

# CONTENTS

## Unit 3 – Area of Study 2 – How do Cells Communicate

<b>Signalling Molecules</b>	<b>1</b>
Local and Long Distance Cell Communication in Animals	2
Categories of Signalling Molecules	4
Hormones	5
Chemical Nature of Hormones	6
Stimulus-Response at the Cellular Level	7
Action of Water-Soluble and Lipid-Soluble Hormones	8
Stimulus-Response Model – Signal Transduction	9
Functioning of a G Protein-Linked Receptor	10
The Action of Adrenalin	11
First and Second Messengers	12
One Chemical Signal: Different Effects	13
Response of the Nucleus to a Peptide Hormone	13
Functioning of a Steroid Hormone Receptor	14
Water Soluble v. Lipid Soluble Hormone Summary	15
A Longer Overview of the Differing Actions of Protein/Peptide and Steroid Hormones	16
The Role of Protein/Peptide Hormones in Activating Second Messenger Molecules	16
A Selection of Important Endocrine Hormones	18
<b>A Variety of Signal Transduction Pathways</b>	<b>19</b>
1. De-etiolation (Greening) Response in Plants	19
2. Defence by Corn Plants Against Predatory Caterpillars	20
3. Blood Glucose Regulation Overview – Negative Feedback	21
Blood Glucose Regulation	22
Diabetes	23
4. Antelopes, Giraffes and the Deadly Acacias	24
5. Cholera and the G Protein	24
6. Viagra and the G Protein	25
Length of Responses from the Action of Signal Molecules	25
Hormones of the Hypothalamus and Pituitary Glands	26
Plant Growth Regulators – Hormones	27
Plant Regulation Summary	27
Do Specialised Cells Produce Plant Hormones	28
<b>The Nervous System</b>	<b>29</b>
Neuron Structure	29
The Impulse (Action Potential)	30
Synapses	31
Signal Transduction in Neurons	33
Neuromuscular Junction	33
Excitatory and Inhibitory Neurons	34

Action of Animal Toxins on the Nervous System	35
Effects of Drugs and Poisons on Synaptic Function	36
Major Neurotransmitters	37
Action of Psychoactive Drugs at the Synapse	38
Stimulants and Depressants	39
Pheromones	39
Comparison of Coordination Systems	39
The Process of Apoptosis	40
Disease and Apoptosis	42
Avoiding Apoptosis – Cancer	43
Intrinsic and Extrinsic Causes of Apoptosis	43
Summary of Apoptosis	44
Cancer – Failure of Apoptosis	45
Tumour Suppressor Genes	45
Oncogenes	46
A Selection of Useful Words to Know	46
<b>Disease</b>	<b>79</b>
History of Disease	79
Disease Definitions	80
Features of a Disease	81
Transmission of Disease	82
Antigens	82
<b>Pathogenic Agents</b>	<b>83</b>
Prions	83
Viruses	85
Viral Life Cycles	87
DNA Viruses and RNA Viruses	89
Summary – Steps in Viral Reproduction	90
HIV (AIDS)	91
HIV (Retrovirus) Reproduction	92
Epidemics and Pandemics	93
Viroids	93
Pathogens	94
Bacteria	94
Structure of a Bacterium	95
Human Control of Microbial Pathogens	96
Antibiotics	96
Antibiotics in Beards	97
Antiseptics and Disinfectants	97
Commonly Used Antibiotics	98

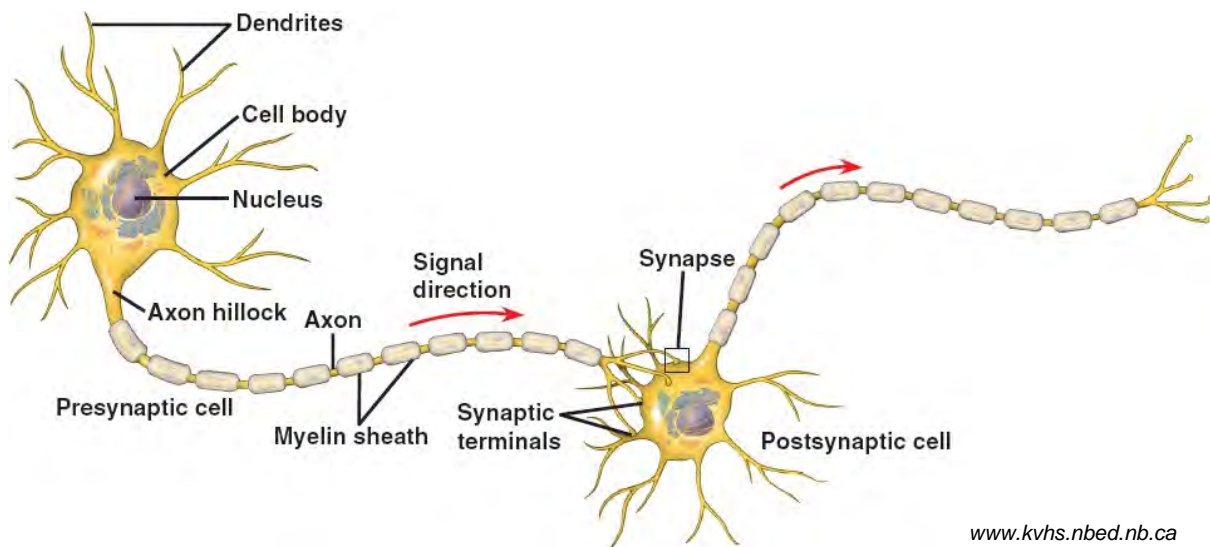
A Selection of Bacterial Scenarios	99
Protozoa	100
Fungi	100
Macroscopic Pathogens	101
Arthropods & Worms	101
Vascular Plants	104
Adaptations of Pathogens	105
Review – Modes of Pathogen Transmission	106
Features of a Disease	106
<b>Defence Against Disease</b>	107
Natural Barriers to Disease	108
Distinguishing Self from Non-Self	109
MHC Markers	109
Antigen Presenting Cells (APCs)	110
Source of Blood Cells	111
The Second Line of Defence: Innate (Non-Specific)	112
Phagocytes	112
Natural Killer Cells	114
Summary of Innate Immune Cells and Modes of Action	115
Proteins that Kill or Impede Invading Microbes	116
Complement	116
Cytokines	116
Inflammation	117
Temperature Response	118
The Lymphatic System	119
Primary Lymphoid Tissue	120
Secondary Lymphoid Tissue	120
Third Line of Defence: Adaptive (Specific)	121
Primary Response	122
Cell Mediated (Cellular) Immunity	123
Summary of the Role of the Four Classes of T Cells	125
Cell Mediated Immunity in Action	126

Humoral Immunity	127
Types of Antibodies (Immunoglobulins)	128
B Cell Antigen Receptors	129
The Humoral Response	130
Antibody Action	131
Opsonisation	132
Secondary Immune Response	132
Humoral Immunity	133
ABO Antigens	135
Transplant Rejection	136
Rhesus Disease	138
<b>Edward Jenner and Vaccination</b>	<b>139</b>
Vaccines	140
Types of Vaccines	141
Acquired Immunity	143
Summary of Acquired Immunity	144
Maintaining Herd Immunity with Vaccinations	145
Autoimmune Diseases	146
Immunodeficiency Diseases	147
HIV (Retrovirus) Reproduction	148
Gene Therapy	149
Allergies	150
Anaphylaxis	151
Hayfever	152
Treatment and Prevention of Allergic Responses	152
The Increase in Allergies in the Western World	153
Plant Defence Systems	154
Games Pathogens Play	155
Rational Drug Design	156
Monoclonal Antibodies	158
Monoclonal Antibodies in Medicine	159
Vocabulary	162
References Used in Compiling This Booklet	203
<b>Solutions</b>	<b>204</b>

# THE NERVOUS SYSTEM

## NEURON STRUCTURE

The nervous system is composed of billions of nerve cells, known as neurons. Each neuron transmits electrical impulses, and the longest cells in your body are the one metre long neurons extending from the base of your spinal cord to your toes. Each neuron possesses the following features:



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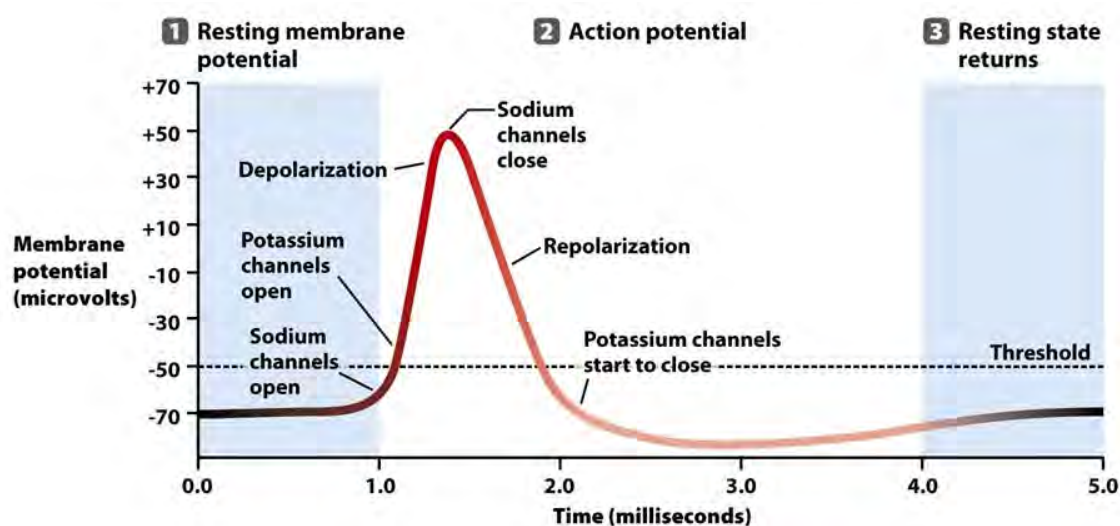
- Dendrites:** Branched extensions of a neuron which receive stimuli from other cells.
- Cell body:** Mass of cytoplasm with contained nucleus, from which branches of neuron arise.
- Axon:** Long extension of a neuron which transmits impulses away from the cell
- Axon Terminals:** Ends of an axon, containing numerous mitochondria and synaptic vesicles. Release neurotransmitter across a synapse to the next cell.
- Myelin sheath:** A white fatty substance that increases the speed of electrical impulses and insulates against the loss of impulses from the neuron. The sheath is mainly composed of lipid. Myelinated fibres make up the **white matter** of the nervous system.

## \*THE IMPULSE (ACTION POTENTIAL)

The message travelling along the neuron is electrical and is initiated by the opening of ion channels (protein channels) in the cell membrane, allowing sodium ions to enter and potassium ions to leave the cell.

- The cell membrane of a neuron is quite unique in that at rest (with no impulses passing through) it is negatively charged inside the cell compared to the outside. The relative difference in sodium and potassium ion concentrations inside and outside of the cell ensures a resting potential of  $-70$  mV.
- To maintain this resting state, active transport proteins (sodium/potassium pumps) in the membrane ensure that a high sodium ion concentration outside of the cell and a high potassium ion concentration inside the cell is maintained.
- When an electrical impulse arrives at any point of the neuron cell membrane, the membrane suddenly becomes permeable to sodium ions. This causes sodium to rush into the cell through newly opened protein channels (facilitated diffusion), causing the inside of the neuron to become positive. Potassium ions immediately leave after sodium ions have entered via their own protein channels (facilitated diffusion again). This change in charge is called an action potential, and only lasts for a millisecond or two.
- Once the impulse has passed the neuron returns to its resting state. The sodium/potassium pumps restore the original balance of sodium outside the cell and potassium inside the cell to resume the resting state.

(Evans B et al, 1999)

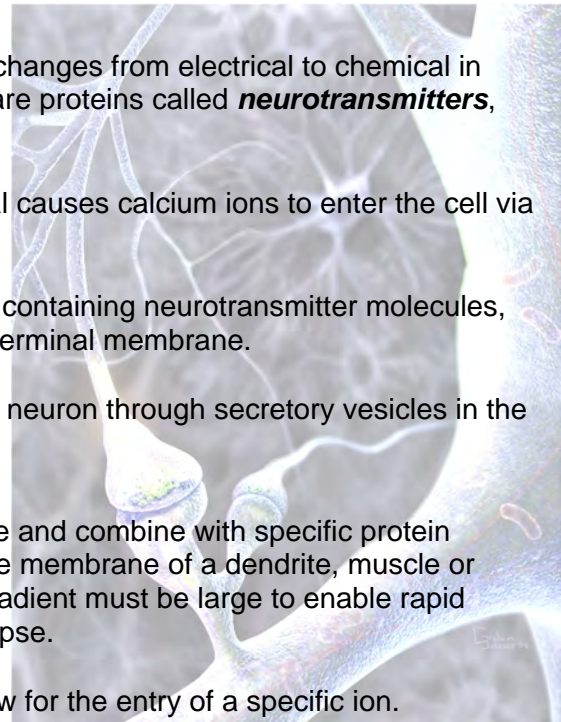


- Impulses or **action potentials are all of the same size**. Due to this mode of operation, the action of impulses in the nervous system is said to operate via an **'all or nothing'** effect.
- The brain can distinguish a stronger stimulus from a weaker stimulus by its higher **frequency of impulses**.

## SYNAPSES

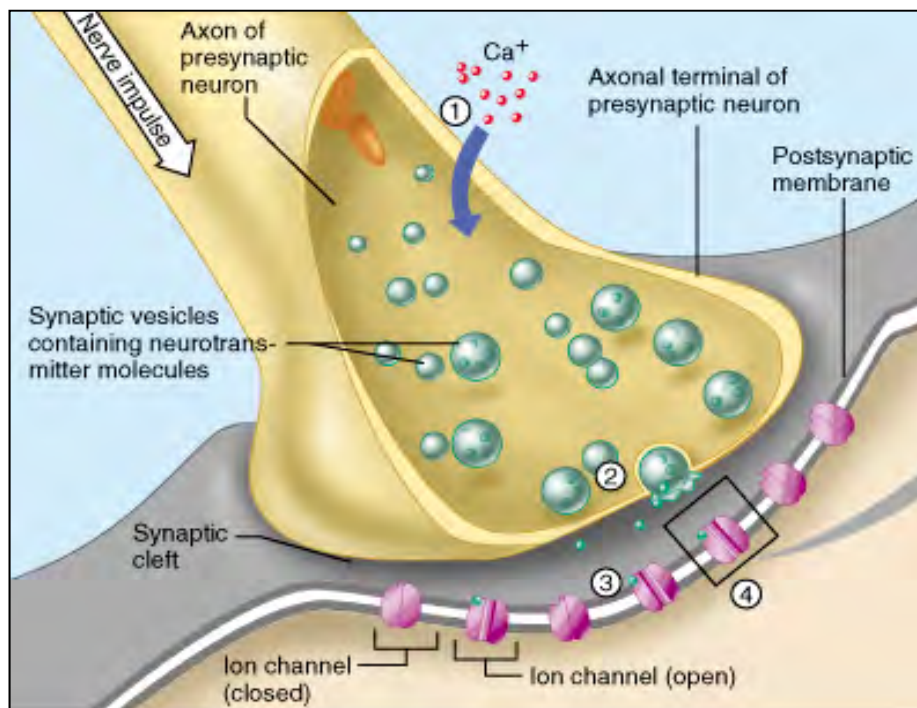
At the end of an axon is a region called the **synapse**. The **synaptic cleft** is a gap between the axon terminal of one neuron and the dendrites of another neuron, or the gap between an axon terminal and a muscle or gland.

- In order to cross the synapse, the message changes from electrical to chemical in nature. The chemicals produced at this site are proteins called **neurotransmitters**, (e.g. Acetylcholine – ACh).
- The arrival of an impulse at the axon terminal causes calcium ions to enter the cell via calcium channels.
- Calcium ions bind to synaptic vesicles, each containing neurotransmitter molecules, and causes the vesicles to bind to the axon terminal membrane.
- Neurotransmitters exit the axon terminal of a neuron through secretory vesicles in the process of \_\_\_\_\_.
- Neurotransmitters diffuse across the synapse and combine with specific protein receptors on the postsynaptic membrane (the membrane of a dendrite, muscle or gland) by a lock and key mechanism. The gradient must be large to enable rapid diffusion of neurotransmitter across the synapse.
- The receptor, a gated channel, opens to allow for the entry of a specific ion.
- If the second cell is a neuron, a new impulse may be generated.



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***In the space provided on the next page, clearly state what is occurring at each of the numbered areas in the synapse depicted below:***

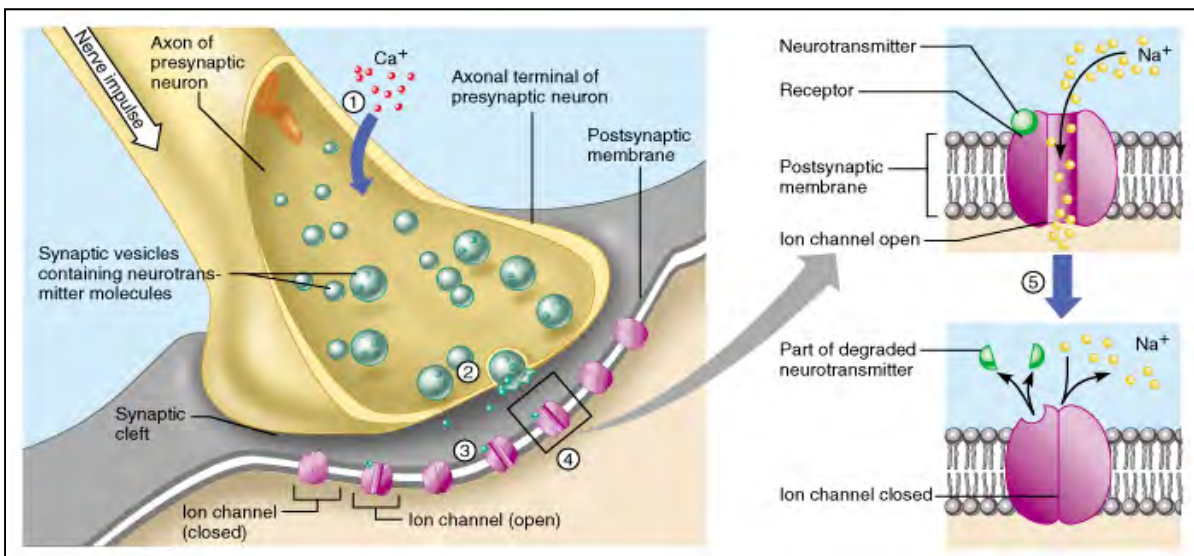


1. \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_
2. \_\_\_\_\_  
 \_\_\_\_\_  
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3. \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_
4. \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

**After the action of a neurotransmitter has been achieved, the neurotransmitters:**

1. Are destroyed by enzymes in the synaptic cleft (e.g. Acetylcholinesterase destroys ACh) and
2. The fragments are taken up by the axon terminal via membrane **transporter proteins** to be resynthesised into neurotransmitters (e.g. Choline resynthesised into ACh) or
3. May instead drift out of the synaptic cleft via diffusion and eliminated from the body via the kidneys, or destroyed in the liver (e.g. Dopamine).

These actions prevent further excitatory or inhibitory signal transduction, and allows new signals to be produced from the adjacent nerve cells.



Benjamin Cummings 2001



## SIGNAL TRANSDUCTION IN NEURONS

### Reception

The binding of a neurotransmitter to its specific complementary receptor on the neuron membrane causes a 3D conformational change of the receptor as it is activated.

### Transduction

After a nerve impulse is generated in the post-synaptic neuron, it travels the length of the axon until it reaches the synaptic terminal.

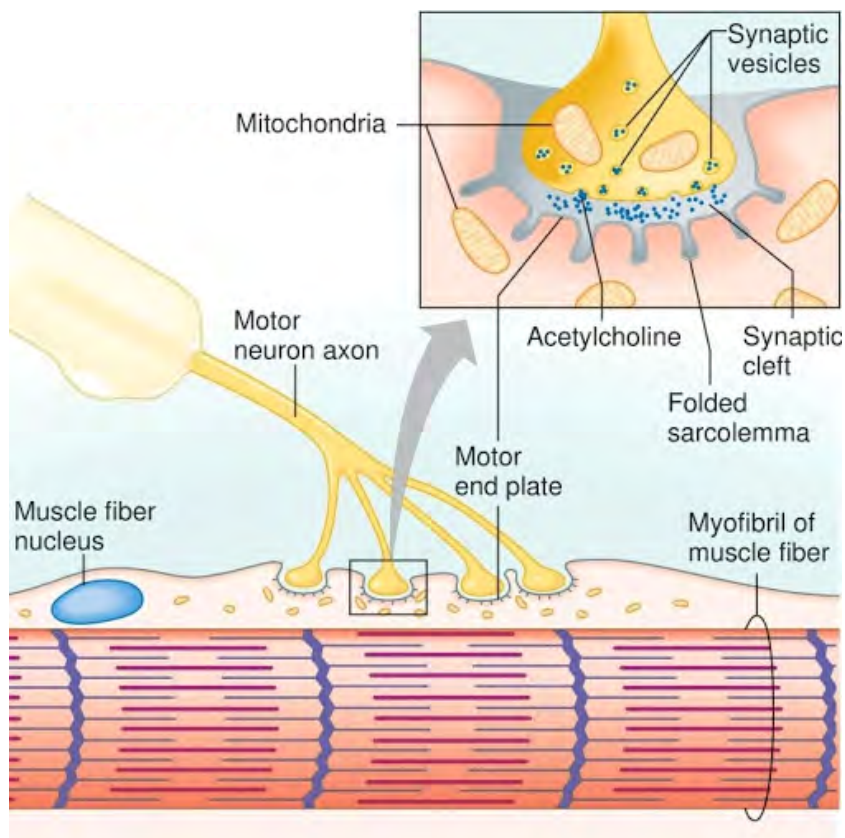
### Cellular Response

When the impulse reaches the synaptic terminal,  $\text{Ca}^{2+}$  ions flow into the terminal via  $\text{Ca}^{2+}$  channels and attach to synaptic vesicles.

Synaptic vesicles then fuse with the presynaptic membrane, releasing neurotransmitter molecules into synaptic cleft via exocytosis.

## NEUROMUSCULAR JUNCTION

The neuromuscular junction is really a synapse between a neuron and a muscle.



The excitatory neurotransmitter is **acetylcholine (ACh)**, and as with other synapses, the axon terminal contains extensive Golgi vesicles and numerous mitochondria.

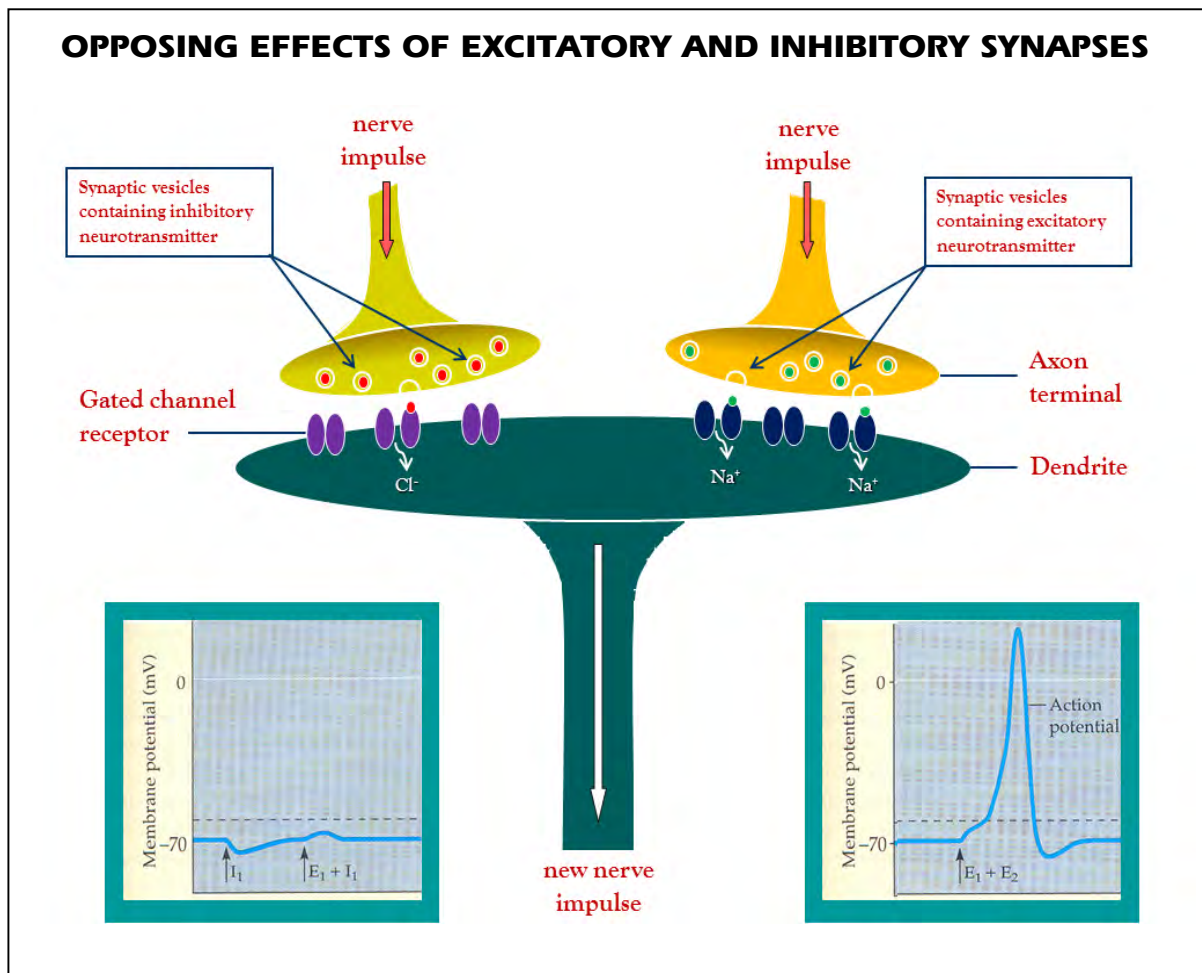
## EXCITATORY AND INHIBITORY NEURONS

A single neuron may receive information from numerous neurons via thousands of synapses, some excitatory and some inhibitory.

Excitatory and inhibitory synapses have opposite effects on the membrane potential of the postsynaptic cell.

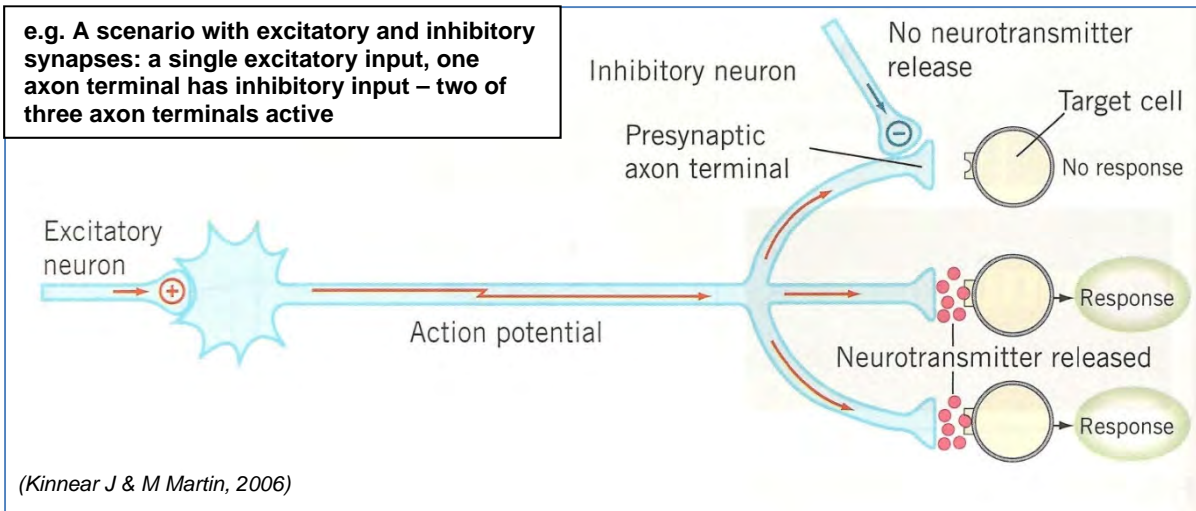
### Excitatory Synapse (e.g. acetylcholine at neuromuscular junctions):

- Once an excitatory neurotransmitter has attached to the membrane-bound receptor (a gated channel), the channel opens up, allowing **sodium ions** to diffuse into the cell, thereby **increasing** the chance of an impulse being generated in the post-synaptic cell.



### Inhibitory Synapses (e.g. endorphins):

- \* Once the inhibitory neurotransmitter has attached to the membrane-bound receptor (a gated channel), the protein channel opens up, allowing **chloride ions** to enter (or potassium ions to leave) the cell, thereby **decreasing** the chance of an impulse being generated in the post-synaptic cell.



**Note:** Students are **not** expected to know which ions enter/leave cells via protein channels in the post-synaptic membrane within excitatory or inhibitory synapses. The question as to how inhibitory synapses differ from excitatory synapses is often asked by students, so the distinction has simply been made to cater for this line of inquiry.

Instead, students are only expected to recognise the different effects of these distinctive synapses on the same post-synaptic membrane.

### \*ACTION OF ANIMAL TOXINS ON THE NERVOUS SYSTEM

The action of different animal toxins on the nervous system can vary significantly. For instance, some toxins act at the synapse, while others act on the axon to cause paralysis.

Action of Toxin	Venom Source
Excessive release of noradrenalin → narrowing of arterioles	Irukandji jellyfish
Prevent transmission of impulses along a nerve	Funnel-web spider, Pufferfish
Block release of neurotransmitter	Bush tick; some snakes
Reduce movement of Na <sup>+</sup> ions across muscle membranes → suffocation	Cone shell
Continuous leakage of acetylcholine → shortage of acetylcholine when required	Red-backed spider
Blocks receptors for neurotransmitter	Some snakes
Break down muscle at neuromuscular junction → clogs nephrons → kidney failure	Some snakes

## \*EFFECTS OF DRUGS AND POISONS ON SYNAPTIC FUNCTION

### Selected Insecticides and Nerve Gases

Some insecticides and nerve gases can inhibit the destruction of neurotransmitters.

- They operate by inhibiting the action of enzymes which destroy the neurotransmitter after it has diffused across the synapse.
- Hence, the neurotransmitter lingers and keeps stimulating the post-synaptic membrane (muscle, gland or neuron) leading to death of the individual.



fotolia

### Pain Killers

- In a similar manner to the action of natural pain-killers (e.g. endorphins), codeine and morphine *hyperpolarise* synapses along pain pathways to the brain.
- They attach to opioid receptors inhibiting impulse transmission along pathways which would generate pain sensations.



### Amphetamines

- Work in a similar manner to insecticides by blocking removal of transmitter at dopamine synapses. Associated symptoms:
  - \* *Increased alertness*
  - \* *Euphoria*
  - \* *Loss of appetite*
  - \* *Insomnia*
  - \* *Increased pulse rate and blood pressure*
  - \* *May increase body temp. and cause hallucinations and convulsions*
  - \* *High potential for psychological dependence*