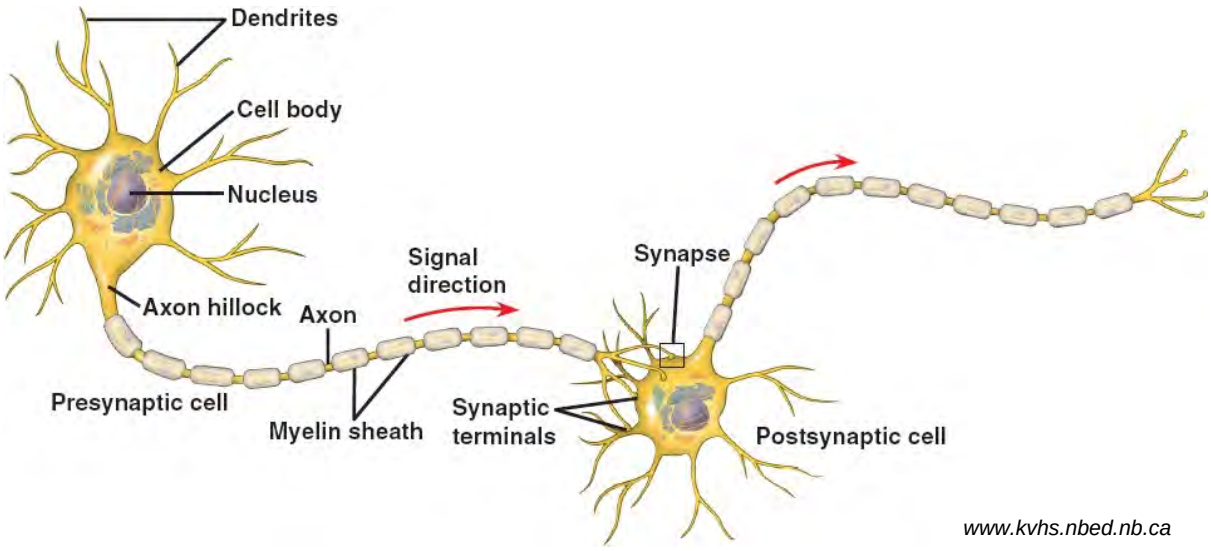
CONTENTS

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

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:



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.

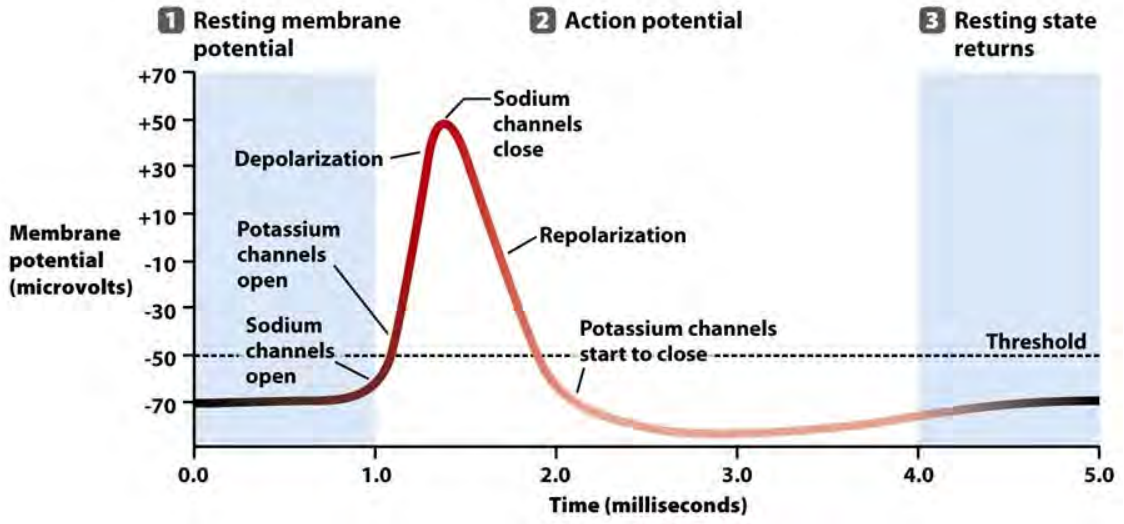
- The cell membrane of a neuron is quite unique in that at rest (with no impulses passing through) it is negatively charged inside the cell compared to the outside. The relative difference in sodium and potassium ion concentrations inside and outside of the cell ensures a resting potential of –70 mV.

- 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)

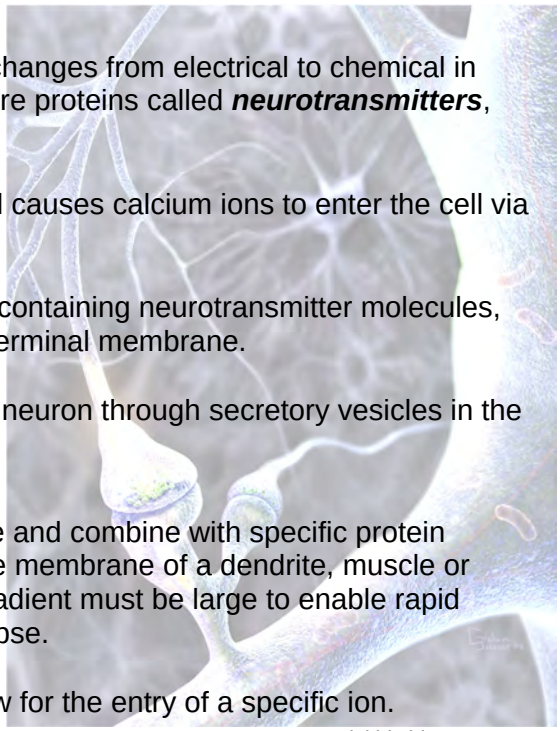


- Impulses or ***action potentials are all of the same size***. Due to this mode of operation, the action of impulses in the nervous system is said to operate via an ***'all or nothing'*** effect.

- 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.



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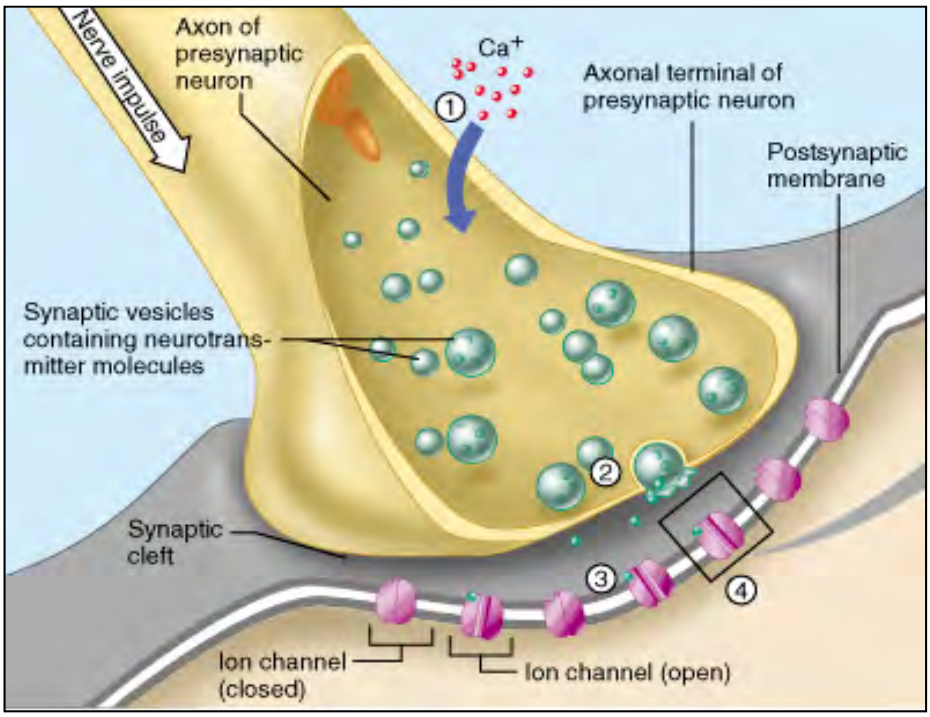
- In order to cross the synapse, the message changes from electrical to chemical in nature. The chemicals produced at this site are proteins called ***neurotransmitters***, (**e.g.** Acetylcholine – ACh).
- The arrival of an impulse at the axon terminal causes calcium ions to enter the cell via calcium 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.

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. _____

3. _____

4. _____

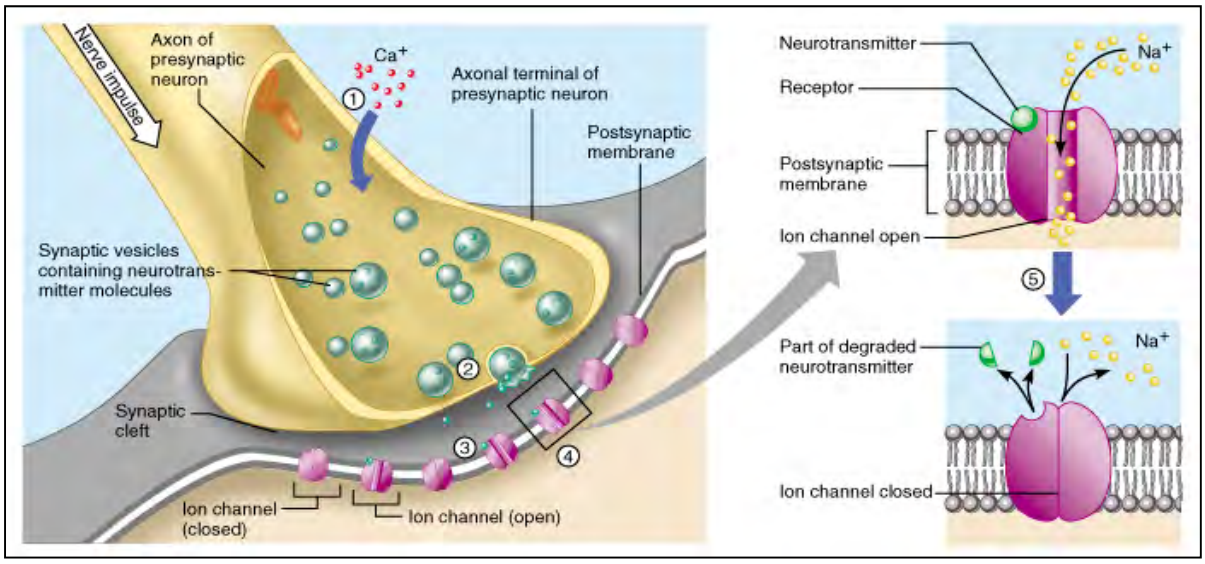
After the action of a neurotransmitter has been achieved, the neurotransmitters:

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.

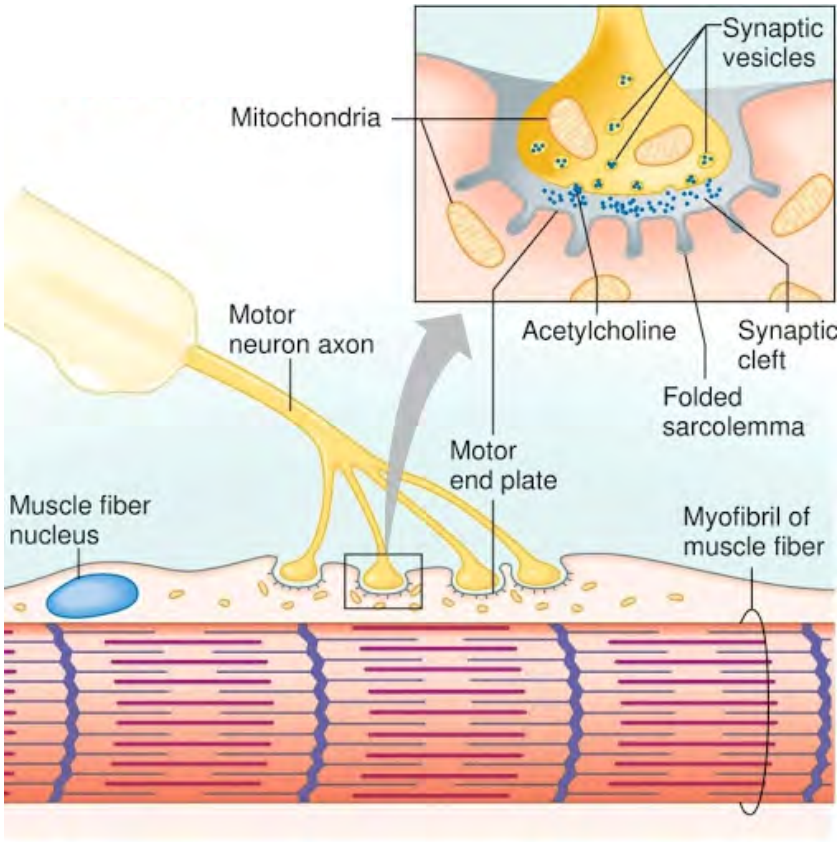
Cellular Response

When the impulse reaches the synaptic terminal, Ca^{2+} ions flow into the terminal via 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

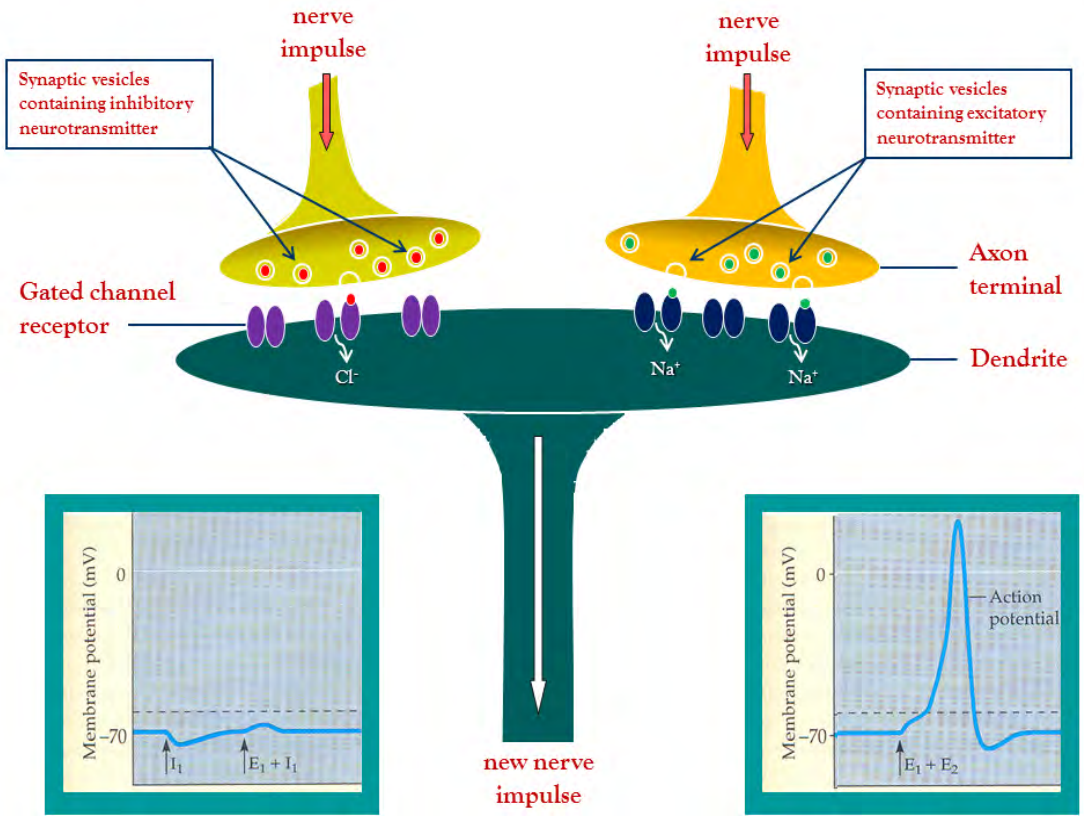
A single neuron may receive information from numerous neurons via thousands of synapses, some excitatory and some inhibitory.

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.

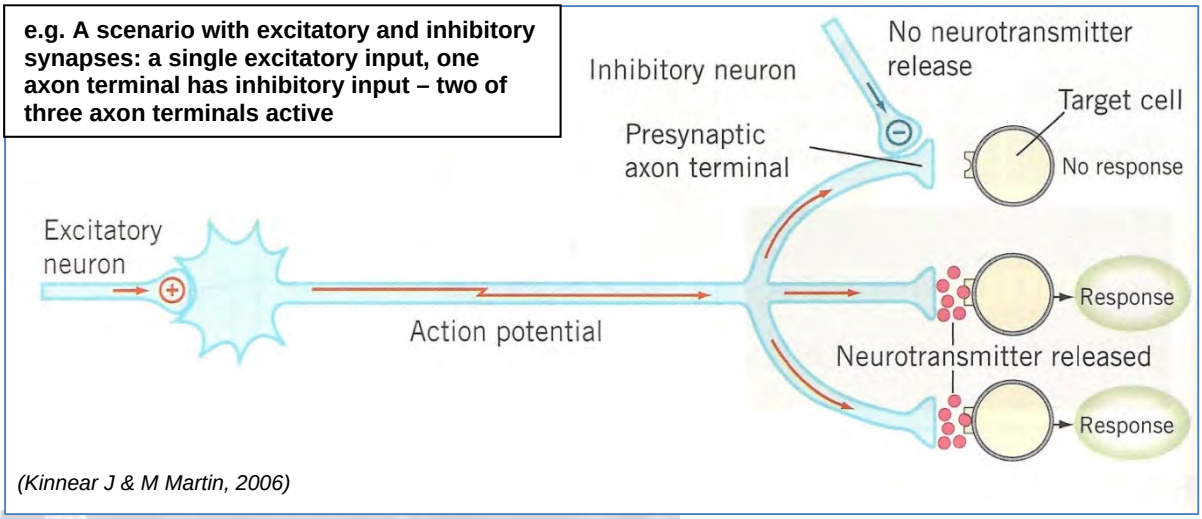
OPPOSING EFFECTS OF EXCITATORY AND INHIBITORY SYNAPSES



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.

e.g. A scenario with excitatory and inhibitory synapses: a single excitatory input, one axon terminal has inhibitory input – two of three axon terminals active



(Kinnear J & M Martin, 2006)

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^+ 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

fotolia

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.

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*