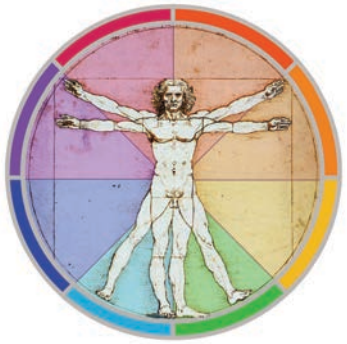
HUBS191 Lecture Material

This pre-lecture material is to help you prepare for the lecture and to assist your note-taking within the lecture,

it is NOT a substitute for the lecture !



Please note that although every effort is made to ensure this pre-lecture material corresponds to the live-lecture there may be differences / additions.

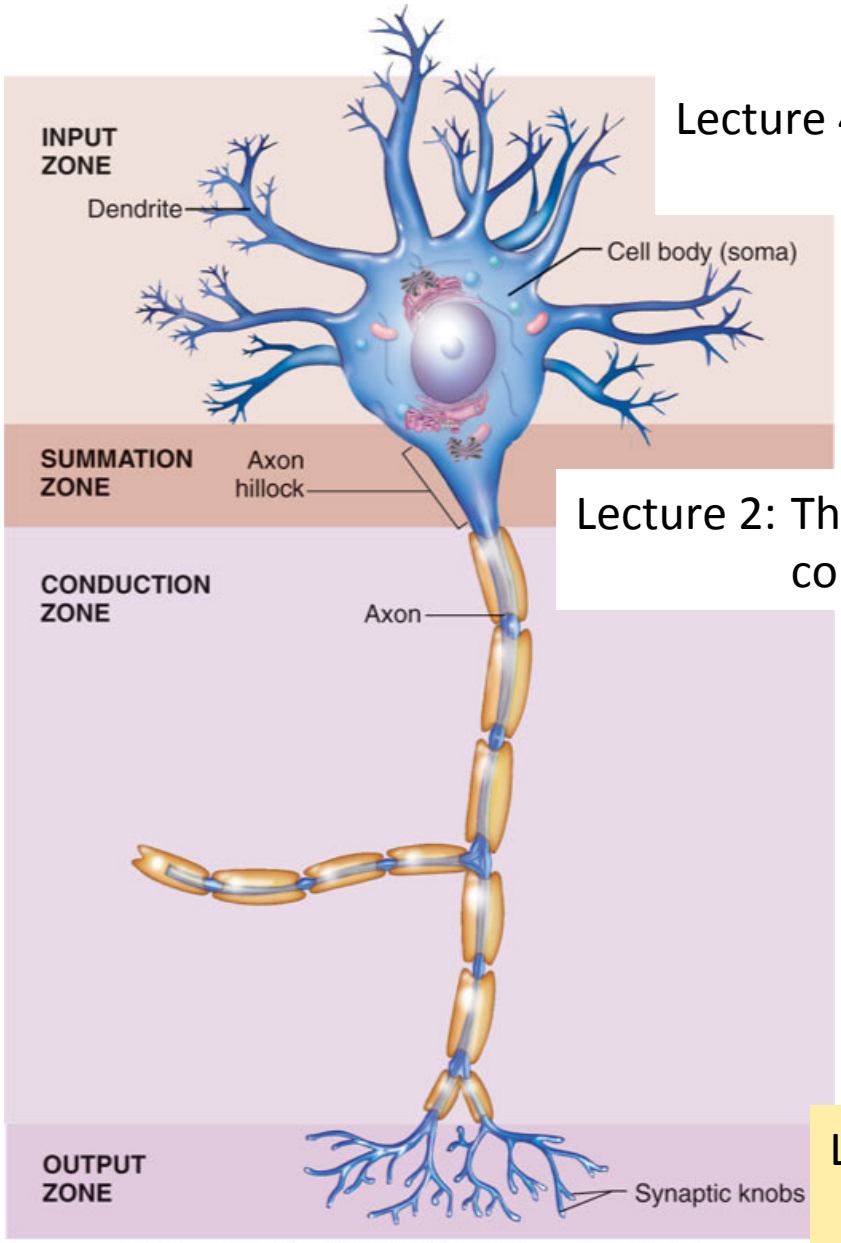
Physiological Principles of Human Movement and Sensation

HUBS191

Lecture 23

Dr Martin Fronius
Department of Physiology
6. April 2017

Lectures outline



Lecture 4: Synaptic Networks and Integration (input zone)

Lecture 2: The Action Potential and its conduction (axon hillock, axon)

Lecture 1: Bioelectricity and membrane potentials

Lecture 3: The Synapse – 'connecting' neurons (output zone)

Aims of Today's Lecture

Lecture 23 – The Synapse 'making connections'

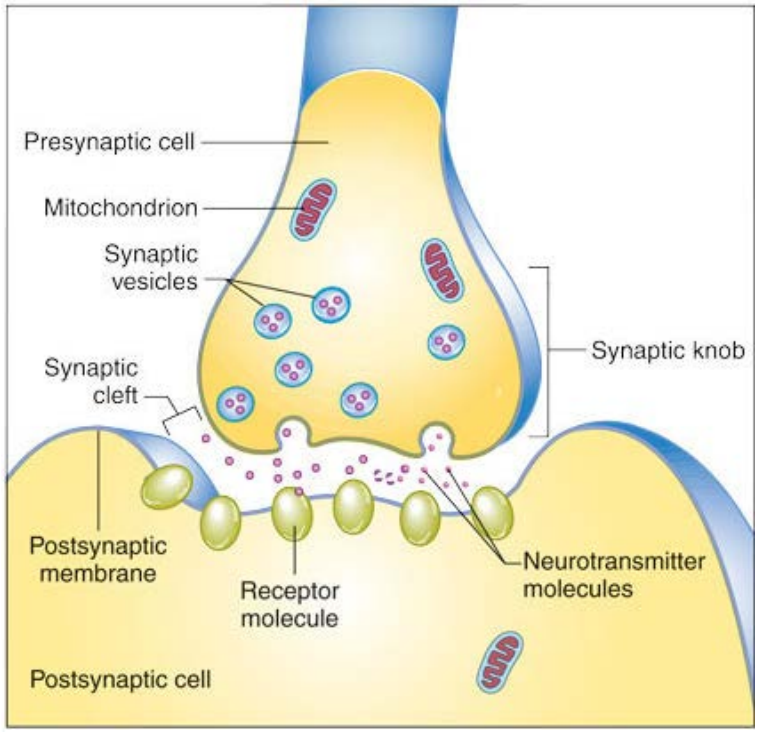


Fig. 13-23 Thibodeau and Patton, 8th Ed, p. 400

Outline

- Recap from lecture 2
- What is a synapse?
- Two types of Synapses: Electrical and chemical
- How does a chemical synapse work?
- How is a synapse switched off?

To summarise the events during an AP…

STEP	DESCRIPTION
1	A stimulus triggers stimulus-gated Na^+ channels to open and allow inward Na^+ diffusion. This causes the membrane to depolarize.
2	As the threshold potential is reached, voltage-gated Na^+ channels open.
3	As more Na^+ enters the cell through voltage-gated Na^+ channels, the membrane depolarizes even further.
4	The magnitude of the action potential peaks (at +30 mV) when voltage-gated Na^+ channels close.
5	Repolarization begins when voltage-gated K^+ channels open, allowing outward diffusion of K^+.
6	After a brief period of hyperpolarization, the resting potential is restored by the sodium-potassium pump and the return of ion channels to their resting state.

Table 13-2 from Thibodeau and Patton, 8th Ed p. 396

- **TIMING IS EVERYTHING !**
- Order of channel events → opening/closing!
- Different types of channels (e.g. stimulus, voltage-gated)

Table 13-1 from Thibodeau and Patton 8th Ed p. 395

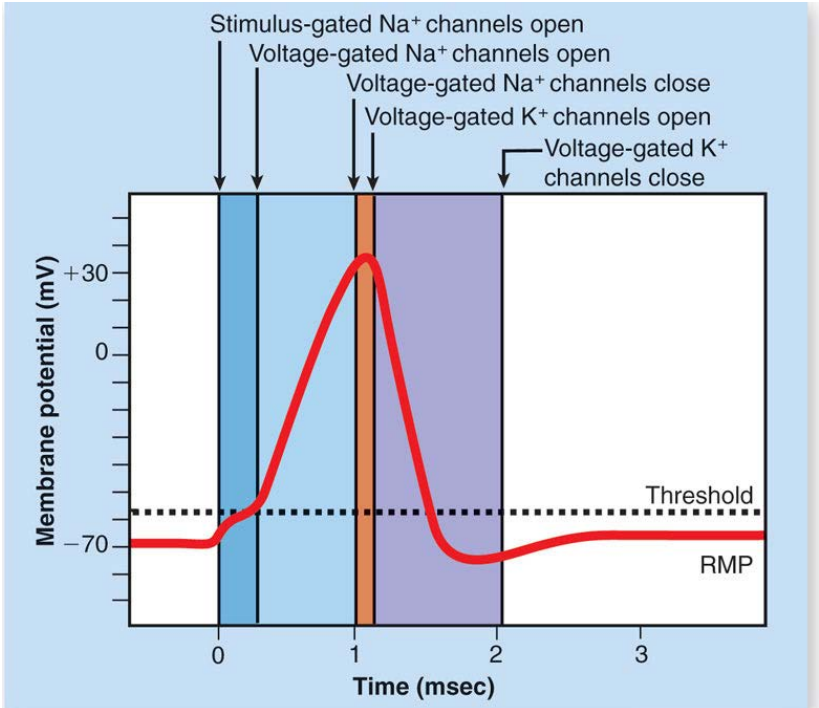
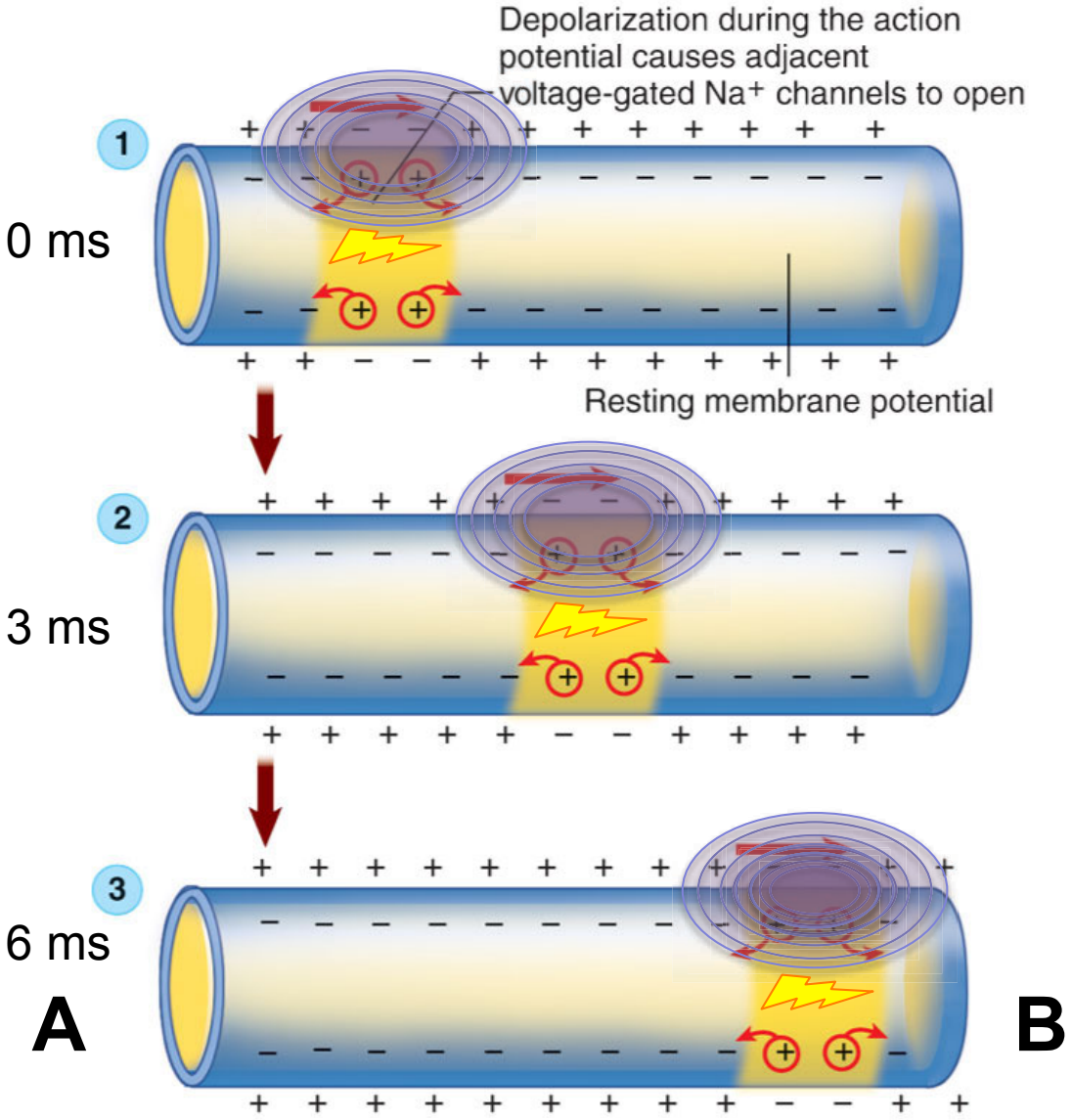


Fig. 13-19 Thibodeau and Patton 8th Ed p.396

Conduction of the Action Potential down Axons



From Fig. 13-21 T+P 8th Ed p. 398

Relies on the spread of the DEPOLARISING electrical signal

Generation of an electric field

ALONG

the axon to instantly activate the next set of voltage gated Na^+ channels

What determines the propagation direction of an Action Potential

→ Refractory period

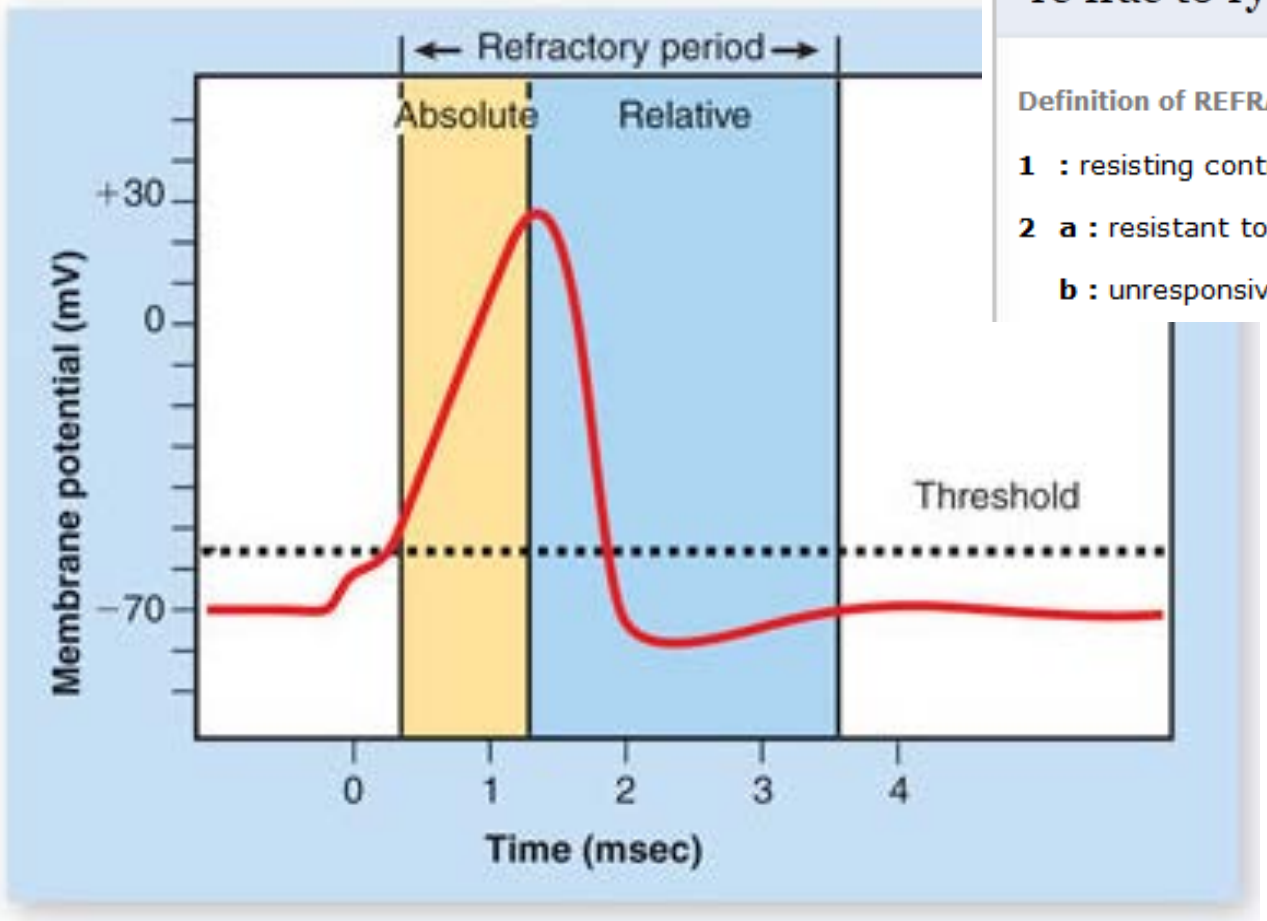
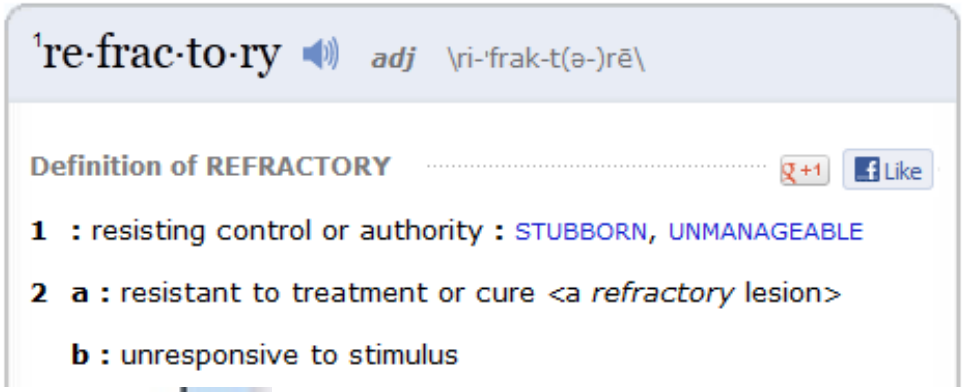


Fig. 13-20 Thibodeau and Patton 8th Ed p. 397



From http://www.merriam-webster.com

REFRACTORY PERIODS:

- **Absolute → no response**
- **Relative → large stimulus required**

REFRACTORY PERIODS:

- **Intrinsic feature of the Na^+ channels**

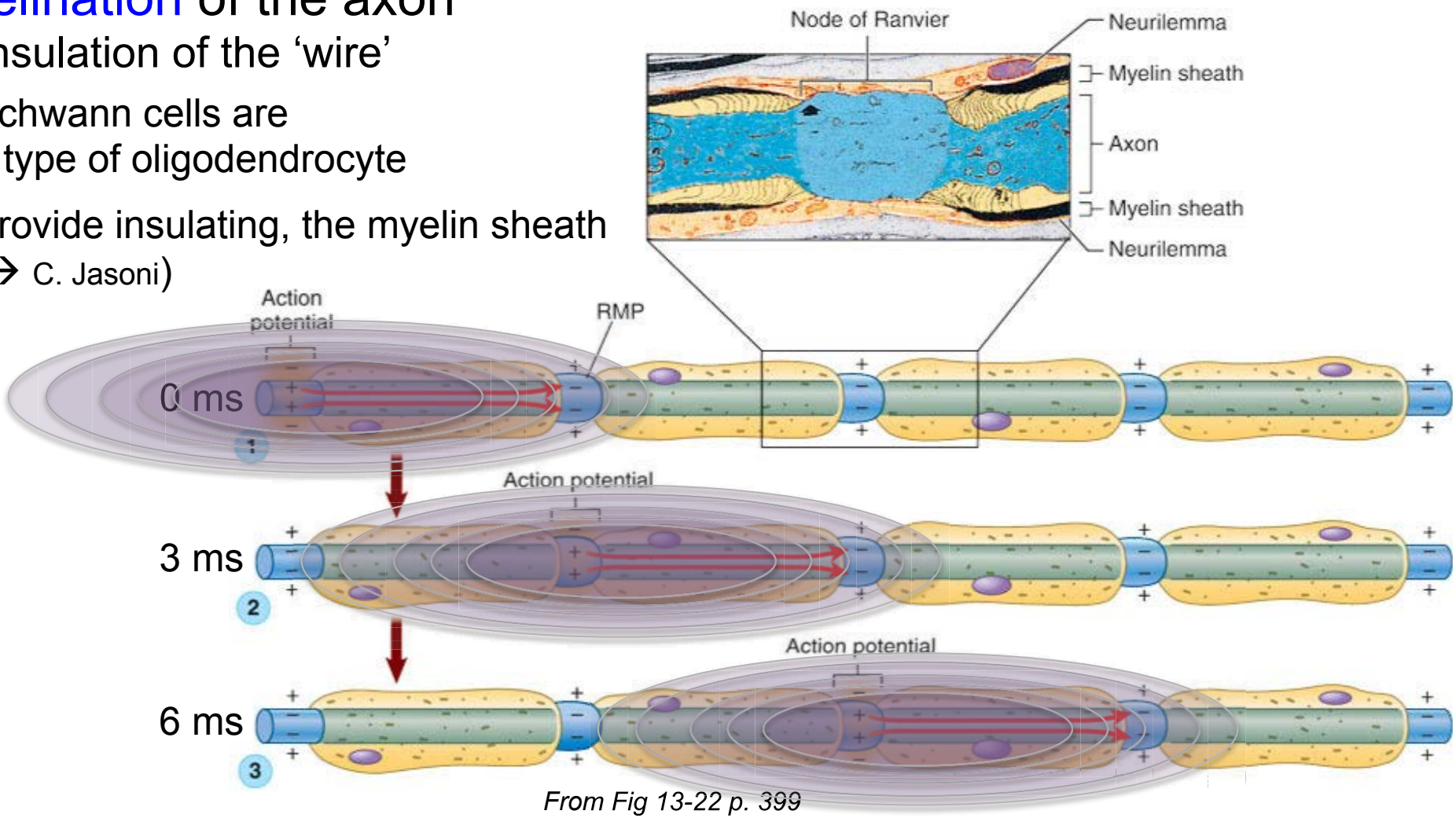
→ It also limits the number of action potentials at a given time (frequency of action potentials)

IMPROVE CONDUCTION SPEED → MYELINATED AXONS

Myelination of the axon

→ Insulation of the 'wire'

- Schwann cells are a type of oligodendrocyte
- Provide insulating, the myelin sheath (→ C. Jasoni)



From Fig 13-22 p. 399

The action potential leaps between the nodes of Ranvier – saltatory conduction

Aims of Today's Lecture

Lecture 23 – The Synapse 'making connections'

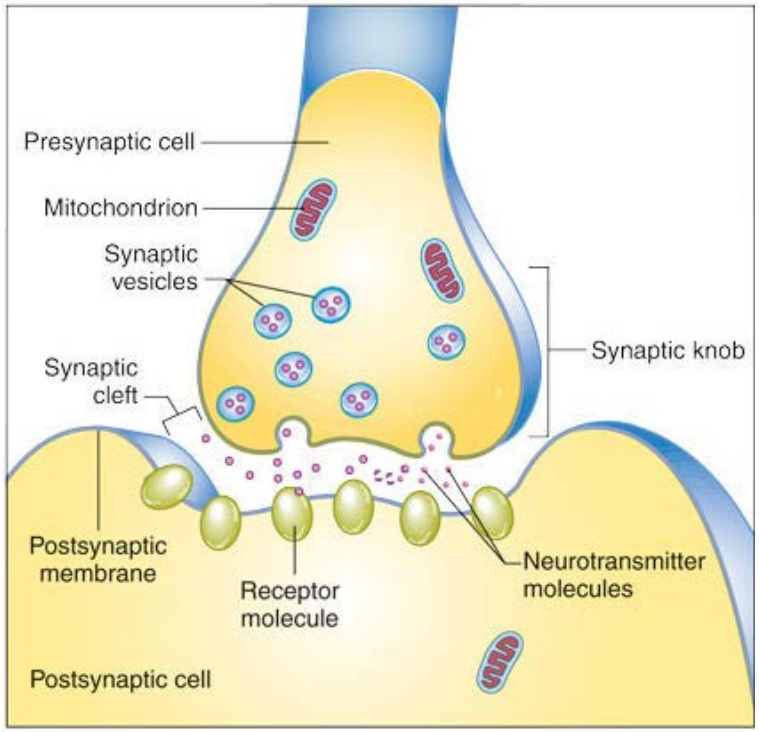


Fig. 13-23 Thibodeau and Patton, 8th Ed, p. 400

Outline

- Recap from lecture 2
- What is a synapse?
- Two types of Synapses: Electrical and chemical
- How does a chemical synapse work?
- How is a synapse switched off?

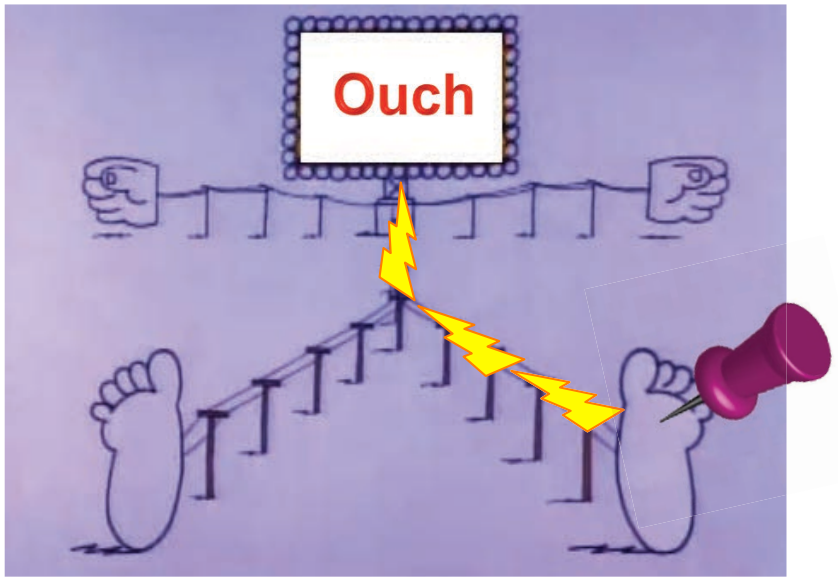
Objectives

- Know the two types of synapse and how they differ
- List the structures that make up a chemical synapse
- Explain the steps that must occur for chemical synaptic transmission to occur
- List the mechanisms that terminate the chemical signal

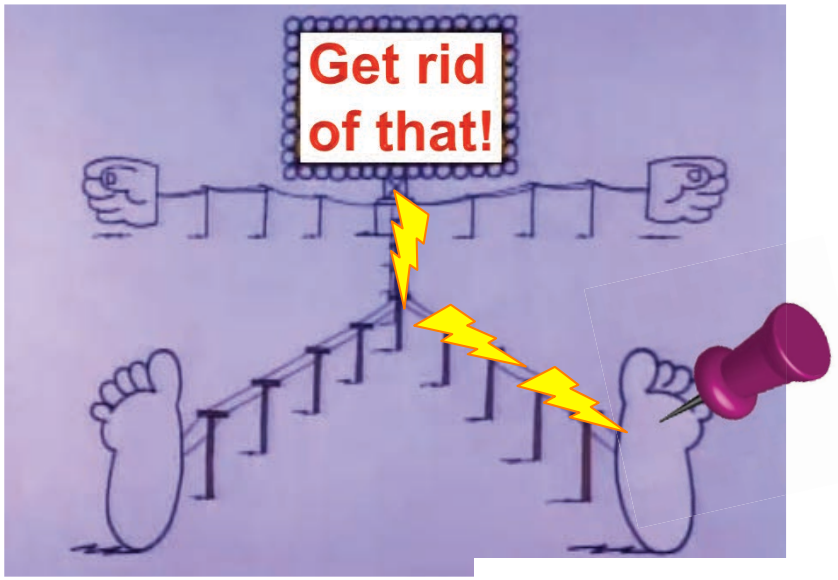
Network Communication within our nervous system

REMEMBER --- From A/Prof Jasoni's Lecture

Integrating...



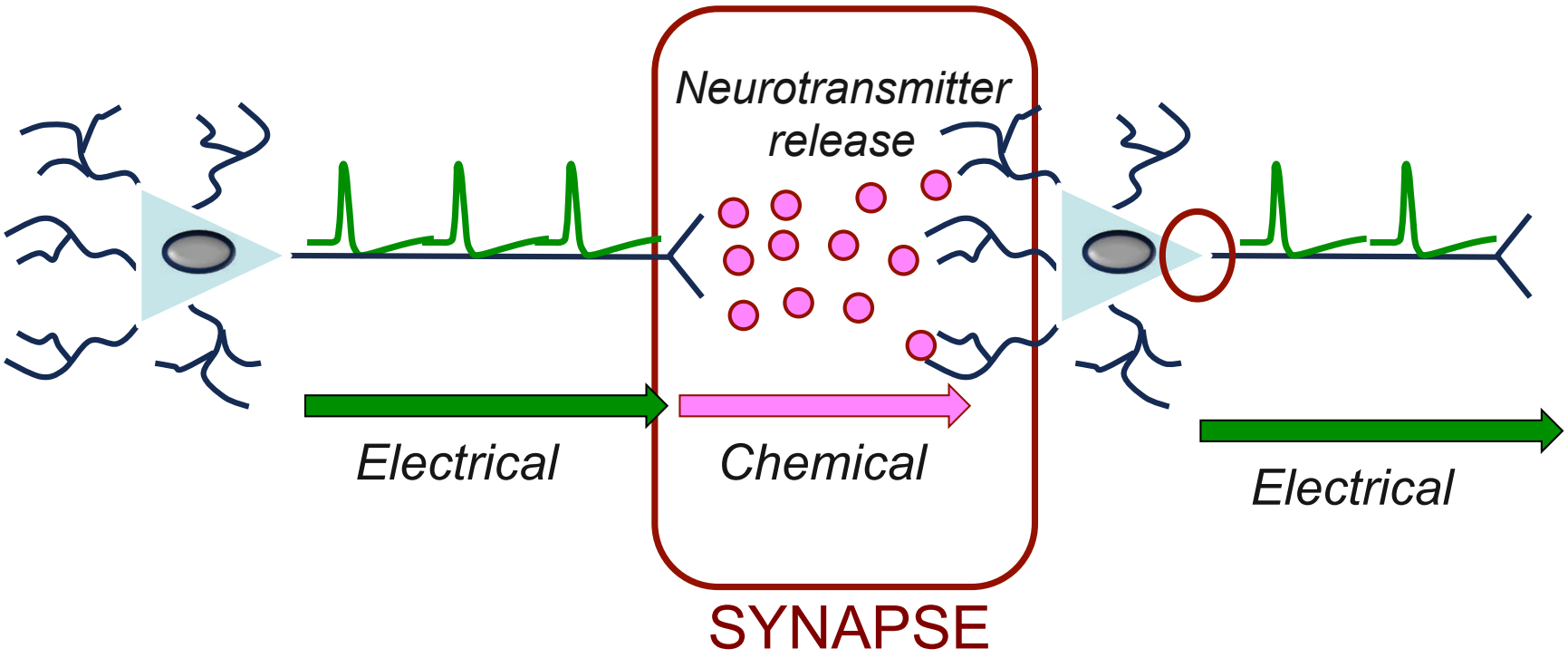
...and coordinating.



Shake foot!

- Action Potentials transmit information "up/down the wire" → between neurons
- Within the NETWORK of the nervous system
- **SYNAPSES** join the network and allow control of information flow

Recap: Cells of the nervous system: Communication between neurons occurs through a junction called a *SYNAPSE*



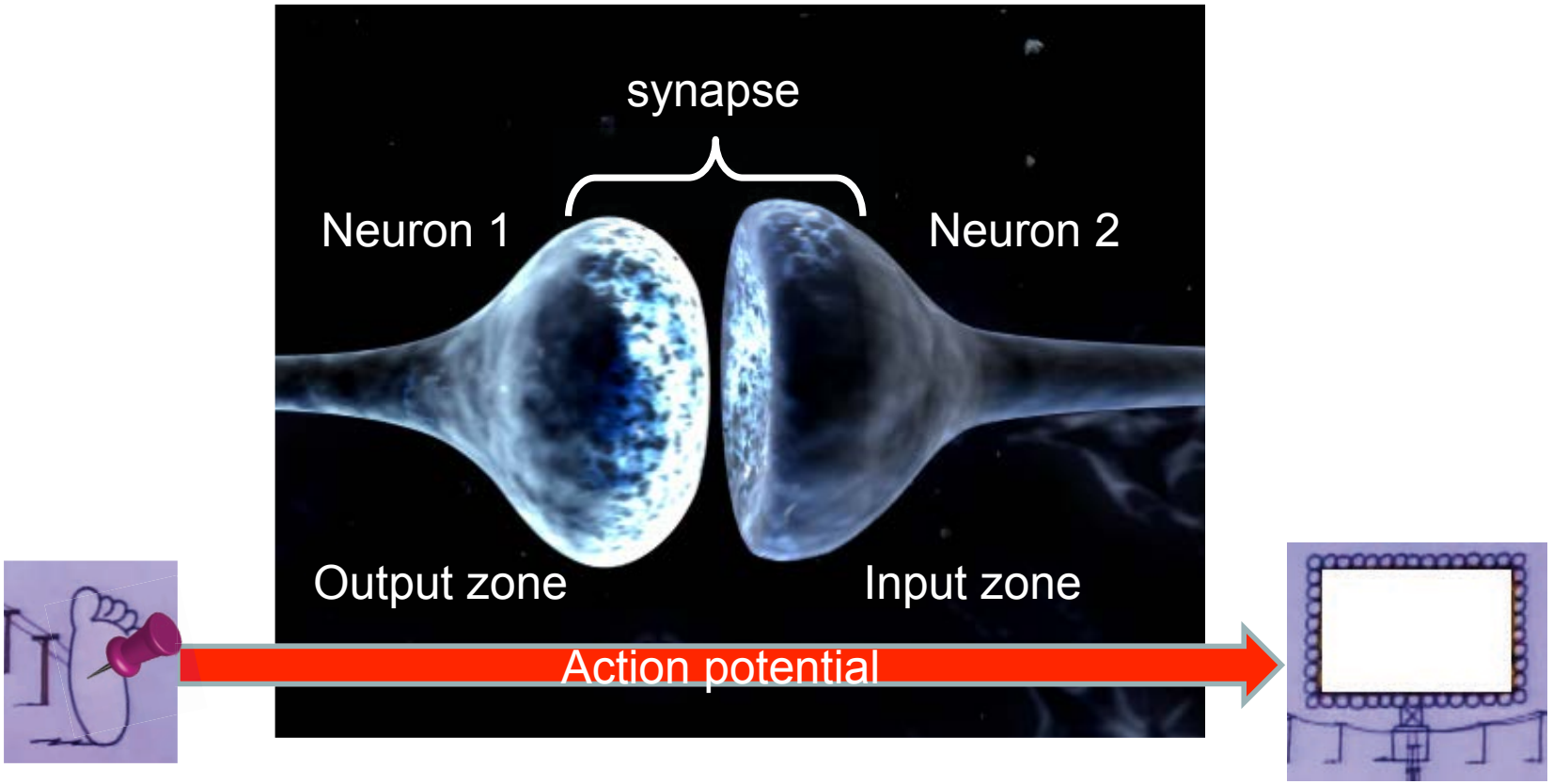
See also: Patton & Thibodeau 8th ed Fig 13-5 (7th ed Fig 12-5)

REMEMBER --- From A/Prof Jasoni's Lecture

What is a Synapse ?

"The junction between nerve cells, where a nerve impulse is transferred from one neuron to another."

http://www.achenet.org/resources/glossary.php



Two different Types of Synapses – Electric

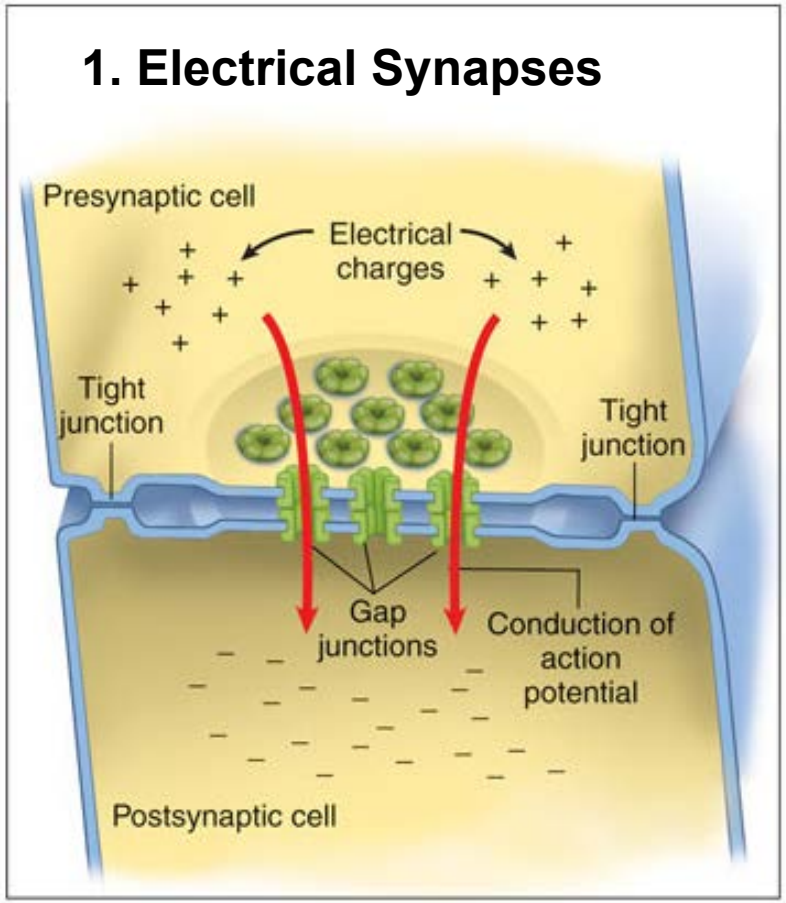


Fig. 13-23, Patton & Thibodeau, 8th Ed, p. 400

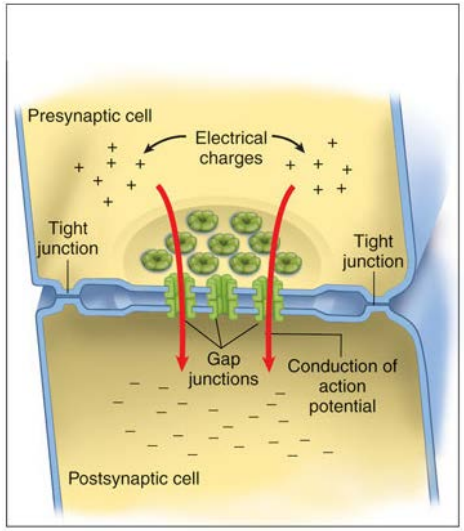
- Gap between neurons
  – linked by gap junctions

- Gap junctions: specific type of membrane channels
- 'Tunnel' connecting 2 different neurons
- Physical link (direct connection)

→ **Direct** propagation of **A**ction **P**otential

→ VERY FAST synapse

Two different Types of Synapses – Electric



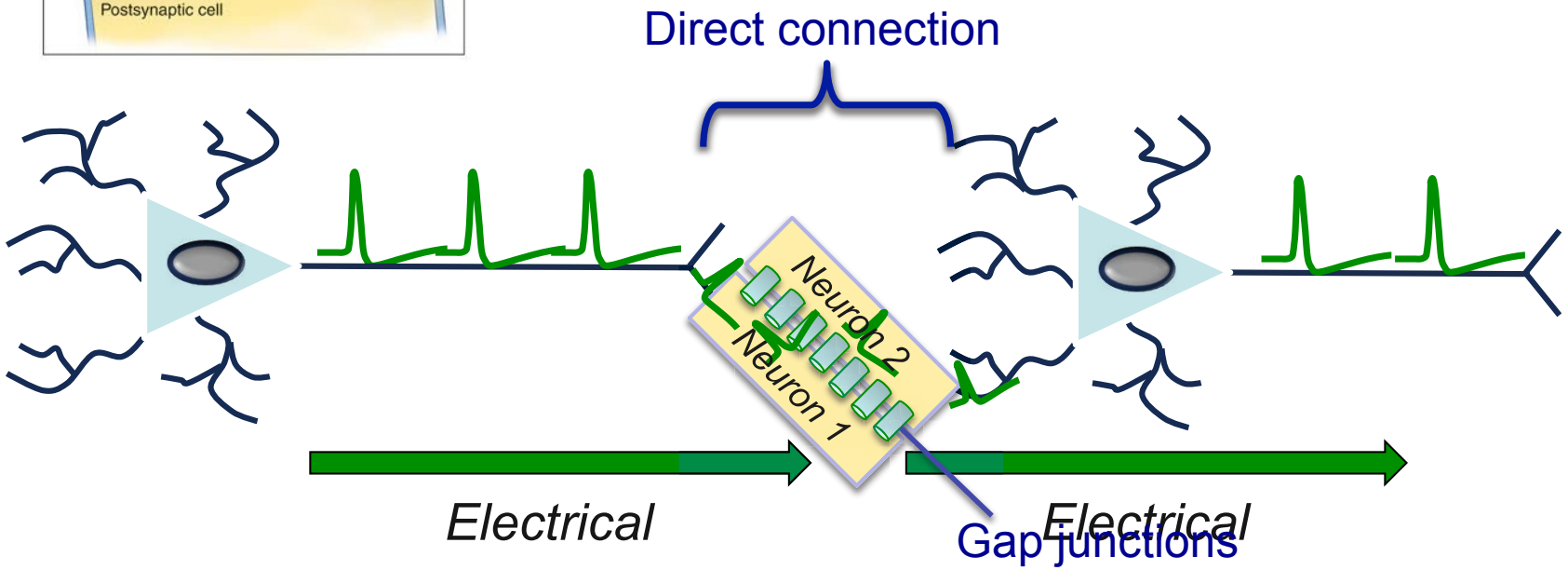


Fig. 13-23, Patton & Thibodeau, 8th Ed, p. 400

Two different Types of Synapses – Chemical

2. Chemical Synapses

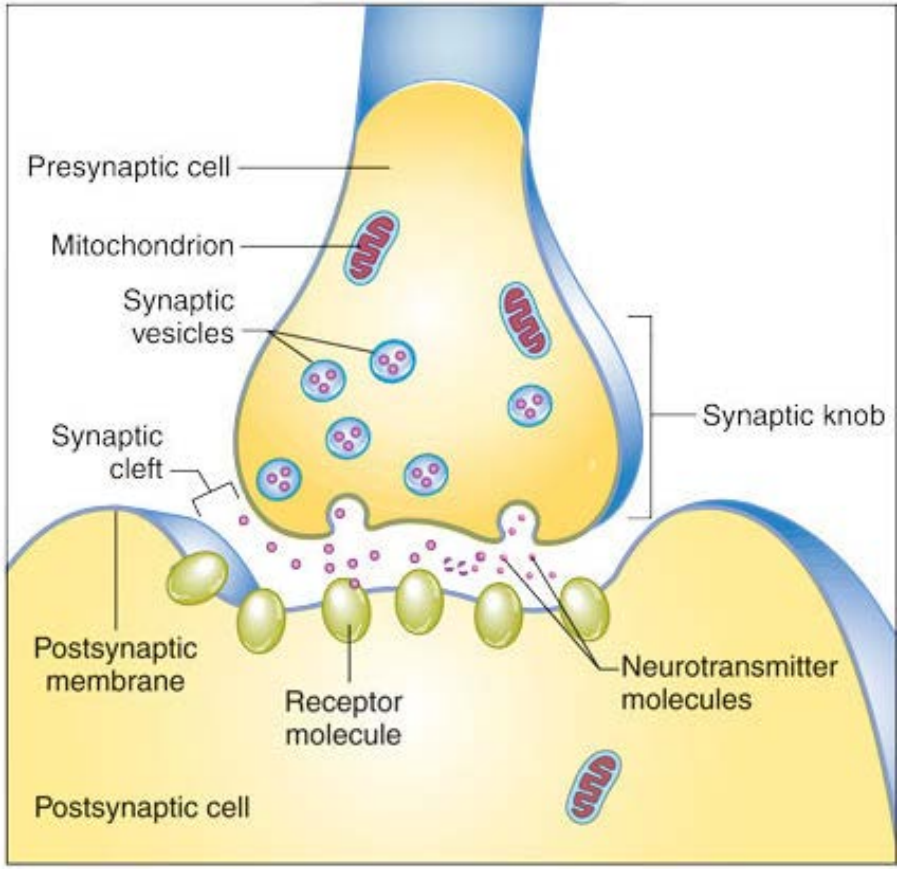


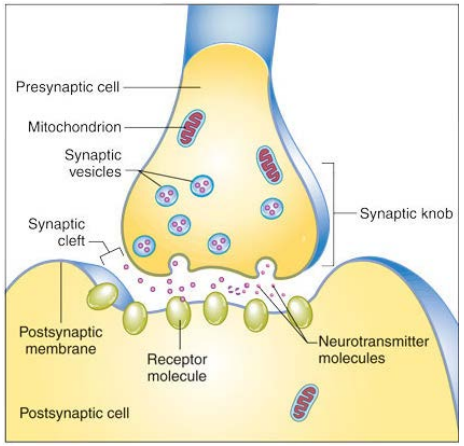
Fig. 13-23, Patton & Thibodeau, 8th Ed, p. 400

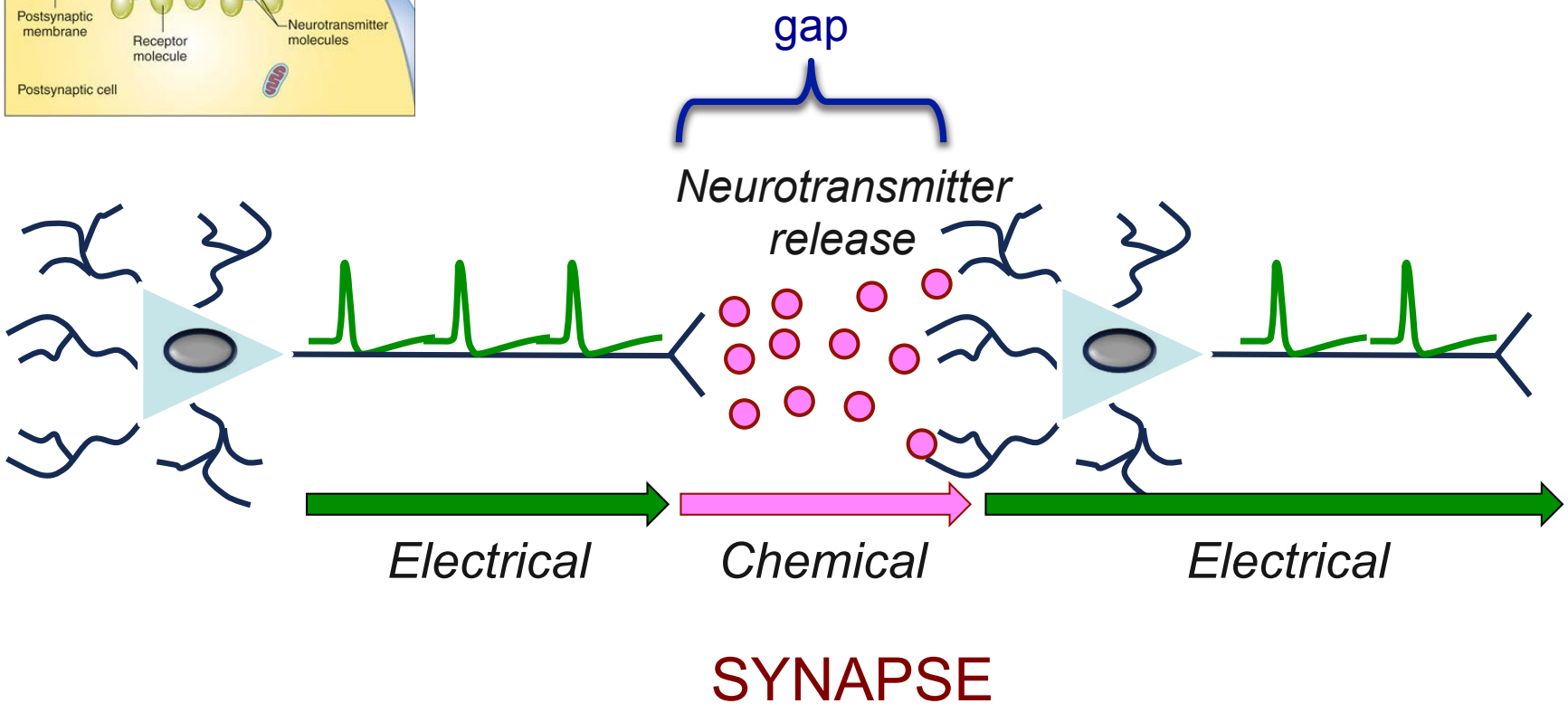
- Physical gap between neurons – linked by a chemical compound
- Neurotransmitter! 'messenger'
- Released into the synaptic cleft
- Bridges the gap

→ **Indirect** propagation of **A**ction **P**otential

→ Slower than electrical synapse

Two different Types of Synapses – Chemical





See also: Patton & Thibodeau 8th ed Fig 13-5 (7th ed Fig 12-5)

Special type of Chemical Synapse

- Nerve to Muscle Synapse – the motor unit

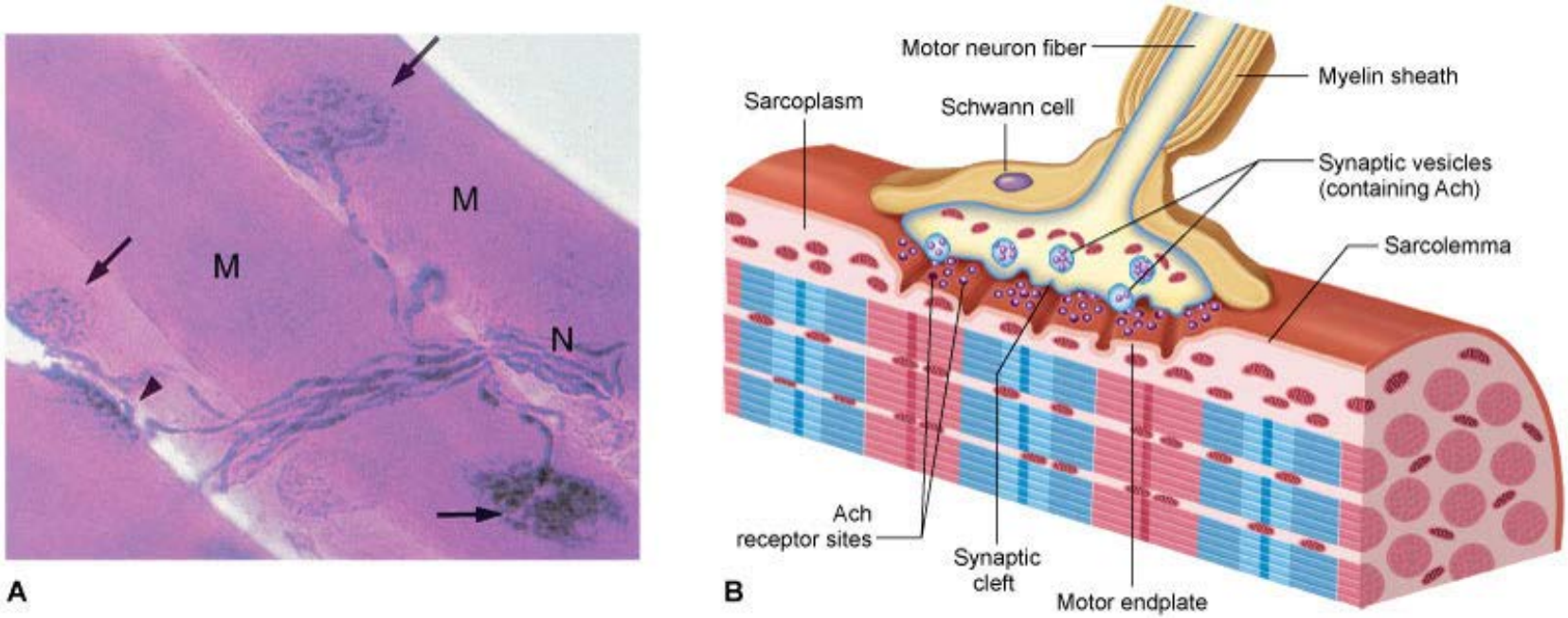


Fig. 13-23, Patton & Thibodeau, 8th Ed, p. 353

Also called the

Neuro-muscular junction

The chemical synapse – the key components

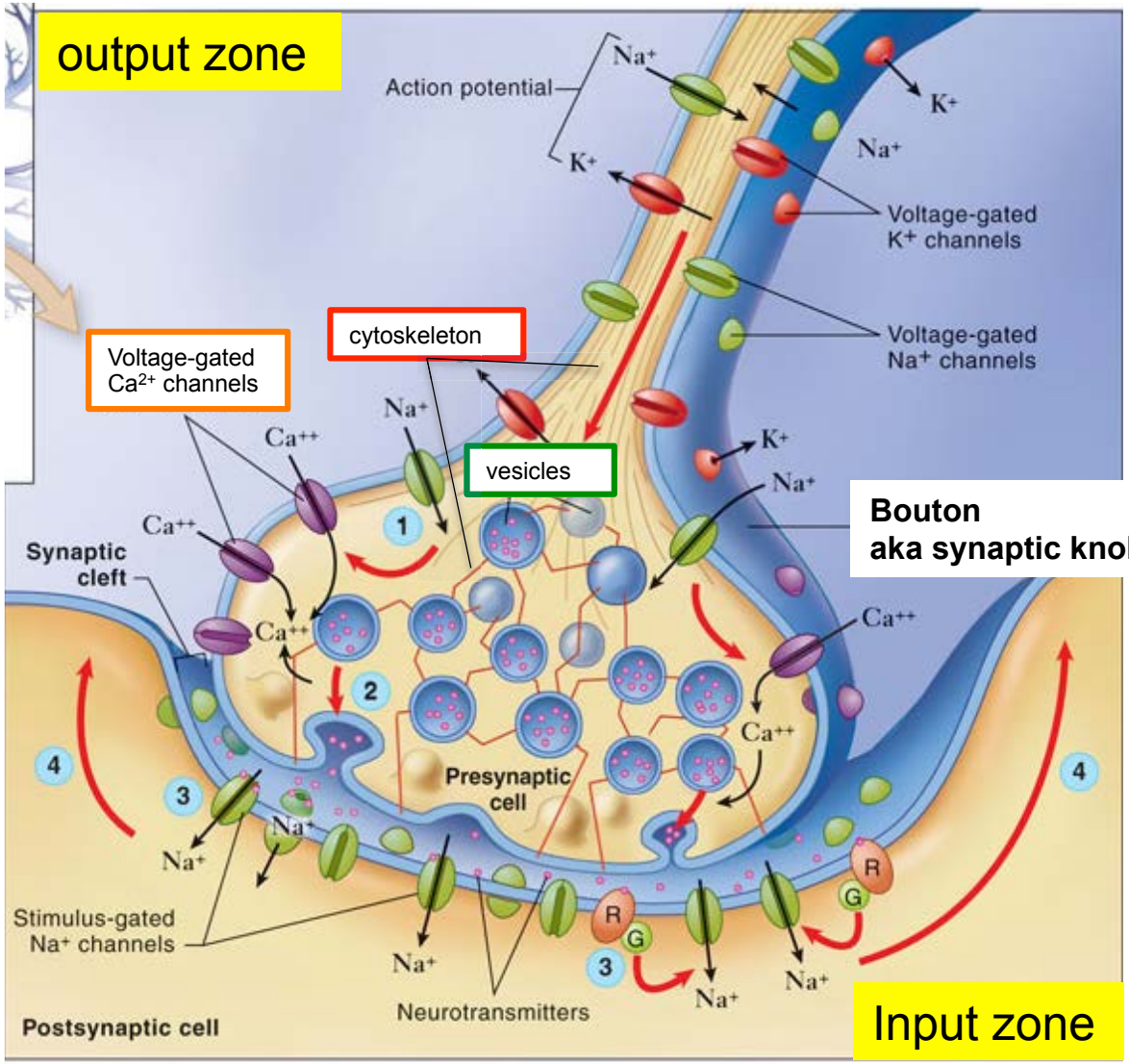
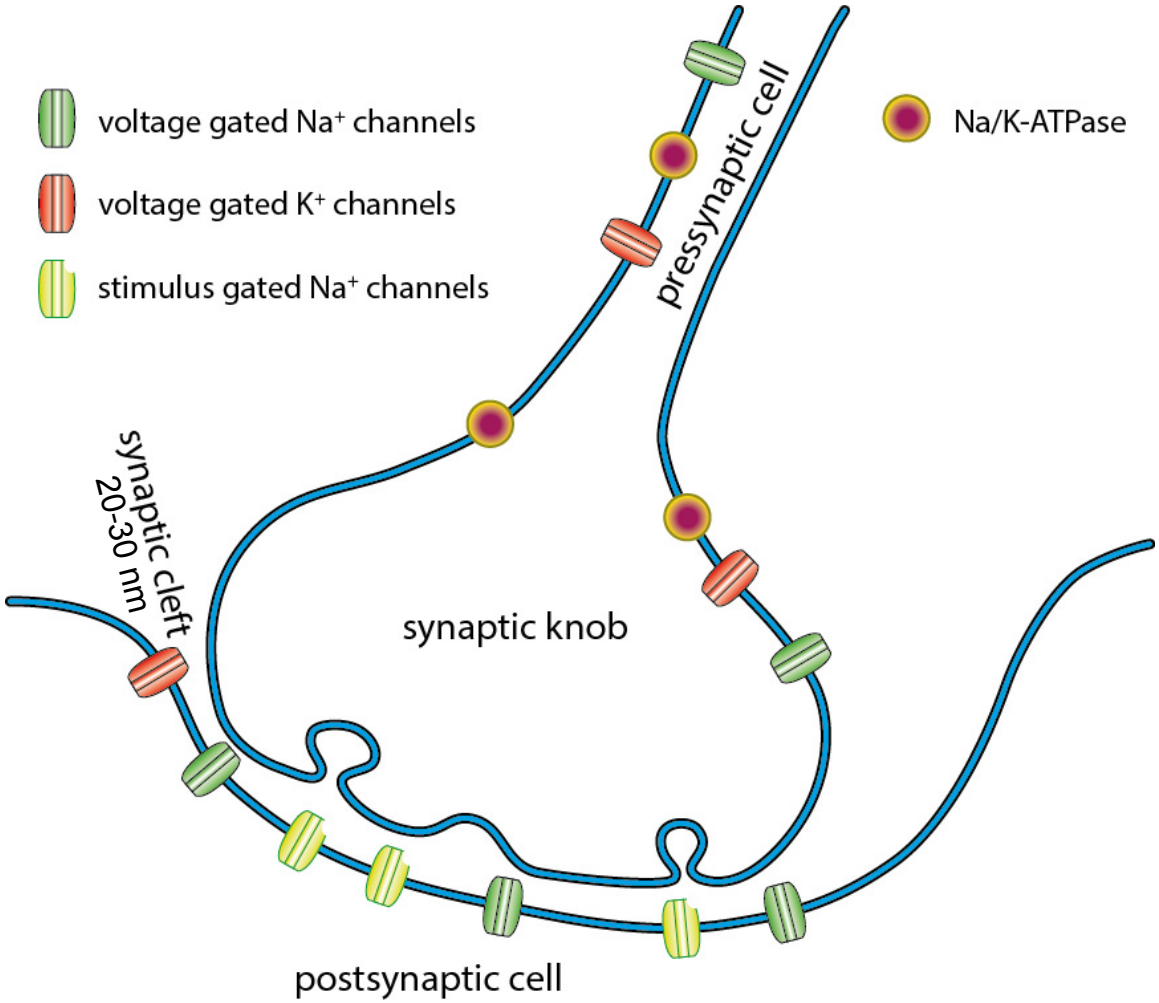


Fig. 13-25, Patton & Thibodeau, 8th Ed, p. 401

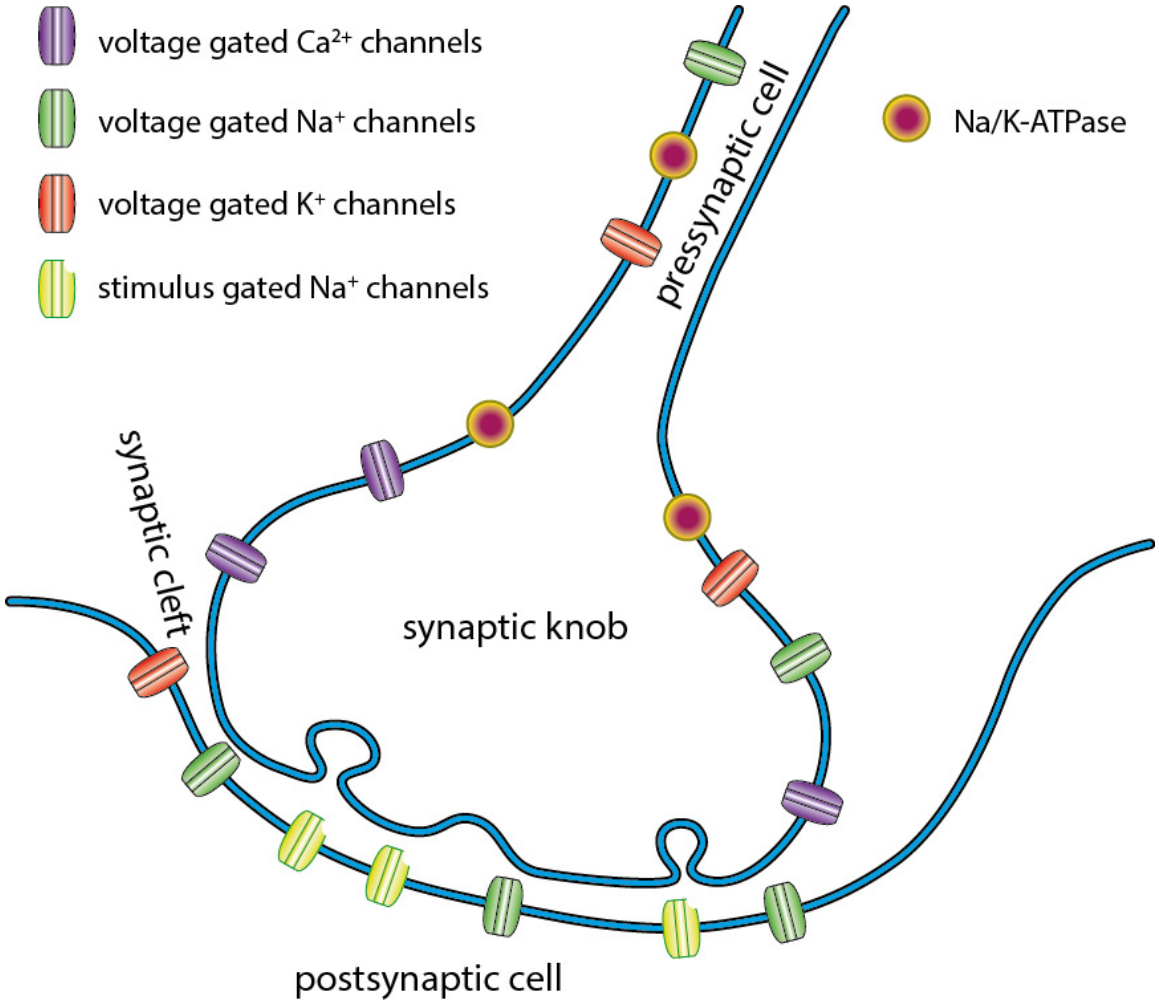
The chemical synapse – the key components I



Adapted from Fig. 13-25, Patton & Thibodeau, 8th Ed, p. 401

1. Presynaptic cell 'output zone'
2. Synaptic knob
3. Synaptic cleft 'the gap'
4. Postsynaptic cell 'input zone' **with ion channels and receptors**

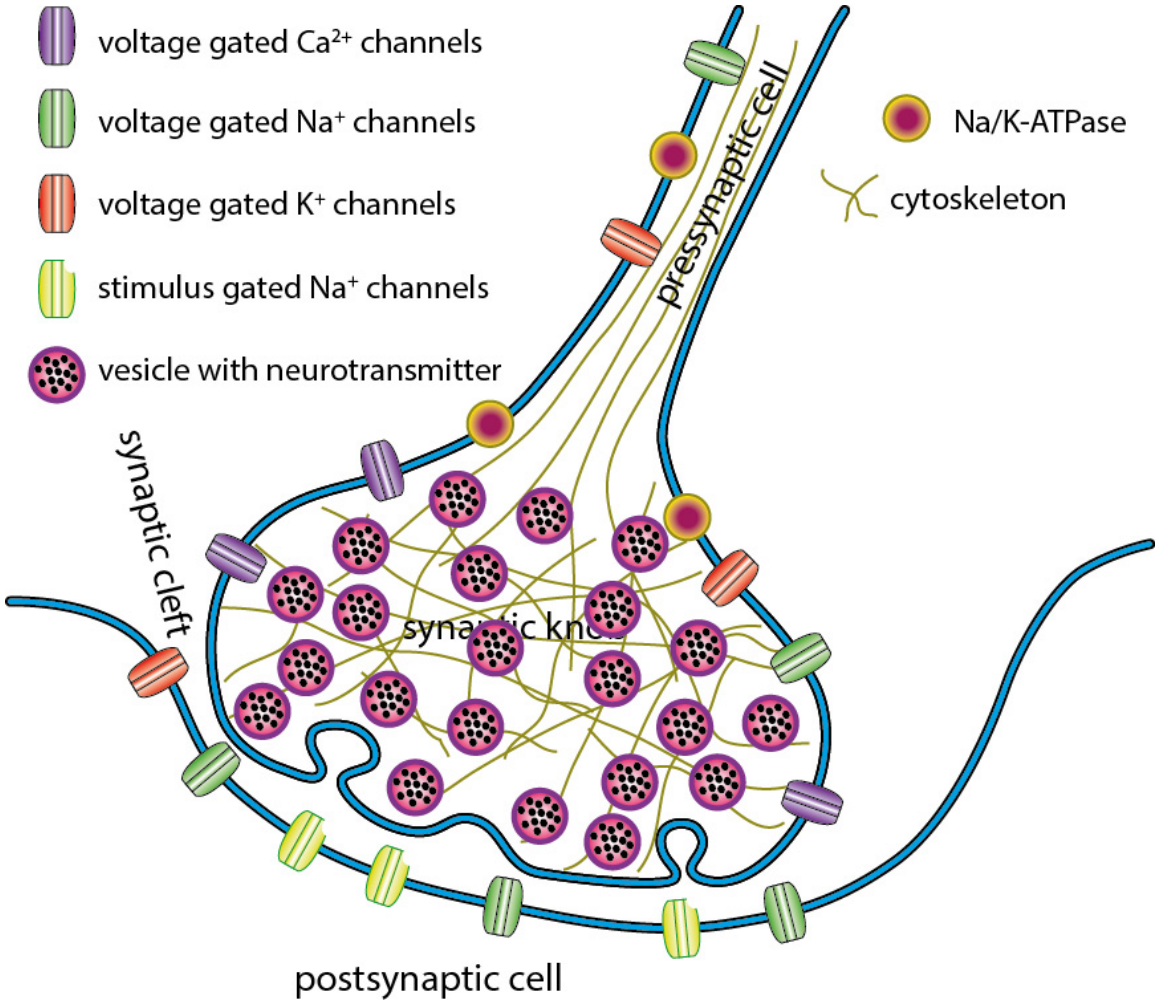
The chemical synapse – the key components II



Adapted from Fig. 13-25, Patton & Thibodeau, 8th Ed, p. 401

1. Presynaptic cell 'output zone'
2. Synaptic knob
3. Synaptic cleft 'the gap'
4. Postsynaptic cell 'input zone'
5. Voltage-gated Ca^{2+} channels

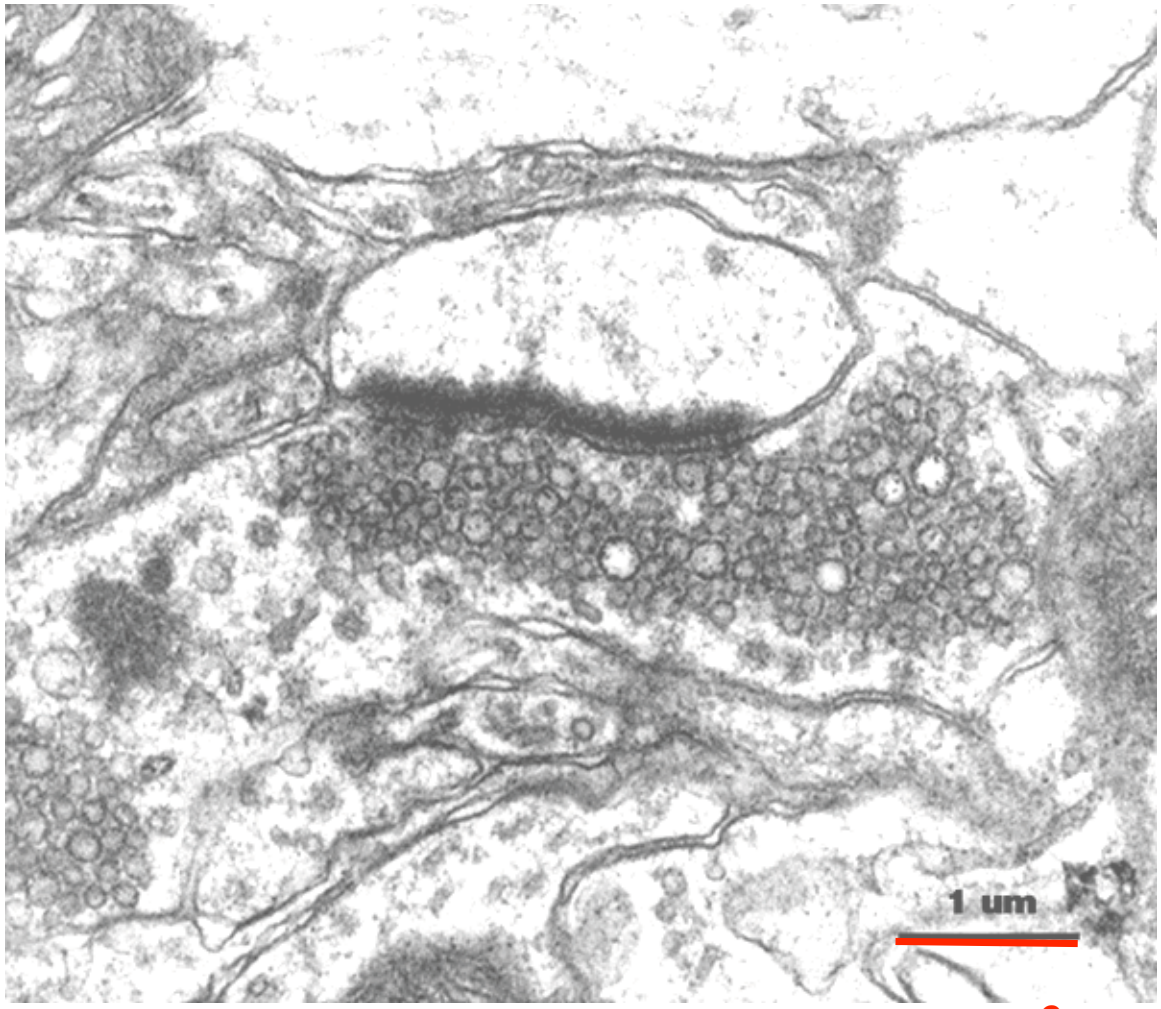
The chemical synapse – the key components III



Adapted from Fig. 13-25, Patton & Thibodeau, 8th Ed, p. 401

1. Presynaptic cell 'output zone'
2. Synaptic knob
3. Synaptic cleft 'the gap'
4. Postsynaptic cell 'input zone'
5. Voltage-gated Ca^{2+} channels
6. Vesicles
7. Cytoskeleton
8. Na/K-ATPAse
9. Mitochondria (not shown)

Electron micrograph of a synapse



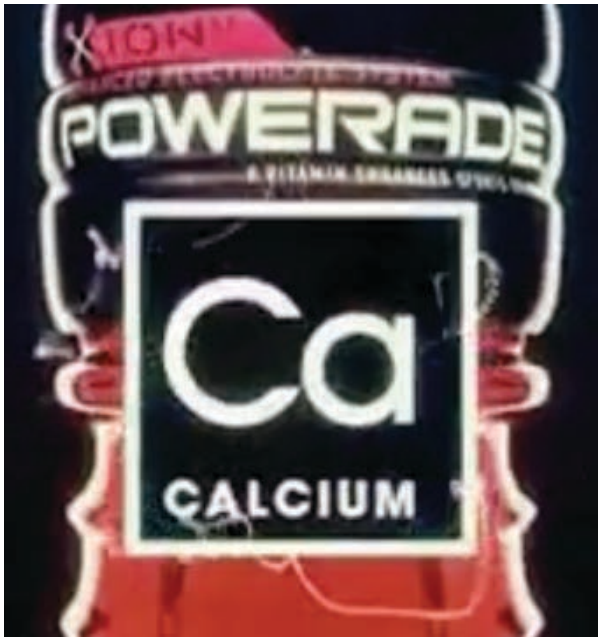
1 x 10^{-6} m

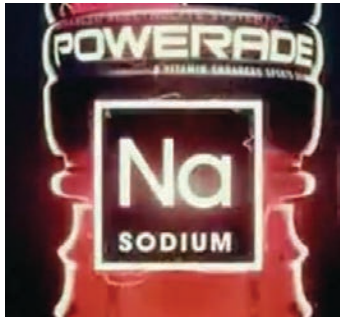
Postsynaptic – why ?

Presynaptic – why ?

From http://www.itg.uiuc.edu/exhibits/gallery/pages/image-51.htm

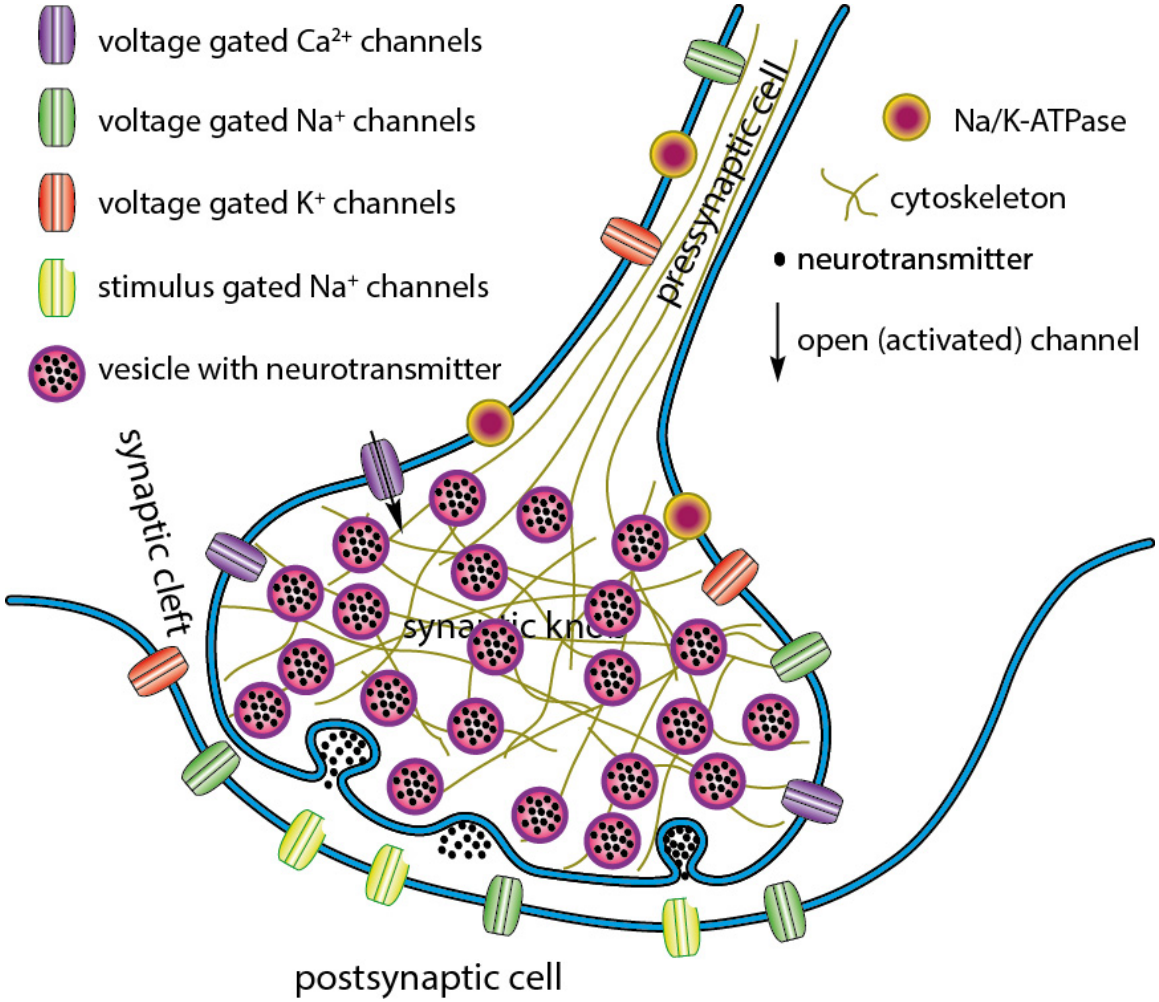
Another CATION – Calcium (Ca^{2+})





- 2 - 2.5 mM in extracellular fluid
- very low concentrations intracellularly (µM range)
- Important for bones…
  …and the **nervous system**
- → **triggers the release of vesicles**

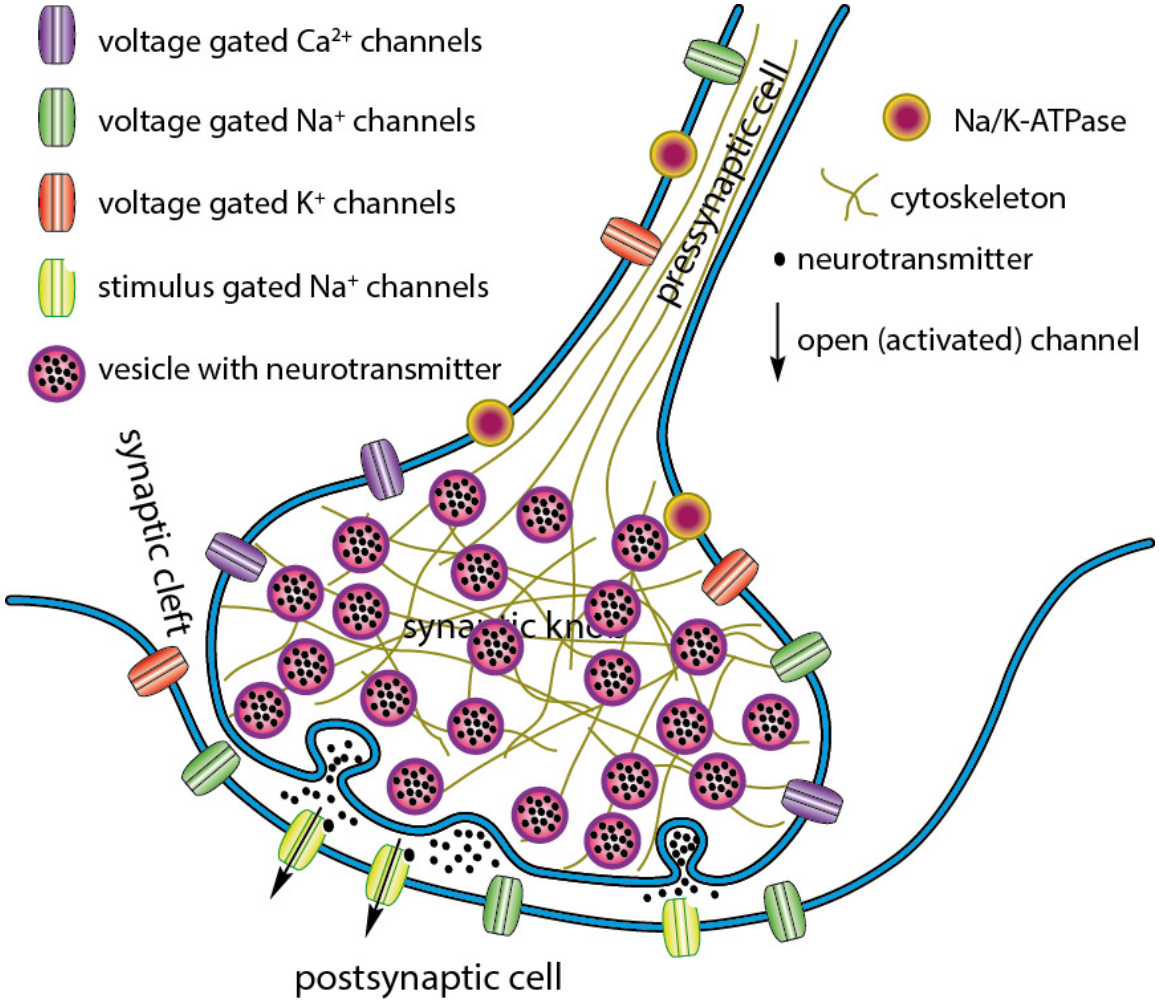
How is the signal transmitted?



Adapted from Fig. 13-25, Patton & Thibodeau, 8th Ed, p. 401

1. Action potential propagates down the axon – to the pre-synaptic knob
2. Pre-synaptic knob is depolarised – **voltage-gated Ca^{2+} channels open**
3. Ca^{2+} enters the cell
4. **Ca^{2+} ions** TRIGGER the fusion of vesicles with the presynaptic membrane.
5. This releases the neurotransmitter into the synaptic cleft

How is the signal transmitted? II



6. Neurotransmitter diffuses across the synaptic cleft to reach the postsynaptic membrane

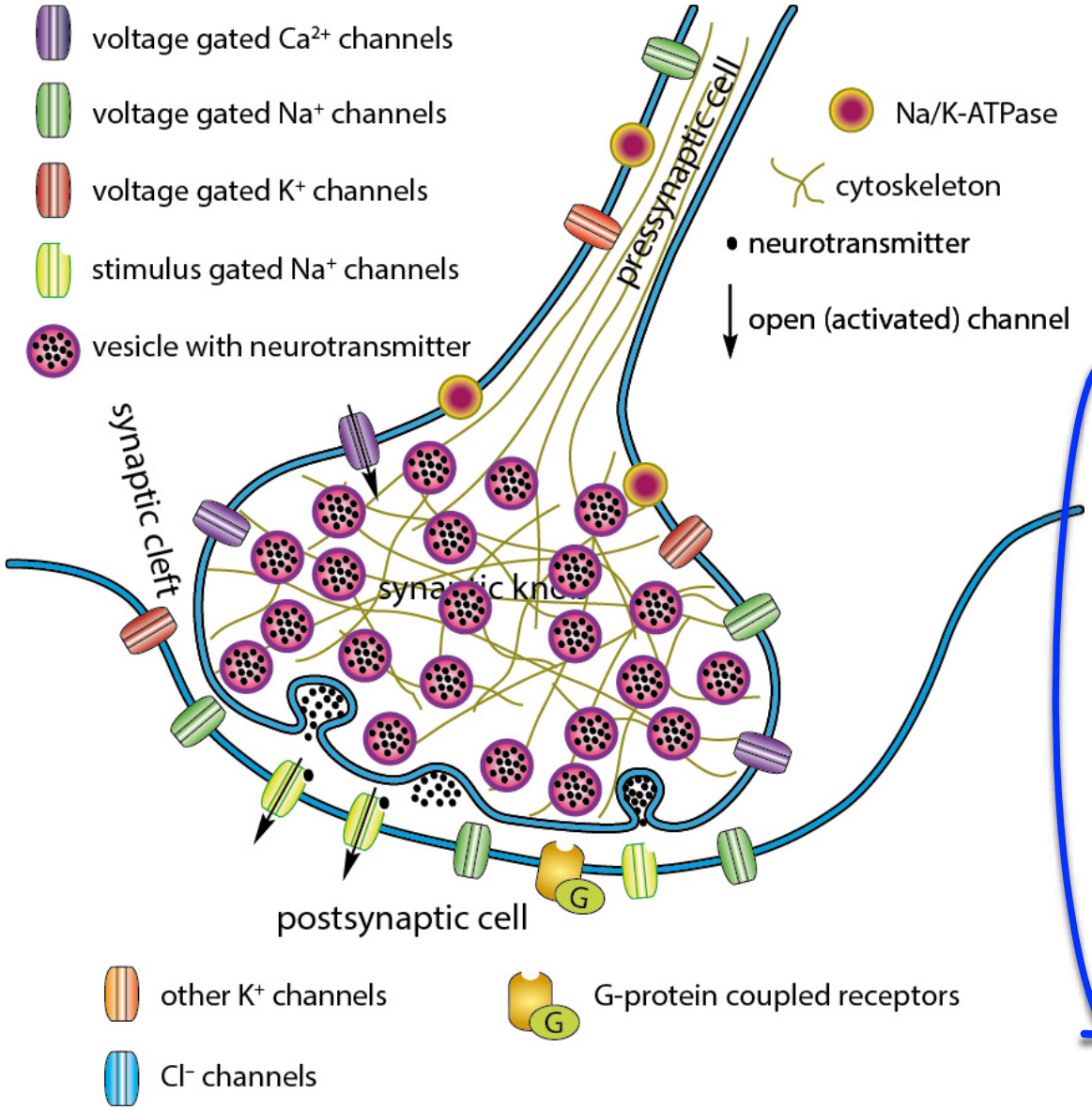
7. Neurotransmitter bind to specific receptors.
   aka 'stimulus gated channels'

8. If 'stimulus gated channels' are Na^+ channels open
   → depolarisation

9. Subsequent activation of K^+ channels
   → repolarisation

Adapted from Fig. 13-25, Patton & Thibodeau, 8th Ed, p. 401

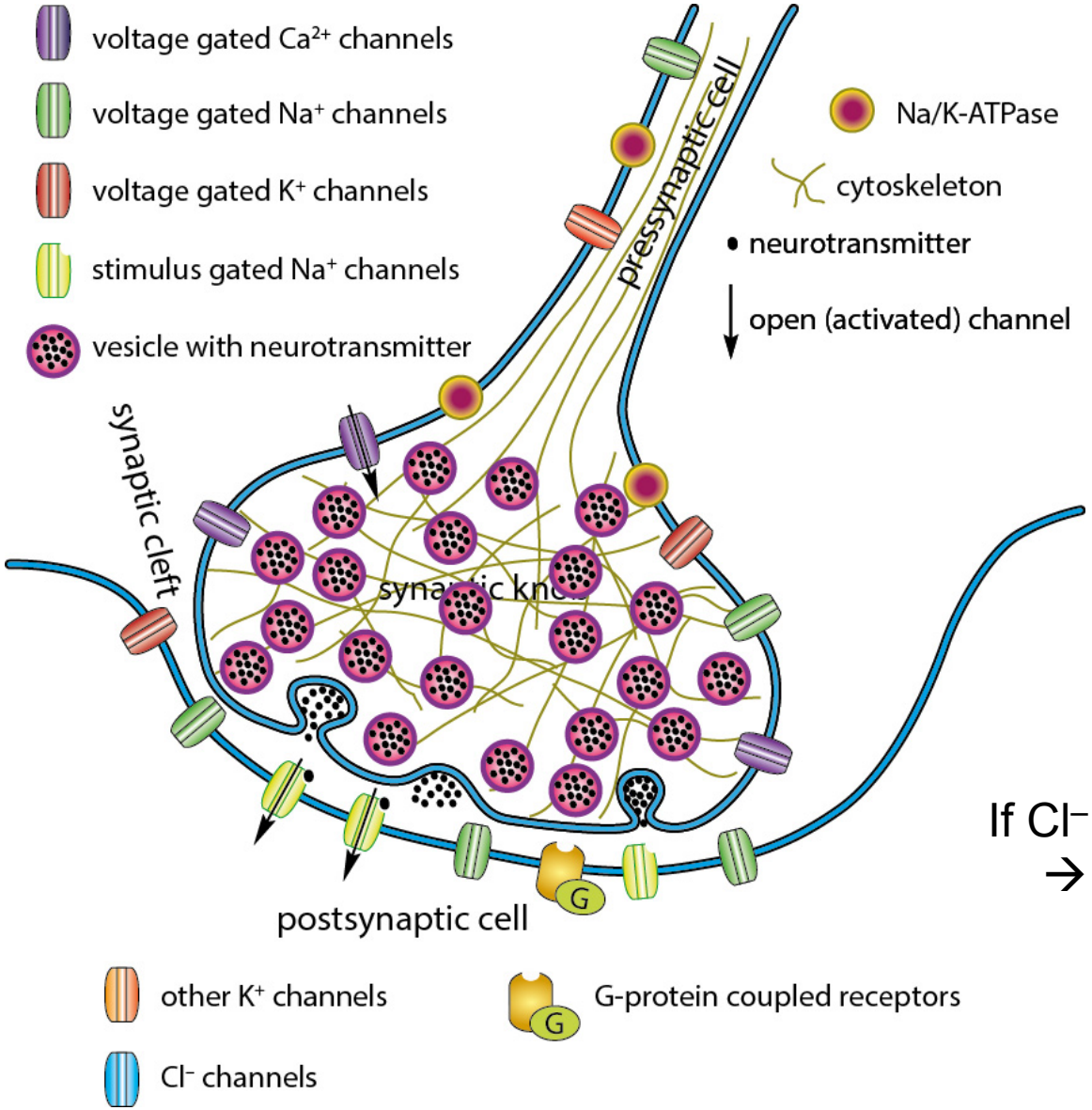
How is the signal transmitted? III



6. Neurotransmitter diffuses across the synaptic cleft to reach the postsynaptic membrane
7. Neurotransmitter bind to specific receptors.
   aka 'stimulus gated channels'
8. If 'stimulus gated channels' are Na^+ channels open
   → depolarisation
9. Subsequent activation of K^+ channels
   → repolarisation

8'. If stimulus gated channels are Cl^- or K^+ channels
   → hyperpolarisation

Excitatory and inhibitory signals



If Na^+ channels open
→ depolarisation

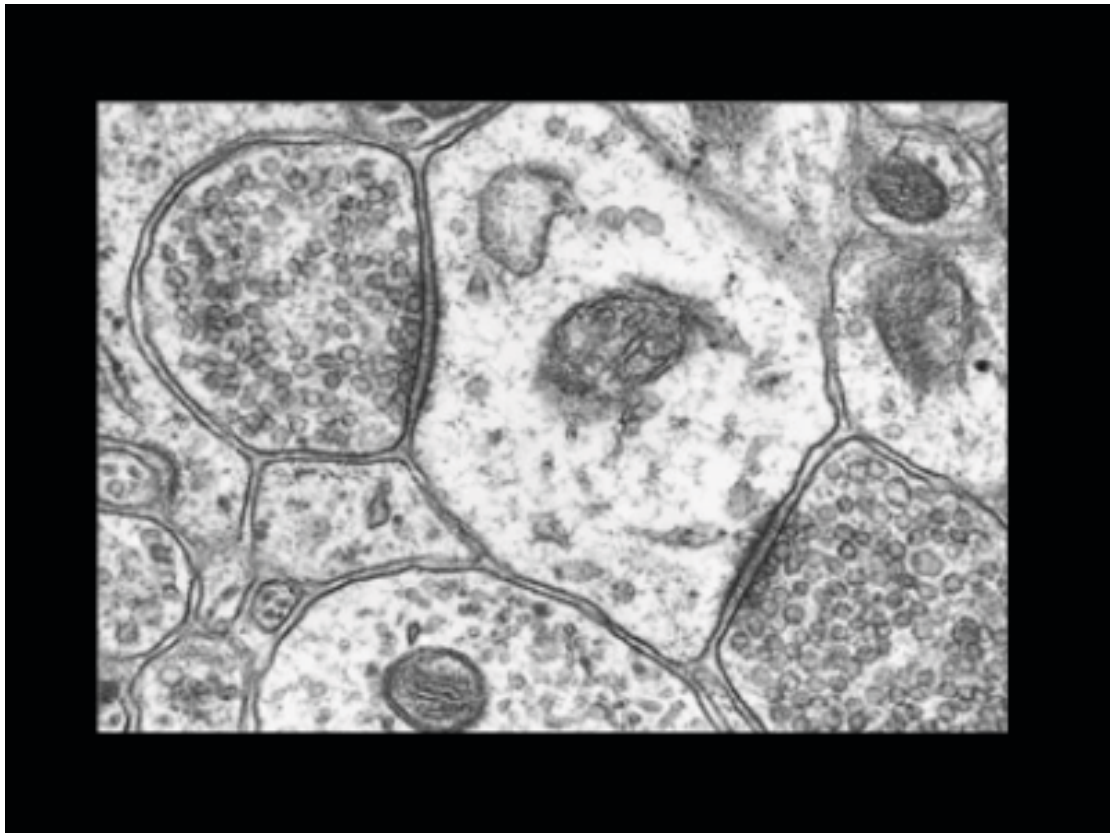
Excitatory signal

If K^+ channels open
→ hyperpolarisation

If Cl^- channel open of
→ hyperpolarisation

Inhibitory signal

Synaptic transmission – chemical synapse



Movie from: Molecular Biology of the Cell, 5th Edition, Alberts et al.

The process of synaptic transmission – form and function

1. Action potential propagates down the axon – to the pre-synaptic knob

2. Pre-synaptic knob is depolarised – voltage gated Ca^{2+} channels open

3. Ca^{2+} ions enter and TRIGGER the release of the neurotransmitter from the vesicles

4. Neurotransmitter is released INTO the synaptic cleft

5. Neurotransmitter diffuses across the cleft and binds to its SPECIFIC receptors (stimulus gated channels) on the POST SYNAPSE

6. If Na^{+} channels open – LOCAL depolarisation of post synaptic cell

7. Net depolarisation – called the

EXCITATORY POST SYNAPTIC POTENTIAL – or EPSP

7'. Net hyperpolarisation (opening of Cl^{-} or K^{+} channels) – called the

INHIBITORY POST SYNAPTIC POTENTIAL – or IPSP

REMEMBER

- Depolarisation – Excitatory
- Hyperpolarisation – Inhibitory

…. Depending on neurotransmitter and targeted receptor (Na^+, Cl^- or K^+ channel)

HOW IS A SYNAPSE SWITCHED OFF ?

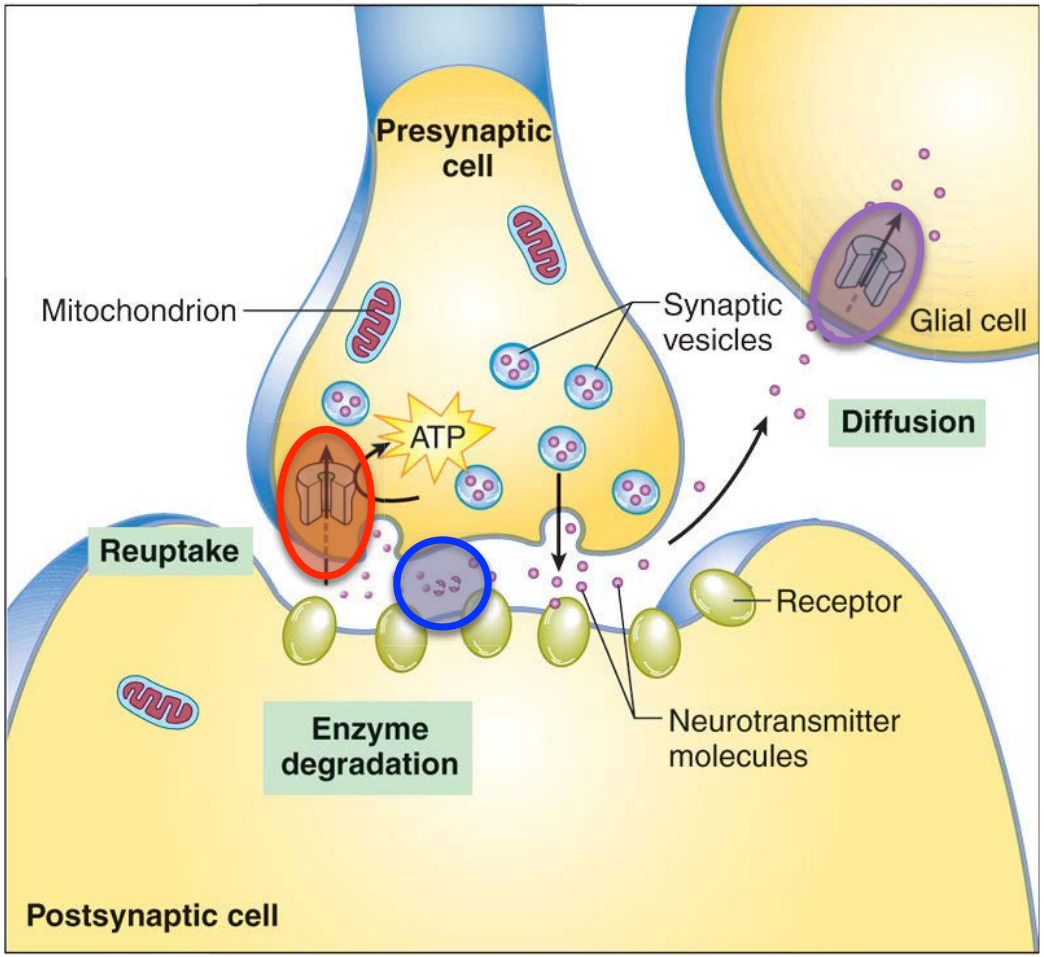


Fig. 13-26, Patton & Thibodeau, 8th Ed p. 402

→ Excess transmitter released into the cleft.

- Excess transmitter must be removed
  a. **Degradation** – by enzymes

  b. **Reuptake** into the knob

  c. Reuptake (diffusion) into **glia cells**

  (GLM3 – revisit)

- Removal requires ATP – energy
- Mitochondria in synaptic knob …

Glia – the supporting cells – and revisit p. 384 T&P 8th Ed.

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