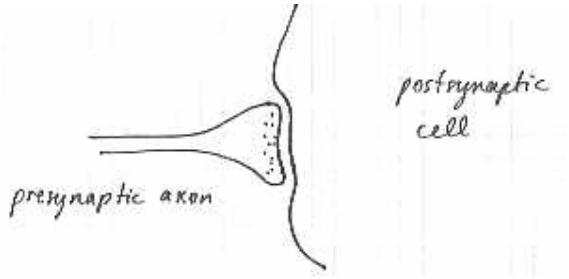
12-1-2008

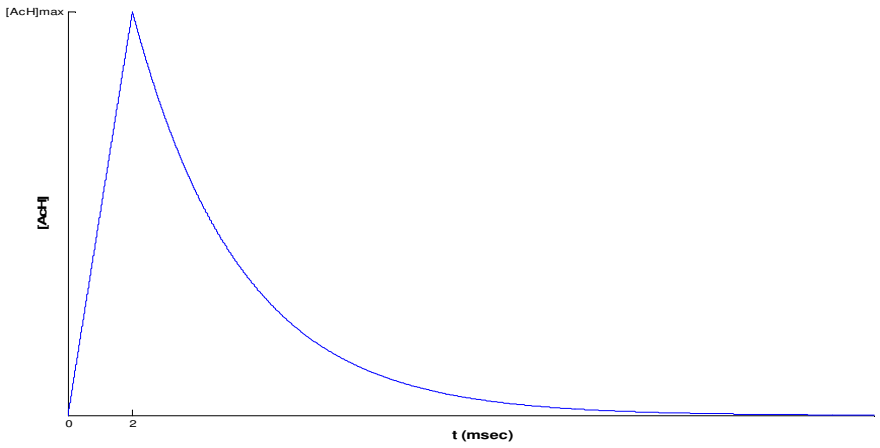
THE SYNAPSE AND ACTION POTENTIAL GENERATION ON THE POSTSYNAPTIC MEMBRANE



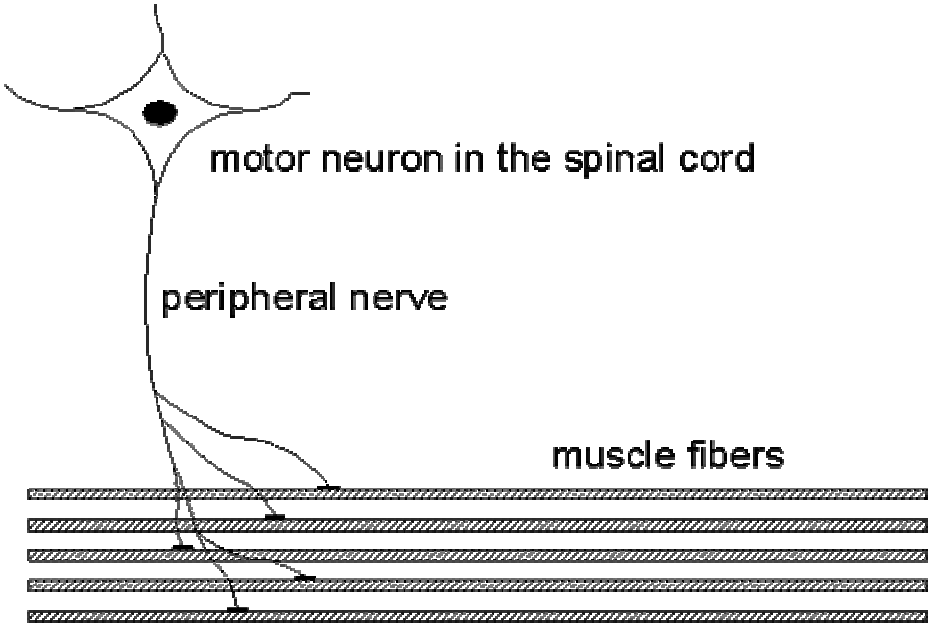
Above is the picture of a synapse which we assume to be using AcH. An action potential propagates along the presynaptic axon and finally the end surface membrane of the axon terminal assumes a positive membrane voltage for a short time (few milliseconds). During this time and as a result of this reversed electrical field in the membrane, AcH molecules are secreted into the synaptic cleft (the space betweeen the two membranes). Therefore in the cleft, AcH concentration suddenly increases. However, after the presynaptic action potential dies away (reverses to negative again), we observe that AcH concentration decays exponentially under the effect of the enzyme AcH dehydrogenase. The action of this enzyme is proportional to AcH concentration, i.e. the rate of decrease of [AcH] is proportional to itself.

Thus in the following figure for t > 2 msec $\frac{d[AcH]}{dt} = -k[AcH]$ where $k > 0$ and therefore

$$[AcH](t) = [AcH]_{\max} e^{-k(t-2)}$$

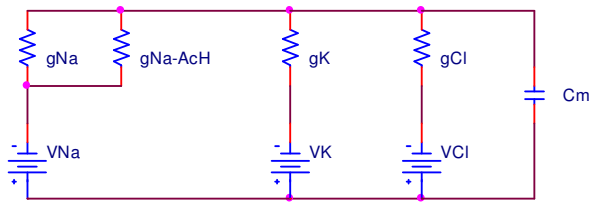


Let us now consider what happens in a **neuro-muscular junction** (a specialized synapse between a neuron and a muscle fiber). In this case the prestnaptic axon that we have mentioned above is the ending of a motor neuron which controls a muscle fiber, and the postsynaptic cell is the muscle fiber cell.



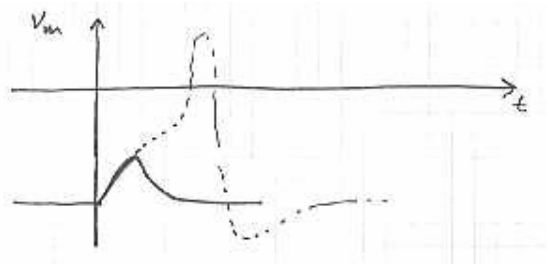
It turns out that a motor neuron's axon makes synapses with many muscle fiber cells. The interesting fact is that if an action potential is generated on the muscle fiber cell then that fiber contracts, a phenomenon called excitation-contraction coupling.

The postsynaptic membrane (of a muscle fiber) facing the cleft has AcH sensitive Na channels in addition to the voltage dependent Na channels we have seen earlier:



$g_{Na\text{-}AcH} = \alpha\,[AcH]$

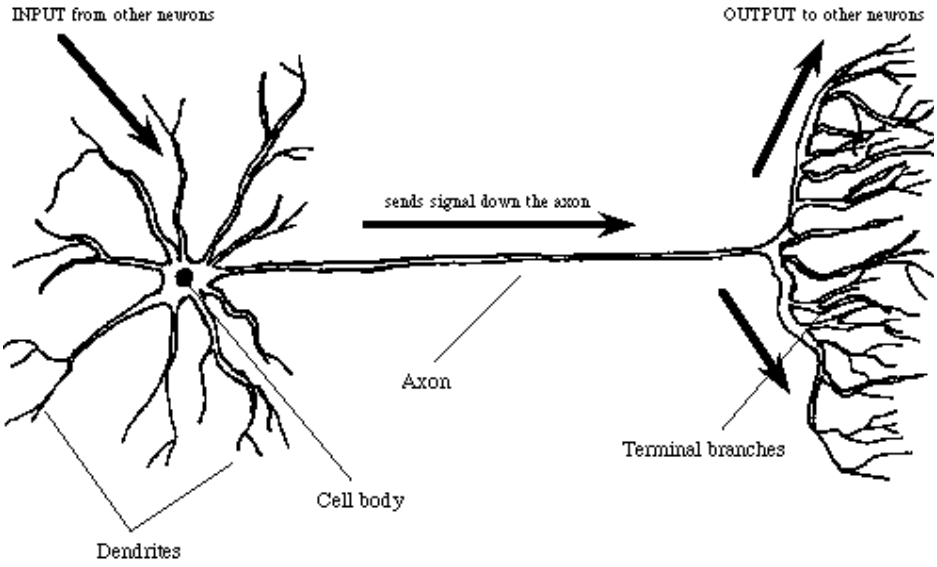
Under the influence of AcH, the postsynaptic membrane at the cleft undergoes a positive shift.



The solid line corresponds to a low amount of AcH secretion and an AP is not generated on the postsynaptic membrane. The dotted line is the case for a large amount of AcH secretion and an AP is generated on the postsynaptic membrane. Whether a low or a large amount of AcH is secreted depends on the chemical properties of the presynaptic cell ending.

The synapse described above is an "excitatory" one. There are also "inhibitory" synapses which utilize other chemical transmitters (i.e. not AcH) and which activate additional K channels with the end result of causing a negative shift in the postsynaptic membrane potential.

In general in a neuromuscular junction, one AP arriving at the junction (from the motor neuron) is enough to elicit an AP in the muscle fiber. However many other synaptic connections in the nervous system have different properties than the neuromuscular junction. Most of the synapses in the nervous system are in the processing centers where decision making is achieved. In these centers a **decision-making cell** receives thousands of synapses from other cells, and the axon of the decision-making cell branches and makes synapses with many other cells. The decision making cell has axtensions on its soma (cell body) called dendrites and most of the incoming axons make synapses on these dendrites, although some synapses are directly on the soma itself.



The membrane of the decision making cell does not have membrane voltage dependent conductances, but only neurotransmitter sensitive conductances (in fact there is some membrane voltage dependence but this is not much). Therefore the membrane of a decision-

making cell cannot generate an AP. In general what happens is that an AP arriving at a synapse on the decision-making cell temporarily increases it membrane potential slightly. If there are many excitatory synapses on a postsynaptic cell acting simultaneously then the increase in the postsynaptic cell membrane potential is more pronounced. Inhibitory synapses have the effect of decreasing the membrane potential. The overall activity of the excitatory and inhibitory presynaptic cells add and subract in time and space (spatiotemporal mapping) to determine the overall level of the somatic membrane potential.

How does a decision-making cell generate an AP then? It turns out that the axon of the decision-making cell has membrane potential dependent conductances and therefore in the axon hillock (which is the initial portion of the axon) an AP can be genarated, which is then propagated down the axon. In myelinated axons the AP is generated in the first Node-of-Ranvier and then propagated to the other nodes. In general if the overall level of the somatic membrane potential is high then the outgoing axon AP frequency is higher.

The processing of the incoming synaptic activity in order to determine the outgoing AP frequency is explained in the chapter entitled SOMATODENDRITIC SIGNAL PROCESSING (or SpatioTemporal Mapping).