Homeostasis worksheet 1

1

		Na^+	K^+	Cl^-
SQUID (axone)	Internal concentration (mM)	50	400	50
	External Concentration (mM)	440	20	560
	Equilibrium Potential (mV)	+55	-75	-60
FROG (muscle)	Internal concentration (mM)	10	124	1.5
	External Concentration (mM)	109	2.3	78
	Equilibrium Potential (mV)	+65	-105	-100
HUMAN	Internal concentration (mM)	10	140	10
	External Concentration (mM)	142	4.2	108
	Equilibrium Potential (mV)	+60	-90	-70

2

The Singer-Nicholson model of a membrane (1972) is more commonly known as the fluid mosaic model. The cell membranes consist of phospholipid molecules and protein molecules. Phospholipids are amphipathic, that is, consisting of both hydrophobic and hydrophilic sections. The structure of phospholipids is such that upon introduction into water, they organise themselves spontaneously, with the hydrophobic fatty acid tails pointing away from the water, and the phosphate group hydrophilic head interacting with the water molecules. As a result, a bilayer is formed which is continuous around the cell, or organelle, it is surrounding. The phospholipid molecules are fluid, that is, they are not stationary. They are free to move, and are capable of changing relative positions with other molecules, for example by the 'flip-flop' mechanism, or by lateral movement. They also rotate about their position. This fluidity is slightly reduced by the inclusion of cholesterol within the lipid bilayer.

There are also protein molecules incorporated within the phospholipid bilayer. These protein molecules can be extrinsic or intrinsic, depending on their function. They are organised in such a way within the phospholipid bilayer that it looks to be a mosaic. As a result, the model is known as the fluid mosaic model

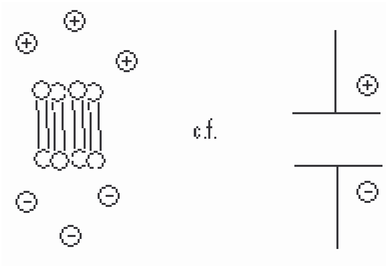
Membranes have many functions. The main function is to control the movement of molecules into and out of the cell, or organelle. This is achieved by the fact that the lipid bilayer is impermeable to any ions in aqueous solution. These are able to pass through protein carrier molecules which have selective permeability to the ions. The membrane is also involved with active transport. There are also some enzymes within the membrane which catalyse specific reactions. Also some of the protein molecules are receptors which upon complexing with the appropriate molecule, such as a hormone, will induce changes within the cell. The glycocalyx of membranes may also be involved with recognition, or adhesion to other cells. Membranes are also involved with the compartmentalisation of products within the cells.

The permeability of a membrane to an electrolyte depends on factors such as the size of the ion, the charge on the ion, the concentration gradient that already exists for this ion and the presence of carrier proteins in the membrane for such an ion.

The permeability of a membrane to a non electrolyte depends on factors such as the size of the molecule, whether the molecule is organic or inorganic, the concentration gradient that exists, and the presence of transport proteins in the membrane for such a molecule.

3

Membrane capacitance is the electrical capacitance of a membrane. Plasma membranes are excellent insulators and can act as dielectrics. Capacitance is the measure of the quantity of charge that must be moved across unit area of the membrane to produce unit change in membrane potential. Most membranes have a capacitance of about $1\mu Fcm^{-2}$.



The structural basis for such capacitance is due to the fact that charges can exist on both sides of the membrane (which is separated by the membrane). The membrane acts as the dielectric, and a simple capacitor is established.

Membrane conductance is the measure of the permeability of the membrane to allow ions to cross the membrane. It is the reciprocal of resistance. Membranes contain intrinsic proteins which act as ion channels. These allow the passage of a specific ion across the membrane. It is the presence of these protein carriers which account for the membranes conductance. The movement of charged ions through the channels constitute a current. Since current flows through the membrane, it must have conductance.

4

Simple Diffusion	Facilitated diffusion	Active transport
Transport of small inorganic molecules and fat soluble molecules	Transport of larger inorganic molecules, and ions	Transport of organic and inorganic molecules and ions
Movement is passive, i.e., along the concentration gradient	Movement is passive	Movement is active, i.e., against the concentration gradient
Molecules pass through the lipid bilayer.	Particles pass through specific protein carrier molecules and ion channels.	Particles pass through specific carrier protein molecules
Rate is relatively independent on space	Rate dependent on number of specific carriers	Rate dependent on number of specific carriers
No energy requirement, is spontaneous	No energy requirement, is spontaneous	Does not occur without and energy source, usually ATP

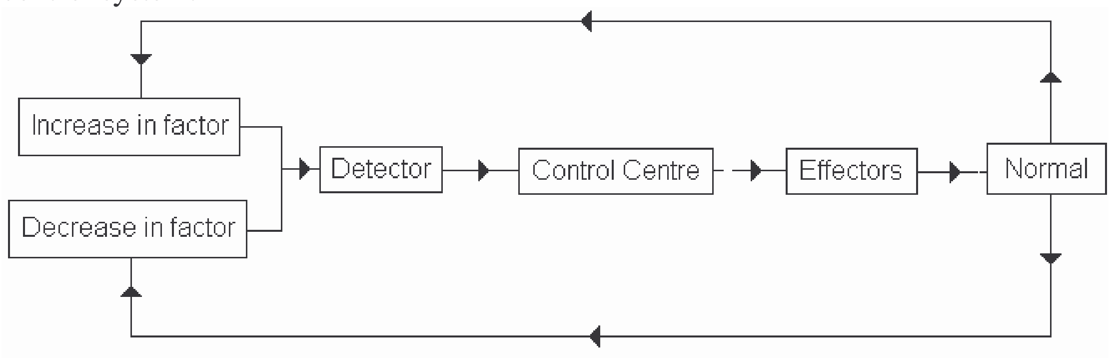
NOTE: ION CHANNELS. These Are also known as gates. They can be opened or closed, and there are three mechanisms for this occurrence:

1. LIGAND GATED CHANNELS. These are channels which have receptor points onto which molecules such as hormones or transmitters can bind to change the opening of the channel
2. VOLTAGE GATED CHANNELS. These are channels whose properties are controlled by the voltage across them
3. MECHANICALLY ACTIVATED (Stretch). Non physiological mechanism. For example upon banging funny bone, a nerve impulse is initiated, thus permeability to sodium altered.

5

If a factor, such as CO_2 concentration or internal body temperature becomes excessive or deficient, a series or changes are initiated by a control system, that return the factor to a certain mean value, thus maintaining homeostasis. This is the process of negative feedback.

Below is a block diagram illustrating the main components of a negative feedback control system:



If we apply this to an example, for example thermoregulation, then the detector would be thermo-sensitive nerve endings; the control centre would involve the thermoregulatory centre in the hypothalamus of the brain; the effectors would include skeletal muscles, blood vessels and behavioural changes.

Positive feedback is where the stimulus progressively increases the response, so that as long as the stimulus is continued the response is progressively being amplified. Such a response usually leads to instability, and can result in death. For example if upon detection of decreasing body temperature, the body responded with positive feedback, the result would be that the temperature would continue to decline, which would eventually lead to the death of the person. As a result, positive feedback is rare in physiology.

However, positive feedback does occur, and there are two common examples. The first is blood clotting. Upon rupture of a vessel, clotting factors are activated, that are enzymes facilitating clotting. These enzymes also activate unactivated enzymes which do the same, etc.. This is the beginning of a cascade reaction that continues until the vessel is plugged with a clot. That is, a positive feedback reaction. The second example is during childbirth. When contractions become strong enough for the babies head to start to push through the cervix, stretch of the cervix sends signals which result in even stronger uterine contractions, resulting in more stretch and more signals. Positive feedback is also involved with the generation of nerve signals. Upon polarisation of the membrane, the sodium ion channel opens allowing passage into the cell. The result of this is to increase the membrane potential which results in the channels opening more, allowing even more sodium to pass through.

NOTE: POSITIVE FEED FORWARD. This is the occurrence whereby the brain anticipates a change in a factor, and accommodates for it, so that no change in the factor in question occurs. For example, if a person starts to walk, the result would be an increased rate of respiration, thus increased carbon dioxide partial pressure in the blood. This, however, does not occur, because a positive feed forward mechanism is present which, at the same time as telling the leg muscles to perform work, also stimulates the ventilation rate to increase slightly to account for the change, so that there is no need for negative feedback.

6

The Donnan equilibrium is defined thus: is diffusible solutes are separated by a membrane that is freely permeable to water and electrolytes but totally impermeable to one species of ion, the diffusible solutes become unequally distributed between the two compartments.

When considering the interface between plasma in capillaries and interstitial fluid, it can be seen that there is a Donnan equilibrium. Most ions and water are able to freely diffuse through the epithelium of the capillary into the interstitial space adding to the fluid. However, there is one totally impermeable species of ion, and here, it is in the form of negatively charged plasma protein molecules present in the capillaries. These molecules are too large to be able to leave the capillary, so remain in the plasma. As a result, if the concentration of sodium ions was measured in both solutions, the readings would be similar. However, it can be seen through the Donnan effect that this is not the case, and in fact the amount of sodium ions within the capillary will be greater than that of the interstitial fluid, because the sodium ions are positively charged, and therefore some interact with the negatively charged protein anions. Thus the protein anions are affecting the distribution of the sodium cations about the capillary boundary.

When considering the animal cell, it can be seen that again, there is a membrane dividing two compartments. There are the intracellular contents, and the interstitial fluid. Since again, we have the protein anions within the cell, there is a Donnan equilibrium affecting the distribution of diffusible ions about the membrane. As a result, intracellular fluid becomes hypertonic to the interstitial fluid, since the anionic protein attracts the cations, causing them to remain in the cell. However, in the membrane of animal cells are positioned sodium-potassium pumps. These are protein molecules within the membrane that are responsible for actively pumping sodium cations out of the cell and potassium cations into the cells (two potassium cations enter for every three sodium cations departing). However, the sodium cations are no longer able to return into the cell, whilst the cell membrane remains unpolarised. As a result, the cell membrane becomes impermeable to sodium ions wanting to enter the cell, down its concentration gradient. As a result, another Donnan equilibrium is established, since the sodium is no longer diffusible. These Donnan effects balance each other, which results in the maintenance of a stable cell volume since it allows the two solutions to exist with similar solute concentrations.

When the sodium pump becomes poisoned, the result is that the volume of the cell increases and the cell swells, eventually bursting. This is due to the fact that since sodium is not removed from the cell, the concentration of them remains high within the cell. This causes the intracellular fluid to remain hypertonic to the interstitial fluid. As a result, osmosis occurs, with water entering the cell from the interstitial fluid. This results in an increase in the volume of the cell, and thus swelling.

Plant cells do not necessarily require sodium pumps because they have rigid cell walls, which limit the expansion of the cell within, so the cell would never burst. The cell wall would exert an osmotic pressure against further entry of water from the surrounding, which would prevent the cell from swelling to extreme extents.

7

The electrochemical gradient of an ion is what drives the flow of an ion through a membrane channel protein. The electrochemical gradient is a representation of two factors. These are: the concentration gradient and the voltage gradient of the ion across the membrane. When these two factors just balance each other, then the electrochemical gradient for the ion is zero, and there is no net flow of the ion through the channel. The voltage gradient, or membrane potential, at which this equilibrium is reached, is called the equilibrium potential for that ion. It can be calculated from the Nernst equation. The below equation is the Nernst equation:

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

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 mol^{-1} $^oK^{-1}$)
T is the absolute temperature (^{o}K)
F is the Faradays constant (2.3 x 10^4 cal $V^{-1}mol^{-1}$)
z is the valance of the ion.

The equilibrium potential for an ion is the potential across the membrane at the point where the electrical work in moving the ions across the membrane is equal and opposite to the chemical work being done due to the concentration gradient.

8

Osmosis is the net movement of water from a region of greater water potential to a region of lower water potential through a partially permeable membrane. As a result, in order for there to be no net movement of water, there needs to be equal water potential in both sides of the membrane. As a result of the effect that water loss and water gain can have on animal cells, it is the aim of the bodies transport systems to continuously ensure that there is constant composition of the cells and interstitial fluid. It is also ensured that there is no net movement of water, which would cause problems. As a result, although the composition with respect to individual ions will vary, the solute potential, and thus water potential, of both interstitial fluid and intracellular fluid will be the same. Thus providing the conditions under which no osmosis will occur.

9

It has been calculated that the change in electrical potential due to the movement of ions is quite large, even with the movement of very few ions. As a result, although the side of the membrane with the highest sodium ion concentration should be expected to have a positive charge, due to the concentration gradient, there is the movement of ions across the membrane. The movement of even a small amount of ions results in there being a large change in the distribution of charge. This is the case because it is not only these ions responsible for the charge. As a result of the movement of some sodium ions, the potential on the side where the concentration is greatest, is negative, whereas, the side with only a small concentration of sodium cations has a positive charge, due to the amount of charge that is transferred upon diffusion of the ions.

10

It has been found that if you consider a small area of tissue and calculate the amounts of each of the electrolytes, that there is a difference in the concentration of positive and negative ions. However, what needs to be mentioned is that the difference is so small that it is not measurable, and therefore can be considered as being negligible. As a result, it can be considered that the rule of electroneutrality does hold in this circumstance.