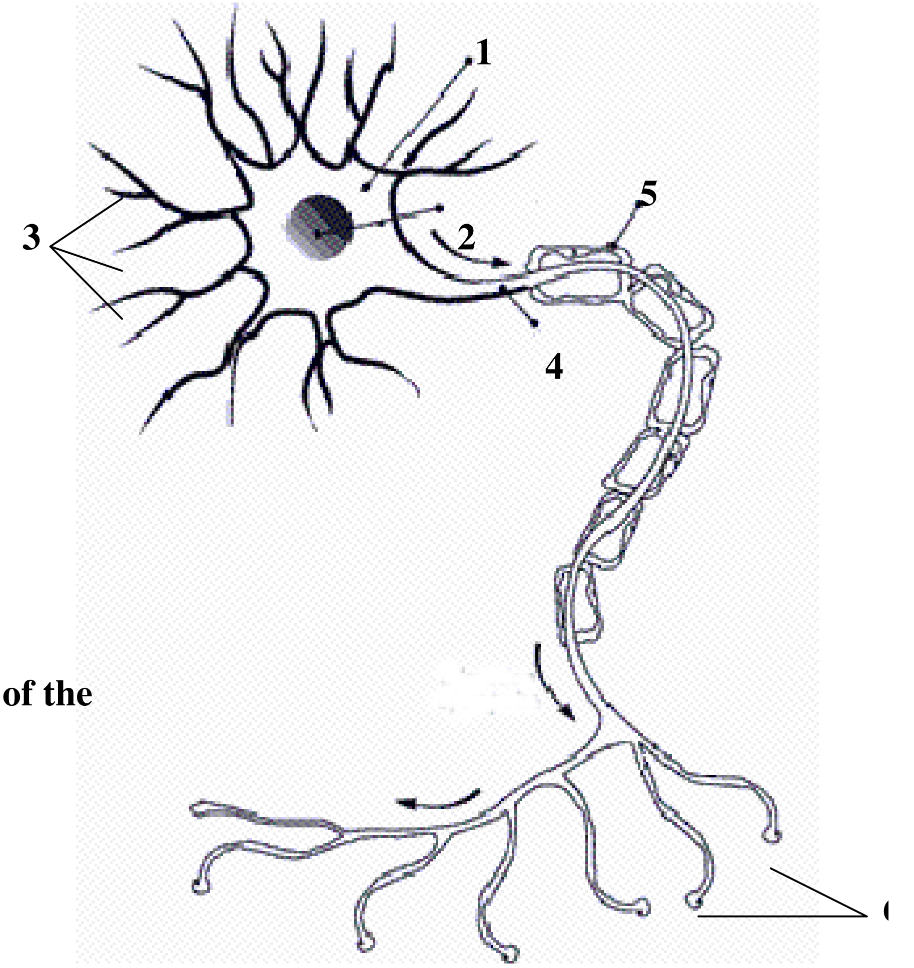
The nerve cell (= neuron)

The nerve cell is the structural and functional unit of the nervous processes and transmits information by electrical and chemical si

Structure:



Direction of the signal

1 = Cell body: It contains the cell nucleus and other cell organelles

2 = Cell nucleus: It contains the genetic information (DNA).

3 = Dendrites: These branched processes receive incoming messag other cells. They carry this information as an electri towards the cell body.

4 = Axon: It conveys outgoing messages electrically towards o Some axons can have a length of more than one met

5 = Myelin sheet: The supporting cells forming this sheath serve as an layer. This leads to a fast propagation of the signal.

6 = Synaptic terminals: These specialized endings relay signals from the ne cells by chemical means.

Nerve cell signalling

Electricity is a phenomena resulting from the flow of electric charge. In the neuron electrical charge is moved in form of ions (= positively or negatively charged atoms or molecules).

A Resting potential

Every cell has a voltage, or membrane potential, across its cell membrane resulting from the different concentration of ions on the inside and on the outside of a cell. A neuron in its **resting state** (not signalling) has usually a membrane potential of –70 mV (mill volts), the inside is negatively charged with respect to the outside.

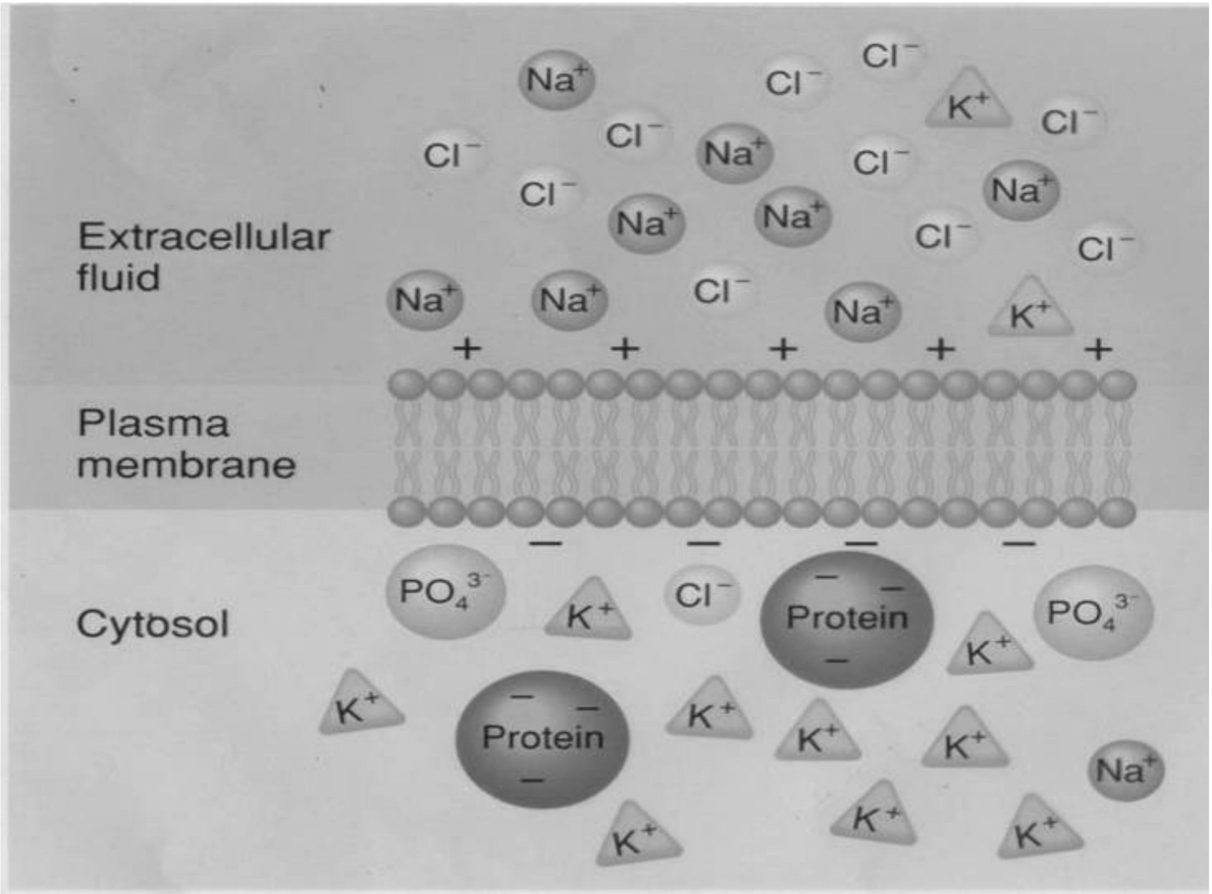
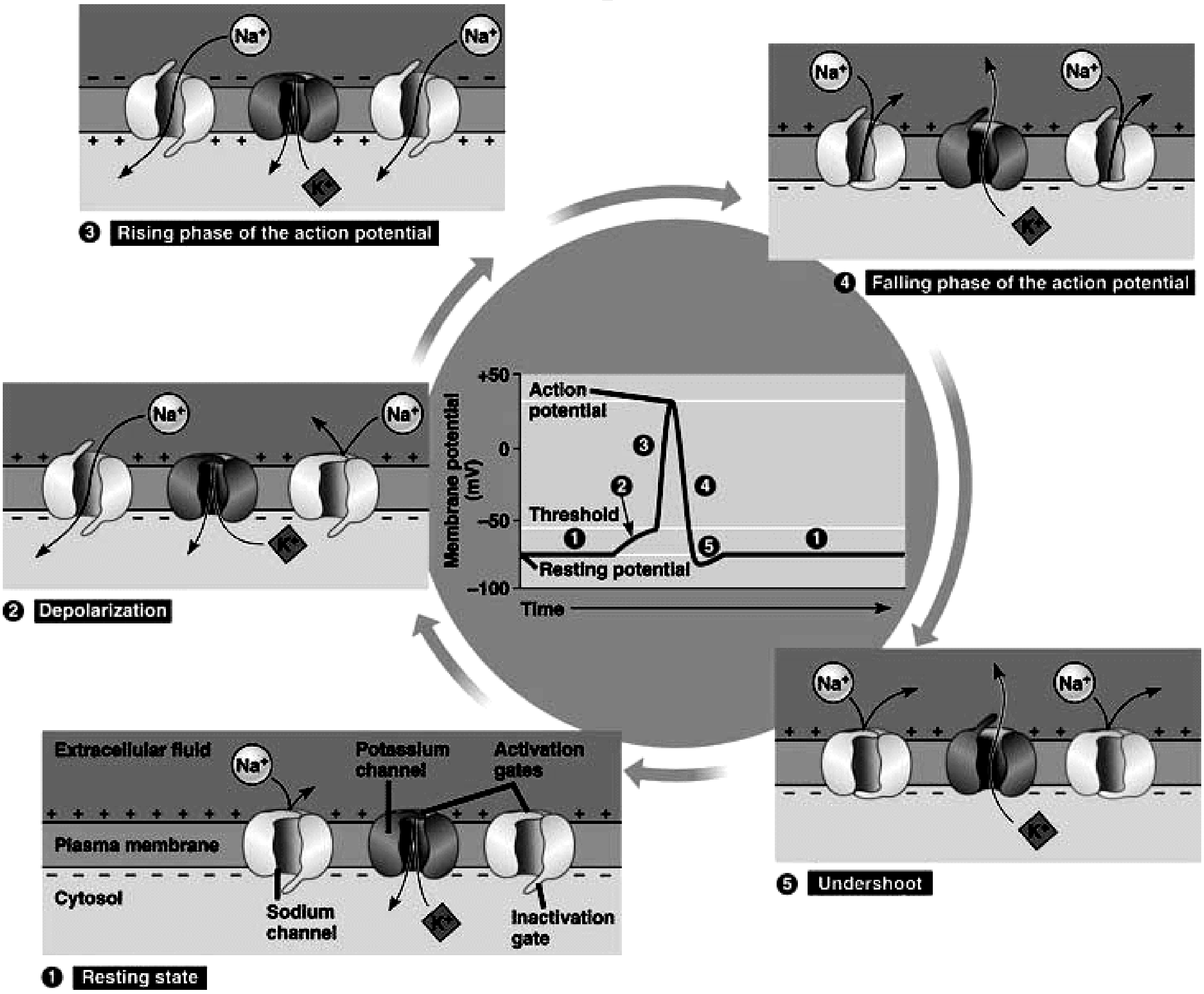


Fig.: Resting potential of a cell

In the propagation of an electric signal through the axon, Na^+ and K^+ ions play a key role. At the resting potential there is more Na^+ ions outside of the cell than on the inside. The other way round it is the case for K^+ ions. There are ion channels (proteins) embedded in the membrane (not shown) that allow the exchange of particular ions between the inside and the outside of the cell.
In order for a message to be sent via a neuron, there needs to be a change in the charge, thus sending a propagating (moving) signal down the axon of the neuron.

Nerve cell signalling

B The action potential



❶ Both, the sodium (Na^+) and potassium (K^+) channels are closed and the membrane resting potential is maintained (-70 mV).

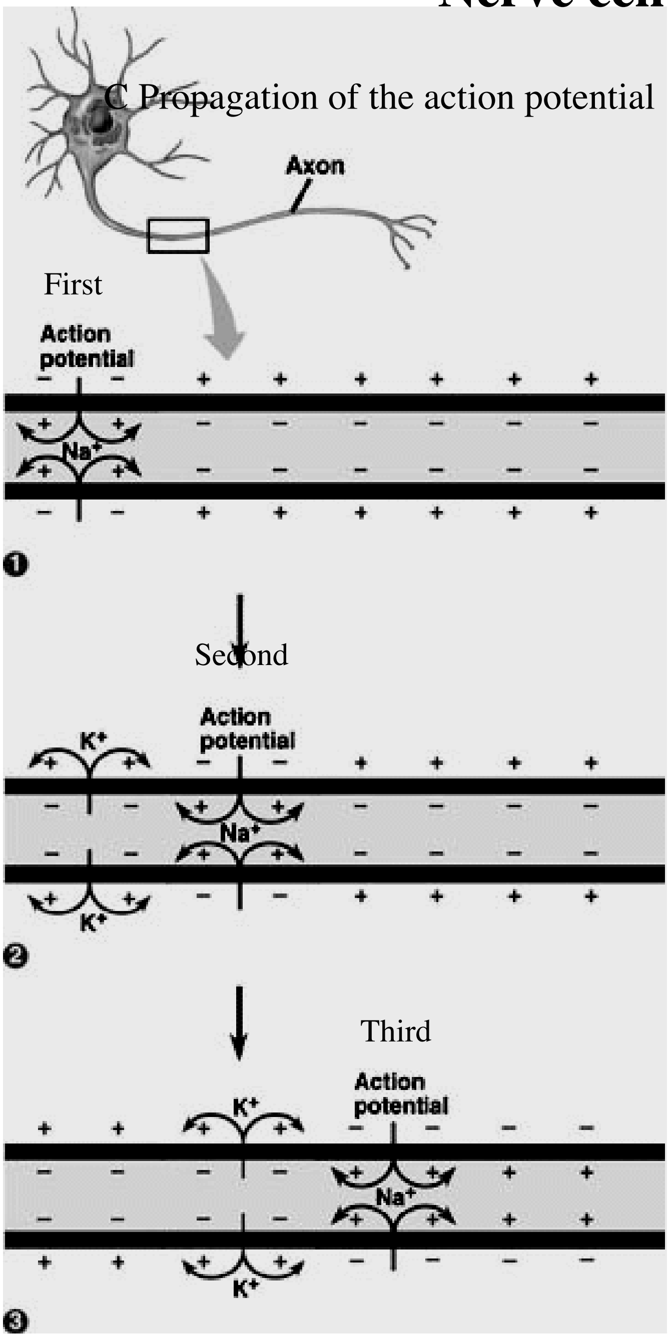
❷ A stimulus (i.e. light waves in a sensory neuron of the eye) leads to a change of voltage across the membrane (we'll see later). If the stimulus is strong enough and reaches threshold potential (-55mV), voltage- gated sodium (Na^+) channels at the beginning of the axon (see figure page 3 at nr. 4) open. This leads to the triggering of an **action potential** (see ❸).

❸ The opening of voltage-gated sodium (Na^+) channels causes an inward movement of sodium (Na^+) ions down the electrochemical gradient. The potassium (K^+) channels still remain closed. The interior of the cell becomes positive.

❹ By the time the peak is reached (usually +50mV) the sodium (Na^+) channels have already begun closing, reducing the rise in the potential. As this happens, the voltage-gated potassium (K^+) channels open and potassium (K^+) ions leave the cell. This causes neurons to return to the negative membrane potential.

❺ The potassium (K^+) channels will begin to close but they don't close fast enough and thus there is an overshoot of depolarization, making the membrane more negative than -70mV.
During the next 1-3 milliseconds (while the potential is below -70mV), there is a **refractory period** where the sodium (Na^+) channels cannot open by a stimulus. After that, a new action potential can be created.

Nerve cell signalling

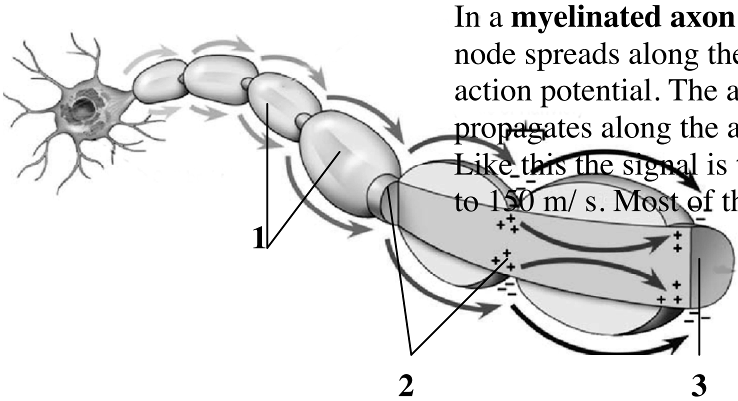


❶ An action potential is generated as sodium (Na^+) ions flow inward across the membrane at one location.

❷ The depolarization of the first action potential has spread to the neighbouring region of the membrane, depolarizing it and initiating a second action potential. At the site of the first action potential, the membrane is repolarizing as potassium (K^+) ions flows outward.

❸ A third action potential follows with repolarization in its wake. In this way, local currents of ions across the plasma membrane give rise to a nerve impulse that is propagated along the axon.

Saltatory conduction



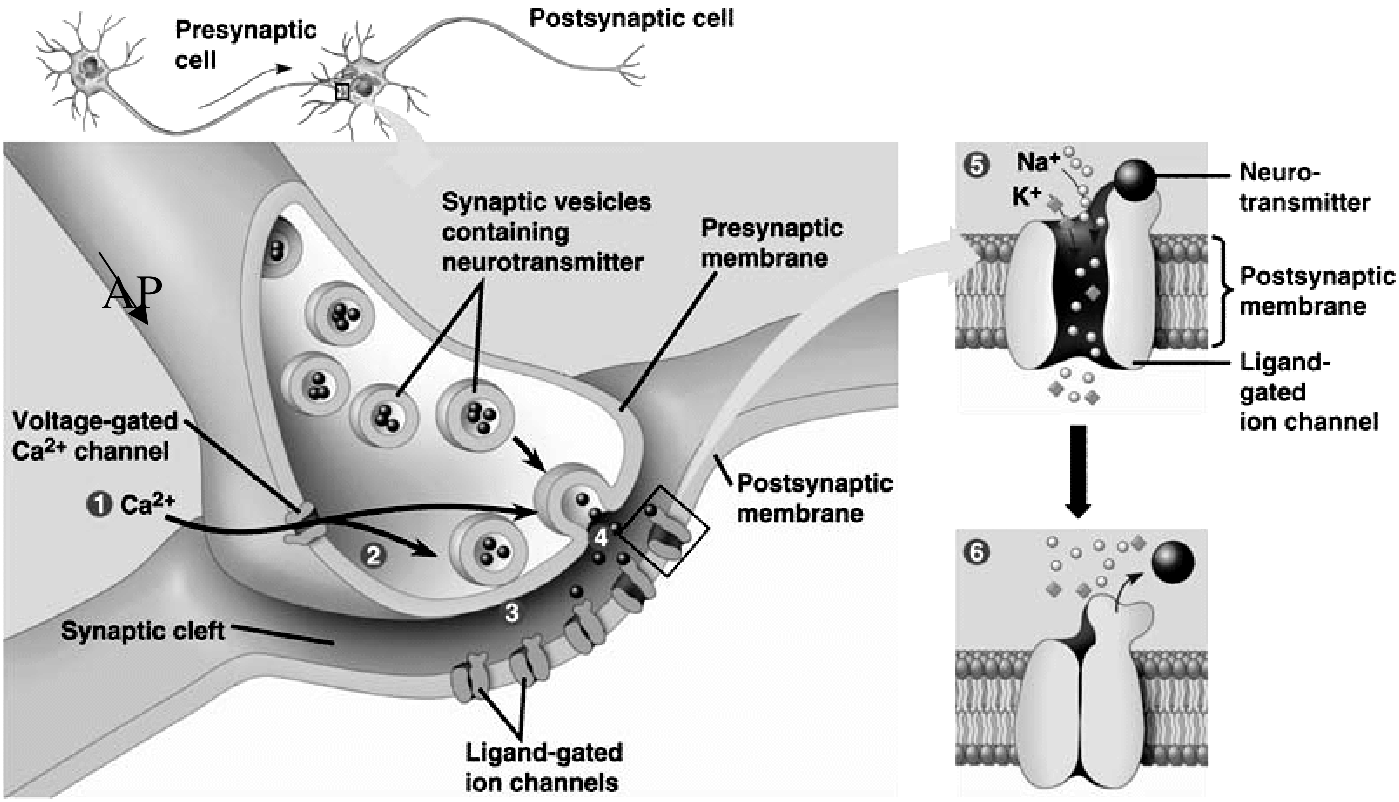
In a **myelinated axon**, the ion current during an action potential at one node spreads along the interior to the next node where it will trigger an action potential. The action potential thus jumps from node to node as it propagates along the axon.
Like this the signal is transmitted much faster, up to 150 m/ s. Most of the vertebrate neurons are myelinated.

1: Myelin sheath
2: Nodes
3: Axon

Nerve cell signalling

D The Synapse

The part of the neuron that connects to the next neuron is called a **synapse**. The synaptic cleft separates the presynaptic cell from the postsynaptic cell. At the synapse an electrical signal from a neuron is transmitted to the next one by chemical means (neurotransmitter molecules).



❶ An incoming action potential (AP) depolarizes the membrane of the synaptic terminals. This leads to the opening of voltage- gated Ca^{2+} channels. Ca^{2+} -ions diffuse into the presynaptic end bulbs.

❷ The presence of Ca^{2+} -ions inside the cell causes vesicles, containing **neurotransmitter** molecules, to fuse with the presynaptic membrane.

❸ The vesicle release neurotransmitter molecules into the synaptic cleft. These molecules diffuse across the cleft and bind to the receptors of ion channels embedded in the postsynaptic membrane.

❹ ❺ The binding of neurotransmitter molecules to their specific receptors opens specific ion channels- e.g. NA^{+} channels- causing a NA^{+} influx that depolarizes the postsynaptic membrane.

❻ The neurotransmitter molecules are quickly degraded by enzymes or are taken up by another neuron. This closes the ion channels and terminates the synaptic response.

SENSORY ORGANS

A THE EAR

ANATOMY AND FUNCTION

If you touch your larynx while you are talking you can feel the vocal cords vibrating. These vibrations are transmitted to the air and manifest as differences in the air pressure that are spread as sound waves.

The outer and the middle ear

Transduction of sound waves:

If sound waves get to our ear they are directed by the ***pinna*** to the ***ear canal***. At the end of the 3 cm long ear canal locates the ***eardrum (tympanic membrane)***, a 0.5 mm thin membrane that separates the ***outer ear*** from the ***middle ear***. Sound waves cause the ***eardrum*** to vibrate.

Behind the ***eardrum*** there is the ***middle ear space (tympanic cavity)***. To vibrate freely, the air pressure within the ***middle ear*** and the ***outer ear*** must be equal. This regulation is managed by the ***Eustachian tube***, which leads to the pharynx. This tube is not constantly open and one can experience fast changes in air pressure (i.e. driving up a mountain by car) resulting in the expansion of the ***eardrum*** and a slightly reduced hearing capacity. By pressing air from the lungs through the closed nose, the ***Eustachian tube*** opens and the difference in air pressure gets equalised again.

The ear bone ***hammer (malleus),*** followed by the ***anvil (incus) and*** the ***stirrup (stapes)***, build a joint connection between ***eardrum*** and the ***oval window*** and transmit vibrations between them. Because the energy, causing the ***eardrum*** to vibrate, is transmitted to the 30 times smaller ***oval window***, the pressure there is much bigger. Like this the vibrations from the ***eardrum*** to the ***oval window*** are enhanced. This is necessary because the ***oval window*** has to be moved against the lymphatic liquid lying behind it.

The inner ear

The structure of the cochlea

The ***cochlea*** (Fig, 1) is a 3 cm long bone tunnel in the shape of a snail shell. Inside there is the ***cochlear duct***, filled with liquid and surrounded by a membrane. Beneath the ***cochlear duct*** locates the ***lower duct (scala tympani),*** above it the ***upper duct (scala vestibuli)***. Both are filled with liquid as well. The membrane between ***lower duct*** and ***cochlear duct*** is called ***basilar membrane***. At the beginning of ***the upper duct*** locates the ***oval window***. From there it leads to the tip of the ***cochlea*** and than turns into the ***lower duct*** to the ***round window***. The ***cochlear duct*** lies, limited by membranes, in between these two ducts. The ***basilar membrane*** carries the ***Corti organ*** (Fig. 2*)* with the ***sensory cells*** (Fig. 3*)*. Their excitation is transmitted through nerve cells to the ***auditory nerve*** (see Fig. 4) and finally to the brain.

The process of hearing

Vibrations of the ***oval window*** are transmitted through the Lymph in the ***upper duct*** and ***lower duct*** to the ***round window***. The compression wave in the two channels moves the ***cochlear duct*** in the middle and therefore the ***basilar membrane***. The movement of the ***basilar membrane*** is different at different locations of the ***cochlea***, depending on the frequency of the sound waves. The vibrations of the ***basilar membrane*** lead to the folding of special structures (= **cilia**) within the ***sensory cells***, causing them to react with signalling.
In order to listen to music or having a conversation, we have to be capable of discriminating different tone pitches. Physically they differ in their frequency. The higher the frequency, the higher we perceive the sound.
High frequencies lead to a maximum stimulation of the ***basilar membrane*** close to the ***oval window***.
Low frequencies lead to a maximum stimulation of the ***basilar membrane*** close to the tip of the ***cochlea***.
Excitations from different regions of the ***cochlea*** are transmitted by different nerve cells to distinct regions of the auditory cortex.

THE COCHLEA (INNER EAR)

ANATOMY AND FUNCTION

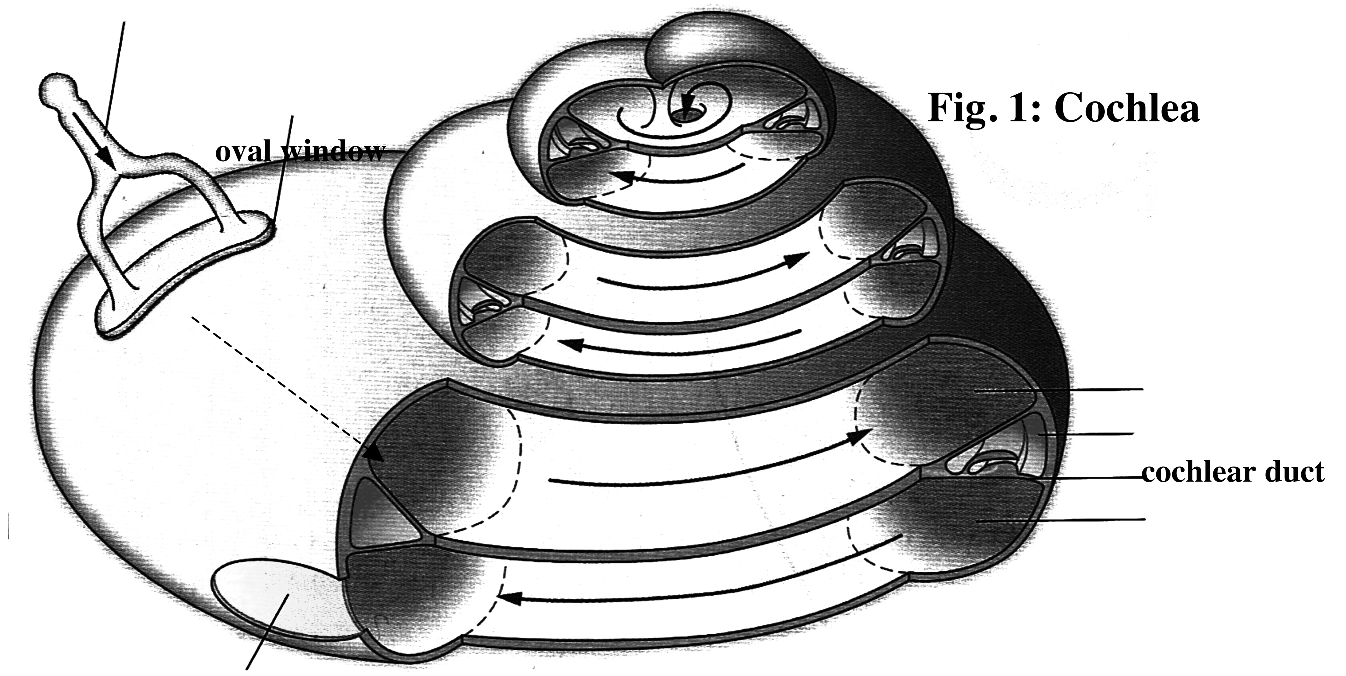


Fig. 1: Cochlea

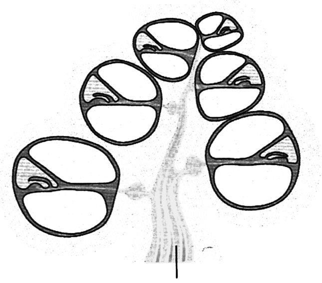


Fig. 4: Auditory nerve

Fig. 2: Corti Organ

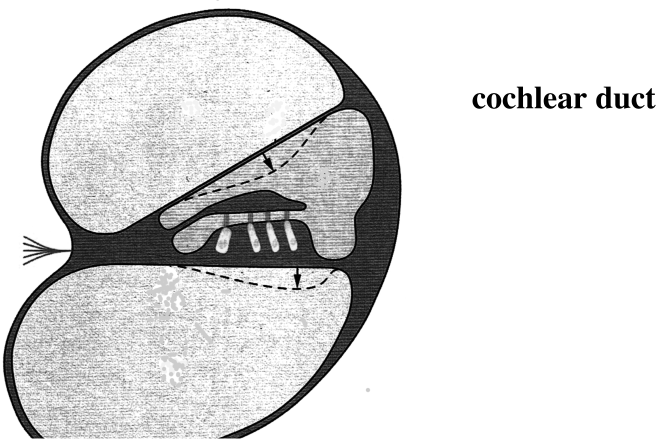
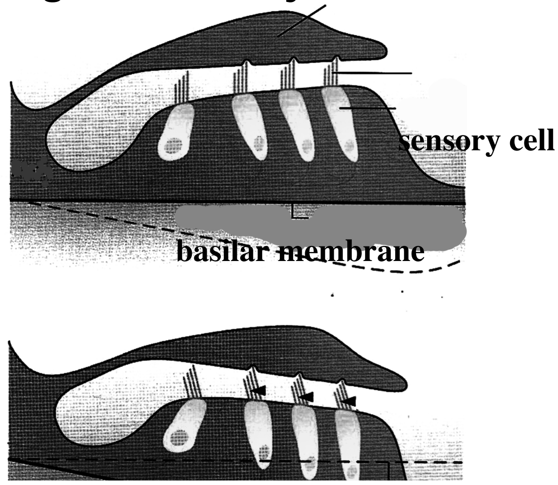
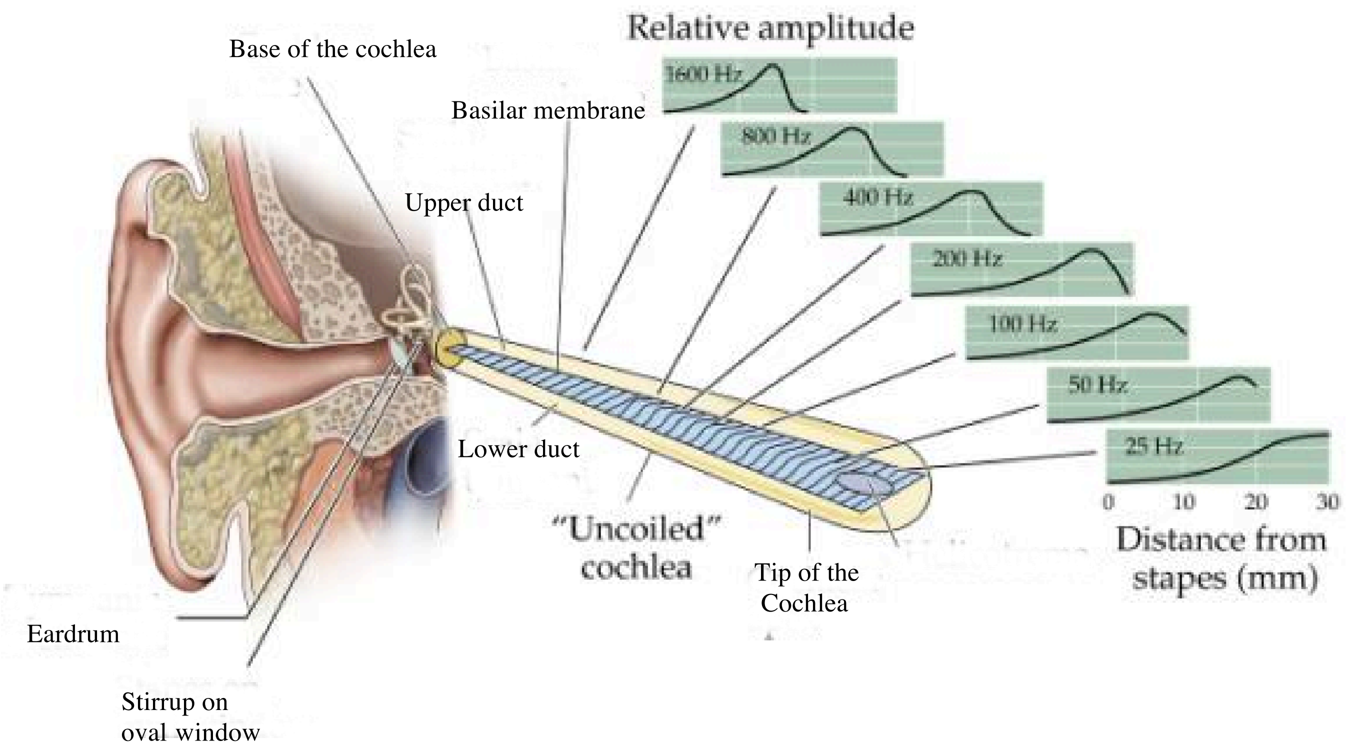


Fig. 3: Sensory cells



"Uncoiled cochlea"



Explanations cochlea:

Structural properties of the basilar membrane determine the way it responds to sound. Stiffness of the basilar membrane decreases from the base to the tip of the cochlea. High frequency sound waves have higher energy and can displace the stiffer part of the basilar membrane (near the base). Lower frequency sound waves have lower energy and displace the basilar membrane at the tip. Therefore sensory cells at different locations of the cochlea signal to the brain, giving information about the frequency (=pitch) of the sound wave.

The Nature of Sound

In order to hear, there has to be a sound source, which is a vibrating object. For example our vocal cords, a tuning fork or a car's engine and so on. The vibrations cause a change of the distribution of air molecules into areas of high density and areas of low density. This "wave" of air density then propagates through the air (speed 340 m/s) and possibly to our ear where it causes the eardrum to vibrate.

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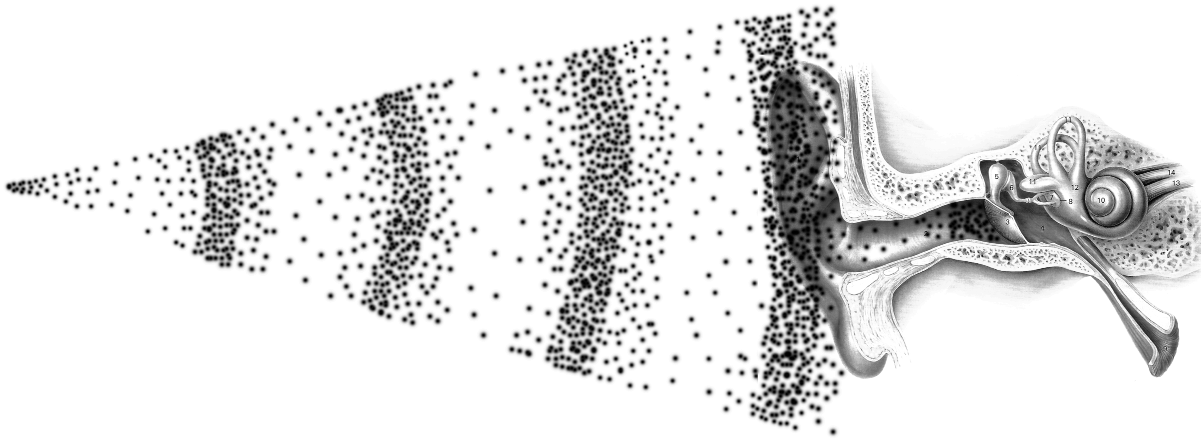
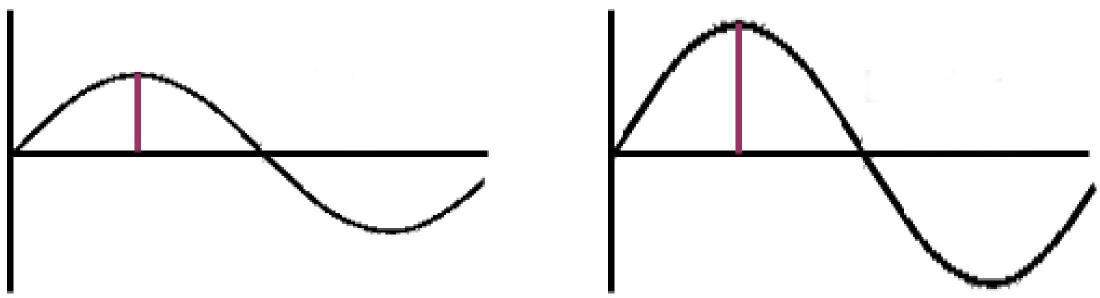
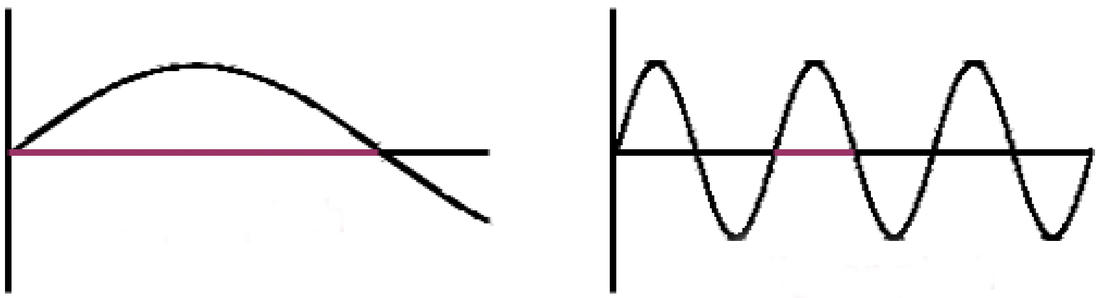


Loudness = Amplitude of the sound wave



What we perceive as loudness is the amplitude of the sound, or the difference between the high- and low- density parts of the sound waves. This corresponds to the "height" of the waves.

Pitch = Wave length of the sound wave



Pitch indicates the frequency (Hz) of the sound, or how far apart or close together the waves are. Sound waves with a long wave length (caused by "slow vibrating objects") we perceive as low sound and sound waves with a short wave length (caused by "fast vibrating objects") as high sound (compare cochlea).

EXPERIMENTS

SENSE OF HEARING

1. „Vibrations becoming sound waves“

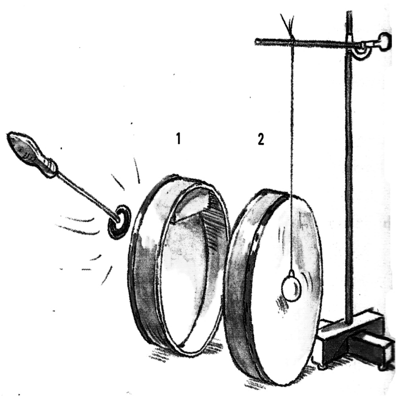
Theoretical background:

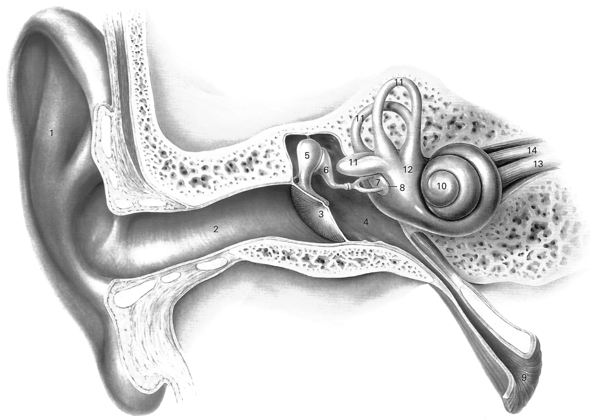
Sound waves spread as differences in air pressure. But sound waves can also be transmitted by solid material, i.e. rail tracks or by water. The more particles (density!) the medium, the faster it transmits the sound waves. Fill in (gas, solid, liquid)

Generally: __________________ faster than __________________ faster than __________________.

Without particles there is no sound. In space there is absolute quiet, since there is a vacuum.

A) Hit the tambourine (gong) and observe the ball in front of the second tambourine.





a) What do you observe?

___

b) Which are the corresponding structures in the human ear?

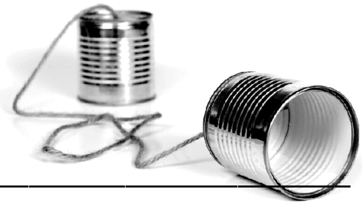
1st tambourine (gong): Source of sound (vibrating object)

Space between 1st and 2nd tambourine: ____________________________________

2nd tambourine: ____________________________________

Ball: ____________________________________

B) Talk through the „tin- telephone“. Try to explain precisely how the sound is transmitted from the speaker to the listener:



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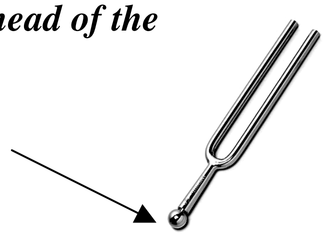
2. Transmission of sound by _______

The examinee closes both ear canals with the tips of the thumbs. The examiner then hits the tuning fork and places the single end directly on top of the head of the examinee.



a) ***What did you experience?***

____

b) Try to explain the experienced phenomena:

____

____

c) The examiner puts a vibrating tuning fork (single end) to the location on the examinees skull indicated by the arrow on the image. As soon as there is no more hearing of sound he holds it in front of the ear. Can you hear the sound again?

Try to explain the phenomena.

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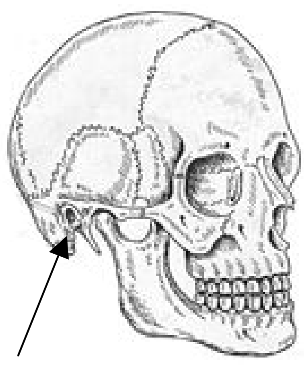
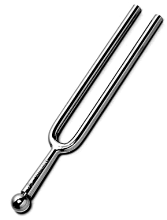


3. High pitch and low pitch- teacher demonstrations



Notes “tuning forks”: ____

____

____

Notes “drinking straw”: ____

____

____

4. Hearing capacity

Theoretical background:

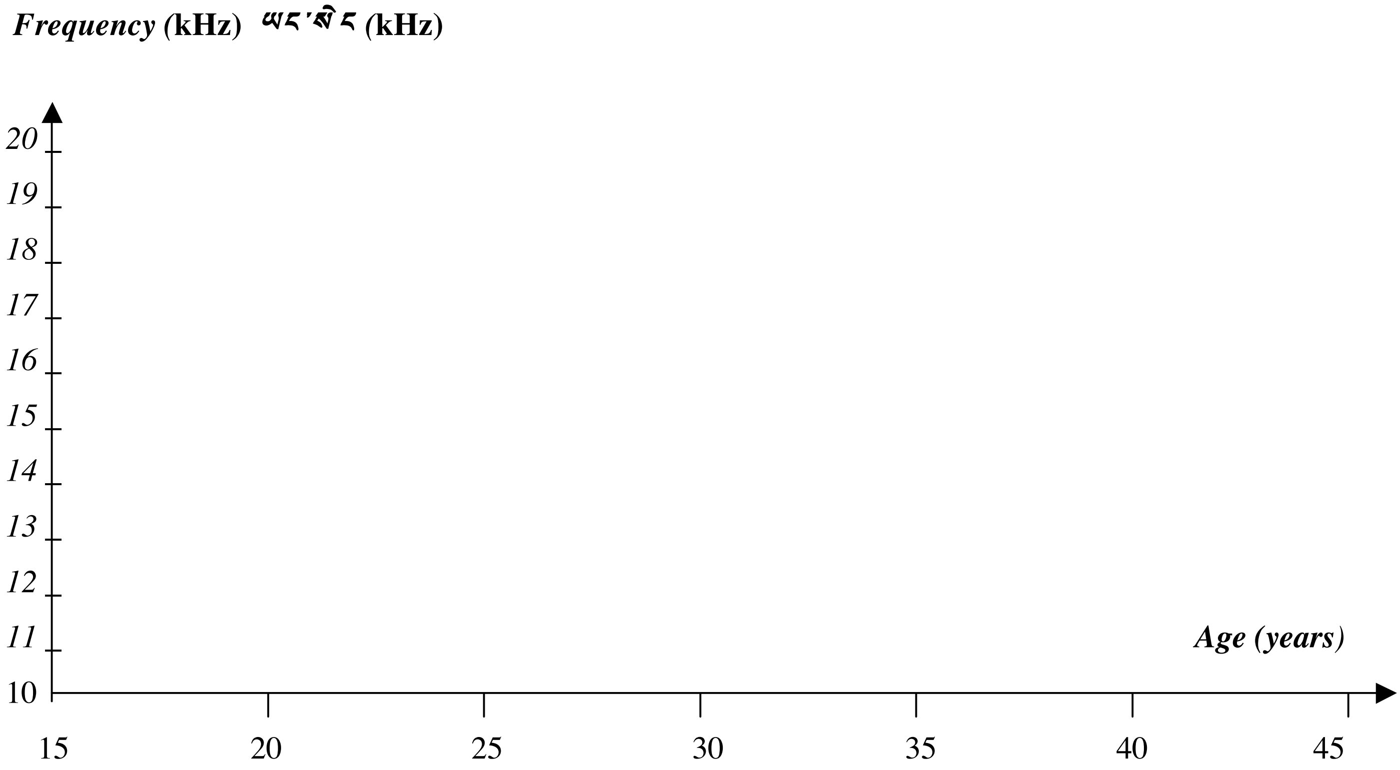
The lowest frequency human ears can perceive lies at 16 Hz. The highest frequency very much depends on the age of a person. At the age of 20 one can perceive frequencies as high as 20 kHz (=20000 Hz), at the age of 45 around 14 kHz and at the age of 65 around 5 kHz.

In a normal conversation frequencies vary mainly between 250 Hz and 5 kHz.

Put on the earphones and measure the highest frequency you are still able to clearly identify as sound.

Highest frequency: ________________ *My age:* ____________

Hearing capacity of the students of __________________________*:*

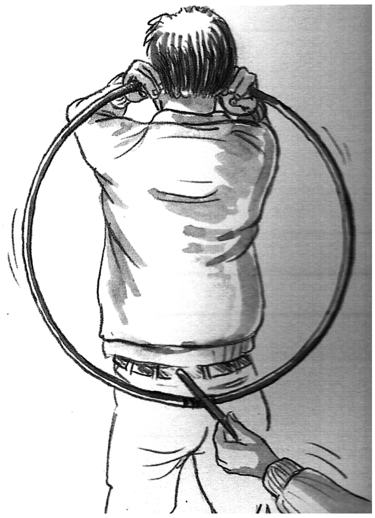


5. Information about the location of a sound source

Theoretical background:

We can locate the position of a sound source with closed eyes. This is possible because we are hearing with two ears. The ear closer to the sound source gets the signal earlier and with a slightly bigger intensity. Out of this minimal difference the brain calculates the location of the sound source. A difference in time, small as 0,00003 s, is still distinguishable!

The examinee puts the funnels of both ends of the tube to his ears. The examiner taps with a pen 10cm from the middle mark (red mark) on the tube. The examinee has to decide, if the sound source is closer to the right or the left. Then approach from each side to the middle by tapping on the tube and measure the smallest distance to the middle, in which a sound source could be allocated to the left or right.



______ cm

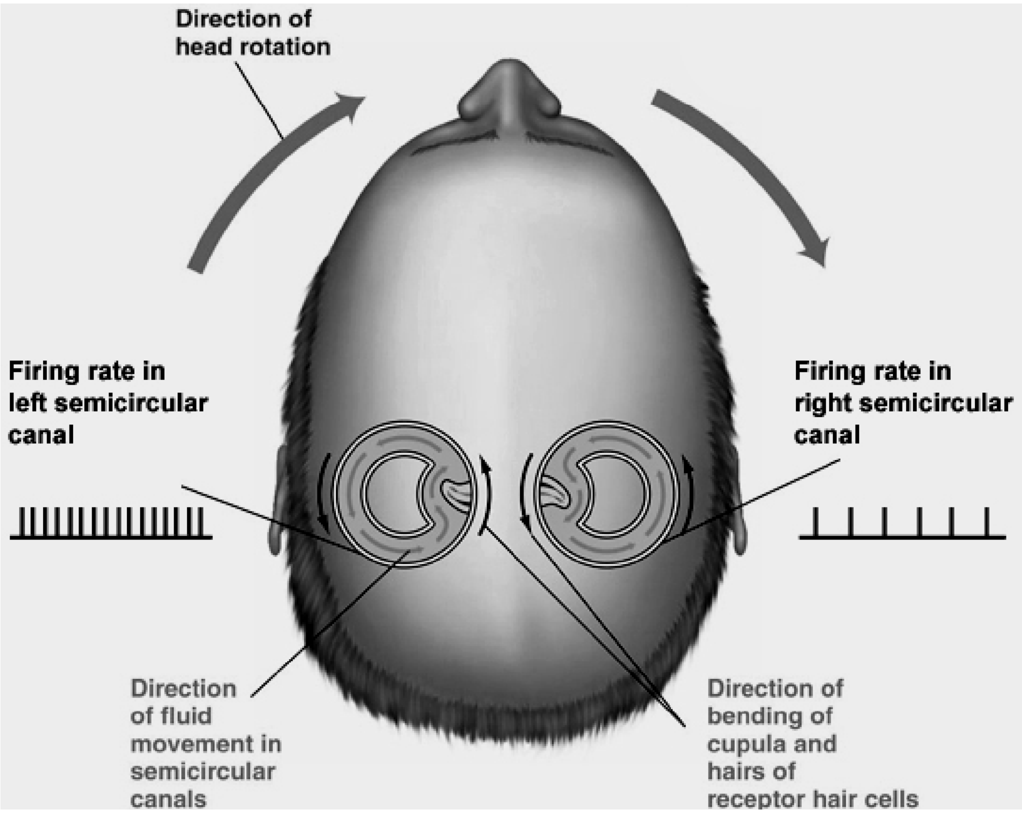
The Sense of Balance

The sense of balance helps prevent humans and animals from falling over when walking or standing still. Balance is the result of a number of body systems working together: The eyes (visual system), the skin (perception of pressure) and the ears (vestibular system in the inner ear). The vestibular system consists of the three **semi-circular canals** and the **otolith organs** (compare page 10, Nr. 11 and Nr. 12)

The semi-circular canals

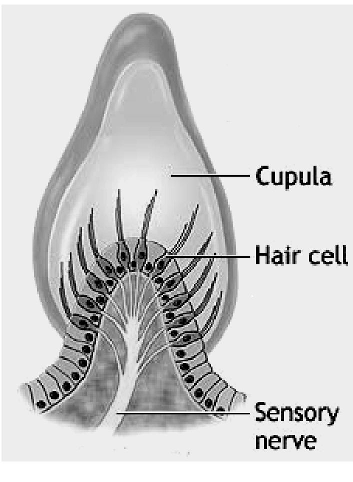
Movement of fluid in the semi-circular canals signals the brain about the direction and speed of the rotation of the head - for example, whether we are nodding our head up and down or looking from left to right (shown in figure a). Each semi-circular canal has a bulbed end that contains hair cells (figure b). Rotation of the head causes a flow of fluid in the semi-circular canal.

Figure a:



The flow of fluid causes displacement of the top portion of the hair cells that are embedded in the jelly-like cupula (figure b). According the direction of the bending, the hair cells increase (figure a, left) or decrease (figure a, right) their signalling.

Figure b:



The otolith organs

The otolith organs are responsible for detecting movement in a straight line. The hair cells of the otolith organs are covered with a jelly-like layer with tiny calcium stones. When the head is tilted or the body position is changed with respect to gravity the displacement of the stones causes the hair cells to bend. According the direction of the bending, the hair cells increase (figure left) or decrease (figure right) their signalling (compare semi-circular canals).

Signalling: