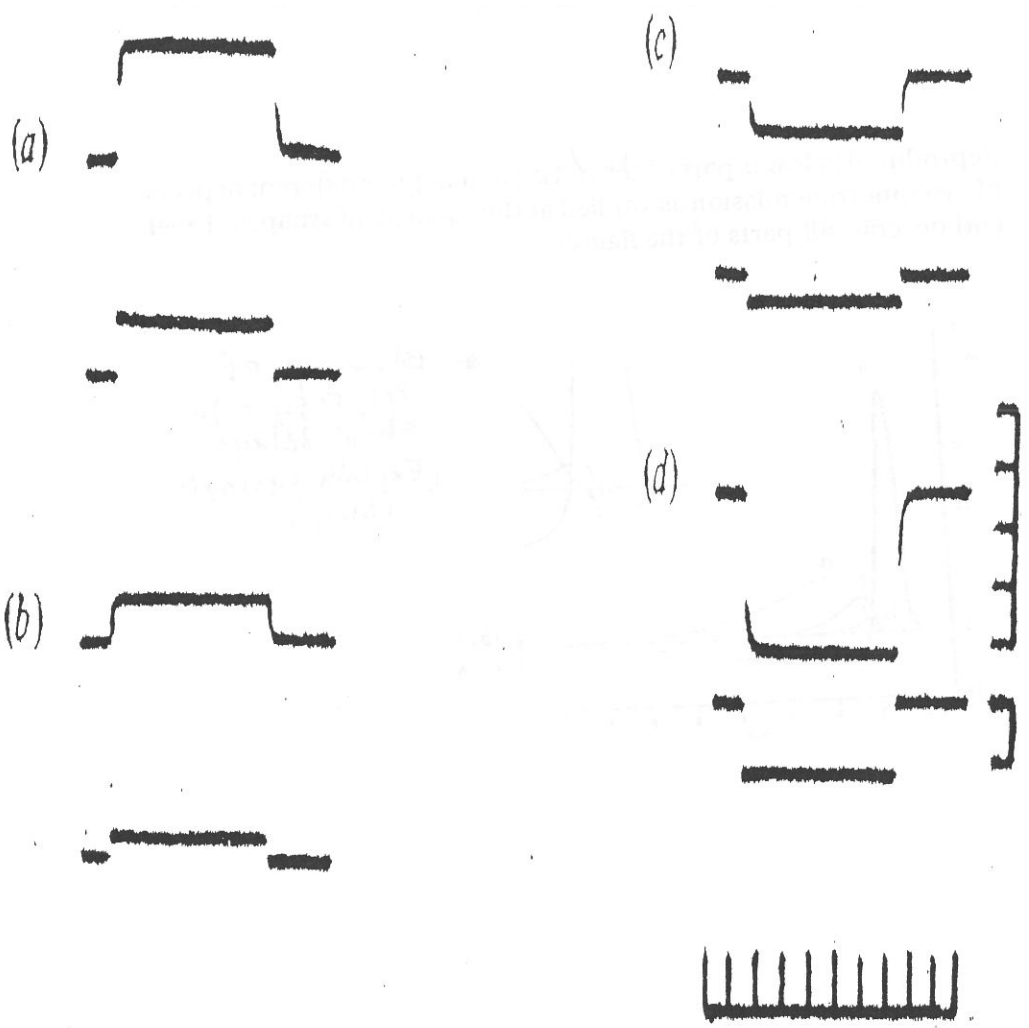
MCB 166 Problem Set #5

1. The coxal muscle receptor of the crab is innervated by two large nerve fibers (Roberts & Bush, 1971). One of them, the T-fibre, is about 60 μm in diameter and 3 mm long. Two microelectrodes were inserted close together into the middle region of the fibre, one to pass stimulating currents and one for recording. Fig. A shows some of the results of one experiment. You may assume that the space constant is long relative to the fiber.

Questions:

(a) Plot the results as a voltage–current graph.
(b) What is the input resistance of the fibre?
(c) Give an estimate of the specific membrane resistance.
(d) If the assumption is untrue and the space constant is comparable to or shorter than the fibre, would the specific resistance of the membrane be higher or lower? Give brief reasons.



A. Potential changes recorded from the T-fibre during passage of stimulating current. The two microelectrodes were approx. 50 μm apart. Upper beam, membrane potentials; lower beam, currents. Calibrations: 20 mV, 0.05 μA and 50 msec per division. (From Roberts & Bush, 1971.)

2. A neuromuscular junction is stimulated 25 times. The amplitudes of the EPPs for each of the 25 trials are (in mV): 0.3, 0, 0.5, 0.7, 0, 1.1, 1.5, 0, 1.1, 0.9, 0, 0, 1.3, 1.1, 0.5, 0.5, 0.7, 0, 0.7, 1.1, 0.5, 0.5, 0, 0.9, 1.3.

J+W prob 11.5

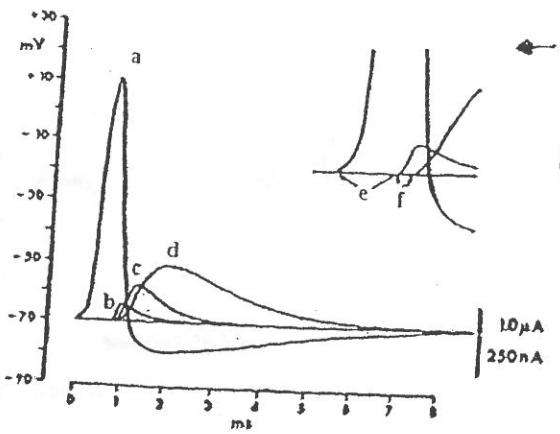
(a) Plot an amplitude histogram of the responses using a bin width of 0.2 mV.

(b) In other experiments you determined that the mean amplitude of the mEPP was 0.5 mV. Calculate m by at least two methods, assuming Poisson statistics for the release process.

(c) Given your value for m, how many times would you predict that 3 quanta would be released in an experiment in which the nerve was stimulated 200 times?

3. Reproduced below is part of J+W 12.16. It depicts different aspects of synaptic transmission as studied at the squid giant synapse. Label and describe all parts of the figure.

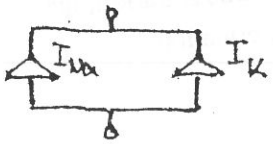
J+W prob. 12.1



← Blow up of key region to show delays. (Explain synaptic delay)

4. We are going to compare two models for Na and K currents in parallel. In the first model (A) the conductors are constant-field rectifiers. In the second model (B), they are linear conductors with Nernst-potential barriers.

(A)



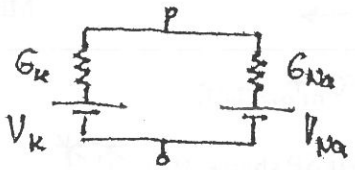
$$I_{Na} = \frac{e^2}{kT} P_{Na} V \frac{[Na]_o - [Na]_i e^{V/V_0}}{1 - e^{V/V_0}}$$

$$I_K = \frac{e^2}{kT} P_K V \frac{[K]_o - [K]_i e^{V/V_0}}{1 - e^{V/V_0}}$$

$$V_0 = \frac{kT}{e} = 25\,mV$$

$$I = I_{Na} + I_K$$

(B)



$$I_{Na} = G_{Na}(V - V_{Na})$$

$$I_K = G_K(V - V_K)$$

$$I = I_{Na} + I_K$$

(a) For each model, write the expression for the resting potential, i.e. the potential at which $I_{Na} + I_K = 0$.

(b) For model (A), show that as $V \to \infty$ or $V \to -\infty$ (i.e. become very large), I(V) becomes linear but with different slopes. The ratio of these slopes is called the rectification ratio. Write the resting potential for rectification ratio = 1.

(c) Show that model (B) can be written as a single element $I = \bar{G}(V - \bar{V})$. Write expressions for $\bar{G}$ and $\bar{V}$.

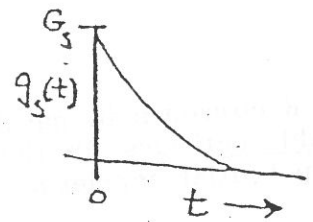
(d) Model (B) makes no sense when any relevant ionic concentration goes to zero. This is because one of the Nernst potentials will become infinite. Explain what is wrong with the model for such a condition. Does model (A) have this trouble? If not, why not? Sketch a curve of $I_K(V)$ when $[K]_o = 0$, and describe the current.

Extra Credit #1

X1. Miniature postsynaptic potential (MPSP). Assume a miniature postsynaptic current originates in a conductance change which has the time course

$g_s(t) = G_s \exp(-t/t_s)$.

The MPSP is observed in a small cell as shown in the equivalent circuit.



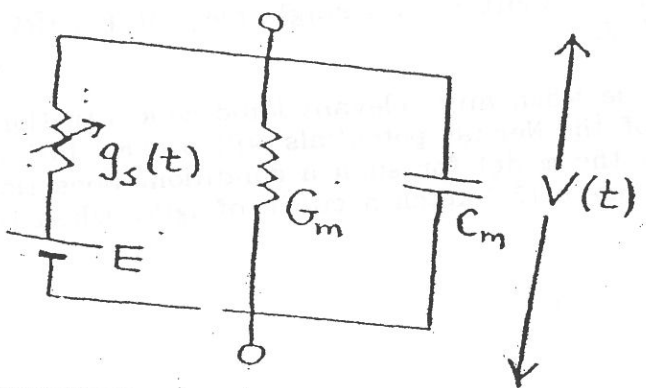
Assume from the outset that $g_s(t) << G_m$, so that the synaptic conductance change has no effect on the membrane RC time constant, $\tau_m = C_m/G_m$. For this situation, the MPSP follows the equation

(1) $dV/dt + V/\tau_m = (E/G_m\tau_m)\, g_s(t)$.

(a) Solve equation (1) for the MPSP shape, V(t). ***

(b) The MPSP reaches a peak at a time t_p. By setting $dV/dt = 0$, solve for the time-to-peak. How does the time-to-peak vary as the ratio t_s/t_m is varied ? This illustrates the effect of membrane capacitance on the observed PSP time course.

(c) For a certain neuron, $t_m = 50$ msec and $t_m = 5$ msec. Two drugs are compared. One lowers t_s by a factor of 2 (by shortening channel open time). The other blocks 50% of the channels irreversibly, thereby lowering the amplitude of the PSP. Can these drugs be distinguished from observations of the MPSP?



* This is a more general 1st order linear de. $\frac{dV}{dt} + \frac{V}{\tau} = f(t)$ for which you can show

$$V(t) = e^{-t/\tau}\left(\int f(t')\, e^{t'/\tau}\, dt' + C\right)$$

Extra Credit #2

X2. This problem concerns aspects of the 'neurophysiology' of the behavioural mutant 'pawn' in *Paramecium* (Schein, Bennett & Katz, 1976). The wild-type exhibit avoidance reactions in which ciliary beat is reversed. This reversal is brought about by Ca^{2+} ions entering the cell during a graded regenerative membrane depolarization which involves calcium activation essentially similar to the sodium activation of nerve axons. There is also delayed potassium activation. Pawn mutants do not have the avoidance reaction.

In the experiments illustrated here, membrane potentials are recorded with one glass microelectrode while stimulating currents are passed with a second microelectrode. In Figs. I. *a* and *b*, pawns are compared with the wild-type.

Questions:

(a) Draw a text-figure graph to illustrate the effects of the strength of applied currents on membrane potential in pawn mutants (use plateau levels).

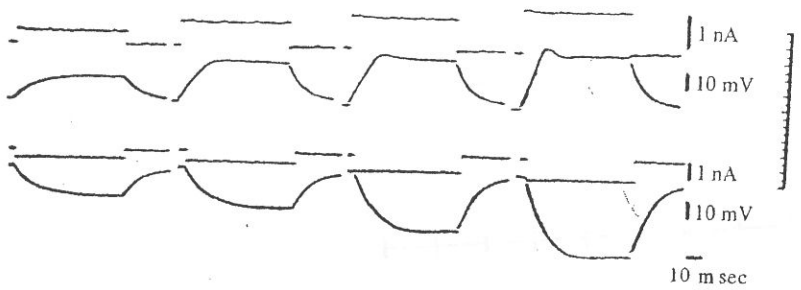
(b) What is the resting input resistance of the pawn?

(c) Measure membrane time constant and so calculate membrane capacitance.

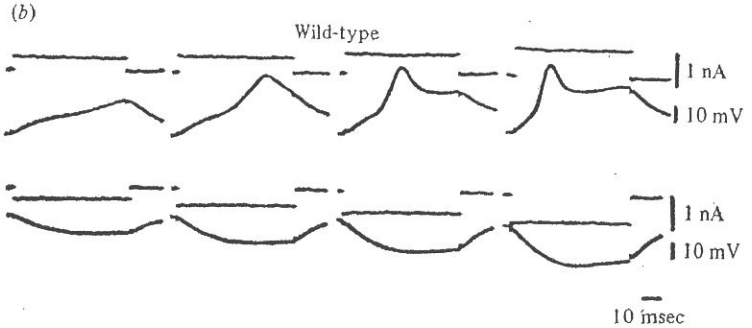
(d) Calculate the specific membrane resistance of the pawn. Assume that the individual has a cylindrical shape, 120 μm

Fig. I. Intracellular records of the membrane potential changes in *Paramecium* during the passage of stimulating currents via a second microelectrode. (*a*): In a pawn mutant; (*b*): In a wild-type individual. Upper traces, currents; upward deflexion = outward current. Lower traces, membrane potentials; upward deflexion = depolarization. (From Schein *et al.*, 1976.)

I (*a*)



I (*b*)



X2. (cont'd) long by 30 μm diameter, and allow an area for the cilia 2.5 times that of the body surface.

(e) Describe the main difference between the results for wild-type and for the pawn. Relate this to the information given in the introduction to the problem.

(f) Fig. II is an enlarged version of the fourth membrane potential record from Fig. I 4*b*. Using the axes provided under it for your graph, sketch the curve of rate of change of potential (dV/dt) on the same time scale. You should attempt to get the numerical values of the main features of your curve approximately correct.

Fig. II. Membrane potential of *Paramecium* during stimulation by an outward current pulse, enlarged from Fig. I (*b*).