Homeostasis worksheet 2

1

Action Potential graphs. See enclosed graphs on separate sheets.

2

The absolute refractory period is the period of time immediately after the firing of an action potential during which time it is not possible for another action potential to be initiated, regardless of the size of the impulse.

The relative refractory period is the period immediately after the absolute refractory period, when the repolarisation of the membrane has just started to occur. During this period of time, a larger than normal stimulus would be able to initiate a second action potential.

3

In biological solutions, and across cell surface membranes, the chief carriers of current are ions that are present in aqueous solution. The most important of which include: sodium ions, potassium ions, calcium ions and chloride ions. Of these, by far the most important are sodium and potassium cations.

4

$$V = \frac{RT}{zF} \ln \frac{C_o}{C_i}$$

Where: V is the equilibrium potential in volts (internal potential – external potential)
C_o and C_i are outside and inside concentrations of the ion, respectively
R is the gas constant (2 cal $\mathrm{mol}^{-1}\,{}^{o}\mathrm{K}^{-1}$)
T is the absolute temperature (^{o}K)
F is the Faradays constant (2.3×10^4 cal $\mathrm{V}^{-1}\mathrm{mol}^{-1}$)
z is the valance of the ion.

If you know the concentration of an ion on either side of the membrane, to use the Nernst equation, knowledge of the absolute temperature would be required. As well as this, it would also be required that the membrane is completely permeable to the movement of the ion in question, and that there is no resistance to the flow of that ion through the selectively permeable membrane. It is also required that there are no other ions affecting the movement of the ions in question through the membrane.

5

The Goldman 'constant field equation' is as follows:

$$E = \frac{RT}{F} \ln \frac{P\,[K]_o + P\,[Na]_o}{P\,[K]_i + P\,[Na]_i}$$

Where the symbols have the same meaning as in the Nernst equation above. But here, P is referring to the membrane conductance of the ion, and [x] refers to the concentration of the ion – i = inside the membrane, o = outside the membrane.

The equation sometimes also involves the chloride ion, but because it does not have such a significant role as the sodium and potassium ions, it is sometimes also ignored in the equation.

The equation is more applicable to membranes than the Nernst equation because it takes into consideration the different species of ion present in both of the solutions. It also takes into consideration, the concentration gradient of each of the ions, and the relative permeability of the plasma membrane to each of the species present. With all of these considerations, it is able to better give an estimate of the membrane potential, than with the Nernst equation which considers there to only be one species of ion present and that the membrane is perfectly permeable to that ion. This is because in reality, there are more than one species of ion present and the membrane has different permeability's to each.

6
It is now thought that it is the inward current of sodium ions that is responsible for the upstroke of the action potential. There are some experiments that were designed to test the hypothesis, and the results concluded that this must be the case. Two such lines of evidence include the following. Hodgkin and Katz suggested that the action potential resulted in permeability of the membrane to sodium increasing rapidly, being the cause of the depolarisation. The first test was with giant squid axons. They placed the axon into solutions of varying composition. It was found that no action potentials could be produced in the absence of sodium ions in the external medium. However, in solutions of sodium, action potentials could be initiated. The second line of evidence for this theory was using voltage clamp experiments, in which current is passed through the nerve membrane so as to hold the membrane potential at a constant level. This allows currents through the membrane to be observed. Using the hypothesis that there is an inward current of sodium initially, the axon being clamped was placed into a solution containing no sodium. It was found that in fact there was an outward current of sodium ions. Also when the membrane potential was clamped at the equilibrium potential for sodium it was found that there was no sodium current, which meant no action potential, which is to be expected. These and other similar experiments strongly imply that the initial current flow under voltage clamp conditions is caused by the movement of sodium ions.

7
The threshold voltage is the minimum increase in the membrane potential that must be applied for an action potential to be initiated in a neurone. For an action potential to be propagated, the membrane potential must be raised to a level where the voltage gated sodium channels open. After they have been opened, the action potential can be initiated due to the influx of sodium ions that can now occur. There is a minimum membrane potential that must be achieved before the voltage gated sodium channels will open, allowing this current to flow. Therefore any stimulus causing a change in the membrane potential less than this amount will not cause an action potential to be fired. The stimulus must cause a change in the membrane potential sufficient to allow the voltage gated sodium channels to open.

The strength of an action potential is an intrinsic property of the cell. Upon stimulation above the threshold level, the voltage gated ion channels open, allowing the sodium to enter the cell. The action potential achieved has its size determined by the amount of sodium which enters, which determines the final charge that enters the cell. This does not change with size of stimulus. What causes the movement of sodium is the opening of the channels. If the stimulus is greater than the threshold, then they will open. If the stimulus is very strong, the same number of channels will open, and to the same extent, thus no greater action potential can be achieved. Therefore, if the threshold level is not achieved then no action potential is produced. If a stimulus greater than the threshold is used, whatever the size, the whole action potential will be fired. Hence, the all-or-none law.

The refractoriness of nerves, i.e., the presence of a refractory period during which no further action potentials can be stimulated can be explained. During the absolute refractory period, the sodium channels are already opened, and there is a large influx of sodium into the cell. This influx causes the membrane to become depolarised. During this time, even if there is another stimulus, since the channels are already opened, then it is not possible to further cause a second action potential. During the relative refractory period, when extra strong stimuli could cause a second action potential, the membrane channels for sodium have been closed, and the membrane is in the process of repolarising, by removing potassium. Since the ion channels are closed, then a strong stimulus would be capable of opening the channels again. The extra strong stimulus is required since the membrane potential has not returned to its normal state. The membrane is not able to effectively fire another action potential until it has fully repolarised. This is because until this stage, the membrane potential is not at its resting stage and so there is movement of ions across the membrane, and it is not at equilibrium. As soon as this is achieved, another action potential can be effectively fired.

Accommodation of the nerves is when nerves lose excitability when held at a membrane potential more positive that approximately -50 mV. For example, if a sub-threshold depolarising potential is held by a nerve membrane, i.e., greater than -60Mv it is found that the threshold potential rises. That is, the membrane becomes less responsive to stimuli. This process is known as accommodation. Accommodation occurs because some of the voltage gated ion channels for sodium become inactivated by the slight depolarisation of the membrane, which inhibits some of the sodium movement into the cell. This reduction in rate means that a greater stimulus is required to ensure that the amount of sodium entering the cell is greater than the amount of potassium leaving, i.e., the threshold potential. Thus accommodation is the process of increasing the threshold potential when the membrane is slightly depolarised.

8

An axon of larger diameter will conduct impulses at a higher velocity than an equal axon, but with smaller diameter. The reason for this is that the larger diameter causes the axon to have less internal resistance to current flow. This is responsible for allowing the action potential to be conducted at a greater rate. Current is inversely proportional to resistance. Therefore, if resistance decreases, current increases. That is, the rate of conduction of the impulse is greater.

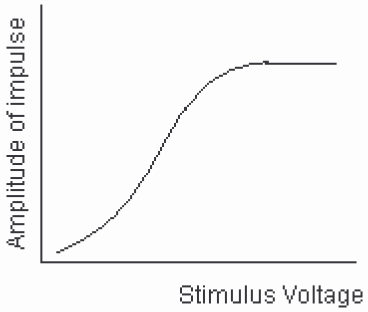
Graph showing relationship between fibre diameter and conduction rate for both unmyelinated and myelinated nerve fibres (Rushton 1951)

9

The velocity of impulse conduction increase with temperature. The reason for this occurrence is that the increased temperature has two effects. The first effect is that the ions, in particular sodium, all have higher kinetic energy meaning that the motion of the ions will be greater and that it will be more likely for the ions to encounter a sodium ion channel, and they will cross the membrane at an increased rate. The second effect of increased temperature is that the permeability of the membrane to sodium changes more rapidly. That is, upon stimulation greater than the threshold, the voltage gated channels respond much quicker, allowing the sodium ions to cross the membrane sooner, than if the gates opened at a normal rate. Therefore, temperature allows the depolarisation to occur at a greater rate. The Q_{10} for the relationship of speed of nervous impulse propagation of around 1.7.

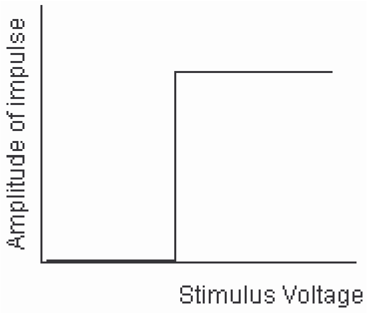
10

If a whole muscle is stimulated with a wave of pulses of increasing voltage, the action potential produced over a certain range of stimuli will increase gradually with increasing voltage, forming a graph of voltage verses action potential that looks like:



This graph appears to conflict with the all or nothing law. If this was obeyed, then it would be expected that a graph of the form shown below would be achieved from the same experiment:

The amplitude would remain at zero until the threshold potential at which point the amplitude would immediate rise to the maximum.



However, the all or nothing law is true for individual neurones. That is each neurone individually will follow the all or nothing law. However, the muscle as mentioned in the question contains many neurones. Neurones do not necessarily have the same threshold potential. Therefore, in the muscle as the voltage rises, more and more of the neurones will achieve their threshold potential, and thus start an action potential. As a result of this, as the voltage increases, there will be an increase in the amplitude of the action potential because more and more of the neurones will be achieving their threshold. Thus this observation does not conflict with the all or none law.

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The answer: ‘The voltage must be above a certain threshold value in order for the sodium gates to open – they are either fully open (all) or closed (nothing). Once initiated, it is a self propagating process.’ The first part of the answer, describing the fact about the open or closed sodium gates is correct. That describes the all or none law with respect to the threshold level correctly. It is true that unless the stimulating voltage is above the threshold voltage, then the sodium gates remain closed, and for whatever voltage above the threshold, the gates open fully. However, the last part of the answer where it says that: ‘once initiated, it is a self propagating process’ is not entirely true. There is what is known as a: safety factor for propagation. This is explained considering that the membrane must produce sufficient voltage to stimulate the next area of the membrane, for the stimulus to be propagated. Occasionally, the action potential reaches a point on the membrane where it does not supply sufficient voltage to be able to stimulate the next area of membrane. There for depolarisation, and the impulse, stops. Therefore, for propagation to occur the ratio of action potential to threshold of excitation must always be greater than one. This is the safety factor for propagation.