.



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Did you know that one of the most important signalling molecules in the development of our bodies is called Sonic hedgehog (SHH)? It plays a vital role in cell differentiation, especially the formation of our limbs, brain, and spinal cord. Without this molecule, our bodies would not know how to grow and develop properly. In fact, mutations in the SHH pathway have been linked to a range of birth defects, including holoprosencephaly, a condition where the brain fails to divide into two hemispheres. By studying how SHH works, we can gain insight into the fascinating world of chemical signalling and the complex processes that shape our bodies. **Video 1** provides a good explanation of how the SHH signalling protein functions.

"Sonic Hedgehog Gene" - Why You Have Thumbs And Not Fins



Video 1. Unlocking the secrets of the Sonic hedgehog gene.

Prior learning

Before you study this subtopic make sure that you understand the following:

- The principles of cell biology — cell structure and function (see section A2.2.4—6 ↗ (/study/app/bio/sid-422-cid-755105/book/prokaryotic-and-eukaryotic-cells-id-43583/)), cell differentiation (see section A2.2.12—4 ↗ (/study/app/bio/sid-422-cid-755105/book/endosymbiosis-cell-differentiation-multicellular-organisms-id-44720/)), structure of cell membrane, transport



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across cell membrane (see [sections B2.1.4–5](#) ↗
[\(/study/app/bio/sid-422-cid-755105/book/membrane-proteins-and-their-functions-id-44638/\)](#) and [B2.1.6–8](#) ↗
[\(/study/app/bio/sid-422-cid-755105/book/facilitated-diffusion-and-active-transport-in-id-44644/\)](#)).

- Biochemical reactions and metabolic processes such as glycolysis, Krebs cycle ([section C1.1.11–13](#) ↗
[\(/study/app/bio/sid-422-cid-755105/book/metabolic-pathways-hl-id-46234/\)](#)) and phosphorylation ([section C1.2.7–8](#) ↗
[\(/study/app/bio/sid-422-cid-755105/book/glycolysis-hl-id-45982/\)](#)).

C2. Interaction and interdependence: Cells / C2.1 Chemical signalling (HL)

Receptors and quorum sensing (HL)

C2.1.1: Receptors as proteins with binding sites for specific signalling chemicals (HL)

C2.1.2: Cell signalling by bacteria in quorum sensing (HL)

Section

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Assign

Higher level (HL)

Learning outcomes

By the end of this section you should be able to:

- Define the term ligand.
- Outline the stages of signal transduction.
- Explain the mechanism of quorum sensing in bacteria and discuss its role in bacterial behaviour.
- Understand bioluminescence and its importance and applications.





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Chemical signalling in cells

Chemical signalling is a process by which cells, tissues and organisms communicate with each other through the use of signalling molecules. Cell-to-cell interactions can be either direct or indirect. Direct interactions involve cell-to-cell contact, whereas indirect interactions occur through the secretion of molecules by one cell that are transported to the target cells. These signalling molecules are called ligands and they include hormones, neurotransmitters, cytokines, calcium ions and growth factors. Ligands cause a cascade of biochemical reactions that lead to a specific response, for example modulation of gene expression. This process is known as ligand binding. The receptors exhibit specificity to ligands due to the structure of their binding sites. In humans, chemical signalling helps in maintaining homeostasis, development, immune response, neural function and metabolic regulation.

Stages of chemical signalling

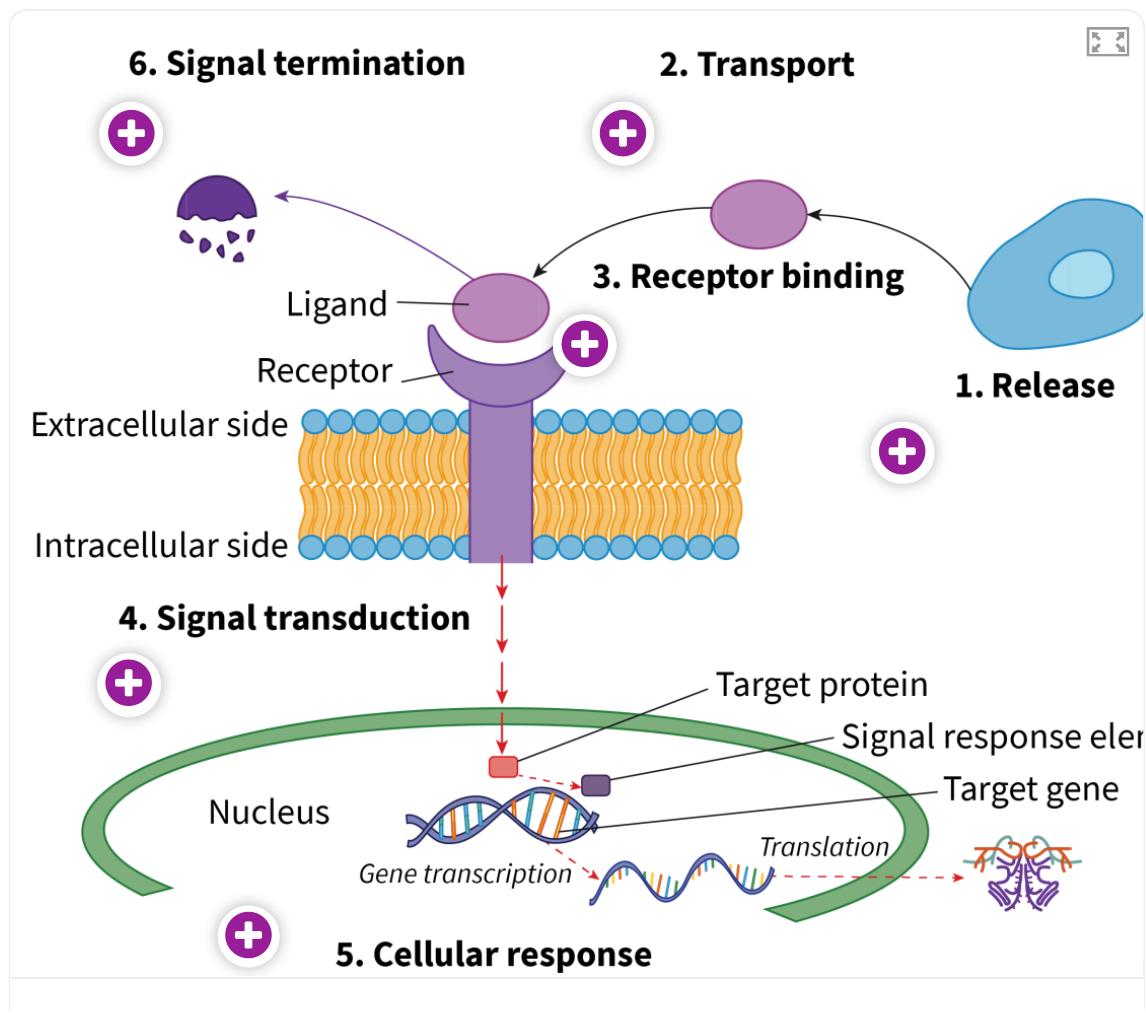
1. Synthesis and release of a ligand from a signalling cell.
2. Transport and diffusion — ligands travel through the bloodstream or by diffusion through the extracellular fluid to reach the target cells.
3. Receptor binding — the signalling molecules bind to specific receptors on the surface of the target cell (called cell surface receptors) or, in the case of intracellular signalling, within the cytoplasm or nucleus of the target cell. Receptors are specific to ligands. For example, hormones such as insulin and glucagon have specific receptors on cells to which they bind.
4. Signal transduction — when the ligand binds to its receptor, it causes a conformational change in the receptor, initiating a cascade of biochemical reactions allowing it to bind to other molecules.
5. Cellular response — the activated signalling pathways lead to specific cellular responses, such as changes in gene expression, activation or inhibition of enzymes, alteration of ion channel activity, or modulation of cellular metabolism.
6. Signal termination — the signalling molecule is either degraded or removed from the extracellular space, and the receptor is inactivated, bringing the signal transduction process to an end.



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These stages are summarised in **Interactive 1**.

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Interactive 1. Stages of Chemical Signalling.

More information for interactive 1

The interactive diagram illustrates the six key steps of chemical signalling, a fundamental process by which cells communicate to coordinate physiological functions. The process begins with the release of a signalling molecule (ligand) and ends with signal termination to ensure precise regulation.

The interactive diagram shows a cell on the right side that releases a ligand. The ligand is then shown as travelling toward the cell. A unidirectional arrow mark is used to show the direction in which the ligand travels toward the receptor. In the middle, there is the cell surface of the target cell with the extracellular side and intracellular side. There is a cell-surface receptor on the extracellular side, where the ligand binds. Below this, the cellular response stage for gene expression is shown, which occurs in the target gene inside the nucleus. Different parts inside the nucleus are labelled. These labels include: Target protein, Signal response element, and Target gene. In the top right corner, the ligand degradation is shown, where the ligand is being broken down. The interactive includes six key stages labelled 1 to 6 with each stage having a title and a hotspot represented by a plus sign. Clicking on these hotspots reveals detailed explanations of each stage.

Read below to learn about each stage and the text in the corresponding hotspot:
The first stage is labelled “Release” and the hotspot reads “Release — Ligand is released from the secreting cell.”



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The second stage is labelled “Transport” and the hotspot reads “Transport — Ligand is transported to the target cell.”

The third stage is labelled “Receptor binding”. The hotspot reads “Receptor binding — Ligand binds to the receptor present on the target cell causing a conformational change in the receptor.”

The fourth stage is labelled “Signal transduction” and the hotspot reads “Signal transduction — A cascade of intracellular signalling events involving several other molecules e.g.: second messengers, protein kinases, etc.”

The fifth stage is labelled “Cellular response” and the hotspot reads “Cellular response — Showing changes in gene expression, enzyme activity, membrane transport, or other cellular processes.”

The sixth step is labelled “Signal termination” and the hotspot reads “Signal termination — Showing degradation of the ligand.”

Chemical signalling is a tightly regulated process essential for homeostasis, growth, and response to stimuli. By breaking down the stages, from ligand release to termination, this interactive diagram helps clarify how cells transmit and interpret signals efficiently.

Watch **Video 1** for an introduction to cell signalling.

Intro to Cell Signaling



Video 1. Introduction to cell signalling.



Theory of Knowledge



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To what extent do the names and labels that we use help or hinder the acquisition of knowledge?

Names and labels that use common language simplify complex information and facilitate knowledge acquisition. They promote effective communication and quick understanding of unfamiliar concepts. However, they can hinder knowledge acquisition by oversimplifying and creating misconceptions. The use of labels can introduce biases and prejudices, limiting comprehensive understanding. Careful examination of names and labels is important to avoid superficial interpretations. By questioning their implications, it is possible to navigate complexity, cultivate holistic understanding and engage in more nuanced discussions.

Cell signalling by bacteria in quorum sensing

Introduction to quorum sensing

In nature, bacteria thrive in a variety of environments. Have you ever thought how some of them are able to survive in conditions where no other living organism can? Or how they rapidly reappear in a place when a prevailing threat is over? Bacteria can communicate with each other to form communities and protect themselves from threats or harsh conditions. One fascinating example is biofilm formation, where they use cell signalling in a process called quorum sensing to stick together and create a protective layer.

Bacterial cells communicate with each other to coordinate their group behaviour in response to cell density. Once a population threshold is reached, the bacteria coordinate the expression of several traits such as biofilm formation, swarming, motility, conjugation and antibiotic production.

Mechanism of quorum sensing

Bacteria involved in quorum sensing release small signalling molecules called autoinducers which diffuse and accumulate in their environment. These autoinducers bind to regulators and induce or repress gene





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expression. Gram-positive bacteria use processed oligopeptides while Gram-negative bacteria use acylated homoserine lactones (acyl-HSLs) to communicate.

For example, the marine bioluminescent Gram-negative bacterium *Vibrio fischeri* is a free-living microorganism that may also be found in a symbiotic association with certain fish and squid. In response to a rise in population density, *V. fischeri* releases N-acyl homoserine lactone (an autoinducer). It binds to regulators and induces the lux operon, allowing the bacteria to regulate its luminescence. The lux operon is a group of genes that encode regulatory proteins and the production of luminescent proteins. Luciferase produces light when it oxidises its substrate, luciferin (**Figure 1**). This is the light that can be seen during bioluminescence. The greater the concentration of autoinducer produced, the brighter the glow. The more bacteria that are present will also mean more autoinducer will be released and more glow. It works in a positive feedback system (see sections C3.1.23 (/study/app/bio/sid-422-cid-755105/book/role-of-ethylene-hl-id-46104/) and D3.1.18–20 (/study/app/bio/sid-422-cid-755105/book/placenta-and-hormonal-control-of-pregnancy-hrt-hl-id-44456/)).

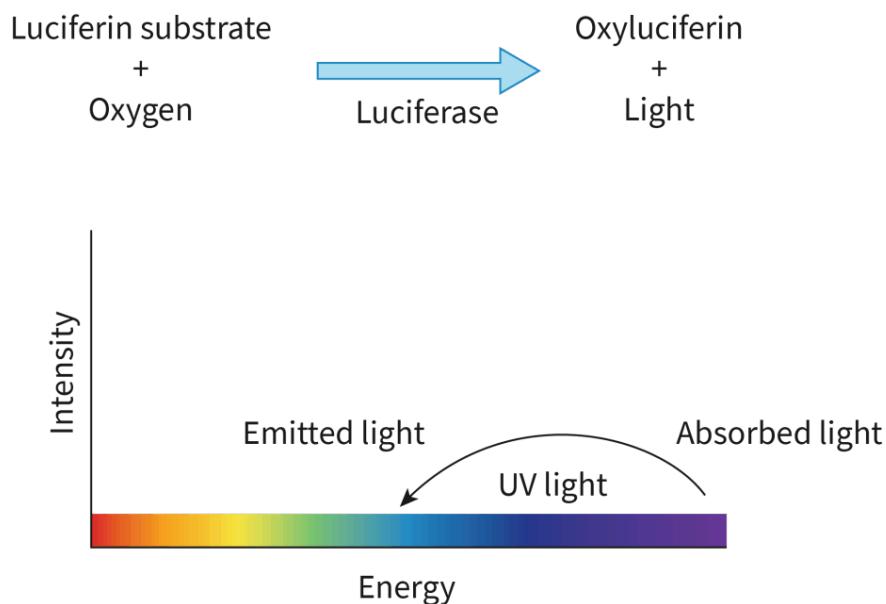


Figure 1. Bioluminescence produced by the luciferin—luciferase reaction.

More information for figure 1



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The image presents a diagram illustrating the chemical reaction involving luciferin and luciferase, commonly associated with bioluminescence. At the top, the diagram depicts luciferin substrate reacting with oxygen and luciferase enzyme, represented by a double-headed arrow pointing from left to right, indicating the transformation into oxyluciferin and light.

Below this reaction schematic, a graph is shown with 'Intensity' on the vertical axis and 'Energy' on the horizontal axis. The spectrum of light is represented as a gradient of colors ranging from red to violet. The graph includes a label for 'Emitted light' starting at the red end of the spectrum and 'Absorbed light' at the violet end. Between these two, an arc labeled 'UV light' connects emitted and absorbed light, suggesting a transition in light energy levels.

[Generated by AI]

Video 2 explains how *Vibrio fischeri* use chemical signals to coordinate their behaviour and work together in quorum sensing. Luciferin gets activated by oxygen and converted into oxyluciferin. This substance creates the light. The reaction is a reversible reaction. This chemical undergoes a redox reaction (electron transfer reactions). Electrons are transferred from a donor to an acceptor. The donor gets oxidised after giving away electrons and gains a positive charge and the acceptor gets reduced after accepting those electrons and becomes negatively charged.

Quorum Sensing



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Video 2. Quorum sensing.



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Targeting quorum sensing

While quorum sensing is a promising tool in the degradation of industrial waste and other environmental contaminants, methods designed to overcome quorum sensing, known as quorum quenching, are of particular interest. In medicine, quorum quenching can be used in the treatment of bacterial infections without the use of antibiotics. In the food industry, N-acyl homoserine can be targeted toward bacteria that cause food spoilage and biofilm formation. There are also potential applications in the fields of bioelectricity generation and fermentation.

Video 3 will help you recap all the terminologies that you have come across in this section. Pause the video at any time to note down any new terminology or to absorb the information.

Common cell signaling pathway



0:00 / 9:41



Video 3. Common Cell Signalling Pathways.

More information for video 3

1

00:00:02,633 --> 00:00:03,867

[soft music plays]

2

00:00:04,733 --> 00:00:06,767

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narrator: To make
a multicellular organism,
3
00:00:06,833 --> 00:00:09,133
cells must be able to communicate
with one another.

4
00:00:09,200 --> 00:00:12,267
And to do it,
cells often send out tiny chemical signals

5
00:00:12,333 --> 00:00:14,433
that act on the receptors of other cells.

6
00:00:14,500 --> 00:00:15,633
[silence]

7
00:00:17,500 --> 00:00:19,600
Signals can be classified
according to the distance

8
00:00:19,667 --> 00:00:22,133
between the signaling
cell and the target cell.

9
00:00:22,533 --> 00:00:26,433
Autocrine signals are produced by a cell
and go to its own receptors,

10
00:00:26,500 --> 00:00:28,833
so the cell sends a signal to itself.

11
00:00:29,333 --> 00:00:33,900
Paracrine signals are produced by a cell
and go to target cells that are nearby

12
00:00:34,033 --> 00:00:36,333
and endocrine signals
are produced by a cell

13
00:00:36,400 --> 00:00:38,767
and go to target cells



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that are further away.

14

00:00:39,167 --> 00:00:40,900

Examples of these include hormones

15

00:00:40,967 --> 00:00:44,167

that are secreted into the bloodstream

as well as cytokines

16

00:00:44,233 --> 00:00:48,200

that can be released at the site of injury

and act on the brain to cause a fever.

17

00:00:50,667 --> 00:00:53,233

Signaling molecules or ligands

can be hydrophobic,

18

00:00:53,300 --> 00:00:56,467

meaning that they tend

to repel water or hydrophilic,

19

00:00:56,533 --> 00:00:58,333

meaning that they tend to stay in water.

20

00:00:58,767 --> 00:01:00,500

Hydrophobic signaling molecules

21

00:01:00,567 --> 00:01:02,867

can't freely float

in the extracellular space,

22

00:01:02,933 --> 00:01:06,567

so they're brought into the target

cells by carrier proteins.

23

00:01:06,967 --> 00:01:09,800

Hydrophobic molecules

can diffuse across the cell membrane

24

00:01:09,867 --> 00:01:12,700

and bind to receptor proteins

inside the target cell,



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25

00:01:12,833 --> 00:01:15,467

either in the cytoplasm or in the nucleus.

26

00:01:16,367 --> 00:01:18,200

Most signal molecules are hydrophilic

27

00:01:18,267 --> 00:01:21,133

so they can freely float

in the extracellular space

28

00:01:21,200 --> 00:01:22,733

to reach the target cells,

29

00:01:22,933 --> 00:01:25,300

but are then

unable to cross the cell membrane.

30

00:01:25,500 --> 00:01:26,867

So to pass on the signal,

31

00:01:26,933 --> 00:01:30,033

hydrophilic molecules bind

in receptors on the cell surface.

32

00:01:30,300 --> 00:01:32,833

These receptors are transmembrane proteins

33

00:01:32,900 --> 00:01:35,733

with an extracellular end

that binds to the ligand

34

00:01:35,867 --> 00:01:40,000

and an intracellular end that triggers

a signaling pathway inside the cell.

35

00:01:40,067 --> 00:01:41,133

[silence]

36

00:01:44,100 --> 00:01:47,400

We can think of the cell

signaling pathway in three stages.



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- 37
00:01:47,533 --> 00:01:49,033
The first stage is reception,
38
00:01:49,100 --> 00:01:52,133
which is when the target cell's receptors
bind to a ligand.
39
00:01:52,233 --> 00:01:54,133
It's like a key fitting into a lock.
40
00:01:54,433 --> 00:01:55,867
Then there's transduction,
41
00:01:55,933 --> 00:01:58,633
which means that the receptor
protein changes in some way
42
00:01:58,700 --> 00:02:00,800
and that activates
intracellular molecules,
43
00:02:00,867 --> 00:02:02,233
the second messengers.
44
00:02:02,467 --> 00:02:05,400
The third stage is the cell's response
to the signal.
45
00:02:05,467 --> 00:02:07,567
Zooming into
these transmembrane receptors,
46
00:02:07,633 --> 00:02:11,633
there are three major classes,
G-protein coupled receptors,
47
00:02:11,933 --> 00:02:15,000
enzyme coupled receptors,
and ion channel receptors.
48
00:02:15,067 --> 00:02:16,267

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[silence]

49

00:02:17,467 --> 00:02:21,533

G-protein coupled receptors are seven-pass transmembrane receptors.

50

00:02:21,600 --> 00:02:23,967

These are like really long proteins that have one end

51

00:02:24,033 --> 00:02:26,300

that sits outside

the cell and binds the ligand.

52

00:02:26,500 --> 00:02:28,267

Then the snake-like protein dips

53

00:02:28,333 --> 00:02:30,800

in and out of the cell membrane

seven times

54

00:02:30,867 --> 00:02:33,200

and finally ends

on the inside of the cell.

55

00:02:33,633 --> 00:02:35,433

The end of the G-protein coupled receptor

56

00:02:35,500 --> 00:02:38,400

that's within the cell

activates intracellular proteins

57

00:02:38,467 --> 00:02:42,233

called guanine nucleotide-binding

proteins or G-proteins.

58

00:02:42,767 --> 00:02:45,933

G-proteins are made up of

three subunits called alpha,

59

00:02:46,000 --> 00:02:49,400

beta and gamma, sort of like



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a flower with three petals.

60

00:02:50,333 --> 00:02:52,133

The alpha and the gamma subunits

61

00:02:52,200 --> 00:02:54,733

are anchored to the cell membrane

and keep the G-protein

62

00:02:54,800 --> 00:02:56,300

right next to the receptor.

63

00:02:56,533 --> 00:03:00,867

G-proteins bind to guanosine diphosphate

or or GDP when they're inactive.

64

00:03:01,033 --> 00:03:03,367

When the alpha subunit is bound to GDP,

65

00:03:03,600 --> 00:03:06,967

the three subunits stay together

so the flower is closed,

66

00:03:07,433 --> 00:03:08,800

but when the ligand binds,

67

00:03:08,933 --> 00:03:11,500

the G-protein coupled receptor changes

its shape,

68

00:03:11,733 --> 00:03:14,533

and this allows the G-protein

to release GDP

69

00:03:14,600 --> 00:03:17,800

and bind GTP instead

activating the protein.

70

00:03:18,267 --> 00:03:20,600

When the alpha subunit is bound to GTP,

71

00:03:20,767 --> 00:03:23,667



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the alpha subunit separates
from the beta and gamma subunits
72
00:03:23,733 --> 00:03:26,700
like one petal opening
and separating from the others.

73
00:03:27,267 --> 00:03:28,233

When that happens,

74
00:03:28,300 --> 00:03:31,600
the alpha subunit is free
to interact with other proteins.

75
00:03:31,700 --> 00:03:34,200

It stimulates some
while inhibiting others,

76
00:03:34,533 --> 00:03:39,667
but to act on other proteins,
the alpha subunit turns GTP into GDP,

77
00:03:39,800 --> 00:03:43,000
and when that happens,
the three subunits come together again.

78
00:03:43,067 --> 00:03:46,267
The flower closes
and the G-protein is turned off.

79
00:03:47,100 --> 00:03:51,433
Overall, there are three
types of G-proteins, Gq, Gi,

80
00:03:51,500 --> 00:03:55,533
and Gs, and each one stimulates
and inhibits a different set of enzymes

81
00:03:55,600 --> 00:03:57,233
and molecular pathways.

82
00:03:57,300 --> 00:03:58,200



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[silence]

83

00:04:00,633 --> 00:04:04,000

The Gq protein activates
the enzyme phospholipase C,

84

00:04:04,067 --> 00:04:05,700

which is found in the cell membrane.

85

00:04:06,100 --> 00:04:08,567

Phospholipase C then cleaves
a phospholipid

86

00:04:08,633 --> 00:04:11,567

called phosphatidylinositol

4, 5- bisphosphate

87

00:04:11,633 --> 00:04:14,867

into inositol
triphosphate and diacylglycerol.

88

00:04:15,333 --> 00:04:19,600

Inositol triphosphate is soluble
and diffuses freely through the cytoplasm

89

00:04:19,667 --> 00:04:23,633

and into the endoplasmic reticulum
where it opens up calcium channels.

90

00:04:23,900 --> 00:04:27,300

Since the calcium concentration is higher
in the endoplasmic reticulum

91

00:04:27,367 --> 00:04:28,800

than in the cytoplasm,

92

00:04:28,867 --> 00:04:32,533

calcium flows out of the endoplasmic
reticulum to the cytoplasm.

93

00:04:32,600 --> 00:04:35,567

The increased calcium concentration



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in the cytoplasm changes

94

00:04:35,700 --> 00:04:39,300

the electrical charge of the cell
and can lead to depolarization.

95

00:04:39,933 --> 00:04:43,667

Meanwhile, diacylglycerol remains
attached to the cell membrane

96

00:04:43,733 --> 00:04:46,367

and binds
to the enzyme protein kinase C,

97

00:04:46,667 --> 00:04:48,867

which also relies
on calcium to fully activate.

98

00:04:49,200 --> 00:04:51,300

Once calcium levels in the cell go up,

99

00:04:51,367 --> 00:04:53,967

protein kinase C starts
to activate proteins

100

00:04:54,033 --> 00:04:55,800

by adding phosphoryl groups to them.

101

00:04:55,867 --> 00:04:56,967

[silence]

102

00:05:00,167 --> 00:05:01,833

Next is protein Gs,

103

00:05:01,900 --> 00:05:04,967

which stimulates
the enzyme adenylate cyclase.

104

00:05:05,100 --> 00:05:09,433

Activated adenylate cyclase takes
adenosine triphosphate or ATP

105



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00:05:09,500 --> 00:05:12,100
and removes two phosphate molecules
transforming it
106
00:05:12,167 --> 00:05:15,533
into cyclic adenosine monophosphate
or CAMP.
107
00:05:16,333 --> 00:05:21,800
CAMP moves throughout the cytoplasm
and binds to the enzyme protein kinase A.
108
00:05:21,867 --> 00:05:24,000
Protein kinase A has two parts,
109
00:05:24,067 --> 00:05:26,800
a regulatory subunit
and a catalytic subunit,
110
00:05:27,033 --> 00:05:32,067
and CAMP specifically binds the regulatory
subunit of protein kinase A.
111
00:05:32,800 --> 00:05:34,567
When CAMP binds,
112
00:05:34,633 --> 00:05:38,200
it makes the regulatory subunit dissociate
from the catalytic subunit.
113
00:05:38,633 --> 00:05:41,467
It's kind of like pulling the pin out
of a fire extinguisher,
114
00:05:41,533 --> 00:05:42,600
allowing it in this case,
115
00:05:42,700 --> 00:05:45,267
it being the catalytic
subunit to do its job.
116
00:05:45,700 --> 00:05:47,467



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So after dissociating,

117

00:05:47,533 --> 00:05:51,900

the catalytic subunit of protein kinase A
is free to phosphorylate target proteins

118

00:05:51,967 --> 00:05:54,033

that trigger a cellular response.

119

00:05:58,200 --> 00:06:00,300

Finally, there's the protein Gi,

120

00:06:00,367 --> 00:06:02,733

which is also bound

to adenylate cyclase.

121

00:06:02,800 --> 00:06:04,733

But in this case it inhibits it

122

00:06:04,800 --> 00:06:07,200

causing negative feedback

on protein Gs.

123

00:06:07,800 --> 00:06:11,367

This is particularly important in helping
to inactivate cells.

124

00:06:16,533 --> 00:06:18,600

Next are the enzyme-coupled receptors.

125

00:06:18,700 --> 00:06:21,867

They're usually single pass
transmembrane proteins,

126

00:06:21,933 --> 00:06:24,367

meaning that they have only one
transmembrane segment

127

00:06:24,567 --> 00:06:28,200

and they're intracellular end
has intrinsic enzyme activity.

128



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00:06:28,300 --> 00:06:31,300

In other words, enzyme coupled-receptors
have two parts.

129

00:06:31,733 --> 00:06:35,033

One domain is the receptor
and the other domain is an enzyme.

130

00:06:35,267 --> 00:06:37,300

Each domain has a separate function

131

00:06:37,367 --> 00:06:41,567

like on a Swiss army knife that's composed
of both a knife and scissors.

132

00:06:41,933 --> 00:06:44,633

The enzymatic domain
is usually a protein kinase

133

00:06:44,700 --> 00:06:47,167

that phosphorylates the receptor domain.

134

00:06:49,667 --> 00:06:53,067

Now, there are three main types
of enzyme-coupled receptors,

135

00:06:53,133 --> 00:06:56,767

based on the amino acid
at which the receptors get phosphorylated.

136

00:06:57,567 --> 00:07:00,800

The first group
are the receptor tyrosine kinases.

137

00:07:00,867 --> 00:07:03,533

These are the most common
enzyme-coupled receptors,

138

00:07:03,600 --> 00:07:05,567

and there are many subfamilies.

139

00:07:05,633 --> 00:07:08,500



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Receptor tyrosine kinase
are generally molecules
140
00:07:08,567 --> 00:07:11,600
that can't phosphorylate
their own tyrosine side chains.

141
00:07:11,933 --> 00:07:16,000
When a ligand binds two receptor chains
come together and dimerize

142
00:07:16,067 --> 00:07:20,367
and they cross phosphorylate one another
at multiple tyrosine residues.

143
00:07:20,600 --> 00:07:24,733
This triggers a confirmational change
that creates high affinity binding sites

144
00:07:24,800 --> 00:07:26,167
for the second messengers,

145
00:07:26,233 --> 00:07:27,833
which can also be phosphorylated

146
00:07:27,933 --> 00:07:30,433
and activated, triggering
the signaling pathway.

147
00:07:32,800 --> 00:07:35,667
Next are the tyrosine
kinase associated receptors,

148
00:07:35,733 --> 00:07:39,433
which work in nearly the same way
as receptor tyrosine kinases.

149
00:07:39,500 --> 00:07:41,733
and their name even
sounds almost the same.

150
00:07:42,100 --> 00:07:45,567



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The key difference is that they have no intrinsic enzyme activity.

151

00:07:45,867 --> 00:07:49,500

Instead, they're associated with cytoplasmic tyrosine kinases.

152

00:07:49,833 --> 00:07:51,600

When the receptors bind their ligand,

153

00:07:51,800 --> 00:07:54,567

the cytoplasmic tyrosine kinases phosphorylate

154

00:07:54,633 --> 00:07:57,000

various target proteins

to relay this signal.

155

00:07:59,733 --> 00:08:03,200

Finally, there are the receptor serine/threonine kinases

156

00:08:03,367 --> 00:08:06,100

and they have a serine/threonine kinase domain

157

00:08:06,167 --> 00:08:07,700

on their intracellular end.

158

00:08:08,200 --> 00:08:11,767

There are two classes of these receptor serine/threonine kinases.

159

00:08:11,833 --> 00:08:15,367

Type one and type two, which are structurally similar.

160

00:08:15,900 --> 00:08:18,067

Ligand binding brings the two together

161

00:08:18,133 --> 00:08:20,733

so that the type two receptor



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can phosphorylate

162

00:08:20,800 --> 00:08:22,567

and activate the type one receptor,

163

00:08:22,633 --> 00:08:24,533

which in turn recruits

and phosphorylates

164

00:08:24,600 --> 00:08:27,000

various target proteins

to relay the signal.

165

00:08:30,200 --> 00:08:32,500

Finally, there are the ion channel

receptors,

166

00:08:32,567 --> 00:08:34,233

which are generally closed,

167

00:08:34,300 --> 00:08:37,533

but then they open up

once they bind a specific ligand.

168

00:08:37,600 --> 00:08:40,500

They allow ions like chloride,

calcium, sodium,

169

00:08:40,567 --> 00:08:43,000

and potassium to passively

flow down their gradient.

170

00:08:43,500 --> 00:08:46,167

This leads to a shift

in electric charge distribution

171

00:08:46,233 --> 00:08:49,233

inside the cell,

triggering a cellular response.

172

00:08:50,733 --> 00:08:54,800

Alright, as a quick recap,



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autocrine signals target the same cell.

173

00:08:55,033 --> 00:08:57,100

Paracrine signals target nearby cells

174

00:08:57,300 --> 00:08:59,767

and endocrine signals

target distant cells.

175

00:09:00,267 --> 00:09:03,500

Hydrophobic ligands are able
to diffuse across the cell membrane

176

00:09:03,633 --> 00:09:06,500

and bind to receptor proteins

inside the target cells.

177

00:09:07,033 --> 00:09:10,000

Hydrophilic ligands are unable
to cross the cell membrane,

178

00:09:10,067 --> 00:09:12,667

so they must bind
to transmembrane receptors,

179

00:09:12,733 --> 00:09:15,867

which have an intracellular end
that triggers a signaling pathway

180

00:09:15,933 --> 00:09:17,233

inside the target cell,

181

00:09:17,800 --> 00:09:20,633

There are three major
transmembrane receptor classes,

182

00:09:20,967 --> 00:09:24,067

G-protein coupled receptors,
enzyme-coupled receptors,

183

00:09:24,167 --> 00:09:25,933

and ion channel receptors.



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184
00:09:26,467 --> 00:09:28,951
[silence]

Try the drag and drop activity below to test your understanding of chemical signalling pathways.

Activity

- **IB learner profile attribute:** Knowledgeable
- **Approaches to learning:** Thinking skills — Providing a reasoned argument to support conclusions
- **Time required to complete activity:** 10 minutes
- **Activity type:** Individual activity

Complete the drag and drop activities in **Interactive 2**.

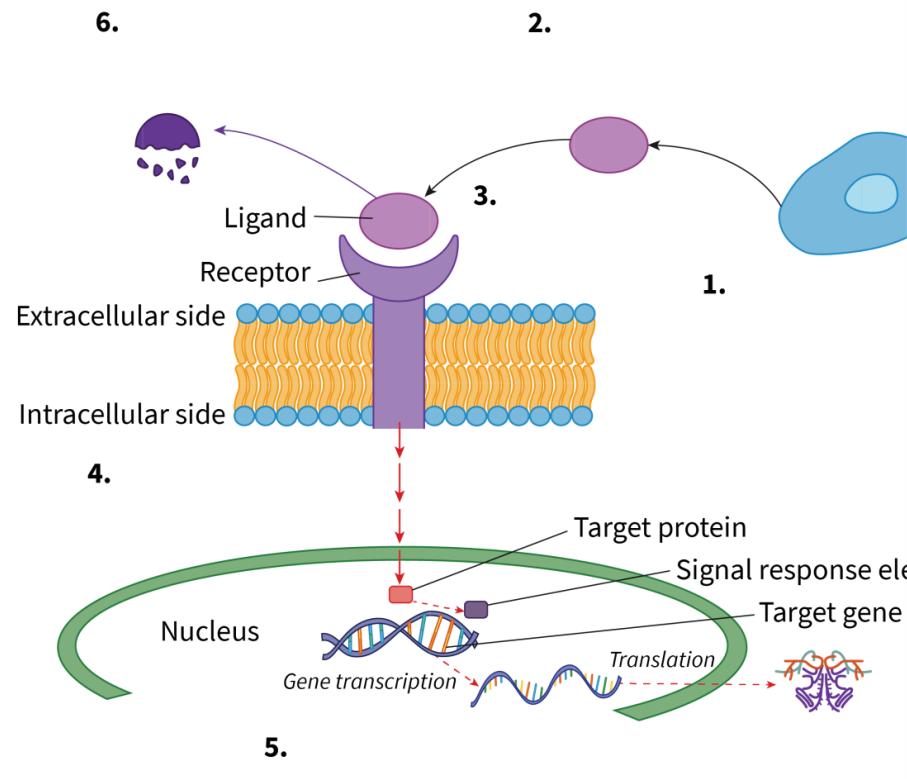
- On slide 1 arrange the labels for the different stages of chemical signalling in the correct order as they occur in the body.
- On slide 2, match the stages to the correct descriptions.



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Receptor binding

Signal transduction

Cellular response

Release of ligand

Transport of ligand

Signal termination

Check



Interactive 2. Stages of chemical signalling.

5 section questions

C2. Interaction and interdependence: Cells / C2.1 Chemical signalling (HL)



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Signalling molecules and transmembrane receptors (HL)



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C2.1.3: Hormones, neurotransmitters, cytokines and calcium ions (HL)

C2.1.4: Chemical diversity of hormones and neurotransmitters (HL)

C2.1.5: Localised and distant effects of signalling molecules (HL)

C2.1.6: Differences between transmembrane receptors in a plasma membrane and intracellular receptors (HL)

Section

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Feedback



Print (/study/app/bio/sid-422-

Assign

cid-755105/book/signalling-molecules-and-transmembrane-receptors-hl-id-46379/print/)

Higher level (HL)

Learning outcomes

By the end of this section you should be able to:

- Identify the categories of signalling chemicals in animals — hormones, neurotransmitters, cytokines and calcium ions.
- Differentiate between different types of signals used by multicellular organisms.
- Describe the difference in structure and function of hormones and neurotransmitters.
- Demonstrate an understanding of mechanisms that signalling molecules use to produce localised as well as distant effects.
- Analyse the role of signalling molecules in the transmission of signals from one part of the body to another.
- Compare and contrast transmembrane receptors and intracellular receptors.
- Describe the different signalling pathways activated by transmembrane receptors and intracellular receptors.

If our hand touches the nettle plant, we can feel a stinging pain (**Figure 1**). This is because a nerve signal travels from the hand to the brain and the information is interpreted as ‘pain’.

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Figure 1. A stinging nettle.

Credit: Judith Haeusler, Getty Images

In the animal kingdom, there are a wide range of chemical substances that can be used as signalling molecules. Different chemicals have the ability to trigger different signalling pathways by activating different receptors. This helps the organisms to react to the changing environment. Signalling chemicals have a wide range of reaction times. Different signalling chemicals may be produced in different tissues or in response to different stimuli. This allows fine-tuning of the response to a particular signal. For example, the hormone insulin is produced by the pancreas in response to high blood glucose levels, while the hormone glucagon is produced by the pancreas in response to low blood glucose levels (see [section D3.3.3–4 \(/study/app/bio/sid-422-cid-755105/book/regulation-of-blood-glucose-id-46246/\)](#)). A wide range of signalling molecules allows for greater specificity and flexibility in the regulation of physiological processes in animals.



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Categories of signalling molecules in animals

Hormones

Hormones are chemicals secreted by endocrine glands into the extracellular fluid (**Figure 2**). They act on the target organs/tissues where they cause the appropriate action. Hormones regulate the metabolic function of other cells, and their effect usually remains for a prolonged time. The target cells possess specific receptors which bind with the hormone. These receptors may be intracellular or located on the plasma membrane (further details will follow later in this subtopic).

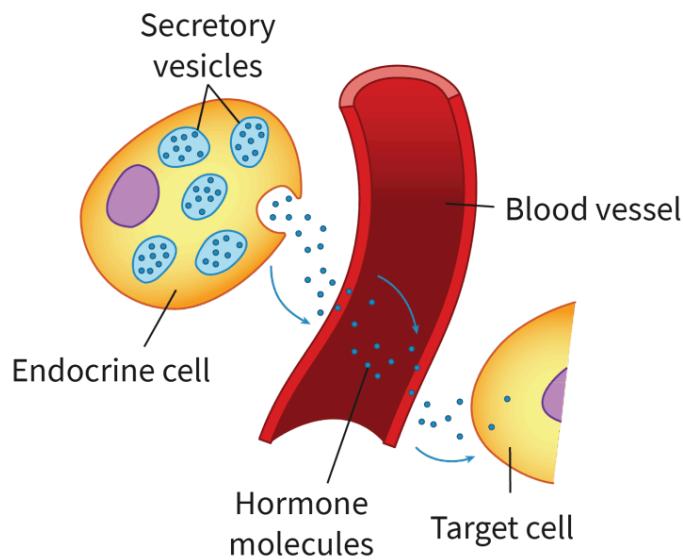


Figure 2. Hormones secreted by endocrine glands.

More information for figure 2

This diagram illustrates the process of hormone secretion by endocrine glands. On the left, there is an endocrine cell depicted as a yellow oval with blue circular secretory vesicles inside. Arrows indicate the release of hormone molecules, shown as blue dots, from the endocrine cell into the surrounding extracellular fluid. These hormone molecules enter a red blood vessel in the center of the diagram, which serves as the transport medium. An arrow moves right from the blood vessel toward a target cell on the right, which is also depicted as a yellow oval. The path of hormone molecules follows through the blood vessel to the target cell, demonstrating how hormones are distributed to specific target sites in the body.

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Neurotransmitters

Neurotransmitters are chemical substances that carry signals from one neuron to the other or from one neuron to a target cell such as muscle cells. Neurotransmitters are released into the synaptic cleft as a result of an action potential. They are short lived and therefore have to quickly perform their function.

Cytokines

Cytokines are small proteins important in cell signalling related to immune response (injury and infection). They are mainly secreted by white blood cells such as macrophages and lymphocytes. They activate the lymphocytes at the site of inflammation. The immune system depends on cytokine signalling for its normal functioning. The foreign particles are engulfed by macrophages, which in turn release cytokines to activate the nearby lymphocytes.

Calcium ions

Apart from organic molecules, metal ions can also act as ligands. Calcium ions (Ca^{2+}) are present in intracellular fluid as well as extracellular fluid. They move in and out of the cell via the calcium pump in the plasma membrane. Ca^{2+} can bind to proteins and activate them.

Chemical diversity of hormones and neurotransmitters

There are three main types of hormones which act as signalling molecules. They can be either water-soluble or lipid-soluble.

Hormones can be classified into the following chemical groups (**Figure 3**):

1. Amines or amino acid-derived hormones — These are small molecules derived from the amino acids tyrosine and tryptophan. For example, epinephrine (adrenaline) and norepinephrine (noradrenaline) secreted by the medulla of the adrenal gland, and thyroxine released by the thyroid gland. Another amino acid-derived hormone is melatonin, secreted by



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the pineal gland situated in the brain. It helps to maintain the circadian rhythm. These are water-soluble hormones.

2. Peptide hormones — These are in the form of polypeptide chains, small proteins, glycoproteins, etc. For example, insulin secreted by the pancreas in response to blood glucose level. It promotes the uptake and metabolism of glucose. Oxytocin, follicle-stimulating hormone and growth hormone are also examples of peptide hormones.

Both peptide and amino acid-derived hormones are water-soluble and therefore cannot pass through the plasma membrane on their own. They require specific receptors on the surface of the target cells.

3. Steroids or lipid-derived hormones — These are derived from cholesterol (parent molecule). For example, oestradiol released by female reproductive organs and testosterone released by male reproductive organs. Other examples include cortisol and aldosterone released by the cortex of the adrenal gland. Steroid hormones are insoluble in water and thus, require carrier proteins to be transported via blood. They remain in circulation for a longer duration. They are lipid-soluble hormones.

Epinephrine is also called adrenaline because it is secreted from the medulla of the adrenal glands situated on top of the kidneys. It has a dual function, as a hormone and as a neurotransmitter.



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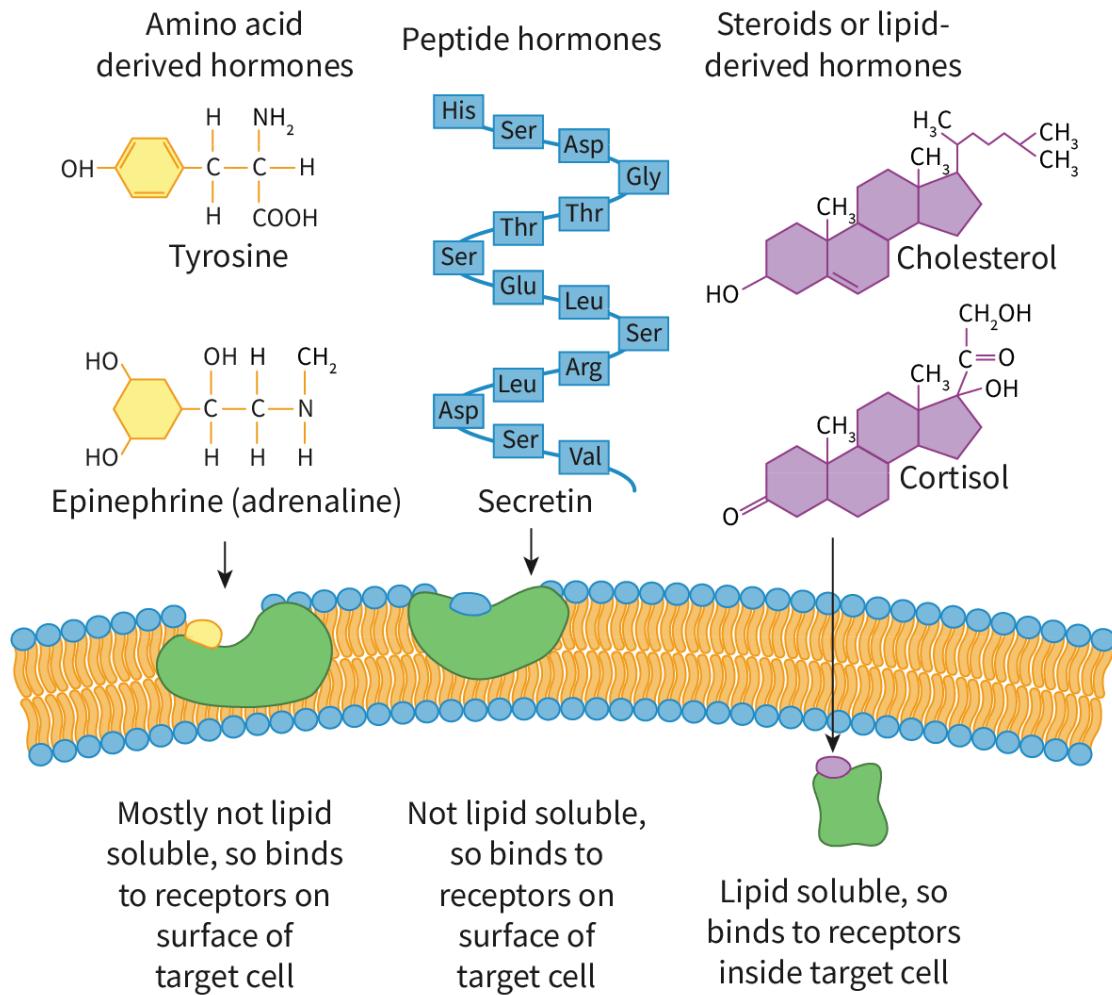


Figure 3. Chemical classes of hormones.

More information for figure 3

The diagram illustrates the chemical classes of hormones with three main categories: amino acid-derived hormones, peptide hormones, and steroids or lipid-derived hormones. It shows structures like Tyrosine and Epinephrine, which are labeled as mostly not lipid soluble, thus binding to receptors on the surface of target cells. Peptide hormones are represented with a sequence of amino acids like Serine, Histidine, and Aspartate, and they too bind to surface receptors due to their lack of lipid solubility. Steroid hormones, such as Cholesterol and Cortisol, are shown to be lipid soluble, hence they bind to receptors inside target cells. Each category is depicted with chemical structures and labeled descriptions of their interaction with cell membranes. The diagram includes colorful molecular structures and chemical bonds to represent the hormones.

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Mechanism of hormone action

Hormones act in different ways depending on the location of the receptors. When hormones bind to the receptors of target cells, they can induce different cellular changes. These range from changes in plasma membrane permeability, activation of protein synthesis, activation or deactivation of enzyme systems to promoting mitosis.

Hormones can act in two ways. They can activate second messengers, which either activate or deactivate enzymes in the cells. They can also activate genes and cause them to be expressed or switched off. Watch **Video 1** for more clarity.

Note: in the section on steroid hormones this video uses the variation 'estrogen' – this should be understood as the DP biology term 'oestradiol'.

Mechanisms of Hormone Action



Video 1. Mechanism of hormone action.

Neurotransmitters are synthesised in the neurons and stored in thin-walled sacs called synaptic vesicles. They are released into the synaptic cleft (see section C2.2.7 ↗ (:sectionlink:141305)) in response to an action potential. Once in the synaptic cleft, the neurotransmitter binds to a specific receptor on the postsynaptic membrane, causing a change in the electrical potential of the neuron and the transmission of the signal.



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These messages help us to move our limbs, feel sensations, keep our heart beating, and respond to all information our body receives from other internal parts of the body and our environment.

Types of neurotransmitters

A range of substances can serve as neurotransmitters including amino acids, peptides, amines and nitrous oxide.

Amino acids – glycine, glutamate and GABA (Gamma-aminobutyric acid) belong to the amino acid neurotransmitter class. They are involved in fast synaptic transmission (see section C2.2.4 (:[:sectionlink:141301](#))).

Peptides – Neuropeptide Y is an example of peptide neurotransmitter. It is responsible for a number of physiological and homeostatic processes. It increases the motivation to eat food.

Amines – Biogenic amines are modified amino acids. For example, serotonin regulates the mood while dopamine is involved in reward and movement regulation in the brain, and norepinephrine (noradrenaline) controls the fight or flight response.

Nitrous oxide – acts as a modulator of neuronal function.

Mechanism of action of neurotransmitters

Neurotransmitters are stored in vesicles in the neuron. When a neuron gets stimulated, these vesicles fuse with the plasma membrane and release the neurotransmitters into the synaptic cleft. They diffuse across the synapse and bind to the receptors on the target cells. See **Interactive 1** to view this process.



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1.00

Presynaptic neuron Neurotransmitter molecules Receptors Postsynaptic neuron

Synapt

0:00 / 0:10

More information for interactive 1

Interactive 1. Mechanism of Action of Neurotransmitters.

More information for interactive 1

The interactive video illustrates the step-by-step process of neurotransmitter release and signaling between neurons, highlighting how chemical messengers facilitate communication in the nervous system and influence critical physiological functions.

The video presents a presynaptic neuron on the left and a postsynaptic neuron on the right. The presynaptic neuron consists of neurotransmitter molecules inside, represented as small red circles. These neurotransmitters are stored inside synaptic vesicles represented by circles with a brown border. The postsynaptic neuron consists of receptors on the extracellular surface, represented by "Y" shaped structures. The space between the presynaptic neuron and the postsynaptic neuron is labeled as a "synaptic cleft".

Upon electrical stimulation, synaptic vesicles release the neurotransmitters into the "Synaptic cleft". Neurotransmitters diffuse across the synaptic cleft to reach the "Postsynaptic neuron" and bind to the receptors on the surface to propagate the signal. Neurotransmitter binding triggers a change or action in the target cell.

"Normal neuronal signaling and functions" are shown at the end of the video. These are linked to neurotransmitter activity and include sleep, homeostasis, signaling, memory, cognition, pain, and emotions.



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Neurotransmitters play an important role in movement, sensation, and homeostasis. This interactive demonstrates how neurotransmitters- transmit signals, from presynaptic release to postsynaptic activation, and how they are controlled, via precise release, receptor binding, and termination mechanisms.

Mechanism of action of cytokines

Cytokines bind to the specific receptors on the membrane of target cells, triggering signal transduction pathways that ultimately alter gene expression in the target cells (**Figure 4**).

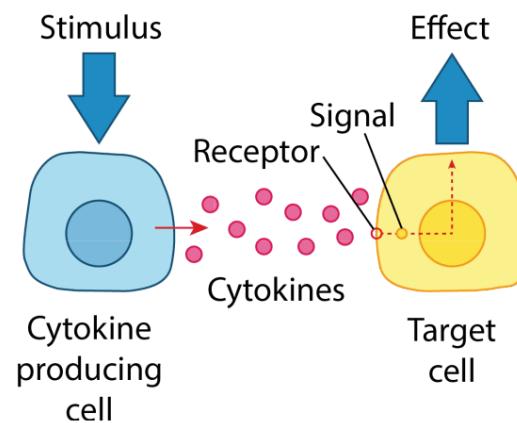
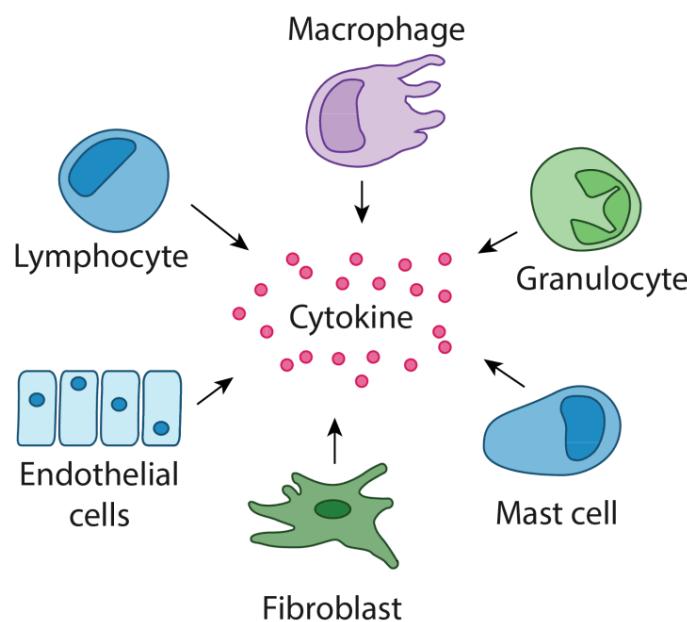


Figure 4. Types and action of cytokines.

More information for figure 4



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The image features two sections representing cytokine interactions. At the top, a central group of pink dots labeled 'Cytokine' are surrounded by various types of immune cells, including Macrophage, Granulocyte, Mast cell, Lymphocyte, Endothelial cells, and Fibroblast,



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with arrows indicating cytokine release from these cells.

Below, a process is depicted showing a cytokine-producing cell releasing cytokines represented as pink dots towards a target cell. Arrows labeled 'Stimulus', 'Receptor', and 'Signal' indicate the process from cytokine release to receptor binding on the target cell, ultimately leading to an 'Effect' arrow pointing out of the target cell.

[Generated by AI]

Mechanism of action of calcium ions

Ca^{2+} can also act as a second messenger in the signal transduction pathway. **Video 2** provides details of how Ca^{2+} enters cells and causes the desired changes. Physiological processes like muscle contraction (see section B3.3.2–4 ([/study/app/bio/sid-422-cid-755105/book/muscle-contraction-hl-id-44815/](#))), nerve impulses (see section C2.2.3 ↗ ([:sectionlink:135514](#))) and fertilisation (section D3.1.5–7 ([/study/app/bio/sid-422-cid-755105/book/menstrual-cycle-and-fertilisation-id-45415/](#))) among others, use calcium signalling. High levels of cytoplasmic Ca^{2+} can also cause the cell to undergo apoptosis. Other biochemical roles of calcium include regulating enzyme activity, permeability of ion channels, activity of ion pumps, and components of the cytoskeleton.

Calcium as a Second Messenger



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Video 2. Calcium as a second messenger.



Localised and distant effects of signalling molecules

Signalling molecules can have either localised or distant effects on the target cells or tissues. Localised effects are restricted to the immediate vicinity of the site of release of the signalling molecule. Depending on the distance between the site of origin (secretion) and target/action, the signalling molecules can be one of the following types:

Autocrine signalling – Auto meaning ‘self’. The cells secrete signalling molecules which act on the same cell. The cell surface has receptors for the binding of the signalling molecules which induce a chemical reaction to occur inside the cell. A good example of autocrine signalling could be cell differentiation during early organ development in the embryonic stage – sonic hedgehog signalling.

Paracrine signalling – The signalling molecules travel a short distance to reach the target cells. Two cells which are closely associated can communicate using paracrine signalling. The signals diffuse out of one cell, travel into the extracellular fluid and reach the neighbouring target cell. An example of paracrine signals is the chemical transmitted from nerve to muscle that causes the muscle to contract.

Endocrine signalling – The signals released by the cells travel a long distance to reach the target cells. Hormones fall under this category. They are secreted by cells and carried via the bloodstream to the target cells which can be located in distant organs or tissues (**Figure 5**). The levels of hormones in blood are closely regulated to have a long-lasting effect.

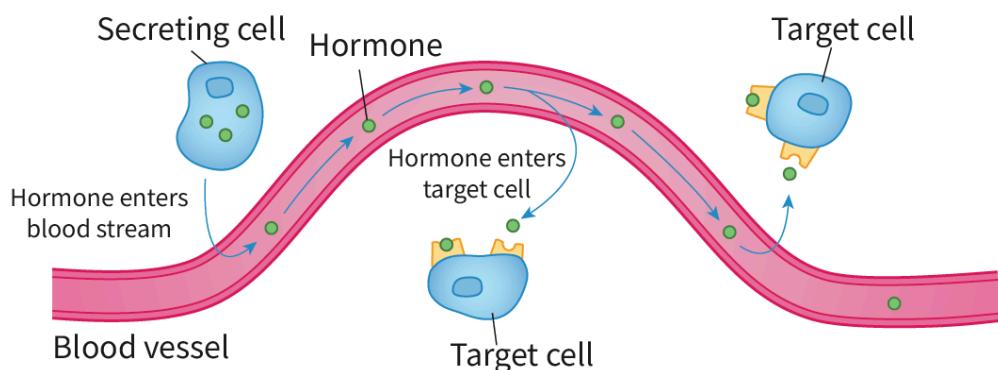


Figure 5. Hormones are the chemical messengers of the endocrine system.

 More information for figure 5

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The diagram illustrates how hormones, depicted as small green circles, are transported from a secreting cell into the bloodstream. The pathway is shown with a pink wavy line representing the blood vessel. Blue arrows indicate the direction of hormone movement along the blood vessel. At the left, a blue secreting cell is shown releasing hormones into the bloodstream. On the right side, target cells are depicted; one hormone is shown entering a target cell represented by a blue cell with a receptor. Labels included are 'Secreting cell,' 'Hormone,' 'Hormone enters blood stream,' 'Blood vessel,' 'Hormone enters target cell,' and 'Target cell.'

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Juxtacrine signalling (contact-dependent) – It occurs when two cells are in physical contact with each other. The signal molecule is not free, instead, is bound to the surface of the signalling cell. It reacts with the receptor on the membrane of the receptor cell. For example, the notch delta pathway.

Sometimes small molecules like ions pass across from one cell to the adjacent cells through gap junctions. In the case of neurotransmitters, the synaptic cleft between two neurons is a small space where the neurotransmitter is released, and its effect is limited to the neighbouring postsynaptic neuron. Similarly, cytokines are signalling molecules produced by immune cells and act locally to influence nearby cells.

Watch **Video 3** for an overview of these different types of cell signalling.



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Cell Signaling Types (Paracrine, Endocrine, Juxtacrine, ...)



Video 3. Cell signalling types.

Differences between transmembrane receptors in a plasma membrane

Receptors

Ligands cannot always cross the cell membrane and must therefore bind to a receptor protein. These receptors are specific to ligands. The receptor-ligand binding produces a response in the target cells which can amplify the response by activating many proteins inside the cells. These are called second messengers. They help to regulate cellular responses by activating an enzyme by phosphorylation (addition of phosphate group), entering into the nucleus through the nuclear pore and altering transcription (gene expression). These processes are part of signal transduction.

Receptors are mainly of two types:

Cell-surface receptors – these are present on the cell membrane of the target cells and are specific to individual cell types

Intracellular receptors – these receptors are located inside the target cells. Their function may occur in the cytoplasm (Type I) or the nucleus (Type II).

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Cell surface receptors are located on the plasma membrane of the cell and are responsible for transmitting signals from outside the cell to the inside. They bind to extracellular signalling molecules, such as hormones, neurotransmitters, or cytokines, to initiate a signalling cascade that can lead to changes in gene expression, ion channel activity, or enzyme activity within the cell.

Intracellular receptors are located inside the cell and bind to small, lipid-derived signalling molecules, such as steroid hormones. These molecules can cross the plasma membrane and bind to their respective intracellular receptors, forming a hormone-receptor complex (**Figure 6**). This complex can then move to the nucleus and directly affect gene expression.

A typical cell-surface receptor has three regions or domains:

1. extracellular ligand-binding domain
2. transmembrane hydrophobic domain
3. intracellular domain.

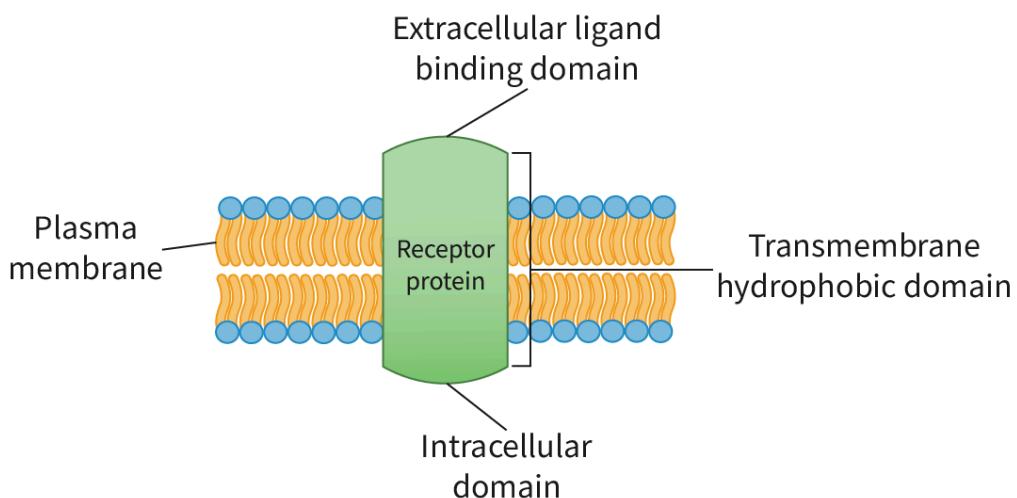


Figure 6. Domains of the receptor protein.

More information for figure 6

The diagram illustrates the structure of a receptor protein integrated into the cell membrane. It shows a vertical, tubular receptor protein embedded across the lipid bilayer. The cell membrane is depicted as two parallel layers with orange and blue dots, representing the hydrophilic heads and hydrophobic tails of phospholipids. The receptor protein is labeled with three domains: the extracellular ligand binding domain at the top, the transmembrane hydrophobic domain in the middle, and the intracellular domain at the bottom. Arrows point to each domain, highlighting their positions in relation to the plasma membrane.



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Watch **Video 4** to see an animation of how intracellular receptors regulate gene expression.

How Intracellular Receptors Regulate Gene Transcription - Anim...



Video 4. Intracellular receptors.

Intracellular receptors interact with ligand molecules that can cross the cell membrane and regulate gene expression by binding to transcription proteins. A good example of this is hormone response element which will be discussed in detail in [section C2.1.7– 9 \(/study/app/bio/sid-422-cid-755105/book/signal-transduction-pathways-hl-id-46380/\)](#).

Type I intracellular receptors are located in the cytoplasm. They are, thus, also called cytoplasmic receptors and are translocated to the nucleus upon ligand binding. Examples include progesterone receptors, androgen receptors and glucocorticoid receptors.

Type II intracellular receptors are located inside the nucleus. They are, thus, also called nuclear receptors, and are directly involved in gene transcription by binding to either the N terminal domain or the core domain. Examples include thyroid receptors, retinoic acid receptors and insulin receptors.



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The insulin receptors are large proteins which are permanently attached to the cell membrane but physically relocate to the nucleus after binding insulin. They have multidomain structure with both extracellular and intracellular domains. Extracellular domains bind insulin and activate the intracellular tyrosine kinase (Tyr-K) catalytic domain (**Figure 7**).

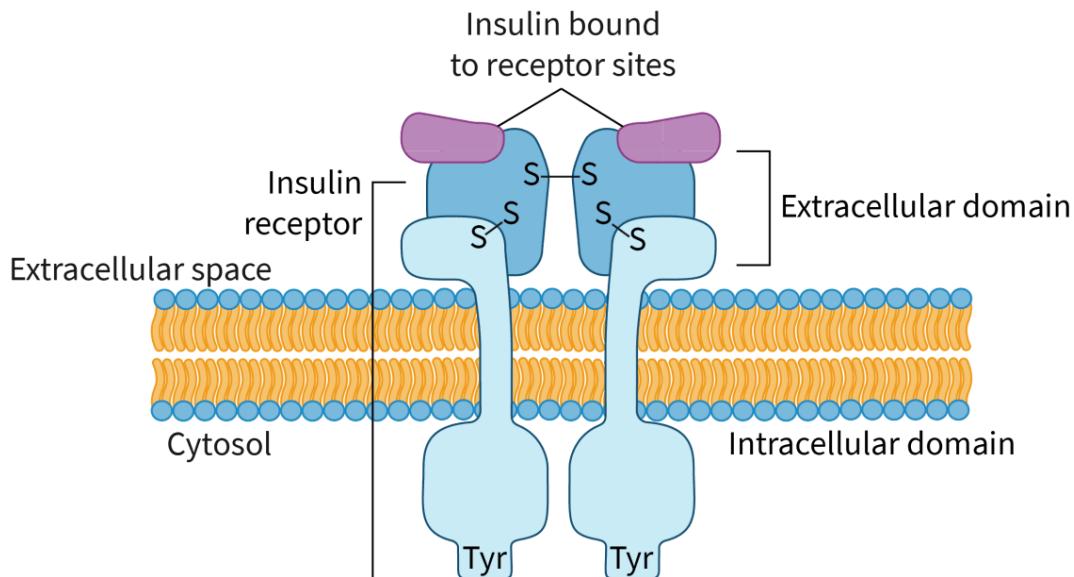


Figure 7. Insulin receptors.

More information for figure 7

The diagram illustrates insulin receptors on a cell membrane. Two identical structures are depicted crossing the membrane, each with distinct extracellular and intracellular domains. The extracellular space, labeled at the top, contains shapes representing insulin bound to receptor sites. The insulin receptors are shown as large, solid structures spanning the membrane layer. The extracellular domain is located above the membrane layer, which is depicted in yellow with a double row of circles to indicate the cell membrane structure.

The receptors themselves are labeled with 'S' symbols or disulfide bonds linking portions of the receptor structure. The intracellular domain is located below the membrane, extending into the cytosol, where it contains a section labeled 'Tyr' representing the tyrosine kinase catalytic domain.

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Upon the binding the ligand to the cell-surface receptor, an intracellular signal is generated which may or may not get amplified. Ligands which bind to these receptors remain outside the cell membrane. There are three



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categories of cell-surface receptors: enzyme-linked receptors, G-protein-linked receptors and ion channel-linked receptors.

Transmembrane receptors are composed of hydrophobic amino acids such as phenylalanine, leucine, isoleucine, tyrosine, tryptophan, valine, methionine and proline that span the cell membrane. The

hydrophilic amino acids for example, tyrosine, glutamine, threonine, serine, asparagine, are located on either side of the membrane.

Hydrophobic signalling chemicals, such as steroid hormones, can diffuse across the cell membrane and bind to intracellular receptors located in the cytoplasm or nucleus. In contrast, hydrophilic signalling molecules, such as cytokines and neurotransmitters, cannot easily penetrate the cell membrane and therefore require transmembrane receptors with hydrophilic amino acids on the extracellular side of the membrane to bind and initiate a signalling cascade within the cell.

Try the activity below to summarise your learning on hormones and neurotransmitters.

Activity

- **IB learner profile attribute:** Inquirer
- **Approaches to learning:** Communication skills — Presenting data appropriately
- **Time required to complete activity:** 1 hour
- **Activity type:** Individual/pair/group activity

Objective: To enhance your understanding of hormones and neurotransmitters by exploring their structural variations, functional roles, and mechanisms of action.

Purpose: By presenting posters, you will engage in research, analysis, synthesis of information and appropriate communication.



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Poster presentation based on GRASP:

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Goal: To demonstrate your understanding of hormones and neurotransmitters. Read the following conceptual question and present your understanding in the form of a handmade or digital poster.

Conceptual question: ‘How do hormones and neurotransmitters vary in their structures, functions and mechanisms of action, and how does this diversity allow for a wide range of signalling outcomes in the body?’

Role: You are going to take up the role of a science journalist given the responsibility of creating an informative visual presentation about how hormones and neurotransmitters work.

Audience: Students in a biology class.

Situation: The science journalists are part of a medical team working in a hospital where some doctors are studying the hormonal imbalance of a patient.

Product: A visually appealing and informative poster.

What to include in the poster:

- an overview
- showcase their structural diversity
- discuss their functions
- mechanism of action
- signalling outcomes
- bibliography or list of works cited

5 section questions ▾

C2. Interaction and interdependence: Cells / C2.1 Chemical signalling (HL)

Signal transduction pathways (HL)

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C2.1.7: Initiation of signal transduction pathways by receptors (HL)

C2.1.8: Transmembrane receptors for neurotransmitters (HL) C2.1.9: Transmembrane receptors that activate G protein (HL)

**Section**

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Feedback



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Higher level (HL)

Learning outcomes

By the end of this section you should be able to:

- Explain the mechanisms of initiation of signal transduction pathways.
- Compare and contrast different types of transmembrane receptors and their mechanisms of action, including neurotransmitter receptors and G protein-coupled receptors.
- Analyse the role of transmembrane receptors in changing membrane potential and activating intracellular signalling pathways.

Cells use a multi-step process to transmit signals quickly, while also amplifying the signals at each step. The binding of the ligand induces a conformational change in the receptor that activates its intracellular domain or associated proteins including enzymes and second messenger molecules. This propagates the signal to the effector proteins or target cells. In the case of intracellular receptors, it involves the direct binding of a ligand to the receptor in the cytoplasm or nucleus. This causes activation of the receptor and its association with other intracellular proteins to form a transcriptional complex that modulates gene expression. The exact mechanism of signal transduction depends on the type of receptor and ligand involved.

Signal transduction cascade

The series of biochemical reactions that occur inside a cell in response to the binding of a signalling molecule, such as a hormone or a neurotransmitter, to its receptor on the cell surface is referred to as a



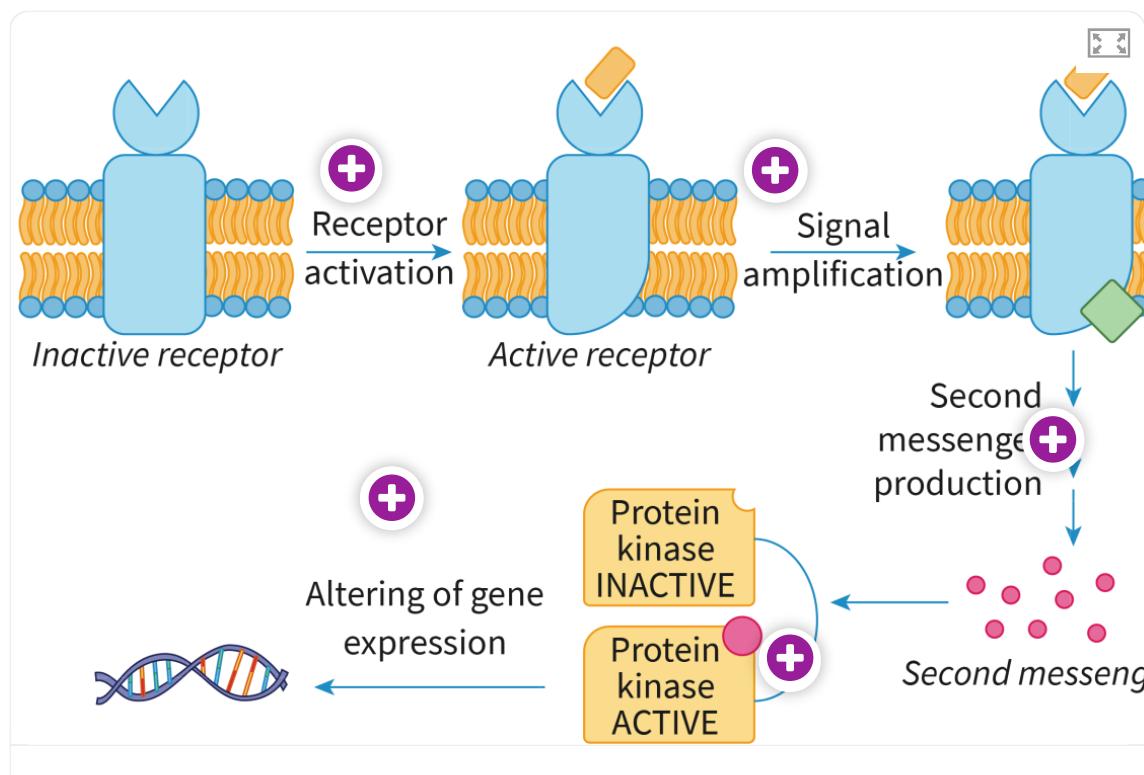
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signal transduction cascade. This cascade involves a series of steps, including:

- receptor activation
- signal amplification
- second messenger production
- activation of protein kinases
- changes in gene expression or cellular function.

The cascade may involve different types of signalling pathways, such as the G protein-coupled receptor pathway, the tyrosine kinase receptor pathway, or the intracellular receptor pathway. The ultimate response of the cell to the signal depends on the type of receptor, the nature of the signal, and the downstream effectors involved in the signalling pathway. These processes are summarised in **Interactive 1**.



Interactive 1. Signal Transduction Pathway.

More information for interactive 1

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This interactive diagram illustrates the step-by-step process of signal transduction, where an extracellular signal triggers a cascade of intercellular events, ultimately leading to a cellular response. The visualisation highlights key stages, from receptor activation to changes in gene expression or function.



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The interactive has a total of 5 different hotspots named Hotspot 1, Hotspot 2, Hotspot 3, Hotspot 4, and Hotspot 5, each represented by a plus sign. Clicking on these hotspots reveals information about each step in the signal transduction.

On the left side of the interactive, there is a model image of the plasma membrane of a cell (cell surface), characterized by the presence of phospholipid bilayer, one layer on top and one layer on bottom. Each phospholipid has a head represented by a blue circle and two tails in orange color that look like threads. In the middle of the plasma membrane, there is an inactive receptor molecule, characterized by a blue-colored rectangle and a small circle with an opening on top. This opening represents a binding site. This structure is labelled as "Inactive receptor".

Next to this structure, there is an arrow mark, with the tip of the arrow pointing toward the right. There is a text on top of this arrow that states "Receptor activation". Hotspot 1 is above this text. Clicking on this hotspot reveals the text "Receptor activation occurs when the ligand binds to the receptor".

Besides the first arrow, there is another model image of the plasma membrane. In this image, a signalling molecule represented by a small orange coloured rectangle is shown binding to the binding site of the receptor molecule. This receptor binding causes a change in the structure of the receptor molecule. So, at the bottom part of the receptor molecule, the blue coloured rectangular part is shown to have a smoothed edge on one side. This structure is labelled as "Active receptor"

There is another arrow beside this structure, with the tip pointing towards the right. The text above this arrow states "Signal amplification". There is a second hotspot above this text, clicking on it reveals the text "Binding of proteins to the intracellular side of the receptor helps to amplify the signal".

Besides this second arrow, there is another model image of a plasma membrane with a receptor molecule. The difference is that, in this step, a protein molecule binds to the smoothed edge at the bottom right of the receptor molecule. This protein molecule looks like a small green-coloured diamond.

There are 3 small arrows below the third model image of the plasma membrane, with their tips pointing toward the bottom. The text for these arrows states "Second messenger production". The Hotspot 3 is located beside these arrows and clicking on it reveals the text "Second messengers are produced intracellularly when ligands bind to the cell surface receptors".

Below these arrow marks on the bottom right corner, second messengers are represented as small pink coloured circles with the label "Second messengers".

There is another arrowmark towards the left side of these second messengers, with the tip pointing towards the left. The hotspot 4 is located below this arrow mark and clicking on the hotspot reveals the text "The protein kinase gets activated by cAMP".

On the left-hand side of hotspot 4, there are two structures. The top structure has the text "Protein Kinase INACTIVE". In the bottom structure, it is shown that a second messenger is attached to it and the text states "Protein Kinase ACTIVE".



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To the left of the protein kinase, there is an arrow mark with a tip pointing towards the left. The text above this arrowmark states “Altering gene expression”. Hotspot 5 is located above this arrow mark and clicking on this hotspot reveals the text “Binding to the transcription factor leads to altering of gene expression”. To the left of this arrow, in the bottom left corner, a strand of nucleic acid is shown indicating changes in gene expression caused by signal transduction.

This interactive clarifies how cells convert external signals into tailored responses through receptor activation, signal amplification and propagation, kinase cascades, and gene regulation.

Receptor activation

The receptors present on the surface of the cell membrane get activated when ligands bind to them. The binding is of a specific nature which means that only a specific type of ligand can bind to a particular type of receptor.

Signal amplification

Signal amplification is a process in which a small amount of signal or stimulus is capable of triggering a larger response. The amplification of signals occurs due to the activation of several downstream messengers/effectors. For example, when a hormone or neurotransmitter binds to the cell surface, it can trigger the activation of protein kinases which phosphorylate several downstream proteins. This chain reaction can continue until a large number of proteins are activated and the original signal gets amplified many times. In physiological processes, it is important that the cells are capable of sensing signals at low levels for the proper functioning of the body.

Second messenger production

Second messengers relay signals inside the cells. A common second messenger is cyclic AMP (cAMP). See section C2.1.10–13 (/study/app/bio/sid-422-cid-755105/book/mechanism-of-action-of-various-signal-receptors-hl-id-46146/) for more information on the role of cAMP in signal transduction.



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Activation of protein kinases

Protein kinases are enzymes that phosphorylate proteins by adding a phosphate group. Under normal conditions they remain in their inactive state. The second messenger, cyclic AMP activates the protein kinases. You will read about protein kinases in detail in the next section ([C2.1.10–13](#) (/study/app/bio/sid-422-cid-755105/book/mechanism-of-action-of-various-signal-receptors-hl-id-46146/)).

Changes in gene expression or cellular function

The ultimate result of the signal transduction is to alter the cellular response. This can be accomplished by altering a gene expression, by opening/closing of the ion channels or by activating an enzyme. On one hand, the binding of a neurotransmitter can cause the opening and/or closing of ion channels, while on the other, the binding of a hormone to its receptor may result in the alteration of a gene expression or an enzyme activity. The important thing to note here is that signal cascade ultimately leads to change in cellular behaviour.



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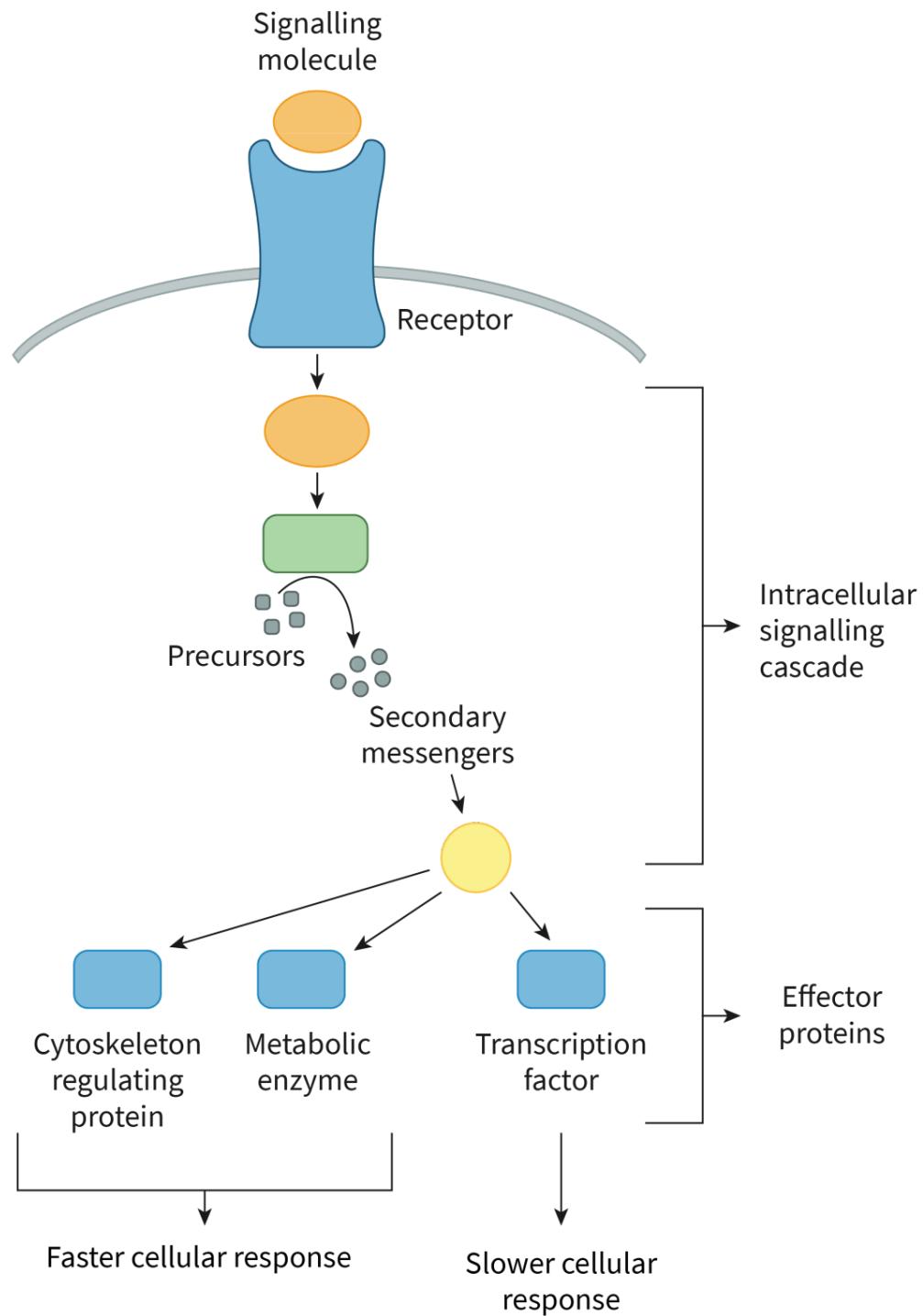


Figure 1. Intracellular signalling cascade.

More information for figure 1

The diagram represents the process of an intracellular signaling cascade. At the top, a signaling molecule binds to a receptor. This interaction leads to the formation of precursors, shown as small circles, which further generate secondary messengers. These secondary messengers play a role in transmitting the signal where paths diverge to three different components: cytoskeleton regulating protein, metabolic enzyme, and transcription factor. Each of these leads to different cellular responses. The pathway to the cytoskeleton regulating protein and metabolic enzyme indicates a faster cellular response, while the



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pathway involving the transcription factor indicates a slower cellular response. The structure and flow of the diagram illustrate how the initial signal from the signaling molecule is processed and leads to varied cellular responses.

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Termination of the signal

Once the signalling molecule has done the desired work, it has to be removed from the system in order to prevent overstimulation. This can be done by:

1. Degradation of the signalling molecule — e.g. the enzyme acetylcholinesterase degrades the neurotransmitter acetylcholine in the synaptic cleft once it has caused the transfer of signal from the presynaptic to the postsynaptic neuron (see **Video 1**).

Acetylcholinesterase Cleaving Acetylcholine



Video 1. Degradation of acetylcholine by acetylcholinesterase.

2. Diffusion of signalling molecules.
3. Reuptake of signalling molecules — e.g. the neurotransmitter serotonin is reabsorbed by the presynaptic neuron using specialised transporters. Watch **Video 2** for a summary of how neurotransmitters such as serotonin are removed from the synaptic cleft after they have performed their function.



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Neurotransmitter removal



Video 2. Neurotransmitter removal.

4. Inactivation of receptor — e.g. the beta-adrenergic receptors are inactivated due to prolonged exposure to epinephrine (adrenaline). The receptor gets phosphorylated by protein kinase and makes it unavailable for binding any further signalling molecules.
5. Feedback inhibition — e.g. the regulation of insulin secretion in response to glucose levels in the blood (see [section D3.3.3—4 \(/study/app/bio/sid-422-cid-755105/book/regulation-of-blood-glucose-id-46246/\)](#)).

Transmembrane receptors for neurotransmitters

Neurotransmitters (see [section C2.1.3–6 \(/study/app/bio/sid-422-cid-755105/book/signalling-molecules-and-transmembrane-receptors-hl-id-46379/\)](#)) are stored in thin-walled sacs called synaptic vesicles. There can be thousands of neurotransmitter molecules present in each vesicle. They carry signals from one nerve cell to a target cell depending on the stimulus received. When signals are transmitted across neurons there occurs a change in the membrane potential, which allows the signals to pass through like waves. There are three possible outcomes of electrical signals depending on the neurotransmitter.

Excitatory neurotransmitters – ‘excite’ the neuron and cause it to send the message forward with great speed to the next target cell. Examples include glutamate, epinephrine (adrenaline) and norepinephrine (noradrenaline).



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Inhibitory neurotransmitters – block or prevent neuronal excitability by inhibiting nerve transmission. Examples include gamma amino-butyric acid (GABA), serotonin and glycine.

Modulatory neurotransmitters – act as neuromodulators which can create both excitatory and inhibitory effects depending on the receptors they bind to. Acetylcholine and dopamine are good examples of this class.

Neurotransmitters cause a change in the membrane potential of the plasma membrane. Membrane potential is the difference in the electrical potential between the interior and exterior of a biological membrane. In electrically excitable cells such as neurons, it is used to transmit signals from one cell to the other. An action potential is generated when the membrane potential of the cell rapidly increases and decreases. There is more detail on this later in this section.

Let us understand the phenomenon of membrane potential with the example of acetylcholine.

Acetylcholine is the primary neurotransmitter associated with motor neurons in the central as well as peripheral nervous system. It helps to regulate heartbeat, blood pressure and gut motility. It also plays an important role in muscle contractions, sleep patterns, memory and motivation.

The following events take place at a neuromuscular junction – a synapse between a neuron and a muscle cell:

1. When an action potential reaches the axon terminal it depolarises the membrane and opens voltage-gated Na^+ channels.
2. Na^+ ions enter the cell, further depolarising the presynaptic knob.
3. This depolarisation causes voltage-gated Ca^{2+} channels to open.
4. As a result, the vesicles containing acetylcholine from the presynaptic knob are released into the synaptic cleft.
5. Here the vesicles release acetylcholine which diffuses through the synapse and binds to its receptors on the postsynaptic knob.



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6. This causes the Na^+ channels in the postsynaptic knob to open.
7. Na^+ ions then enter into the cells resulting in depolarisation of the postsynaptic knob.
8. An action potential is generated which helps in propagation of the signal for as long as acetylcholine is present in the synaptic cleft.
9. Once released, the acetylcholine stays in the cleft and can continually bind and unbind to postsynaptic receptors.
10. Acetylcholinesterase continuously breaks down acetylcholine to give choline and acetate molecules.

Transmembrane receptors that activate G protein

G proteins are molecular switches inside cells which are bound to G protein-coupled receptors (GPCRs) present in the plasma membrane. They undergo a conformational change when GPCRs bind to ligands and work as exchange factors for guanosine diphosphate (GDP)/guanosine triphosphate (GTP) exchange in the cell. The GPCRs are only found in eukaryotes and are the largest class of membrane receptors. Each GPCR is specific to a particular function. There are around 800 GPCRs encoded by the human genome and their ligands range from neurotransmitters and hormones to odours and light-sensitive compounds. They are responsible for our sense of taste, smell, behaviour and mood. They play a very important role in drug (medicine) mechanism of action as they are the target sites of many medicinal drugs.

G proteins consist of three subunits – α , β and γ . In its inactive state, the α subunit is bound to GDP.

A typical GPCR has seven transmembrane α helices. **Figure 2** provides a clear illustration of the structure of a GPCR. The α , β and γ subunits are closely attached to its transmembrane receptor. The α and γ subunits are attached to the plasma membrane by lipid anchors.



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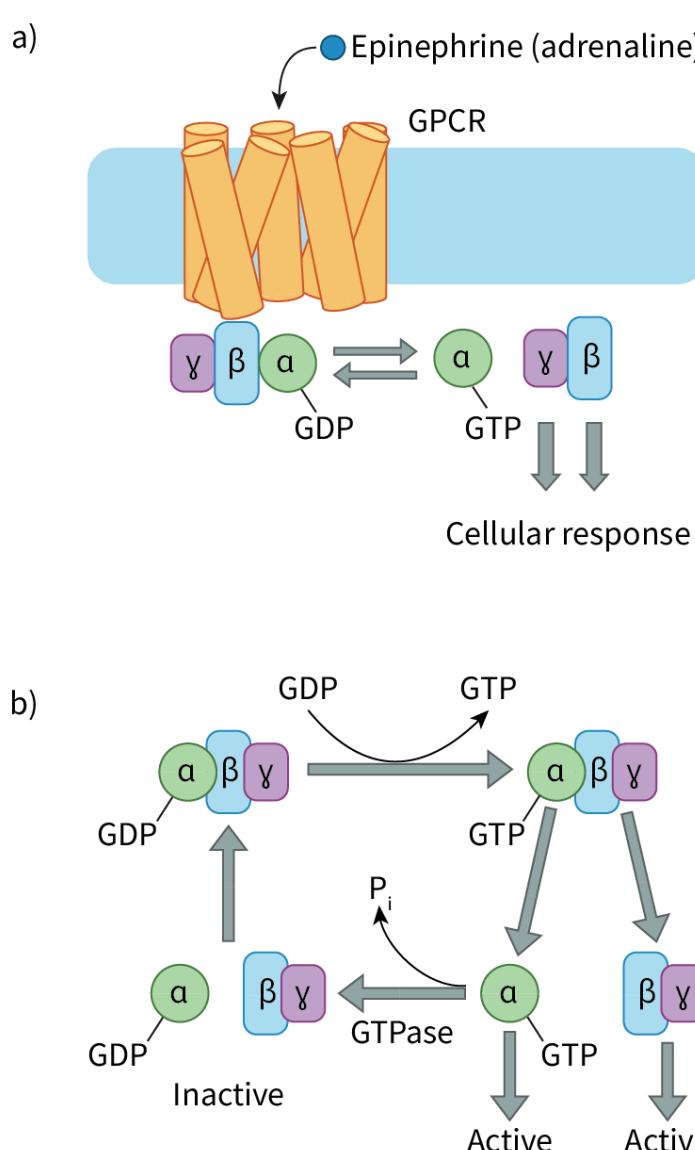


Figure 2. (a) Structure of GPCR. (b) Activation and inactivation of G protein.

[More information for figure 2](#)

The diagram illustrates two sections: (a) the structure of a G protein-coupled receptor (GPCR) and (b) the activation and inactivation cycle of a G protein.

Section (a) depicts the GPCR embedded within a cell membrane, represented as seven transmembrane alpha helices shown as spirals. Above, a label indicates the presence of epinephrine (adrenaline) interacting with the GPCR. Below the GPCR, the diagram shows G protein subunits: alpha (α), beta (β), and gamma (γ). The alpha subunit is shown binding to GDP, transitioning to binding with GTP, which leads to a cellular response.

Section (b) presents the cycle of G protein activation and inactivation. The G protein is shown in two states: inactive, with GDP bound to the α subunit along with β and γ subunits, and active, where GDP is replaced by GTP, leading to separation of the α subunit from the β



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and γ subunits. The inactivation process involves GTPase activity, where GTP is hydrolyzed into GDP and an inorganic phosphate (P_i), allowing the α subunit to reassociate with β and γ subunits, completing the cycle.

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🔗 Nature of Science

Aspect: Science as a shared endeavour

The contribution of Brian K. Kobilka and Robert J. Lefkowitz in the field of GPCR based cell signalling has been recognised in the 2012 Nobel Prize in Chemistry.

These studies were important in unravelling the mysteries of cell signalling and deeper understanding how the GPCRs function.

In 2011, Kobilka achieved another breakthrough when his research team captured an image of the β -adrenergic receptor at the exact moment that it is activated by a hormone and sends a signal into the cell.

Watch **Video 3** for an overview of GPCRs and how they work.



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G Protein Coupled Receptors (GPCRs) - Structure, Mechanism of...



Video 3. The structure and function of G protein-coupled receptors.

Try the research activity below to summarise your knowledge of receptor pathways.

Activity

- **IB learner profile attribute:** Knowledgeable
- **Approaches to learning:** Communication skills — Presenting data appropriately
- **Time required to complete activity:** 1.5 hours
- **Activity type:** Individual activity

Your task

1. Choose a blank concept diagram template from the internet.
2. Create two columns or sections labelled ‘Transmembrane receptors activated by neurotransmitters’ and ‘Transmembrane receptors activated by G proteins’.
3. Research and identify specific examples of transmembrane receptors in each category. For neurotransmitter-activated receptors, examples may include dopamine receptors, or serotonin receptors. For



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G protein-activated receptors, examples may include adrenergic receptors or opioid receptors.

4. Fill in the identified receptor examples in the respective columns.
5. Describe the activation process for each type of receptor, including the binding of neurotransmitters or the activation of G proteins.
6. Within each column, note the downstream effects or signal transduction pathways initiated by the activation of these receptors.
7. If possible, include additional details such as receptor subtypes, associated second messenger systems, and specific physiological responses.
8. After completing your concept diagram, review and discuss your findings, comparing and contrasting the characteristics and signalling mechanisms of the different types of transmembrane receptors.

5 section questions ▾

C2. Interaction and interdependence: Cells / C2.1 Chemical signalling (HL)

Mechanism of action of various signal receptors (HL)

C2.1.10: Mechanism of action of epinephrine receptors (HL)

C2.1.11: Transmembrane receptors with tyrosine kinase activity (HL)

C2.1.12: Intracellular receptors that affect gene expression (HL)

C2.1.13: Effects of the hormones oestradiol and progesterone on target cells (HL)

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Higher level (HL)

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Learning outcomes

By the end of this section you should be able to:

- Explain the mechanisms of action of epinephrine (adrenaline) receptors and different types of transmembrane receptors, including those with tyrosine kinase activity, and their role in regulating physiological processes.
- Analyse the impact of epinephrine on target cells, including its role in the stress response, and evaluate the mechanisms by which hormones bind to intracellular receptors and activate signal transduction pathways.
- Distinguish between different types of hormones, such as oestradiol and progesterone, and their specific effects on target cells, and analyse the role of intracellular receptors in regulating gene expression and their impact on cellular responses.

Have you ever noticed your heart racing and your breath becoming rapid – perhaps just before you are called upon the stage for a performance or before you enter an examination hall? Along with a fluttery feeling in your stomach and sweaty palms, these are all effects of epinephrine (adrenaline) which you will learn about in this section.

Signalling molecules such as epinephrine, tyrosine kinase, and hormones like oestradiol and progesterone might offer insights into the various ways that chemical signalling can control cellular responses.

Epinephrine: The fight or flight hormone

Epinephrine, also known as adrenaline, is a hormone secreted by the adrenal glands in response to stress or danger. It causes the heart rate and blood pressure to increase and boosts the energy supply substantially for a short while. **Video 1** provides a clear explanation of how epinephrine





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binds to specific receptors. This class of GPCRs is specifically involved in initiating a cascade reaction involving the production of the second messenger, cAMP (see below), which in turn activates protein kinase A. The activated protein kinase A is capable of adding a phosphate group to specific cellular proteins (enzymes). The two major outcomes of this activation are inhibition of glycogen synthesis and initiation of glycogen breakdown. Note: this video uses the variation ‘adenylyl cyclase’ which should be understood as the DP biology term ‘adenylate cyclase’.

action of epinephrine



Video 1. Mechanism of epinephrine.

cAMP

Second messengers are small molecules that are generated intracellularly in response to binding of the signal molecule such as hormone or neurotransmitters to the cell surface. They relay signals inside the cells by either activating or inhibiting certain intracellular proteins and enzymes causing a cellular response to occur. As mentioned, cyclic AMP or cAMP is one of the most common second messengers in the signal transduction pathway.

Figure 1 gives a clear picture of how cAMP is formed during the signalling process and how it facilitates a change in the cellular response. When a ligand binds to the receptor, adenylate cyclase gets activated and converts



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ATP to cAMP. Many signalling molecules can activate adenylate cyclase and thus result in formation of cAMP. The increased levels of cAMP causes activation of protein kinase A which further results in the activation of several other proteins leading to a cellular response.

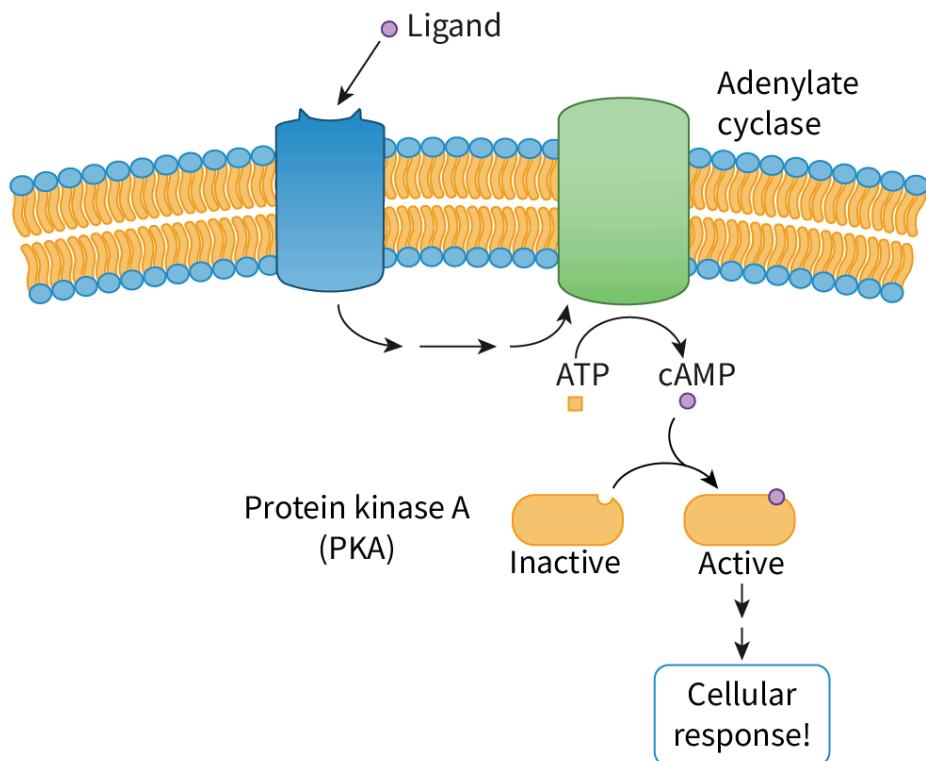


Figure 1. Formation of cAMP in a signal transduction pathway.

More information for figure 1

The diagram illustrates the process of cAMP formation in a signal transduction pathway. It shows a cell membrane with embedded proteins. A ligand binds to a receptor on the blue membrane protein, leading to an interaction with adenylate cyclase, depicted as a green component on the right. This interaction converts ATP to cAMP, indicated by arrows showing the flow of this process. The formation of cAMP activates Protein kinase A (PKA), highlighting a transition from inactive to active states, depicted with orange shapes. The active PKA then leads to a cellular response, signified at the bottom. Labels identify key components and steps in the sequence: Ligand, ATP, cAMP, Adenylate Cyclase, Protein kinase A (inactive and active), and Cellular response. Arrows indicate the direction of the interactions and processes.

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Mechanism of action of epinephrine

Refer to the flowchart in **Interactive 1** while reading this description.



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- Epinephrine binds to its receptor, GPCR, and activates the G protein [1] causing a conformational change in GPCR where the alpha helices separate in the cell membrane [2] and activation of the G protein [3].
- The GDP attached to the α subunit gets replaced by GTP [4]. (Like ATP, GTP is also an energy rich molecule. The main role of GTP is to bind to macromolecules and induce a conformational change in them, leading to their dissociation.)
- The α subunit now dissociates from the rest of the protein [5] leaving behind the $\beta\gamma$ subunit and binds to adenylate cyclase which mediates the conversion of ATP to cAMP [6].
- In this signal pathway, cAMP acts as a second messenger causing the activation of several protein kinase A (PKA) molecules [7].
- The PKA molecules phosphorylate several enzymes and proteins in the cell [8]. In the liver, protein kinase A activates another enzyme, phosphorylase, which breaks down glycogen to glucose [9].
- After the desired action is completed, the GTP is hydrolysed to GDP resulting in the dampening of the signal.

Interactive 1. Flowchart for the Mechanism of Action of Epinephrine.

More information for interactive 1

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The interactive slideshow illustrates the step-by-step process of epinephrine signalling through a G protein-coupled receptor (GPCR) pathway, culminating in glucose release for the “fight or flight” response. It is divided into two slides. The two slides have a diagram of the cell membrane. The first slide shows the first four steps of epinephrine signalling labelled



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1-4 while the second slide shows the remaining five steps of epinephrine signalling, labelled 5-9.

The first slide focuses on GPCR activation. There is a GPCR receptor on the extracellular surface of the cell where the epinephrine binds. This is step 1 and it is labelled as "Epinephrine binding to GPCR". This causes a conformational change which is the second step labelled as "Conformational change in GPCR". The third step is labelled as "G-protein activation", in the intracellular surface, where there are three subunits of G-protein labelled as alpha, beta, and gamma. The alpha subunit of g-protein releases GDP and binds GTP. This is indicated by unidirectional arrow marks between the alpha subunit and GDP, GTP. This is the fourth step and is labelled as "Exchange of GDP with GTP".

The second slide highlights signal amplification. Step 5 is labelled as "α subunit dissociates" and it is shown that the alpha subunit of G-protein gets dissociated from the other two subunits. Step 6 is labelled as "Adenylate cyclase converts ATP to cAMP". Step 7 shows the activation of protein kinase by cAMP. Step 8 shows the activation of phosphorylases. In step 9, the glycogen is broken down to glucose by the phosphorylase enzyme.

The end result is a rapid release of glucose into the bloodstream, providing energy for the "fight or flight" response. This process is vital for stress responses, metabolism regulation, and understanding drug targets.

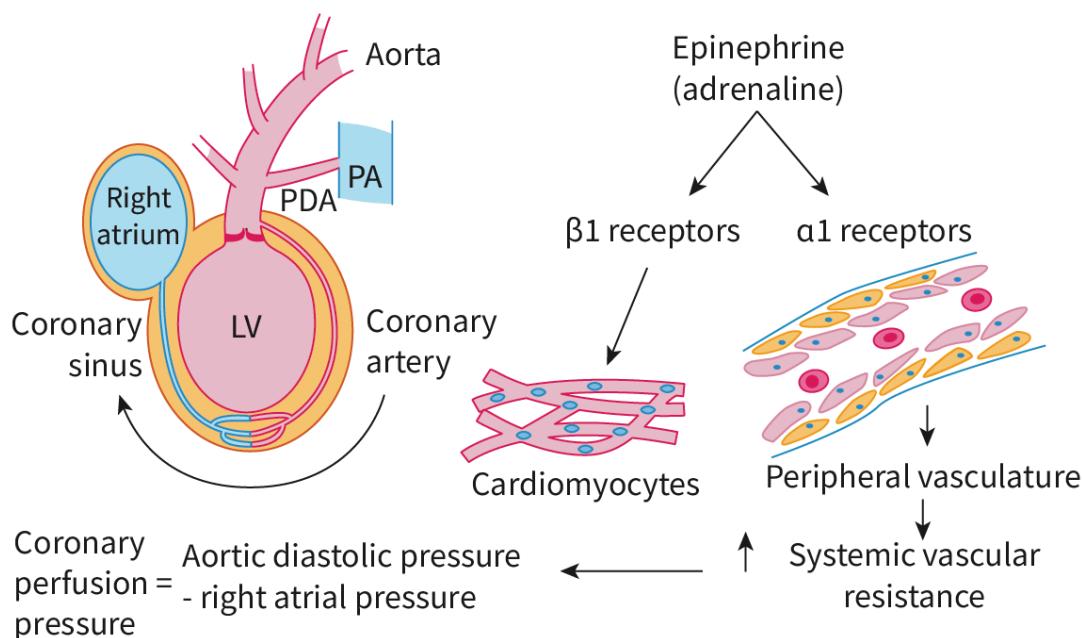


Figure 2. The physiological effects of epinephrine.

More information for figure 2

Student view

The diagram illustrates the physiological effects of epinephrine (adrenaline) on the cardiovascular system. It shows two main pathways: one affecting cardiomyocytes via β1 receptors and another affecting the peripheral vasculature via α1 receptors. The left part of the diagram focuses on the heart, labeled with components such as the right atrium, left



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ventricle (LV), aorta, coronary sinus, coronary artery, and patent ductus arteriosus (PDA).

Additional text states "Coronary perfusion pressure = Aortic diastolic pressure - right atrial pressure," indicating the balance of pressures in the heart.

Arrows indicate the flow from these heart components to cardiomyocytes, and how the epinephrine binds to β_1 receptors affects them. On the right side of the diagram, arrows lead from the epinephrine to the peripheral vasculature, focusing on α_1 receptors, and describing its effect on systemic vascular resistance. The diagram emphasizes the dual effect of epinephrine on the system: increasing cardiac output through β_1 stimulation and altering vascular tone through α_1 stimulation.

[Generated by AI]



Aspect: Science as a shared endeavour

Naming conventions are an example of international cooperation in science for mutual benefit. Both 'adrenaline' and 'epinephrine' were coined by researchers and are based on production of the hormone by the adrenal gland; 'adrenaline' comes from Latin *ad* = at and *ren* = kidney and 'epinephrine' comes from old Greek *epi* = above and *nephros* = kidney, respectively. Unusually, these two terms persist in common use in different parts of the world.

Tyrosine kinase activity: switching on the signal

Transmembrane receptors with tyrosine kinase activity are a class of cell surface receptors that are involved in many important cellular processes, including cell growth, differentiation, and proliferation. These receptors are characterised by the presence of a tyrosine kinase domain within the receptor molecule, which is activated upon ligand binding. The activation of the tyrosine kinase domain triggers a signalling cascade that ultimately



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leads to changes in gene expression, protein synthesis, and cellular metabolism. Atypical activation of these receptors has been linked to a number of diseases, including cancer, diabetes, and cardiovascular disease. Understanding the structure and function of transmembrane receptors with tyrosine kinase activity is therefore essential for developing targeted therapies for these diseases.

Mechanism of action of insulin in maintaining glucose homeostasis

Insulin is a hormone secreted by the pancreas. Insulin increases the uptake of glucose into adipose and muscle cells at the same time as reducing the synthesis of glucose in the liver. It therefore maintains glucose homeostasis. The insulin receptor is a dimer consisting of alpha(α) and beta(β) subunits held together in position by disulfide bonds (S-S). A tyrosine kinase present in the β subunit gets activated when insulin binds to it. Look at **Figure 3** for a detailed understanding of how binding of insulin activates tyrosine kinase. Upon activation, tyrosine kinase phosphorylates itself (by a process called autophosphorylation) and some other intracellular signalling molecules, such as insulin receptor substrate (IRS) proteins. The IRS-2 proteins contain multiple tyrosine residues which get phosphorylated, which then cause activation of the downstream signalling pathway, which includes activation of a variety of second messengers. This cascade will eventually result in the attraction of vesicles containing GLUT-4 (a glucose receptor) in their membranes. GLUT-4 is typically inactive but the cascade results in its activation. The vesicles move to and fuse with the cell membrane, embedding GLUT-4. The cell is now ready to accept glucose.



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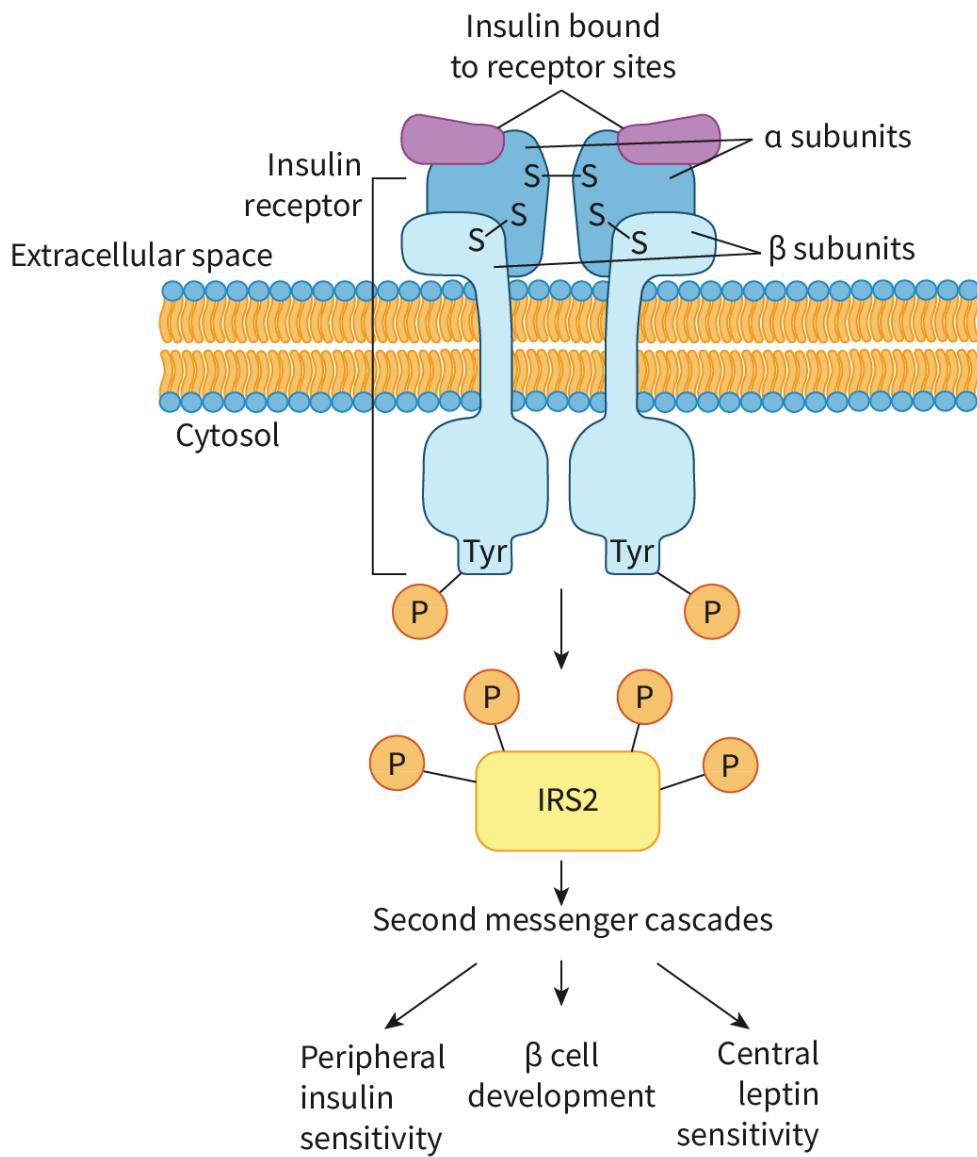


Figure 3. The role of IRS2 in insulin signalling.

More information for figure 3

The diagram illustrates the role of IRS2 in insulin signaling. At the top, two insulin molecules are bound to receptor sites on the extracellular portion of the insulin receptor, which is embedded in a cell membrane. The receptor is labeled with alpha (α) and beta (β) subunits, held together by disulfide bonds (S-S). Below the membrane, in the cytosol, are two identical sections of the receptor ending with tyrosine (Tyr) residues.

Upon insulin binding, the tyrosine residues are phosphorylated, indicated by orange 'P' (phosphate) symbols. This phosphorylation is a part of the activation process. The IRS2 protein, depicted below the insulin receptor, also binds phosphates. This protein is crucial in triggering second messenger cascades.

Below IRS2, the diagram shows the effects of these cascades with three branching arrows leading to labels for different physiological effects: "Peripheral insulin sensitivity," " β cell development," and "Central leptin sensitivity." These outcomes illustrate the influence of IRS2 activation in the broader insulin signaling pathway.



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Watch **Video 2** for more clarity on how insulin receptors work.

Insulin Receptors animation



Video 2. Mechanism of action of insulin.

Intracellular receptors affect gene expression

As we know, intracellular receptors typically act by modifying transcription during gene expression (see [section C2.1.3–6 \(/study/app/bio/sid-422-cid-755105/book/signalling-molecules-and-transmembrane-receptors-hl-id-46379/\)](#)). Steroid hormones such as oestradiol, progesterone and testosterone play important roles in regulating many physiological processes. These hormones signal their effects by binding to intracellular (nuclear) receptors. Since these signalling molecules are lipid-soluble they can easily pass through the phospholipid bilayer of the plasma membrane. Upon entering the cell, the signalling molecules bind to the receptors in the nucleus.

Oestradiol receptors are associated with [heat shock proteins \(HSP90\)](#) which get detached once the hormone attaches to the receptor. The dimerisation of the receptor-hormone complex takes place and it is then translocated into the nucleus. Here, the complex interacts with specific



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DNA sequences known as hormone response elements (HRE) located close to the promoter. In some cases it may even bind to the transcription factors, resulting in a cellular response. This interaction may activate or inhibit gene transcription, leading to changes in protein synthesis and ultimately affecting cellular responses.

Watch **Video 3** for an overview of the oestradiol signalling pathway. Note: this video uses the variations ‘oestrogen’ and ‘estrogen’ – both names should be understood as the DP biology term ‘oestradiol’.

Estrogen signaling in breast cancer



Video 3. Oestradiol signalling pathway.

In the non-genomic signalling, the G-protein coupled oestradiol receptor (GPER), which is present on the surface of the cell membrane, binds to the oestradiol molecule. This in turn activates the oestradiol receptor interacting protein which further gives rise to second messengers like cAMP. Further downstream, the cAMP activates protein kinase A which phosphorylates many proteins that cause the activation of a transcription factor leading to a cellular response.

Effects of oestradiol on target cells

Oestradiol plays a vital role in regulating the secretion of gonadotropin-releasing hormone (GnRH) from the neurons in the hypothalamus by acting on specific receptors (**Figure 4**). When the level of oestradiol increases it enhances GnRH, which causes the release of follicle-

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stimulating hormone (FSH) and luteinising hormone (LH) (see section D3.1.5–7 (</study/app/bio/sid-422-cid-755105/book/menstrual-cycle-and-fertilisation-id-45415/>)) from the anterior pituitary gland. These hormones are essential for ovulation and the menstrual cycle (see section D3.1.13–14 (</study/app/bio/sid-422-cid-755105/book/puberty-and-gametogenesis-hl-id-45735/>)).

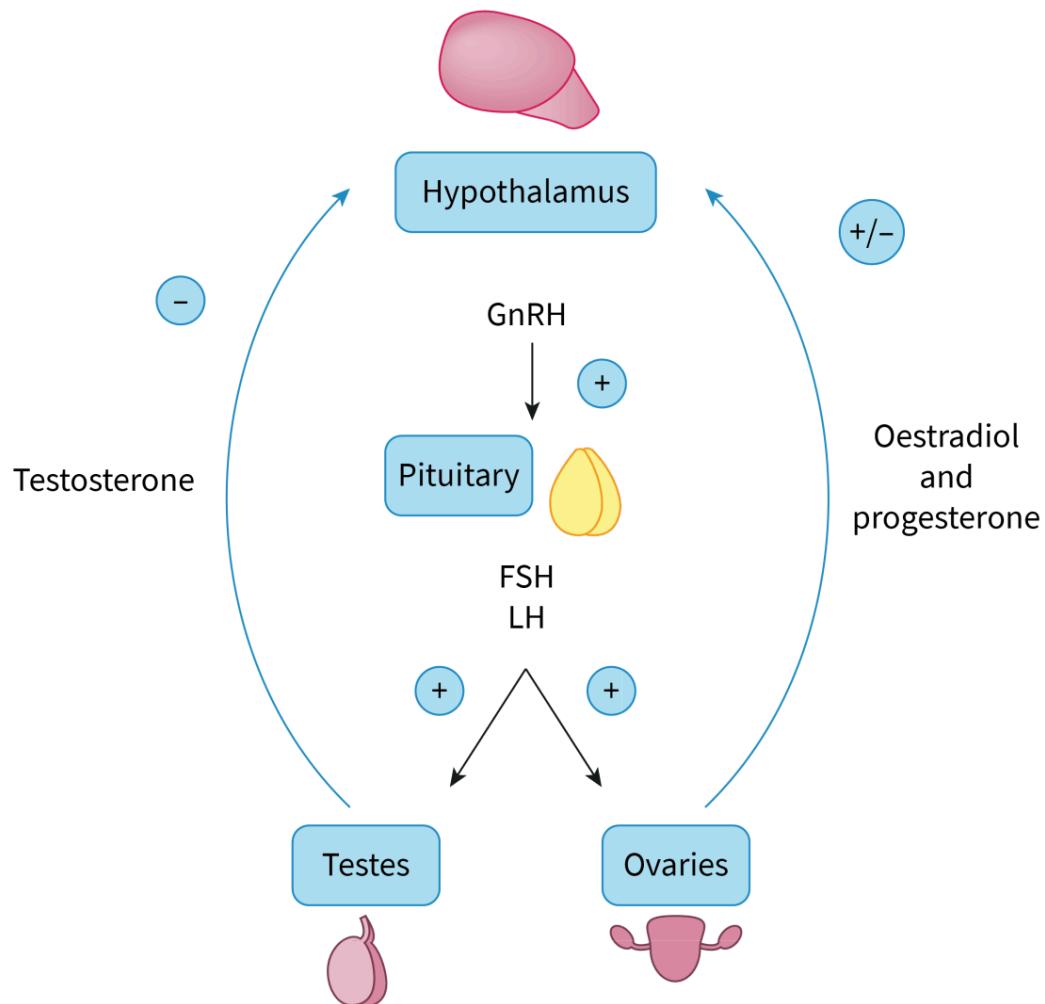


Figure 4. The hypothalamic-pituitary-gonadal axis.

More information for figure 4

This diagram illustrates the hypothalamic-pituitary-gonadal (HPG) axis, which shows the flow of hormones and their effects in the body. At the top, the hypothalamus releases gonadotropin-releasing hormone (GnRH) which stimulates the pituitary gland. This results in the production of follicle-stimulating hormone (FSH) and luteinizing hormone (LH). The FSH and LH hormones then act on the testes and ovaries. Arrows indicate the direction of hormone flow and feedback loops. There's a positive feedback loop represented by a plus symbol (+) and a negative feedback loop represented by a minus symbol (-) for testosterone and oestradiol/progesterone production.

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Effects of progesterone on target cells

Progesterone is a steroid hormone which is responsible for maintaining the menstrual cycle and reproductive system (see [section D3.1.5–7](#) (/study/app/bio/sid-422-cid-755105/book/menstrual-cycle-and-fertilisation-id-45415/)). Upon binding with progesterone, the progesterone receptor (PR) regulates a network of gene expressions, which control the development, differentiation and proliferation of target tissues. One of its main effects is on the cells of the endometrium, the lining of the uterus. Progesterone acts on these cells to prepare them for possible implantation of a fertilised egg. The hormone causes the endometrial cells to undergo differentiation, where they become specialised to support a potential pregnancy. It also increases the thickness of the endometrial lining and causes proliferation of blood vessels in the tissue, providing nutrients to a developing embryo. Additionally, progesterone promotes the secretion of a type of mucus in the cervix that helps sperm to reach the egg. If pregnancy does not occur, progesterone levels decline and the endometrial lining is shed during menstruation.

Try the activity below in which you will analyse some case studies relating to levels of oestradiol.



Activity

- **IB learner profile attribute:** Thinker
- **Approaches to learning:**
 - Research skills — Using search engines and libraries effectively
 - Thinking skills — Providing a reasoned argument to support conclusions
- **Time required to complete activity:** 45 minutes
- **Activity type:** Individual/pair activity



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In this activity you are given two case studies to analyse. Read through the information and then answer the question in the task that follows.

Scenario 1

A 45-year-old woman presents with a suspicious lump in her breast. She undergoes diagnostic tests, and the results confirm the presence of oestradiol receptor-positive breast cancer.

Patient's medical history

- Age: 45
- Sex: Female
- Family history of breast cancer: Negative
- Previous medical conditions: None reported
- Current medication use: None reported
- Reproductive history: Gave birth to two children, breastfeeding for a total of 12 months

Diagnostic reports

- Mammogram: Detected a suspicious lump in the left breast
- Biopsy: Confirmed oestradiol receptor-positive (ER+) breast cancer
- Pathology report: Tumour size, grade and stage are indicated

Task

Analyse the role of oestradiol in breast cancer development, the mechanism of oestradiol receptor activation and the possible symptoms that the patient might be experiencing.

Scenario 2

A 60-year-old postmenopausal woman presents with recurrent fractures and decreased bone density.

Patient's medical history



- Age: 60
- Sex: Female



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- Menopausal status: Postmenopausal
- Previous medical conditions: None reported
- Current medication use: None reported

Diagnostic reports

- Dual-energy X-ray absorptiometry (DEXA) scan: Revealed decreased bone mineral density (T-score below -2.5) at the hip and spine
- Blood tests: Confirmed low levels of oestradiol and elevated levels of bone resorption markers

T-score	Classification
0.0	Normal
-1.0	Osteopenia
-2.0	Osteopenia
-2.5	Osteoporosis
-3.0	Osteoporosis
-4.0	Severe osteoporosis

Your task

Explore the role of oestradiol in maintaining bone health and the mechanisms behind oestradiol's protective effects on bone density.

5 section questions



C2. Interaction and interdependence: Cells / C2.1 Chemical signalling (HL)

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C2.1.14: Regulation of cell signalling pathways (HL)

Regulation of cell signalling pathways by positive and negative feedback (HL)

Section

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Feedback



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Higher level (HL)

Learning outcomes

By the end of this section you should be able to:

- Explain that positive feedback amplifies the response.
- Explain that negative feedback dampens or inhibits the signalling response.
- Explain that a balance of both positive and negative feedback is necessary for proper cellular response.

All systems in nature have a tendency to attain balance. Have you ever noticed a thermoregulated waterbath in the lab? When you set a temperature the thermostat ensures that the heating is cut off when the set temperature is reached. As soon as the water in the waterbath begins to cool below the set temperature, the thermostat switches on and the water is heated up again. This makes sure that equilibrium is maintained.

How organisms balance signalling pathways?

Living organisms use a variety of mechanisms to maintain a balanced and stable internal environment. One of the key players in this process is the regulation of signalling pathways. Feedback loops connect the output signals back to their inputs. Positive and negative feedback mechanisms are critical components of this regulation, helping to fine-tune the activity of signalling molecules and their receptors to ensure that they are functioning optimally. From the simplest bacteria to the most complex multicellular organisms, feedback mechanisms play a crucial role in



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maintaining homeostasis (see [section D3.3.1–2 \(/study/app/bio/sid-422-cid-755105/book/homeostasis-and-negative-feedback-id-46245/\)](#)) and allowing life to flourish.



International Mindedness

Survival of all microorganisms depends on their interaction with the immediate environment. This takes place through chemical signalling. The chemicals which are involved in regulating the microbial growth can act as inducers, nutrients, mediate communication or impose toxicity. In the field of medicine we often come across the term ‘drug resistance’. It means that some pathogenic microorganisms undergo random mutation and one of these mutations may provide the capability of surviving even in the presence of certain drugs. This is a universal problem and scientists all over the world are trying to find solutions to counteract these instances.

It is not surprising to note that in today’s world microbes are generally exposed to so many small molecules, for instance the ones used in agrochemicals and antimicrobials, that their tendency to find a way out of this has increased. Drug resistance is a serious threat to both immunosuppressed as well as immunocompetent individuals.

Positive feedback and signal amplification

Positive feedback mechanisms result in amplification of cell signals. It is a regulatory mechanism that enhances or reinforces an existing response to a stimulus. Various signalling pathways are governed by positive feedback mechanisms (**Figure 1**). During blood clotting for example, where platelets are activated by a signal to aggregate and form a clot. Once activated, the platelets release chemicals that further activate nearby platelets, resulting in amplification of the clotting response (see [section C3.2.1–3 \(/study/app/bio/sid-422-cid-755105/book/barriers-to-the-entry-of-pathogens-id-46387/\)](#)).



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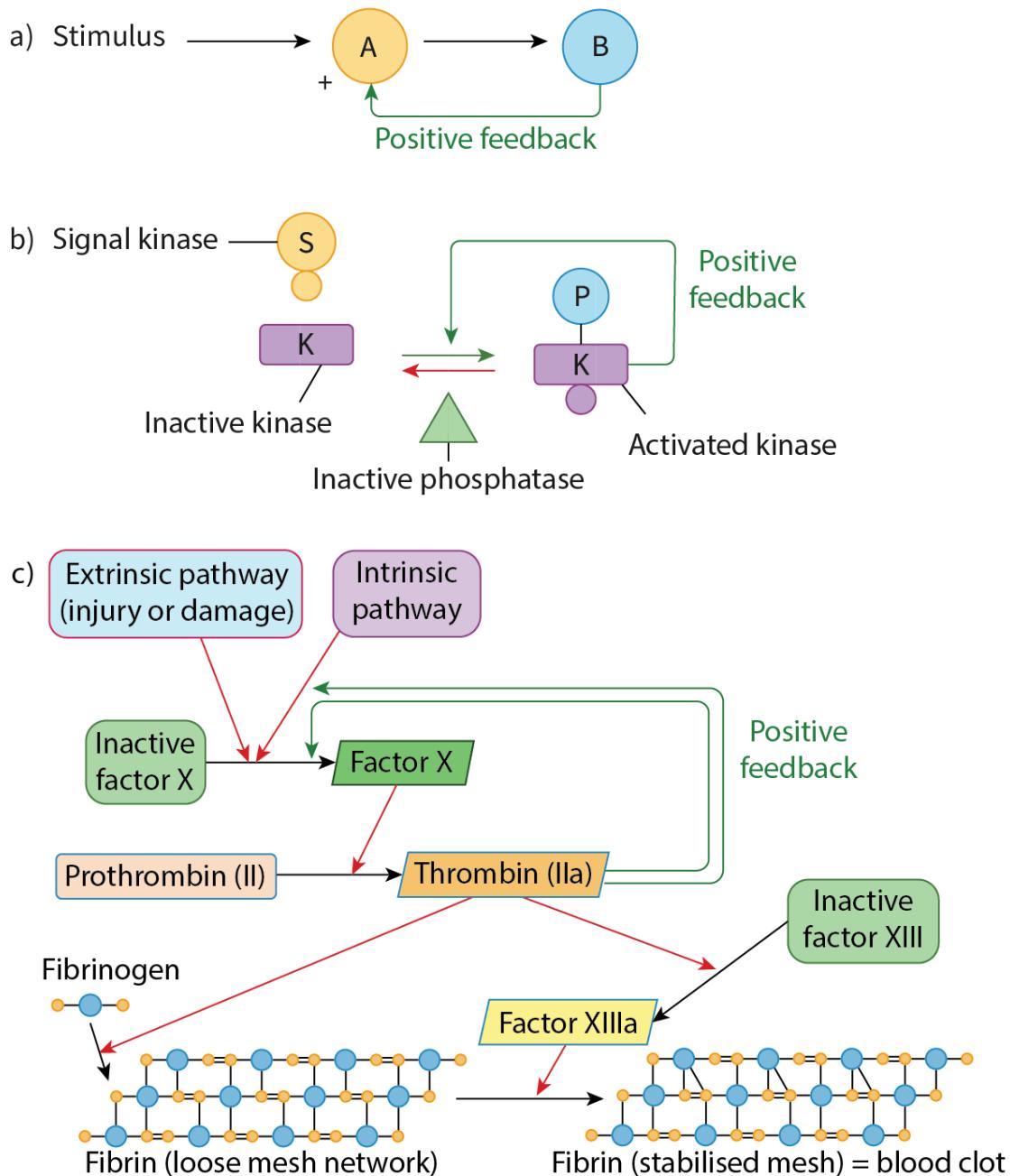


Figure 1. Regulation of enzyme kinase by positive feedback mechanisms, a) a simple positive loop, b) kinase, c) in blood clotting.

More information for figure 1

The image consists of three diagrams labeled a, b, and c.

Diagram a) Depicts a simple positive feedback loop. It starts with a stimulus leading to the activation of component A, which then activates component B. Component B feeds back to further stimulate A, enhancing the response loop, characterized as positive feedback.

Diagram b) Shows the regulation of a signal kinase. It involves an inactive kinase labeled K that can be activated by a signaling molecule S. The kinase activation is regulated by a feedback loop involving a phosphatase. The positive feedback loop, represented by arrows, amplifies the activation of the kinase.

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Diagram c) illustrates the blood clotting process with various factors. It includes extrinsic and intrinsic pathways triggering Factor X activation. Prothrombin is converted to thrombin, which then acts on fibrinogen to form an initial fibrin mesh. Factor XIII stabilizes this mesh into a blood clot. Positive feedback mechanisms enhance the activation of these factors.

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Negative feedback and dampening of amplification

Negative feedback plays a crucial role in regulating the amplification of signals in cell signalling pathways. In negative feedback, the downstream effectors of the pathway inhibit the activation of the upstream components, effectively dampening the amplification of the signal. This ensures that the signal does not get amplified excessively, leading to unnecessary activation of the pathway and possibly causing harm to the cell (**Figure 2**). For example, insulin regulates the blood glucose level. When the level of blood glucose rises, insulin is secreted from the pancreas and binds to insulin receptors on targets such as liver and muscle cells. The activation of insulin receptors causes glucose to be taken up by the cells and stored as glycogen. When the level of blood glucose falls, it inhibits the release of insulin allowing a balance of glucose in blood to be maintained (see section D3.3.3–4 (/study/app/bio/sid-422-cid-755105/book/regulation-of-blood-glucose-id-46246/)).



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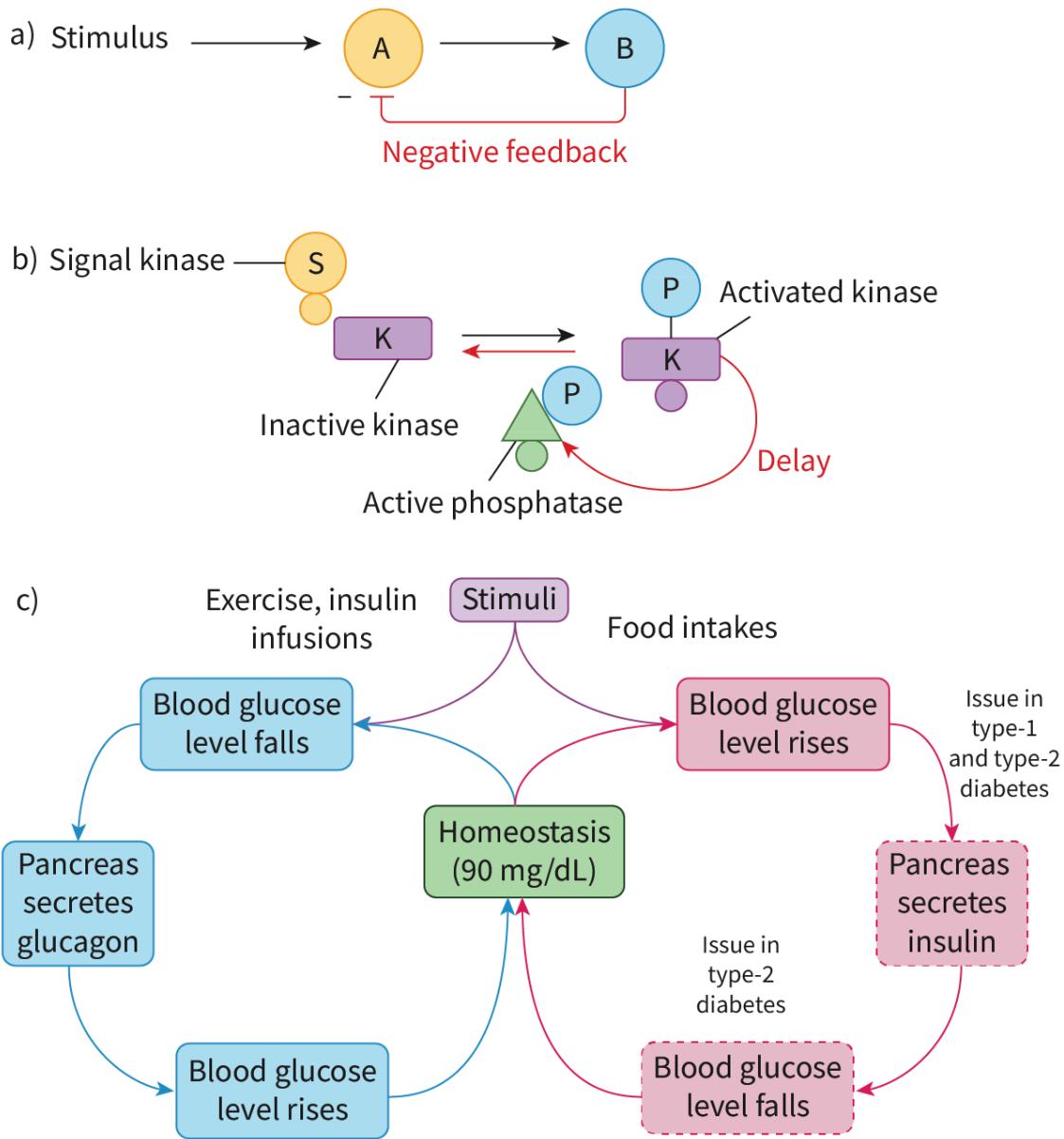


Figure 2. Regulation of enzyme kinase by negative feedback mechanisms, a) a simple negative loop, b) kinase, c) insulin.

More information for figure 2

The image is a multifaceted diagram explaining negative feedback regulation in enzyme kinase and insulin pathways, composed of three parts labeled a, b, and c.

Part a) illustrates a simple negative feedback loop involving a stimulus (A) leading to a response (B), which in turn inhibits the original stimulus through negative feedback.

Part b) describes the regulation of a signal kinase. It shows the kinase (K) being activated by a signal (S), converting it into an activated kinase (P), which then triggers an inactive phosphatase to become active, thus delaying the process through a feedback loop.

Part c) depicts the homeostasis of blood glucose levels regulated by insulin and glucagon secretion. It shows different stimuli like exercise and insulin infusions causing blood glucose levels to fall, prompting the pancreas to secrete glucagon, which raises the levels again.

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Conversely, food intake causes the levels to rise, leading to insulin secretion by the pancreas, restoring homeostasis at 90 mg/dL. Notes highlight issues caused by type-1 and type-2 diabetes affecting these processes.

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Positive and negative feedback loops couple together to form the foundation of the cellular signalling pathway. Reactions are constantly turned on or off depending on the type of signal they receive. A collective response of all components involved in the signalling process ensures that the cell continues to function properly.

Theory of Knowledge

Is it possible to determine what might be the ethical consequences to manipulating feedback mechanisms in biological systems?

The question of whether or not it is possible to answer the above question depends upon the ethical framework being used to come to a judgement. A deontological ethical framework argues from a set of objective principles which must be followed irrespective of the consequences. On the other hand, a consequentialist ethical framework will determine the rightness or wrongness of an outcome based solely on the benefits to the system under consideration.

From this perspective, then, the consequences are irrelevant if looked at from a deontological perspective. Yet, one of the issues around consequentialist ethics is the problem of predicting accurately both likely and probable outcomes.

With regard to gene expression, a deontological approach would look at whether the manipulation of gene expression is, in principle, a good thing to do or not, whereas from a consequentialist point of view the manipulation of the gene itself is not a guarantee of success given that other factors play an important role.



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Creativity, activity, service

Strand: Service

Learning outcome: Demonstrate how to initiate and plan a CAS experience

You should plan to conduct an awareness campaign on drug resistance. Work collaboratively and also engage with experts to clarify any doubts about the topic.

Try the drag and drop activity in **Interactive 1** to classify negative and positive feedback pathways.

START

END

Transduction pathway	Signalling molecule	Response
Receptor	Stimulus	Effector

Check

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Interactive 1. Regulation of cell signalling pathways in blood clotting.

Try the activity below to help with your understanding about positive and negative feedback pathways.



Activity

- **IB learner profile attribute:** Knowledgeable
- **Approaches to learning:** Thinking skills — Reflecting at all stages of the assessment and learning cycle
- **Time required to complete activity:** 15 minutes
- **Activity type:** Individual activity

Your task

Read the following scenarios of chemical signalling pathways, identify whether they are positive or negative feedback mechanisms, and then present your understanding to the class.

Scenario 1: Oxytocin and uterine contractions during childbirth — Oxytocin is a hormone that causes the uterus to contract during labour and delivery. As contractions become stronger, oxytocin is released in larger amounts, leading to strengthening of contractions.

Scenario 2: Calcium regulation in muscle cells — Calcium ions play an important role in muscle contraction. When a muscle cell is stimulated, calcium is released from storage sites and binds to proteins that help initiate and maintain contraction. As calcium levels increase, the cell prevents excessive calcium influx to avoid stiffening of muscles.



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Scenario 3: Cortisol and stress response — Cortisol is a hormone released in response to stress that helps regulate blood sugar levels and suppress immune function. Excessive secretion is reduced and a balance of hormones in the body is maintained.

5 section questions ▾

C2. Interaction and interdependence: Cells / C2.1 Chemical signalling (HL)

Summary and key terms (HL)

Section

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 Feedback

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 Assign

Higher level (HL)

- Chemical signalling is a process by which cells communicate with each other through the use of chemical signals.
- Chemical signals can be classified into autocrine, paracrine, endocrine and synaptic signalling.
- Autocrine signalling involves the cell producing a chemical signal that affects its own behaviour. Paracrine signalling involves the release of chemical signals that affect nearby cells. Endocrine signalling involves the release of chemical signals into the bloodstream to affect distant cells. Synaptic signalling involves the release of chemical signals between neurons and their target cells.
- Chemical signals can bind to membrane-bound receptors or intracellular receptors to initiate signal transduction pathways.
- Signal transduction pathways involve a series of events that amplify and transmit the signal to produce a response.
- A major component of cell signalling cascades is the phosphorylation of molecules by enzymes known as kinases.
- Second messengers, such as cAMP, IP₃ and DAG, play a crucial role in signal amplification.
- Some pathways activate enzymes that interact with DNA transcription factors. Others modify proteins and induce them to change their location





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in the cell. Depending on the status of the organism, cells can respond by storing energy as glycogen or fat or making it available in the form of glucose.

- The termination of the signal is important to prevent over-stimulation of the target site, and can occur through reuptake of the signalling molecule, inactivation of the receptor or negative feedback inhibition.



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↓^A Key terms



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Review these key terms. Do you know them all? Fill in as many gaps as you can using the terms in this list.

1. In cellular communication, signalling molecules known as interact with specific on target cells. One such signalling mechanism is , which allows cells to coordinate their activities based on population density. During , the binding of a ligand to a receptor initiates a cascade of events involving leading to cellular responses.
2. are a diverse group of receptors that activate intracellular signalling pathways through the interaction with G proteins. On the other hand, receptors activate signalling cascades by triggering the activation of protein kinases that phosphorylate target proteins.
3. bind to epinephrine and play a crucial role in coordinating the body's response to stress or danger. These receptors initiate physiological changes to prepare the body for fight or flight responses.
are chemical messengers secreted by various glands that travel through the bloodstream to exert their effects on target cells with specific receptors.
4. In neuronal signalling, function as signalling molecules that transmit information across synapses, allowing communication between nerve cells. This transmission is critical for processes such as learning, memory, and coordination of body movements.
5. The is the electrical charge difference across a cell membrane, which plays a vital role in the transmission of signals. It enables the generation of action potentials and allows cells to communicate electrically.
6. Feedback mechanisms are essential for maintaining homeostasis in living organisms.



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amplifies the initial signal,

leading to an intensified response, while
dampens the signal, bringing
the system back to equilibrium.

Epinephrine receptors Hormones

signal transduction receptors tyrosine kinase

negative feedback GPCRs quorum sensing

ligands neurotransmitters Positive feedback

second messengers membrane potential

Interactive 1. Key Terms: Cell Signaling

C2. Interaction and interdependence: Cells / C2.1 Chemical signalling (HL)

Checklist (HL)

Section

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Feedback

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Assign

Higher level (HL)

What you should know

After studying this subtopic you should be able to:

- Define the term ligand.
- Outline the stages of signal transduction.
- Explain the mechanism of quorum sensing in bacteria and discuss its role in bacterial behaviour.
- Understand bioluminescence and its importance and applications.
- Identify the categories of signalling chemicals in animals — hormones, neurotransmitters, cytokines and calcium ions.



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- Differentiate between different types of signals used by multicellular organisms.
- Describe the difference in structure and function of hormones and neurotransmitters.
- Demonstrate an understanding of mechanisms that signalling molecules use to produce localised as well as distant effects.
- Analyse the role of signalling molecules in the transmission of signals from one part of the body to another.
- Compare and contrast transmembrane receptors and intracellular receptors.
- Describe the different signalling pathways activated by transmembrane receptors and intracellular receptors.
- Explain the mechanisms of initiation of signal transduction pathways.
- Compare and contrast different types of transmembrane receptors and their mechanisms of action, including neurotransmitter receptors and G protein-coupled receptors.
- Analyse the role of transmembrane receptors in changing membrane potential and activating intracellular signalling pathways. Use the protein hormone insulin as an example.
- Describe the effects of oestradiol and progesterone on target cells.
- Explain that positive feedback amplifies the response.
- Explain that negative feedback dampens or inhibits the signalling response.
- Explain that a balance of both positive and negative feedback is necessary for proper cellular response.

C2. Interaction and interdependence: Cells / C2.1 Chemical signalling (HL)

Student view

Investigation (HL)

Higher level (HL)

- **IB learner profile attribute:** Thinker
- **Approaches to learning:**
 - Thinking skills — Engaging with, and designing linking questions
 - Applying key ideas and facts in new contexts
- **Time required to complete activity:** 40 minutes
- **Activity type:** Individual/pair activity

Your task

Watch **Video 1** to see how to set up the experiment and make your own changes to it in order to perform this investigation.

Science – Yeast Experiment: measuring respiration in yeast – Th...



Video 1. Measuring respiration in yeast.

Using the information provided in the video design your own experiment.



Use the information given below to write a focused research question.



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Materials

- dry yeast
- sugar (sucrose)
- vinegar (acetic acid)
- salt
- boiling tubes/long glass of the same dimension
- water
- measuring tools (ruler)
- notebook and pen for recording observations

You may want to read these articles for additional information on the effect of specific chemicals on growth and development of yeast cells:
[vinegar ↗](https://onlinelibrary.wiley.com/doi/full/10.1002/yea.3651) (<https://onlinelibrary.wiley.com/doi/full/10.1002/yea.3651>)
and [salt ↗](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2441982/) (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2441982/>).

Method

Preparation of yeast culture:

1. Dissolve 1 teaspoon of sugar in 200 mL of warm water.
2. Add 1 teaspoon of active dry yeast to the sugar solution and mix well.
3. Allow the yeast mixture to sit for about 15 minutes to activate.

Preparation of chemicals:

1. Salt solution: Dissolve 1 tablespoon salt (NaCl) in 25 mL of water and stir to make a uniform solution.
2. Vinegar (acetic acid): 10 mL.

Experiment:

1. Label the boiling tubes with the name of the chemical you will be testing.
For example: salt, vinegar.
2. Stir the yeast culture well and pour 25 mL of solution into each of the boiling tubes.
3. Add 5 mL of each chemical substance to the corresponding boiling tube.
4. Leave one boiling tube as the control group, containing only the yeast culture without any additional chemical substance (Figure 1).



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5. Allow the yeast to grow for a specified period (e.g. 2–4 hours). Preferably use a dark area to set up the experiment.

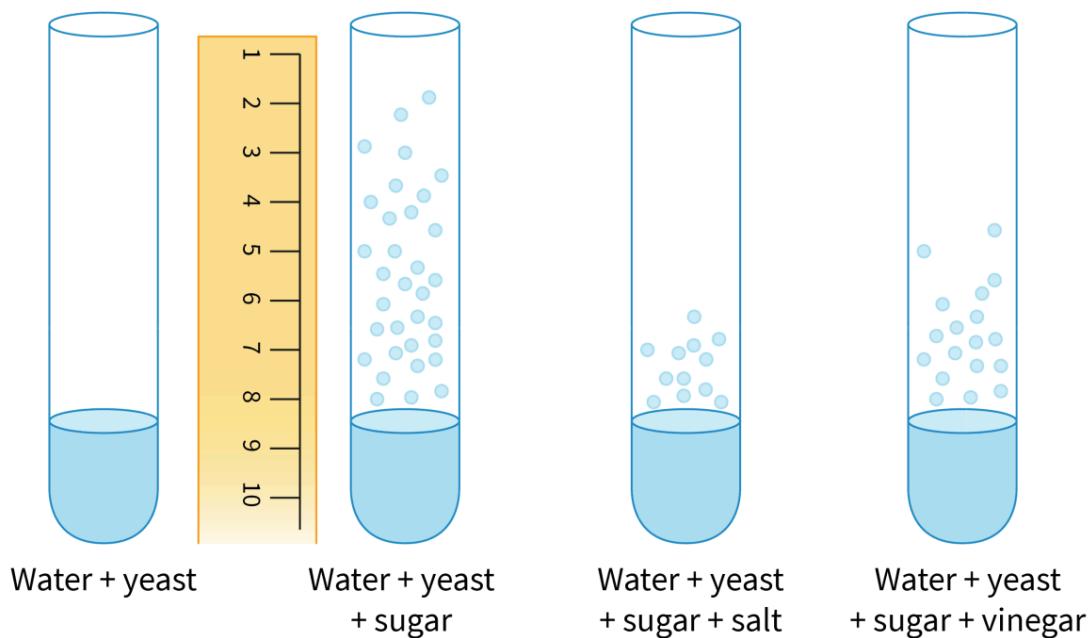


Figure 1. Measuring respiration in yeast.

More information for figure 1

The image is a diagram showing four test tubes side by side. Each test tube contains a different mixture causing varying levels of bubble production.

1. The first test tube is labeled "Water + yeast" and shows no bubbles, indicating no respiration activity.
2. The second test tube is labeled "Water + yeast + sugar," showing a high level of bubbles, suggesting strong respiration.
3. The third test tube is labeled "Water + yeast + sugar + salt," with moderate bubble activity, indicating some respiration but less than the mixture with only sugar.
4. The fourth test tube is labeled "Water + yeast + sugar + vinegar," showing bubble activity similar to the second test tube but less intense, demonstrating the effect of vinegar on yeast respiration.

A ruler is placed behind these test tubes, likely indicating the level of gas production or rise within the test tubes, used to compare the extent of respiration visually.

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Observation and data collection

1. After the incubation period, carefully observe and record the growth of yeast in each container, noting any changes in size, texture or colour.
2. Measure the height or diameter of the yeast growth in each container using a ruler or measuring tape, and record the measurements.
3. Take a sample of the yeast cells from the boiling tube and observe it under the microscope.
4. Note the changes in the size and shape of yeast cells. Pay special attention to yeast budding.

Data analysis and conclusion

1. Analyse the data by comparing the growth of yeast in the different containers with the control group. Look for patterns or differences in growth rates.
2. Organise and analyse the collected data in an excel spreadsheet, comparing the growth patterns and characteristics of the groups treated with chemicals with the control group.
3. Draw conclusions based on the data collected, considering the effects of different chemical signals on the growth of yeast cells. Discuss the role of cell signalling in this context.



Practical skills

Tool 1: Experimental techniques — Measuring variables

Reminder of key terms:

- The independent variable is the variable that you manipulate in an investigation to determine its effect on the dependent variable.
- The dependent variable is the variable that you measure or observe.
- Control variables are the variables you keep constant (same) throughout the experiment to ensure that the effect on the dependent variable is solely due to the independent variable.



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Things to remember:

- Collect data using correct measurement and uncertainties.
- Justify your sampling strategy.
- Take necessary precautions and follow safety guidelines when handling chemicals.
- Ensure consistent environmental conditions, such as temperature and lighting throughout the experiment.

C2. Interaction and interdependence: Cells / C2.1 Chemical signalling (HL)

Reflection (HL)

Section

Student... (0/0)

 Feedback Print (/study/app/bio/sid-422-cid-755105/book/reflection-id-46884/print/)**Assign**

Teacher instructions

The goal of this section is to encourage students to reflect on their learning and conceptual understanding of the subject at the end of this subtopic. It asks them to go back to the guiding questions posed at the start of the subtopic and assess how confident they now are in answering them. What have they learned, and what outstanding questions do they have? Are they able to see the bigger picture and the connections between the different topics?

Students can submit their reflections to you by clicking on 'Submit'. You will then see their answers in the 'Insights' part of the Kognity platform.

Higher level (HL)



Reflection

Now that you've completed this subtopic, let's come back to the guiding question introduced in [The big picture \(/study/app/bio/sid-422-cid-755105/book/big-picture-hl-id-43540/\)](#).



Overview
(/study/ap
422-
cid-
755105/o

- How do cells distinguish between the many different signals that they receive?
- What interactions occur inside animal cells in response to chemical signals?

With these questions in mind, take a moment to reflect on your learning so far and type your reflections into the space provided.

You can use the following questions to guide you:

- What main points have you learned from this subtopic?
- Is anything unclear? What questions do you still have?
- How confident do you feel in answering the guiding questions?
- What connections do you see between this subtopic and other parts of the course?

Once you submit your response, you won't be able to edit it.

0/2000

Submit

Rate subtopic C2.1 Chemical signalling (HL)

Help us improve the content and user experience.



Student
view