Synapses

Introduction

communication is the central task of the nervous system

there are sites (and plenty of them) where nerve cells communicate
with other nerve cells .... and with sensory cells, muscle cells and gland cells

points of communication - synapses

at synapse, a change in the membrane potential
of one cell may produce a change in the membrane potential of another cell

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Electrical Synapses  (Electrotonic Synapses)

structure:  opposed plasma membranes of cells at an E synapses
are in near contact

proteins acting like membrane-spanning pores align in adjacent cells

passage through gap junction pores

direction of electric current
if one neuron depolarizes, the other neuron ...  
if one neuron hyperpolarizes, the other neuron ... 

found in human CNS  
excitatory neurons in the retina, inferior olive, thalamus, hippocampus, olfactory bulbs  
inhibitory neurons in cerebral cortex

functional characteristics  
cell-to-cell transmission

looking at a larger picture  
rapid synaptic communication

synchronization of activity
electrical synapses-like structures are present in some glial cells

a role in helping astrocytes regulate extracellular [K⁺] and modify interneuronal signalling

a role in intracellular transport within Schwann cells

malfunction of connexin proteins in Schwann cells

group of disorders

inherited peripheral neuropathy

Chemical Synapses

“chemical” due to the involvement of chemical molecules to carry a signal from one cell to the next

relevance
Chemical Synapses

two major classes

channel-linked chemical synapses

G protein-linked chemical synapses

1) **Axon Terminal** of Presynaptic Neuron
2) **Ca**^{++} **Channels** in Plasma Membrane of Axon Terminal
3) **Synaptic Cleft**
4) **Postsynaptic** Neuron
5) **Neurotransmitter** Vesicles in Axon Terminal
6) **Receptors** for Neurotransmitter and **Ion Channels** (together in same structure)

variations in chemical synapses

“boutons en passage”

one way to modulate synaptic effect
Chemical Synapses

Basic function:

- AP in presynaptic neuron
- depolarization of axon terminal
- entrance of calcium ions into axon terminal
- exocytosis of neurotransmitter
- diffusion of neurotransmitter across synaptic cleft
- binding of neurotransmitter to receptor molecules of postsynaptic cell
- initiates response in postsynaptic cell
  - hyperpolarization = inhibitory
  - depolarization = excitatory
- removal of released neurotransmitter

Some more details for channel-linked chemical synapses:

First Step - Presynaptic neuron fires action potentials which travel toward axon terminal:

- Action potentials reach axon terminal.
- Action potentials depolarize axon terminal.
- Depolarization of terminal opens Ca++ channels in axon terminal; Ca++ diffuses into axon terminal.
- After entrance of Ca++, neurotransmitter vesicles dock with plasma membrane.
- Neurotransmitter vesicles fuse with plasma membrane; exocytosis of neurotransmitter.
- Neurotransmitter molecules diffuse across synaptic cleft.
- Neurotransmitter molecules bind with receptors on postsynaptic cell.
- Receptors binding neurotransmitters become activated.
- Activated receptors lead to opening (or closing) of ion channels.

Last Step - Membrane potential of postsynaptic neuron depolarizes (or hyperpolarizes).
Chemical Synapses

basic function

how they function in general:

> AP in presynaptic neuron
> depolarization of axon terminal
> entrance of calcium ions into axon terminal
> exocytosis of neurotransmitter
> diffusion of neurotransmitter across synaptic cleft
> binding of neurotransmitter to receptor molecules of postsynaptic cell
> initiates response in postsynaptic cell
  hyperpolarization = inhibitory
  depolarization = excitatory
> removal of released neurotransmitter

some more details for channel-linked chemical synapses

**First Step** - Presynaptic neuron fires action potentials which travel toward axon terminal

- action potentials reach axon terminal
  - AP

- action potentials depolarize axon terminal
  - depolarization of terminal opens Ca\(^{++}\) channels in axon terminal; Ca\(^{++}\) diffuses into axon terminal
  - Ca\(^{++}\)

- after entrance of Ca\(^{++}\):
  - neurotransmitter vesicles dock with plasma membrane

- neurotransmitter vesicles fuse with plasma membrane; exocytosis of neurotransmitter

- neurotransmitter molecules diffuse across synaptic cleft

- neurotransmitter molecules bind with receptors on postsynaptic cell

- receptors binding neurotransmitters become activated

- activated receptors lead to opening (or closing) of ion channels

**Last Step** - Membrane potential of postsynaptic neuron depolarizes (or hyperpolarizes)
Chemical Synapses

fusion of vesicles with plasma membrane of axon terminal

neurotransmitter in vesicle

docking proteins

axon terminal

receptors

postsynaptic membrane

neurotransmitter vesicles

lighter and smaller diameter

dense cores and larger diameter

axon terminals

cleft

postsynaptic membrane

postsynaptic membrane
Chemical Synapses

Neurotransmitters

Why are chemical messengers needed at chemical synapses?

Classes of neurotransmitters

Acetylcholine (ACh)

In PNS
- Neuromuscular junction receptors:
- Preganglionic autonomic receptors:
- Postganglionic parasympathetic receptors:

In CNS
- Brain stem and basal forebrain receptors

Cathecholamines (monoamines, biogenic amines)

Tryptophan
- Tryptophan hydroxylase
- 5-Hydroxytryptophan decarboxylase
- Serotonin

Tyrosine
- Tyrosine hydroxylase
- Dihydroxyphenylalanine (DOPA)
- Dopa decarboxylase
- Dopamine
- Dopamine beta-hydroxylase
- Norepinephrine
- PNMT
- Epinephrine

Acetylcholine (ACh)

Nucleus

Postganglionic cell

Axon

AP

Postsynaptic cell

Figures 8-20 and 8-21
Chemical Synapses

Neurotransmitters

**Amino Acids**
- Glutamate and aspartate
- Glutamate receptors
  - Most are channel-linked
  - Special type: NMDA receptor

(“NMDA” = N-methyl-D-aspartate)

**Glutamate Receptors**
- Conventional glutamate receptor
- NMDA glutamate receptor

**Small Depolarization of Neuron’s Membrane Potential**

**Larger Depolarization of Neuron’s Membrane Potential**
- Lasting change in synapse
- Long-term potentiation
- Possible excitotoxicity

**Amino Acids**
- Glutamate
- Decarboxylation of glutamic acid
  - GABA (gamma amino butyric acid)
  - Glycine

**Peptides**
- Substance P
- Endogenous opioids
- Nitric oxide
Chemical Synapses

fate of neurotransmitters

interaction of NT and receptors

inactivation
reuptake
uptake
diffusion

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figure 8-7
Chemical Synapses
changes in membrane potential of postsynaptic cell

**excitatory postsynaptic potential**
regarded as excitatory ...

**inhibitory postsynaptic potential**
regarded as inhibitory ...

commonly, a combination of excitatory and inhibitory chemical synapses
Chemical Synapses

summation of synaptic potentials recorded at initial segment

temporal and spatial summation - synaptic potentials occurring at same time at different sites

note:

from figure 7-9

postsynaptic cells

why focus on membrane potential of the axon’s initial segment?

a much simplified example of neuronal integration