

Information Transmission across Synapse

The basic process in a presynaptic neuron

Action potential from the axon



Depolarization of the presynaptic terminal



Opening of voltage-gated Ca^{2+} channels



Ca^{2+} entry into presynaptic terminal



Fusion of synaptic vesicle with presynaptic plasma membrane

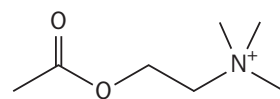


Neurotransmitter release

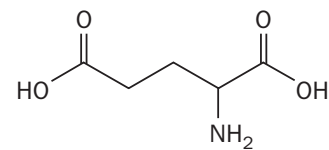
Neurotransmitters

Table 3–2: Commonly used neurotransmitters

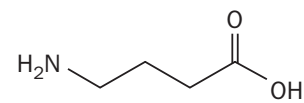
Neurotransmitter	Major uses in the vertebrate nervous system ¹
Acetylcholine	motor neurons that excite muscle; ANS ² neurons; CNS excitatory and modulatory neurons
Glutamate	most CNS excitatory neurons; most sensory neurons
GABA	most CNS inhibitory neurons
Glycine	some CNS inhibitory neurons (mostly in the brainstem and spinal cord)
Serotonin (5-HT)	CNS modulatory neurons
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Norepinephrine	CNS modulatory neurons; ANS ² neurons
Histamine	CNS modulatory neurons
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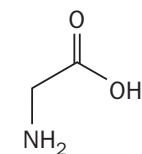
acetylcholine (ACh)



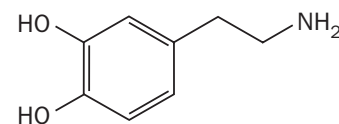
glutamate



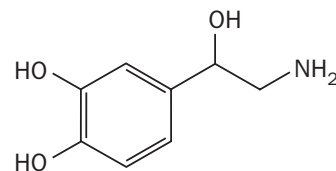
GABA



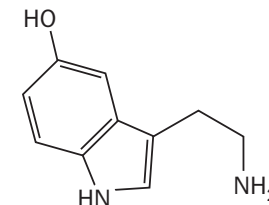
glycine



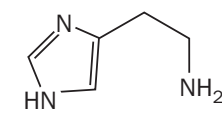
dopamine



norepinephrine



serotonin



histamine

Neurotransmitters are released in discrete packets

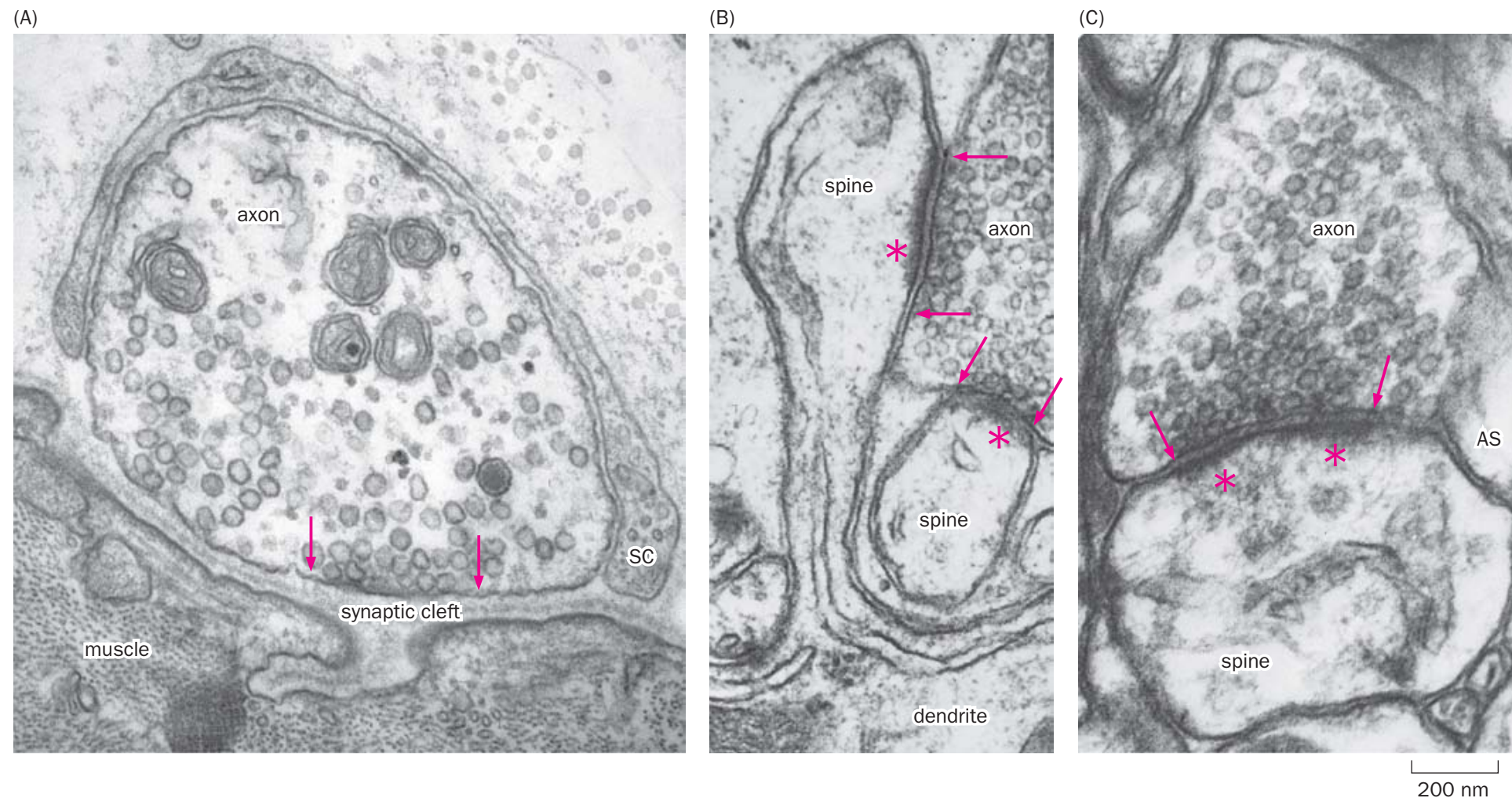


Figure 3–3 Structures of synapses revealed by electron microscopy.

All images share the scale bar. Red asterisks indicate postsynaptic density. Pairs of arrows define the extent of the active zones in the presynaptic terminals. Note the abundance of ~40 nm diameter synaptic vesicles in each presynaptic terminal; some of these vesicles are 'docked' at the active zone ready for release. **(A)** A frog neuromuscular junction. The synaptic cleft is considerably wider than at the CNS synapses shown in the other two panels. SC indicates

a Schwann cell process that wraps around the motor axon terminal.

A typical motor axon forms hundreds of such presynaptic terminals onto a muscle fiber. **(B)** Two synapses formed between a single axon and two Purkinje cell dendritic spines in rat cerebellar cortex.

(C) A synapse from human cerebral cortex. AS indicates an astrocyte process that wraps around many CNS synapses. (A, courtesy of Jack McMahan; B & C, courtesy of Josef Spacek and Kristen M. Harris, Synapse Web.)

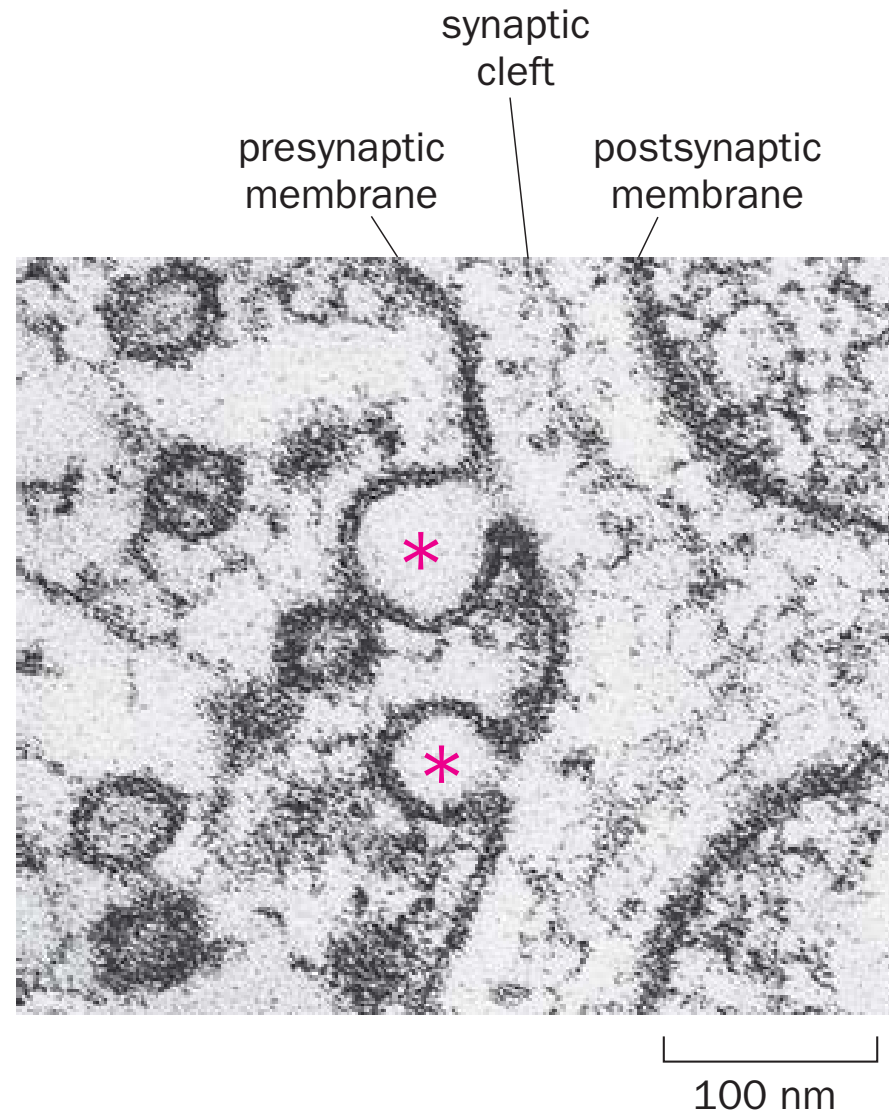
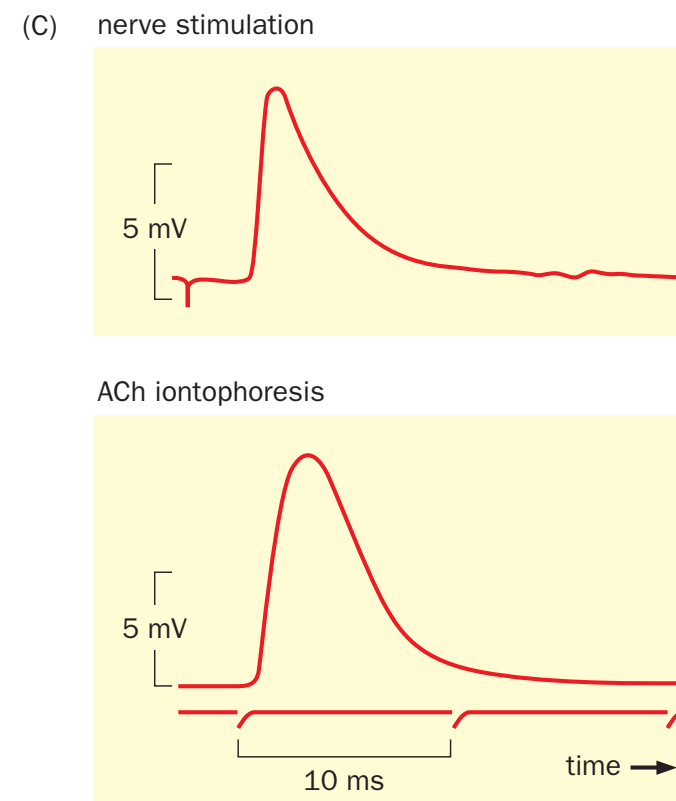
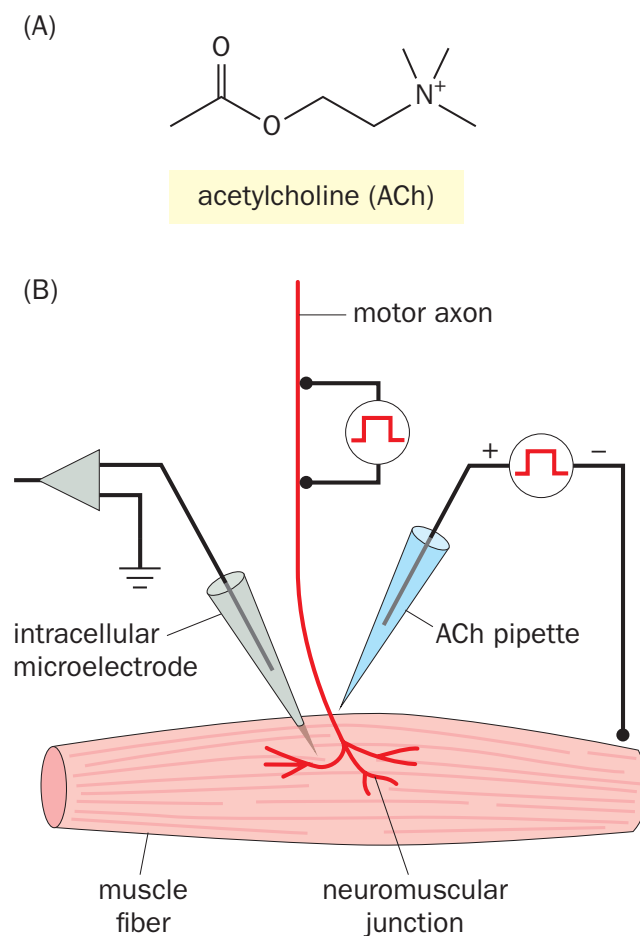
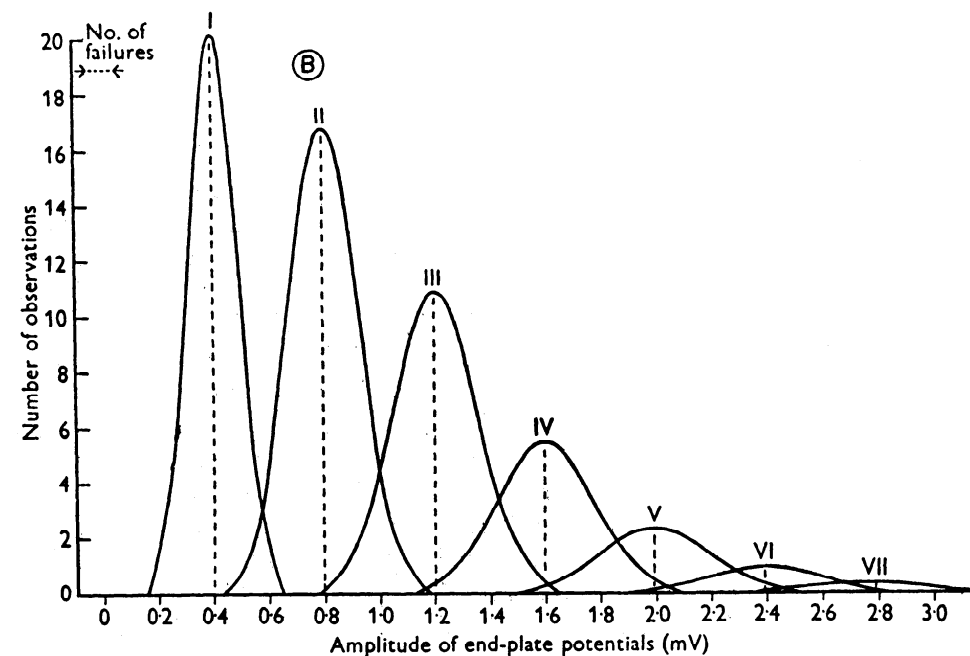
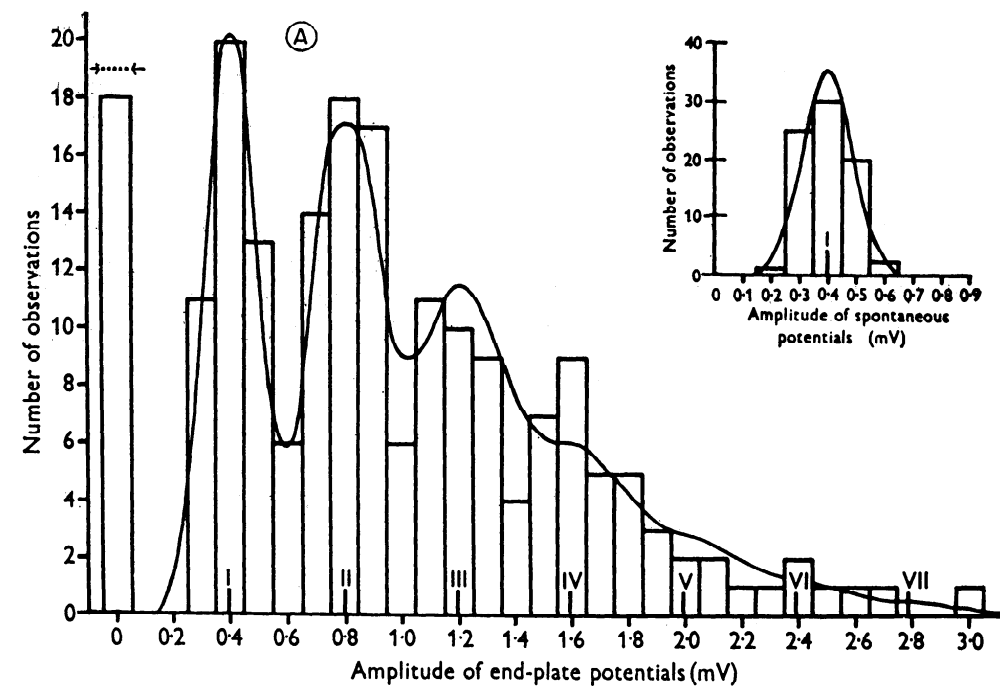
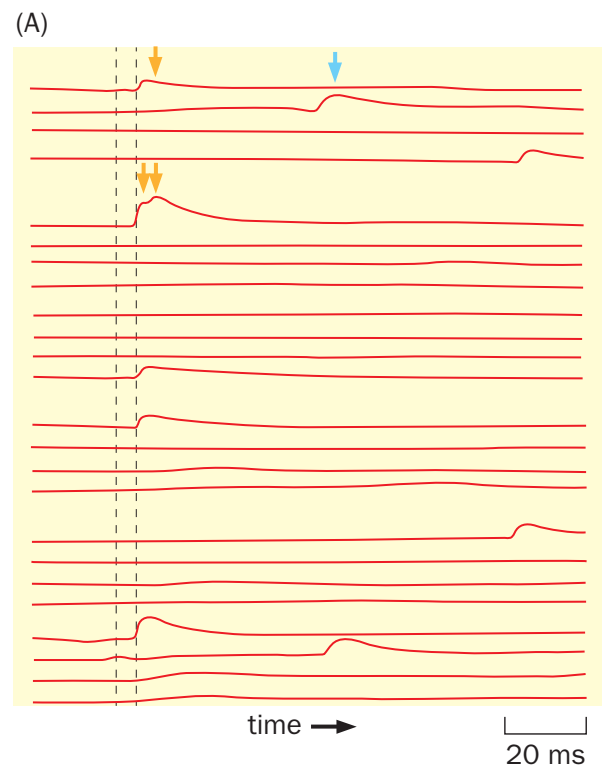


Figure 3–4 Synaptic vesicle fusion caught in action. This electron micrograph was taken from a frog neuromuscular junction preserved 3–5 ms after nerve stimulation, revealing the fusion of two synaptic vesicles (red asterisks) with the presynaptic plasma membrane. (Courtesy of John Heuser. See also Heuser JE & Reese TS [1981] *J Cell Biol* 88:564–580.)

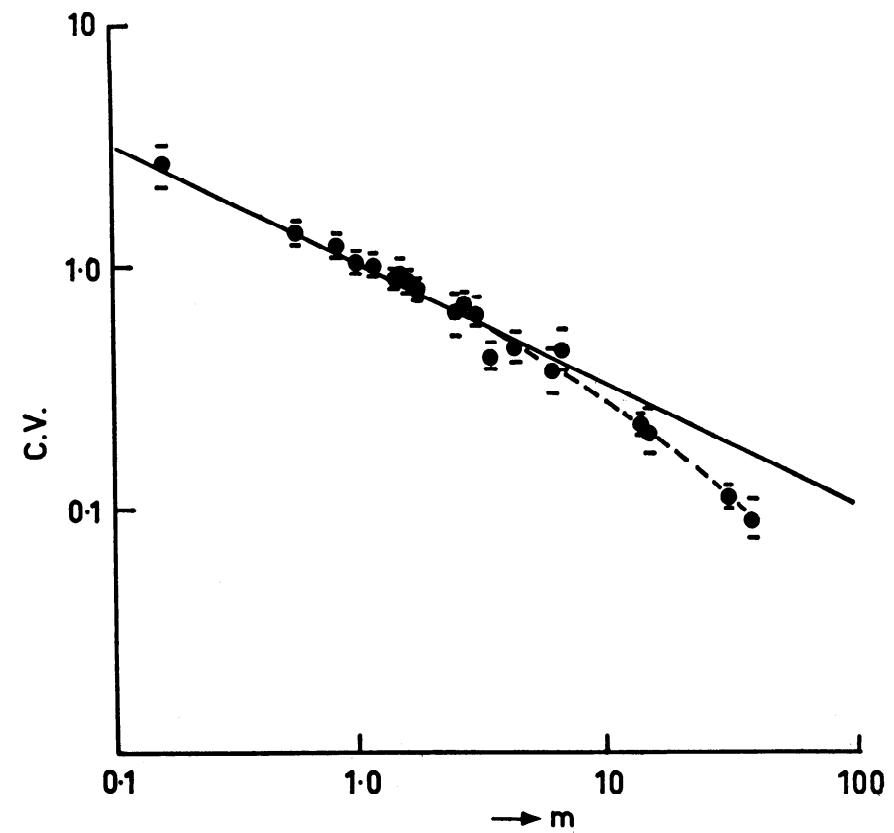
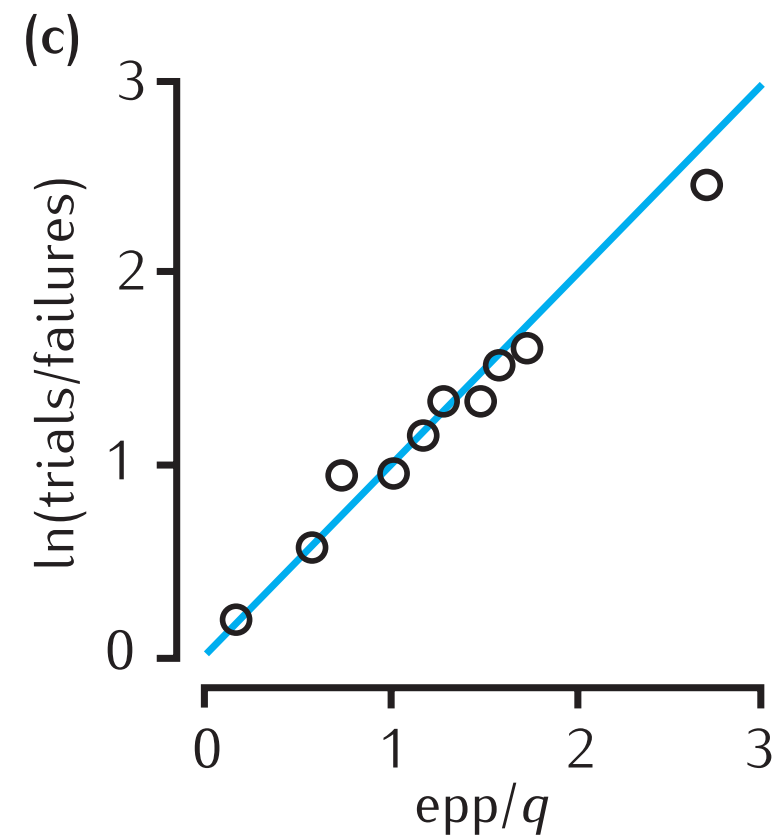
Neurotransmitter release evokes membrane potential change in the postsynaptic neuron



Quantal hypothesis of neurotransmitter release



Quantal hypothesis of neurotransmitter release



How do neurotransmitters act on postsynaptic neurons?

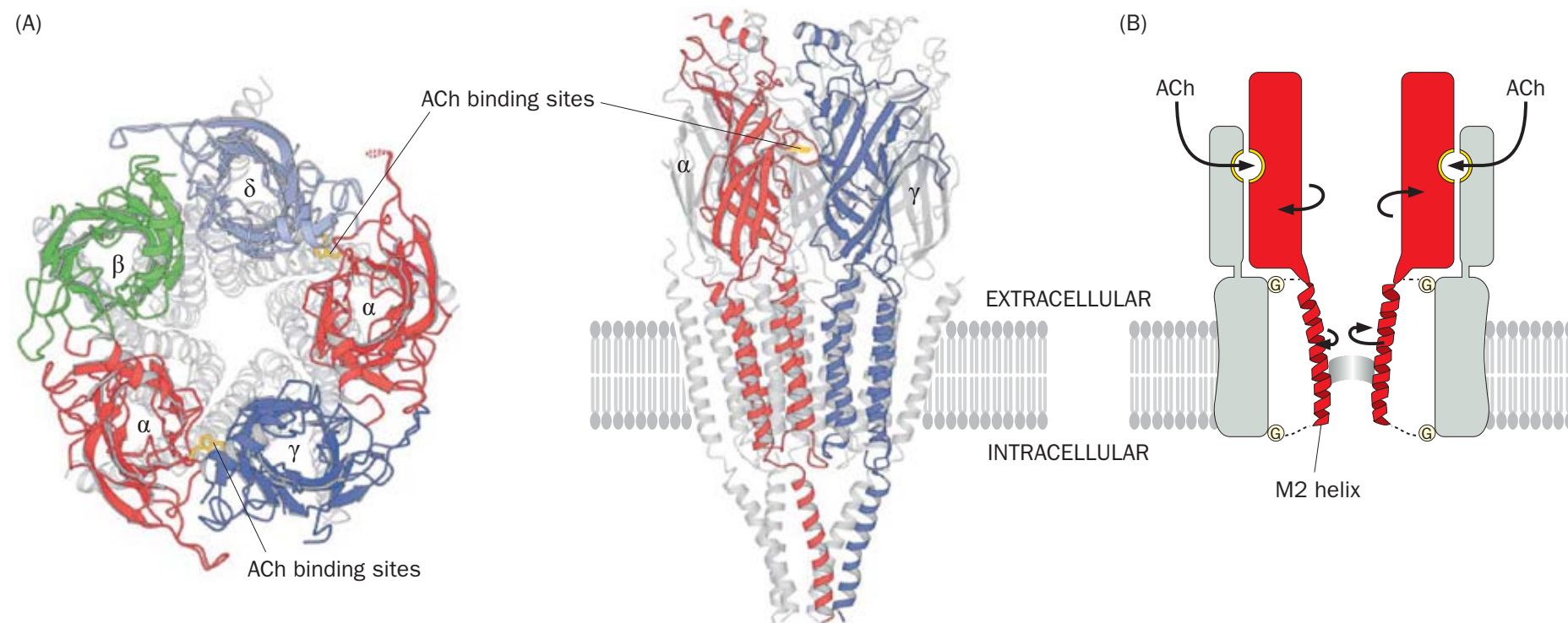
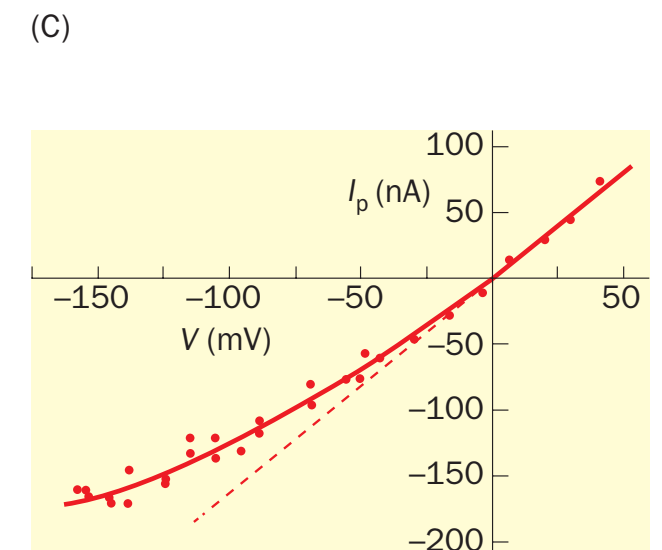
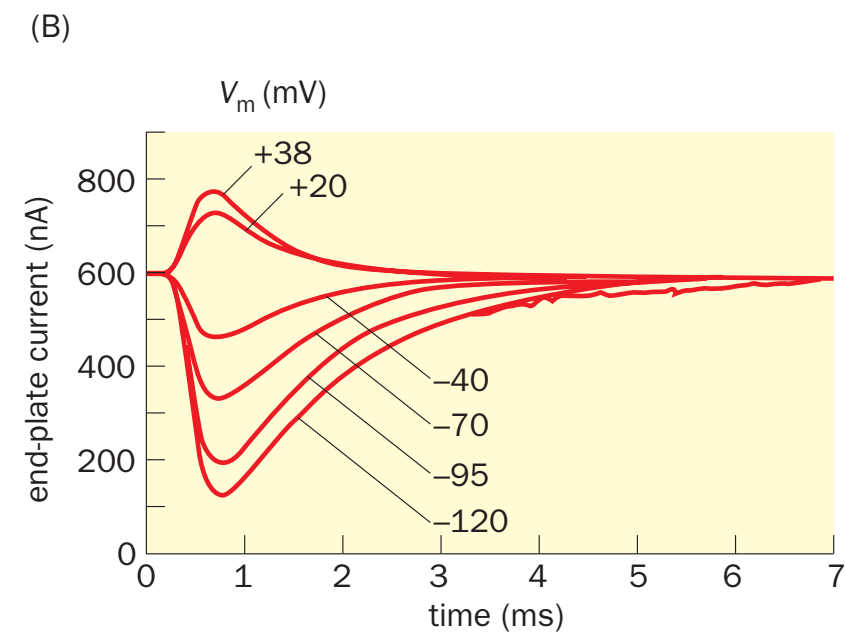
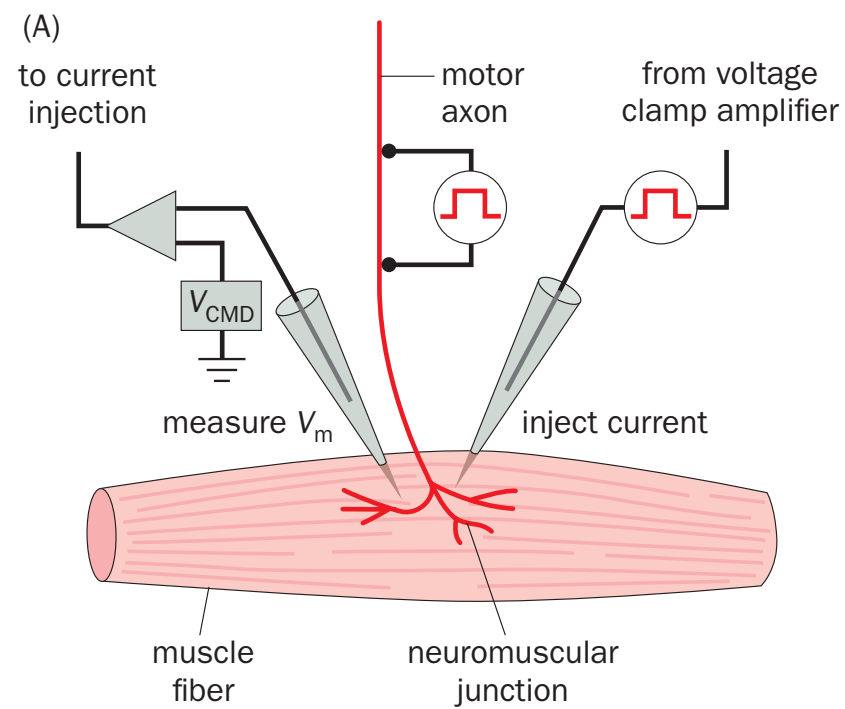


Figure 3-20 AChR structure and gating model. (A) Structure of *Torpedo* AChR in a closed state at a resolution of 4 Å as determined by electron microscopy. Left, a surface view from the extracellular side. The tryptophan in the α subunit implicated in ACh binding is highlighted in gold. Only the extracellular portions are colored. Right, a side view showing the transmembrane helices. The front α and γ subunits are highlighted in color. **(B)** A model for AChR activation. ACh binding induces a rotation of part of the extracellular domain of the

α -subunit (red). This rotation triggers a conformational change in the transmembrane helix M2 that lines the ion conduction pore, leading to the opening of the ion gate. Dotted lines with circled Gs (for glycine residues) indicate that M2 is connected with the rest of the protein by flexible loops. (A, from Unwin N [2005] *J Mol Biol* 346:967–989. With permission from Elsevier Inc.; B, adapted from Miyazawa A, Fujiyoshi Y & Unwin N [2003] *Nature* 423:949–955. With permission from Macmillan Publishers Ltd.)

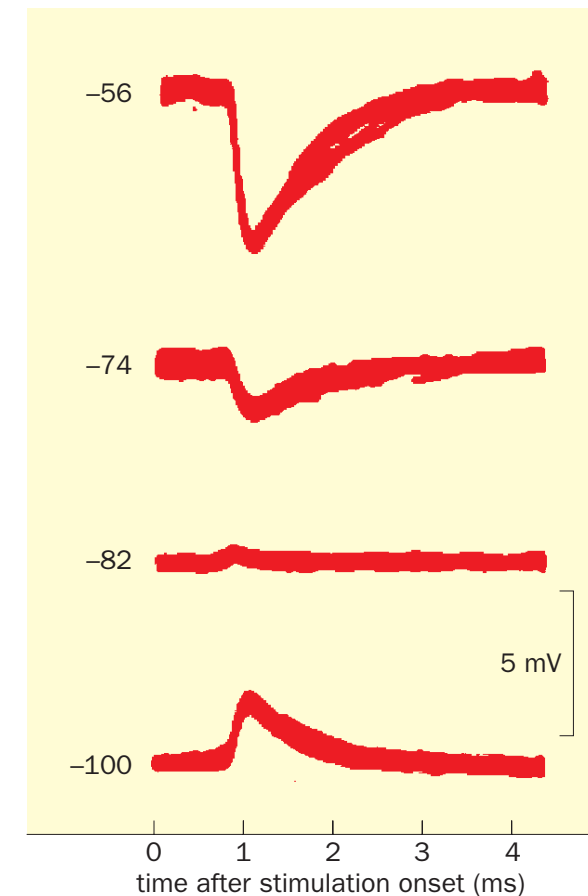
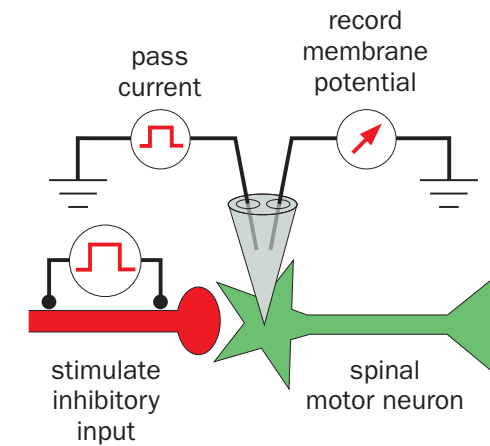
Reversal potential of a synapse



Excitatory and Inhibitory Synapses

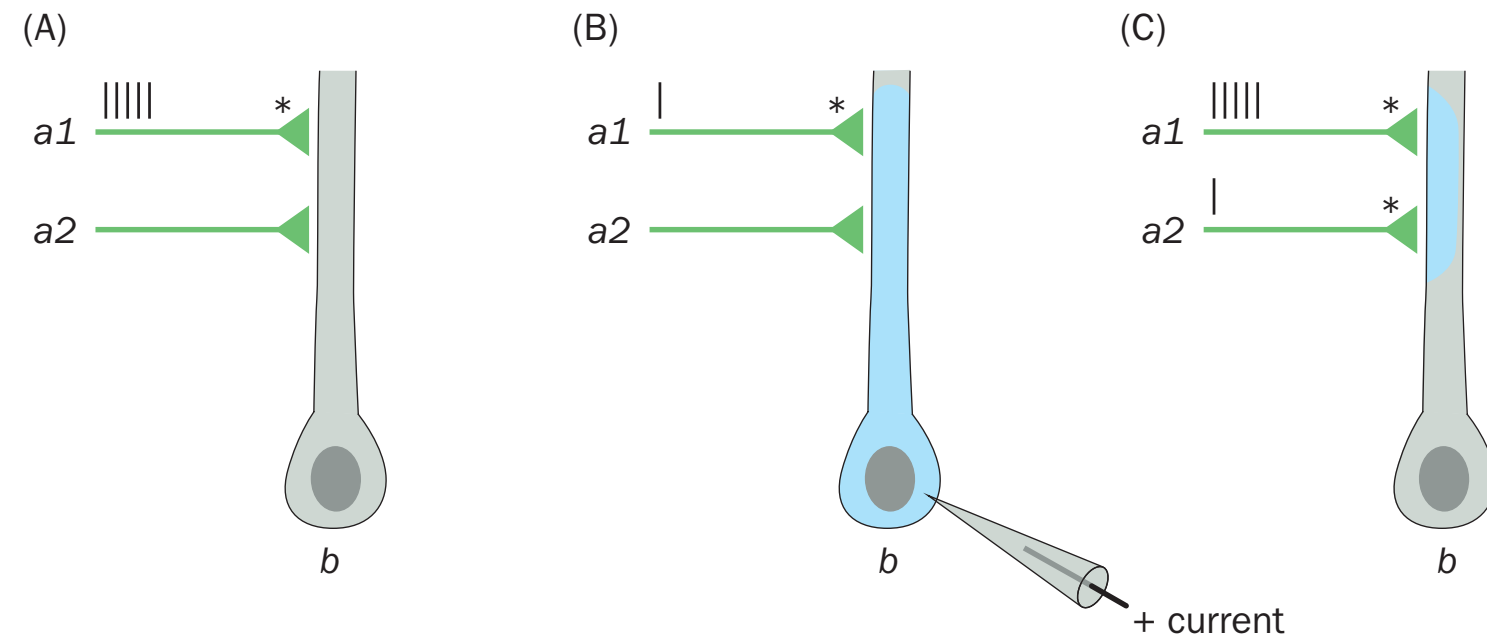
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Synaptic Plasticity

Figure 10–9 Input specificity, cooperativity, and associativity of long-term potentiation. In each experiment, two sets of presynaptic axons from CA3, *a1* and *a2*, form synapses with the same postsynaptic CA1 neuron *b*. **(A)** LTP exhibits input specificity. In the schematic shown here, only the *a1* → *b* synapses that have undergone high-frequency stimulation (represented by repeated vertical bars) exhibit LTP (* indicates potentiated synapses). **(B)** LTP exhibits cooperativity. Depolarization (blue) of postsynaptic cell *b* by current injection enables a weak stimulus (single shock) at axon *a1* to induce LTP. **(C)** LTP exhibits associativity. A weak stimulus at the *a2* → *b* synapses normally would not induce LTP at that synapse. However, when the timing of a weak *a2* stimulus coincides with high-frequency stimulation of *a1*, the *a2* → *b* synapse also becomes potentiated, because local depolarization at the *a1* → *b* synapses spreads to the *a2* → *b* synapses (blue represents the extent of depolarization spread). (See Bliss TVP & Collingridge GL [1993] *Nature* 361:31–39.)



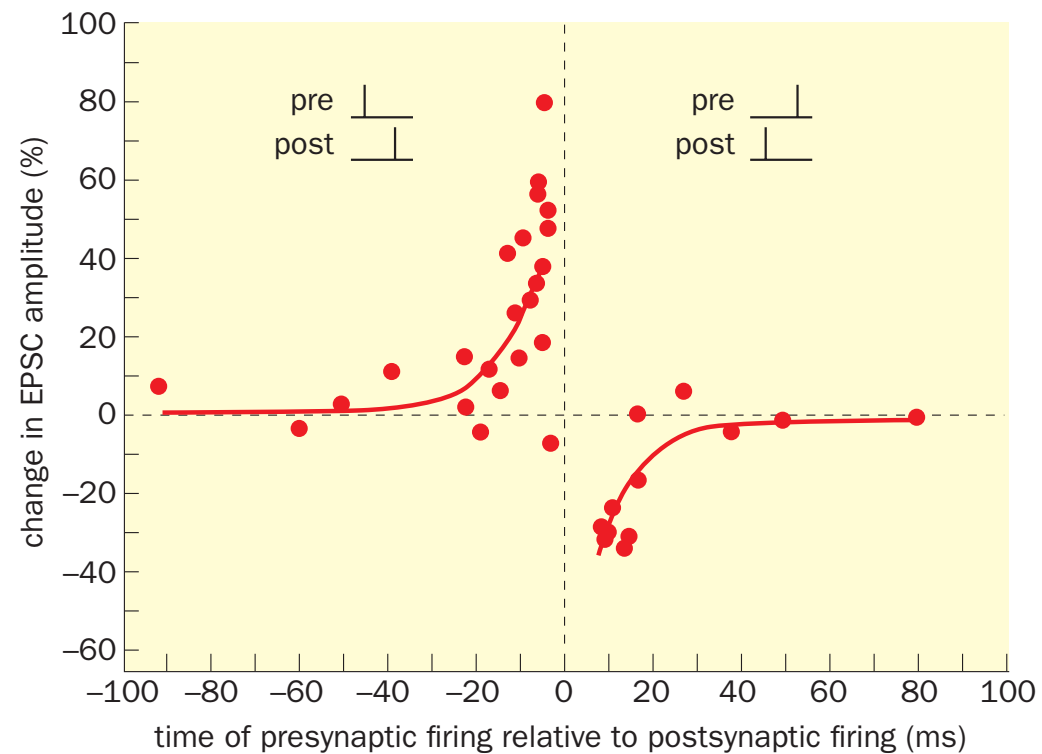
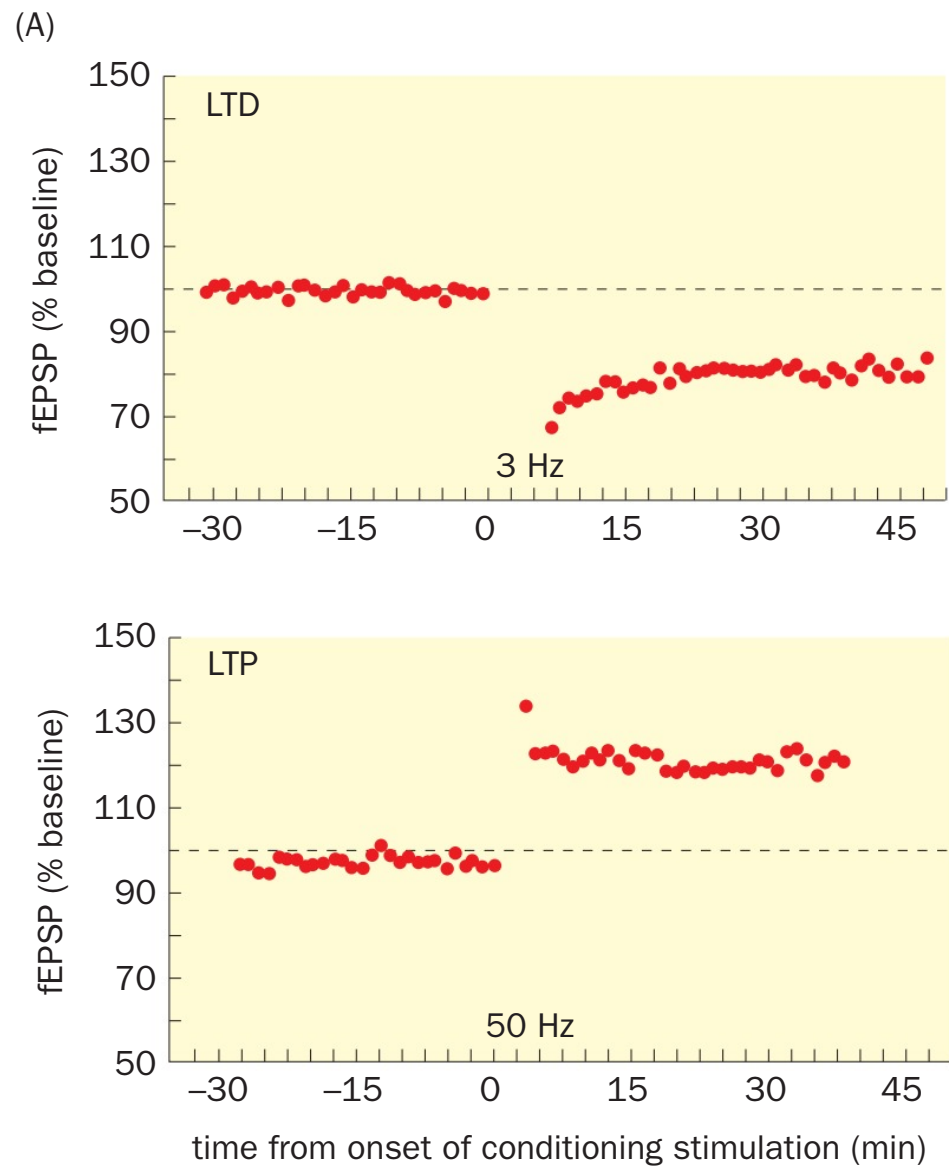


Figure 10–15 Spike timing-dependent plasticity (STDP). If the presynaptic neuron repeatedly fires before the postsynaptic neuron, the synapse is potentiated (left). If the presynaptic neuron repeatedly fires after the postsynaptic neuron, the synapse is depressed (right). Data here were taken from retinotectal synapses in developing *Xenopus in vivo*, where the presynaptic neuron was a retinal ganglion cell and the postsynaptic neuron was a tectal neuron. (Adapted from Zhang IL, Tao HW, Holt CE et al. [1998] *Nature* 395:37–44. With permission from Macmillan Publishers Ltd.)

Cascade Model

