# Chapter 16

## Question 16.6

Changes in the resting membrane potential ($V_M = V_{in} – V_{out}$) of a neuron are predicted from the Goldman-Hodgkin-Katz (GHK) equation (Equation 3.9) which we discuss in Sections 3.1.3, 16.2.1 and 16.2.2. Figure 16.16 summarizes how the membrane potential of a neuron changes as a function of the ratio between membrane permeability to sodium and potassium ($P_{Na}/P_K$). If the $P_{Na}/P_K$ value rises, then the membrane potential becomes more positive (membrane depolarises). In contrast, if $P_{Na}/P_K$ value decreases, then the membrane potential becomes more negative (membrane hyperpolarises). However, if the ratio $P_{Na}/P_K$ does not change, then the membrane potential does not change.

(i) If $P_{Na}$ rises by a factor of 2 from $P_{Na}$ to $2P_{Na}$ and $P_K$ rises by a factor of 3 from $P_K$ to 3 $P_K$, then the ratio between the sodium and potassium permeability decreases by one third from $P_{Na}/P_K$ to $2P_{Na}/3P_K$ and the **membrane potential becomes more negative (membrane hyperpolarises** - see Figure 16.16).

(ii) If the membrane permeability for both $Na^+$ and $K^+$ both decrease by a factor of two, then the ratio between the sodium and potassium permeability does not change and **the membrane potential does not change**.

(iii) If the membrane permeability for $Na^+$ rises and the permeability for $K^+$ does not change, then the ratio between the sodium and potassium permeability rises and the **membrane potential becomes more positive (membrane depolarises** - see Figure 16.16).

## Question 16.8

Changes in the resting membrane potential ($V_M = V_{in} – V_{out}$) of a neuron are predicted from the Goldman-Hodgkin-Katz (GHK) equation (Equation 3.9) which we discuss in Sections 3.1.3, 16.2.1 and 16.2.2. The simplified version of the GHK equation introduced in Box 16.3 (Equation A) is reproduced below:

$$V_M = V_{in} – V_{out} = 59 \text{ mV} \log ([K^+]_{out} + (P_{Na}/P_K) \times [Na^+]_{out}) / ([K^+]_{in} +( P_{Na}/P_K) \times [Na^+]_{in}))$$

where $[K^+]_{out}$ and $[K^+]_{in}$ are the potassium ion concentrations outside and inside the neuron, respectively, $[Na^+]_{out}$ and $[Na^+]_{in}$ are the sodium ion concentrations outside and inside the neuron, respectively, and $P_{Na}/P_K$ is the ratio between the membrane permeability to sodium and the membrane permeability to potassium. The increase in the extracellular potassium concentration ($[K^+]_{out}$) by 60% (from 2.5 to 4 mmol $L^{-1}$) markedly increases the value of the numerator in the log fraction causing the log value, and therefore the $V_M$ value, to become more positive. This means that **the membrane becomes depolarised, or that the membrane potential decreases (in absolute value), or that the membrane potential becomes less negative, or that the membrane potential becomes more positive** as already stated.

## Question 16.9

Most of the voltage-gated sodium channels in neurons are closed when the membrane potential is around – 60 mV. However, these channels rapidly activate and open when the membrane depolarises and the membrane potential changes polarity after which these voltage-gated **sodium channels rapidly inactivate and close and stay closed if the membrane potential is maintained at + 40 mV**.

These properties of the voltage-gated sodium channels play a central role in the generation of action potentials in neurons because the voltage-gated sodium channels open rapidly, in an explosive manner, upon a certain level of depolarisation. This causes further membrane depolarisation, which, in turn, opens more $Na^+$-channels (positive feedback) and the membrane polarity changes to become generally more positive inside than outside when the peak of the action potential is reached. However, when the membrane potential becomes more positive inside than outside, the voltage-gated sodium channels rapidly inactivate and close, now permitting the membrane potential to return towards the resting level as the ratio between sodium and potassium ion permeabilities ($P_{Na}$ /$P_K$) decreases towards its resting level value after the action potential was triggered.