The body is controlled by chemical and electrical impulses i.e. by electrochemical signalling. Mesurement of the electrical signals generated by the body is used as diagnostic tools.

Measurement of electrical signals of the body

i.e. Electrophysiological Measurements

Electro

- **C**ardo**g**raphy (**ECG**) , the heart
- **E**ncephalo**g**raphy (**EEG**), the brain
- **M**yo**g**raphy (**EMG**) , the muscles
- **G**astro**g**raphy (**EGG**), the gut
- **O**culo**g**raphy (**EOG**), the eyes
- **R**etino**g**raphy (**ERG**), the retina

How can we record electrical signals that are generted in the body?

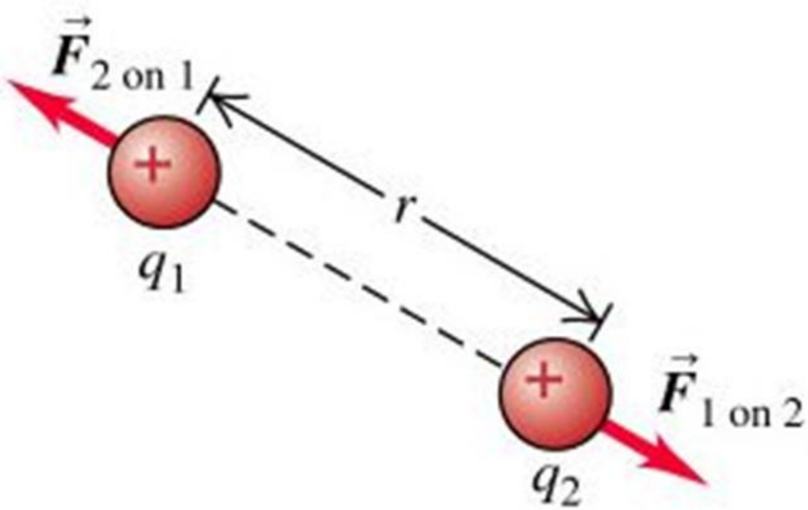
A little bit of physics

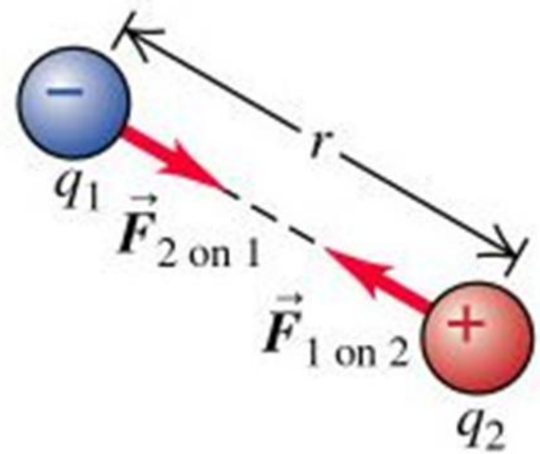
Electric charge is a basic property of matter

Positive and Negative charge (each has a value of 1.6×10^{-19} Coulombs

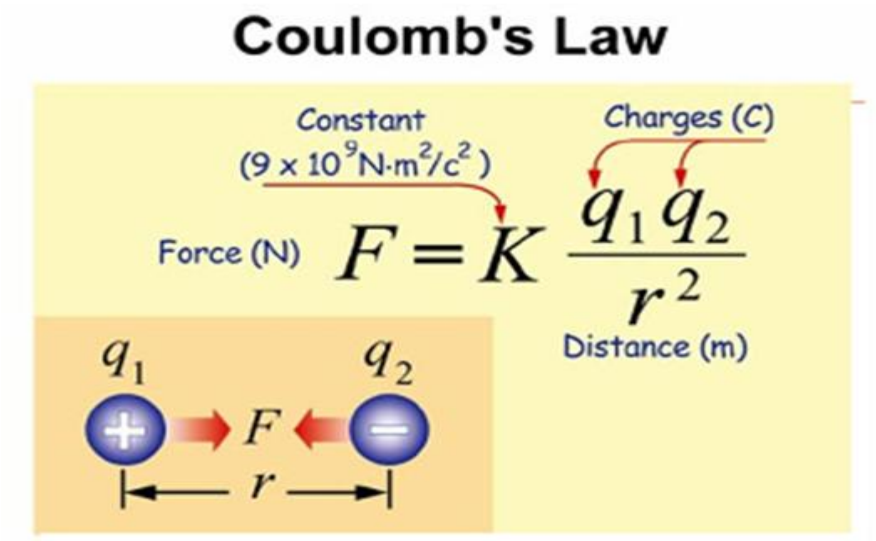
Like charges repel , Unlike charges attract

In an isolated system, the net charge of the system remains constant (Charge Conservation)





Force between charges



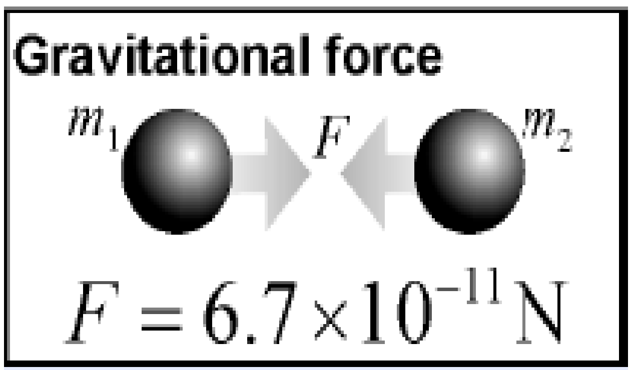
k proportionality constant (the value of 8.988×10^9 Nm^2/c^2)

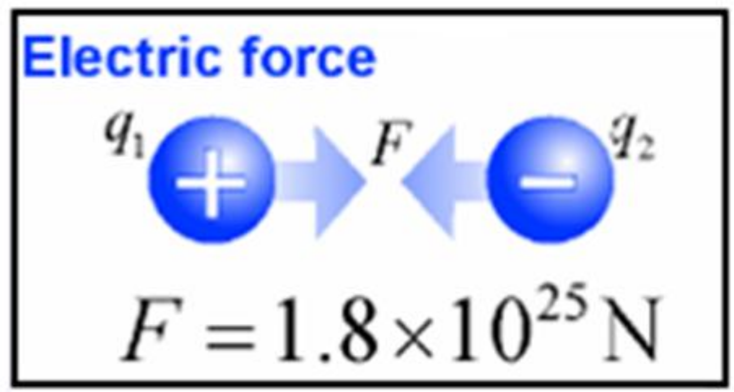
Like all forces, the electric force is a **Vector** and the force between two charges is <u>directed</u> along the **line connecting their centers**

The equation gives the vectorial force on charged object 2 due to charged object 1

$$F_{12} = k \frac{q_1 q_2}{r^2} \hat{r}_{12}$$

The Electric Force is like the Gravitational Force except that it is much much stronger



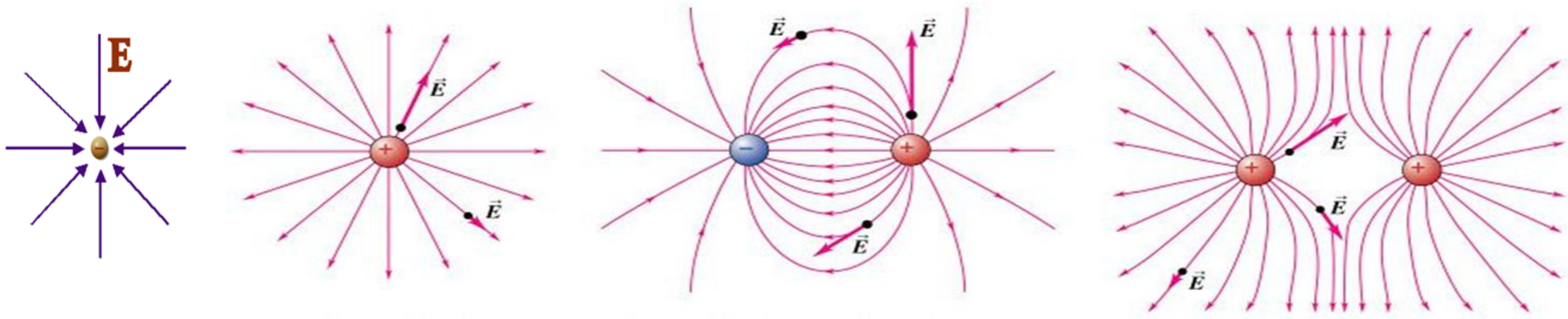


Electric Field

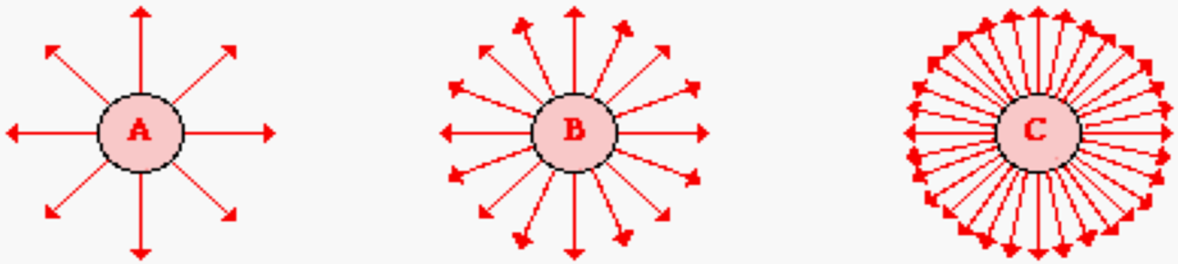
The term "field" means the space in whic a quantity is defined for each point of this space.
The field can be scalar if the quantity is a scalar quantity like the temperture, or it can be vectorial , if we have a vectorial quantity.
If we measure the temperature of air at different points in the room we get the temperature field for this room. This will be a scalar field as temperature is a scalar quantity, it does not have direction only magnitude.
But if e measure the weight of a given object at different points above the surface, we will get the gravitational field, which is a vector field as the weight of an object is a vector quantity, it has magnitude as well as direction.

Electric Field

The electric field is formed around any electric charge or charges. If electric charges do not move, electric field is called – an **electrostatic field**.

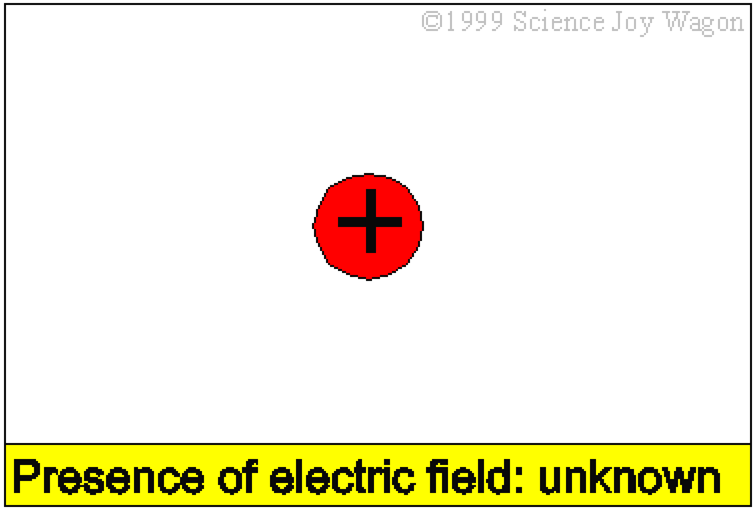


Density of Lines in Patterns



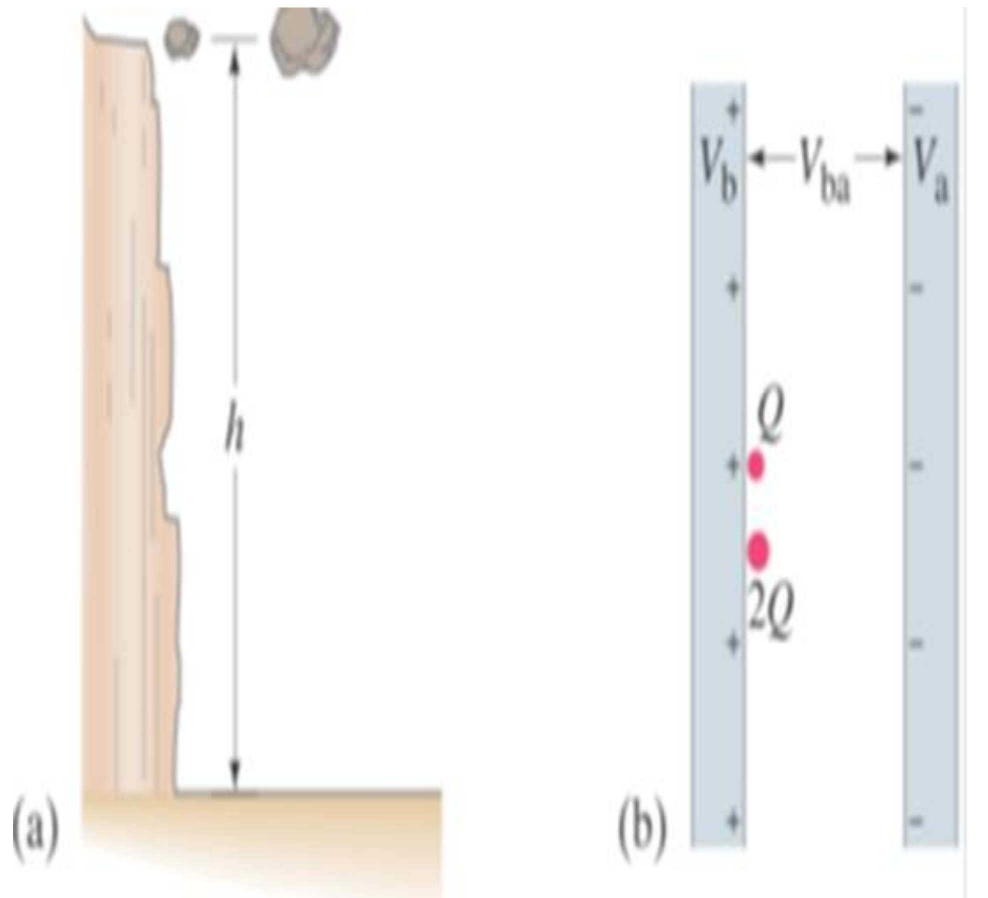
The density of electric field lines around these three objects reveals that the quantity of charge on C is greater than that on B which is greater than that on A.

An electric field is defined as being present in any region where a charged object experiences an electric force.
i.e a field exists if a test charge (+) feels a force at that spot



Electrostatic Potential Energy and Potential Difference

Moving an object upward against the gravitational field increases its gravitational potential energy. the electric field created by a positive charge. Work would be required to move a positive test charge towards the field source (+ fiels sorce) against the electric field and so it will increase the electric potential energy. The electric potential energy is dependent upon the **amount of charge** on the object experiencing the field and upon the **location** within the field



Electrostatic Potential Energy and Potential Difference

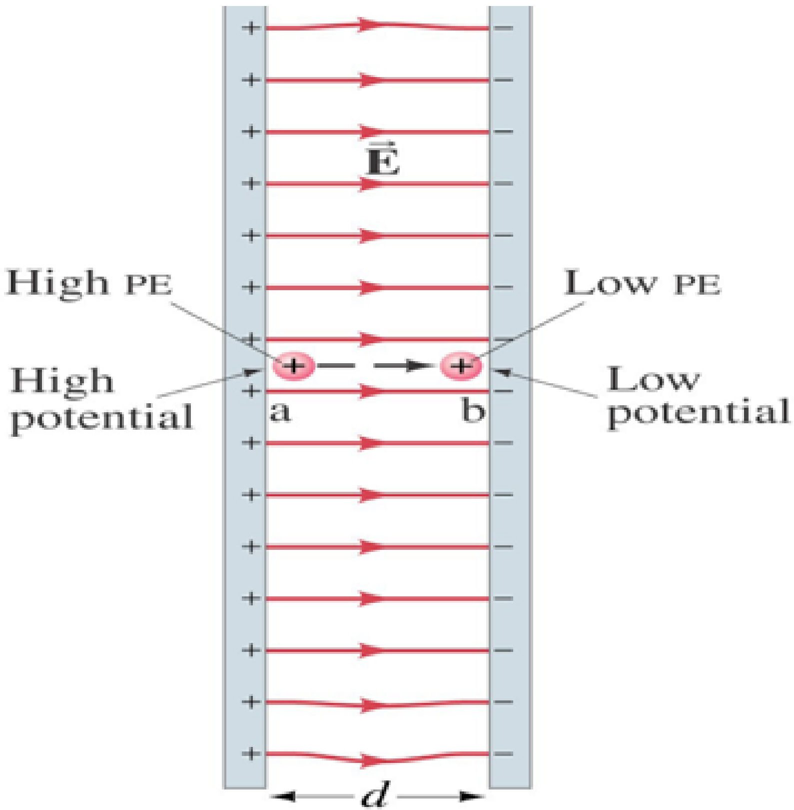
Basic Definition:

Electric potential is defined as potential energy per unit (test) charge:

Unit of electric potential: the **volt (**V**). 1** V **= I** J/C**.**

$$V_a = \frac{PE_a}{q}$$

electric potential energy has a dependency upon the charge of the object experiencing the electric field, electric potential is purely location dependent

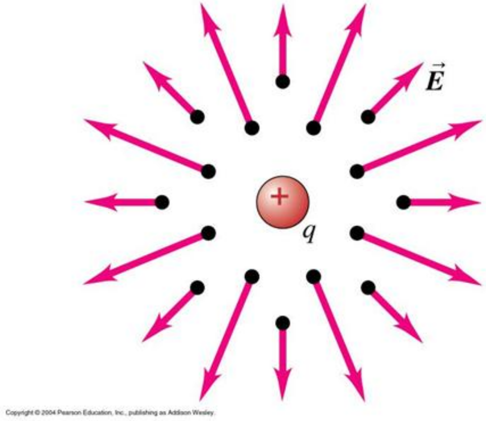


Electrostatic Potential Energy and Potential Difference

Only **differences in potential** can be measured,
So at infinite r, $V = 0$.

Electric Potential Due to a Point Charge

$$V = k\frac{Q}{r} = \frac{1}{4\pi\epsilon_0}\frac{Q}{r}$$

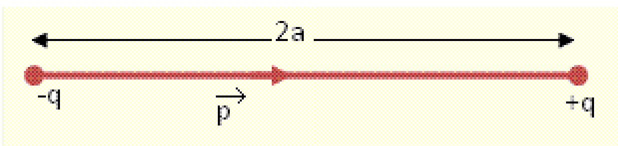


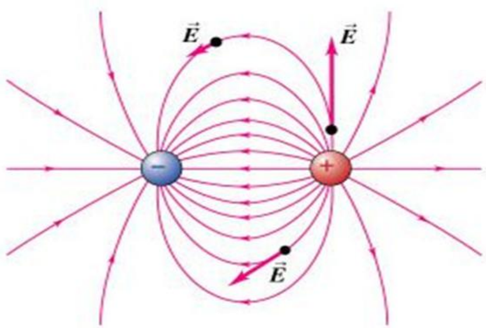
V is a scalar it has no direction.
r is the distance from Q to observation point.

ELECTRIC DIPOLE

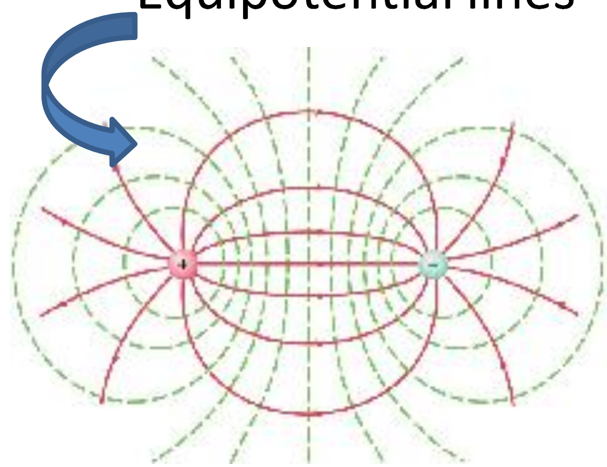
An electric dipole is formed from two charges of opposite sign and equal magnitude separated by a (very small distance with respect to oberver) distance **d**

The line between two charges is called **dipole axis.**





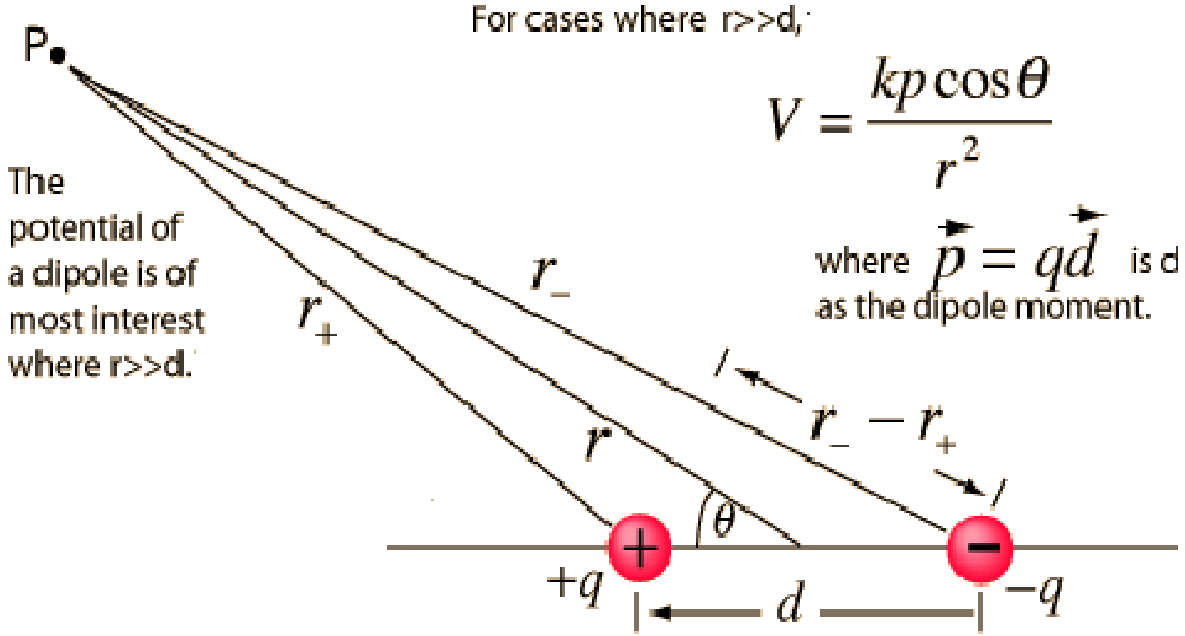
Equipotential lines



The potential due to an electric dipole is just the sum of the potentials due to each charge,

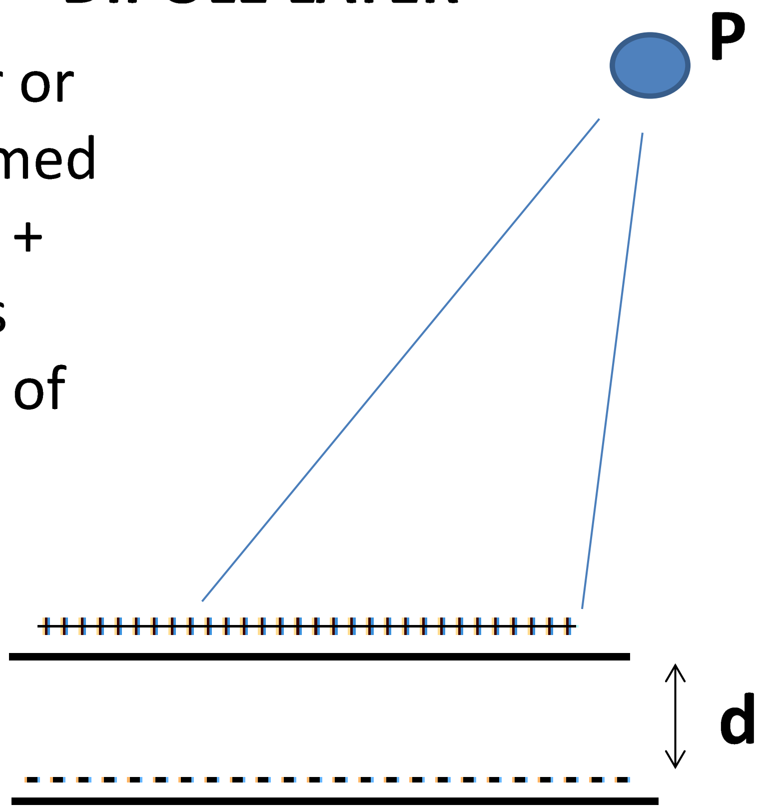
$$V = \Sigma_Q V_{\text{due to } Q} = (V+) + (V-)$$

Potential Due to Electric Dipole

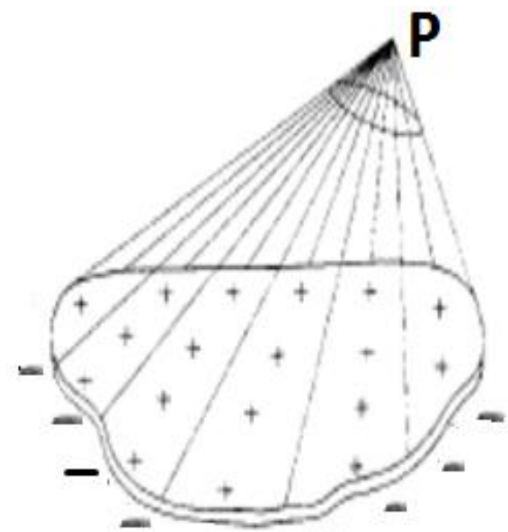


DİPOLE LAYER

A dipole layer or surface is formed by separating + and – charges across a layer of thickness **d**



Actually point P sees a surface with a certain angle which is a three dimensional angle



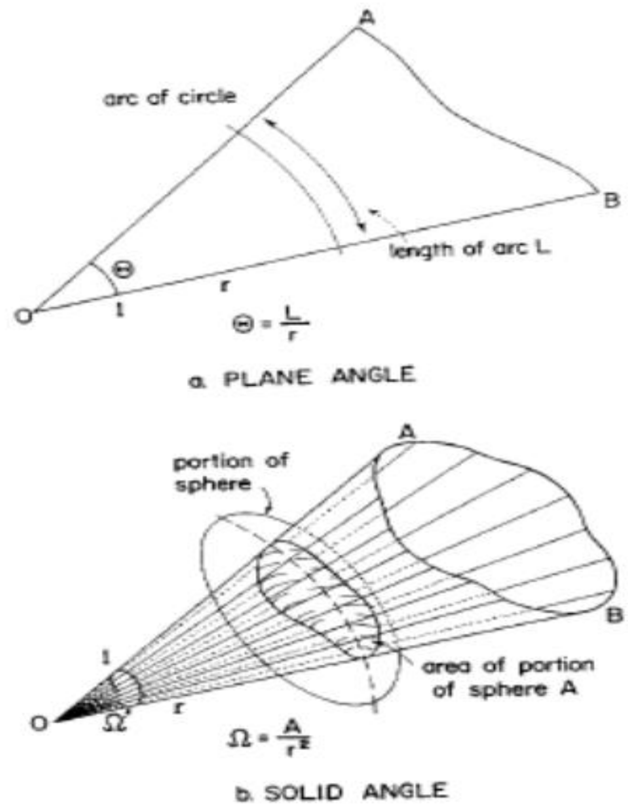
a dipole layer

The dipole layer will create a potential at point **P** but now this depends on how much the point P **“sees”** the dipole layer.

DİPOLE LAYER

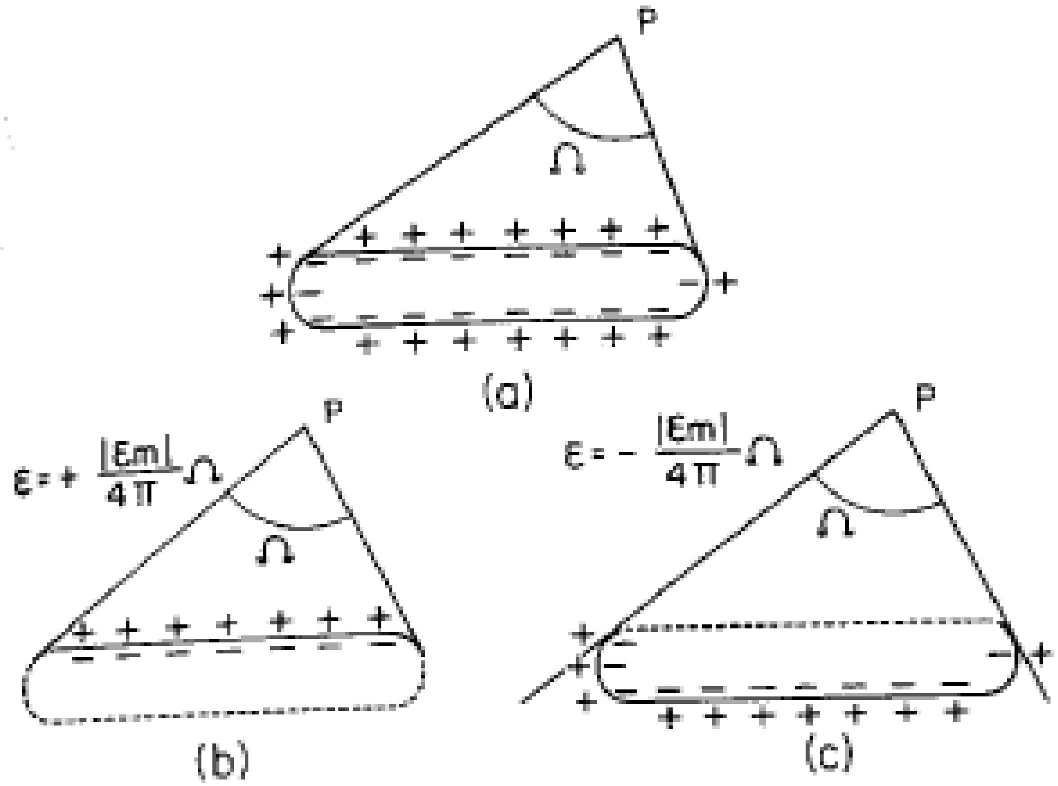
The **Solid Angle**
A solid angle is the three dimensional equivalent of a plane (two dimensional) angle. unit **steradian**

At any point, the potential due to a dipole layer is proportional to the solid angle subtended by the surface at that point



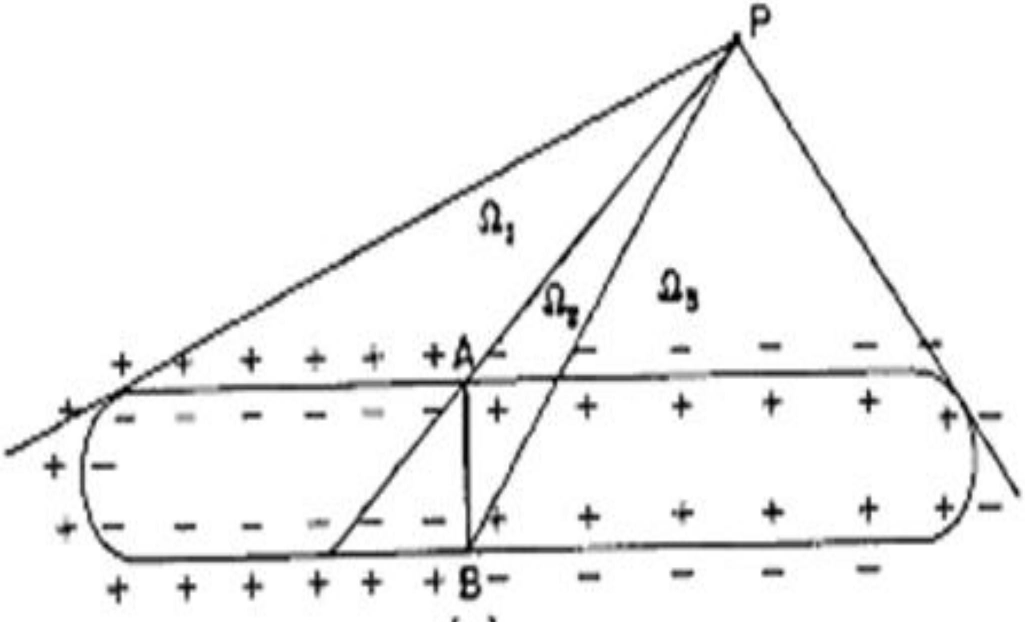
$$V = Vm/\ 4\pi\ .\ \Omega$$

where Ω is the solid angle

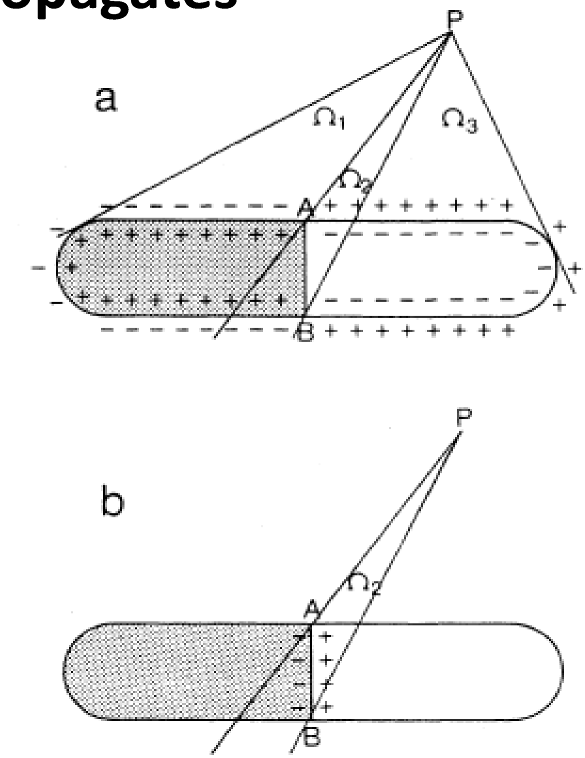


Cross-section of a closed cylindrical cell,
The potential of a resting cell at P is zerov
From point P the electrode "sees" two equally and oppositely polarized cell subtending the angle Ω ,
At **b** V is + because the + side faces the P
At **c** V is – because the negative side faces **P**
the total potential at **a** is then zero

Potential at P as depolarization wave propagates



(a)

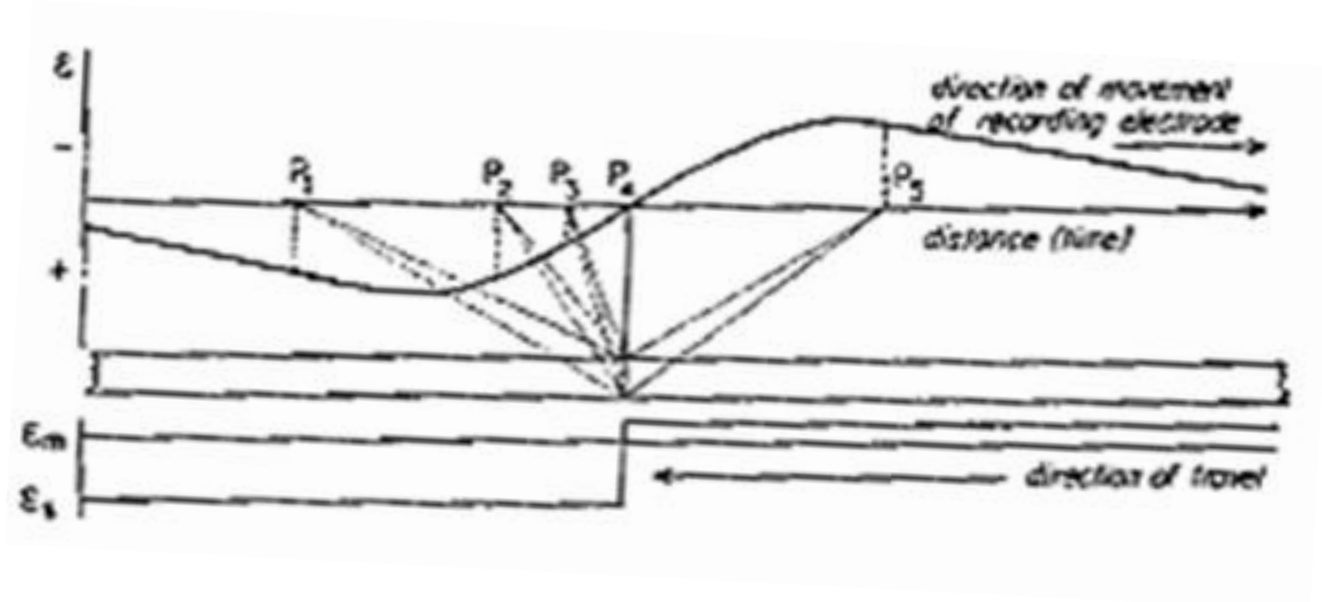


Total solid angle is divided into three : $\Omega 1$, $\Omega 2$, $\Omega 3$

Potential at $\Omega 1$, and $\Omega 3$ is zero.

But at $\Omega 2$ both membranes facing P have the same sign so total is not zero. At AB membrane potential reverses.

For a simple representation charges of the nearer and farther membranes subtending solid angle Ω 2 are placed on the axial section through a cylindrical cell.



Potential generated by a propagating wave:
Diphasic potential.
When recording electrode is at P1,P2,P3 it sees positive side of wavefront (dipole).
As the recording electrode moves toward right, solid angle of first increases and then decreases and becomes zero at P4 and then becomes negative.

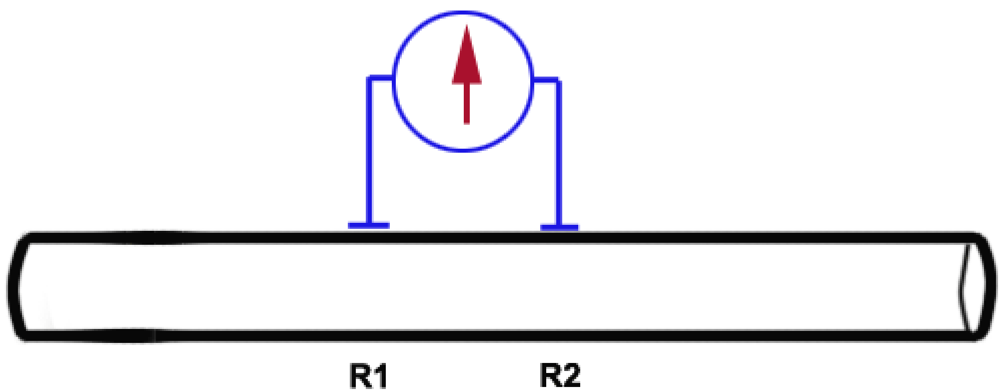
Diphasic and Monophasic Recording

A **biphasic** system is one which has two phases.

In biphasic recording both (two) electrodes are active recording the change in potential subtended by their solid angle.

Biphasic recording: the potential **difference** between two electrodes is measured.

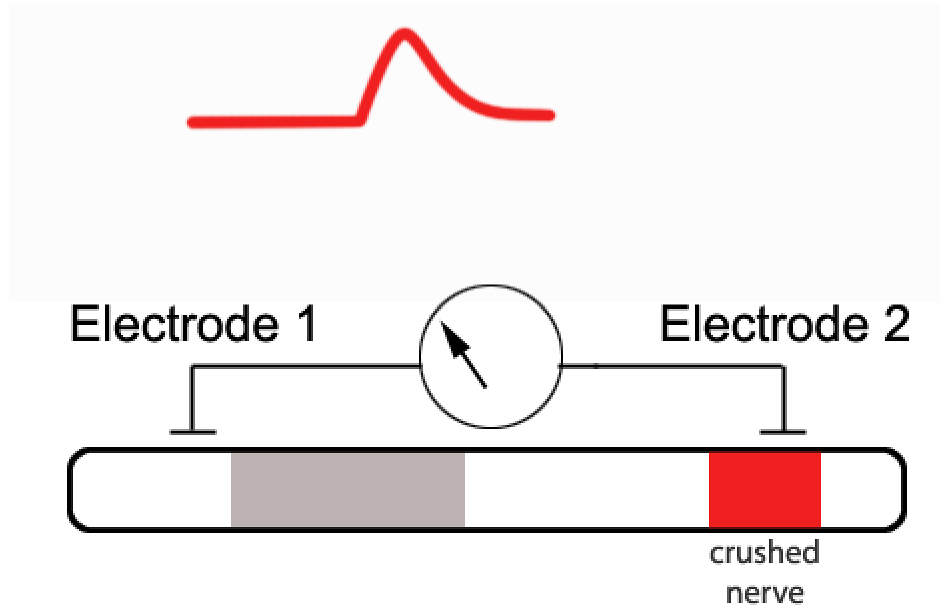
Depolarization passes the first electrode: The first electrode becomes negative with respect to the second electrode. Depolarization passes the second electrode: The two electrodes are now both depolarized and therefore have the same volt-potential. Depolarization then reaches second electrode while first depolarizes.


R1
R2

Monohasic Recording

Utilizes one electrode plus an electrode of constant voltage (also called demarcation potential){the tissue is crushed so that there is a constant potential}.

The electrical potential outside the neuron is then recorded as action potentials pass through.



DEPOLARIZATION is represented as an upward peak on the graph, where up is more negative and down is more positive. As the action potential passes the electrode, the outside of the neuron becomes more negative, as Na+ flux in.

ELECTROENCEPHALOGRAPHY

The recording machine, the **electroencephalograph** produces a 16-channel ink-written record of brain waves, called the **encephalogram**

The electroencephalogram (EEG) is a recording of the electrical activity of the brain from the scalp. (it may be recorded from electrodes placed directly on or in the brain itself.) The recorded waveforms reflect the cortical electrical activity.

The EEG is considered to be a macroscopic phenomenon, i.e. it results from activity of large populations of neurons.

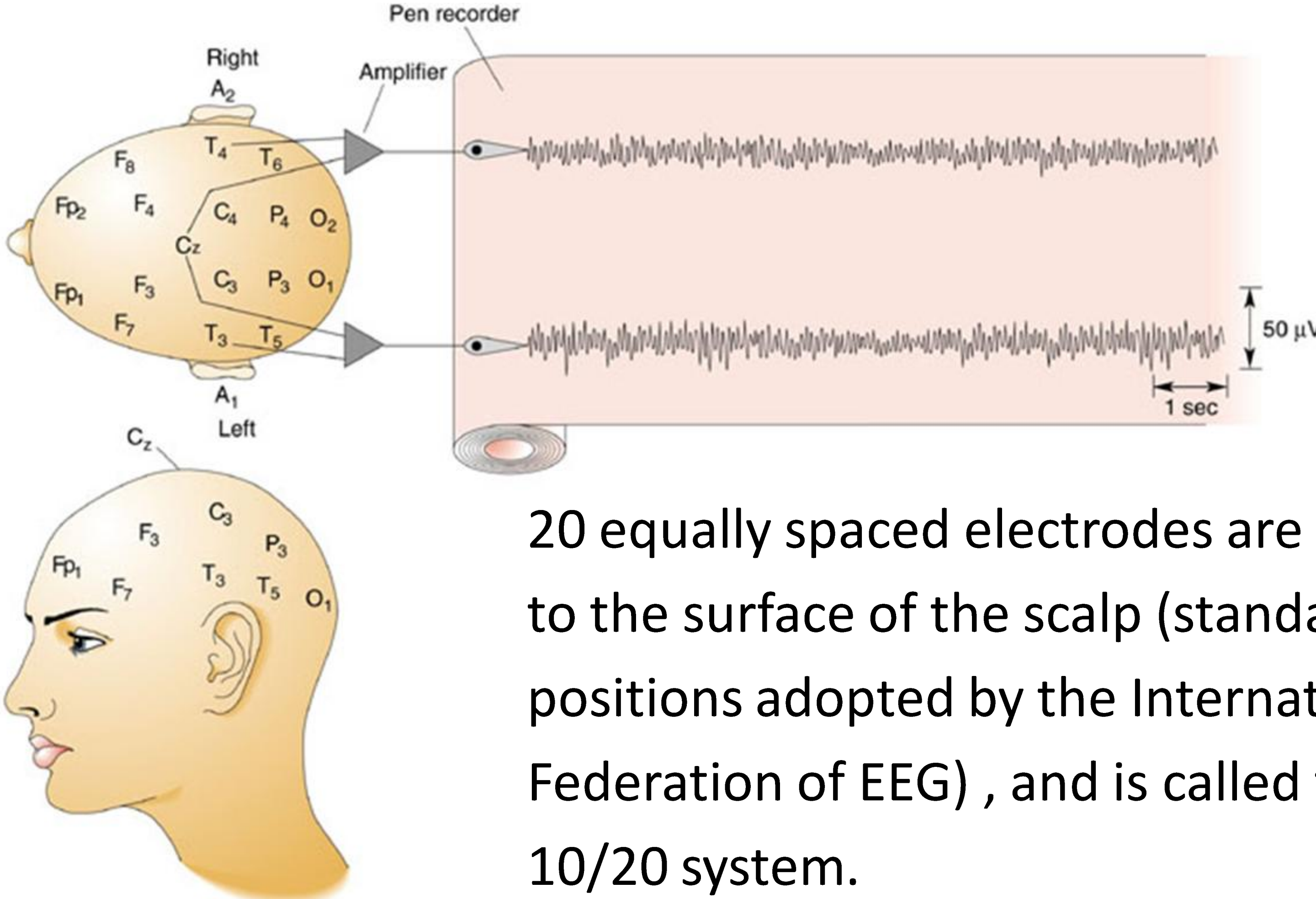
The EEG measured directly from the cortical surface is called electrocortiogram while when using depth probes it is called electrogram

used to:

(1) monitor alertness, coma and brain death;
(2) locate areas of damage following head injury, stroke, tumour, etc.;
(3) test afferent pathways (by evoked potentials);
(4) monitor cognitive engagement (alpha rhythm);
(5) produce biofeedback situations, alpha, etc.;
(6) control anaesthesia depth (“servo anaesthesia”);
(7) investigate epilepsy and locate seizure origin;
(8) test epilepsy drug effects;
(9) assist in experimental cortical excision of epileptic focus;
(10) monitor human and animal brain development;
(11) test drugs for convulsive effects;
(12) investigate sleep disorder and physiology.

In 1875, English physician Richard Caton became the first to publish what are now known as the Electroencephalogram (EEG) and Event-Related Potentials (ERPs). Caton observed the EEG from the exposed brains of rabbits and monkeys

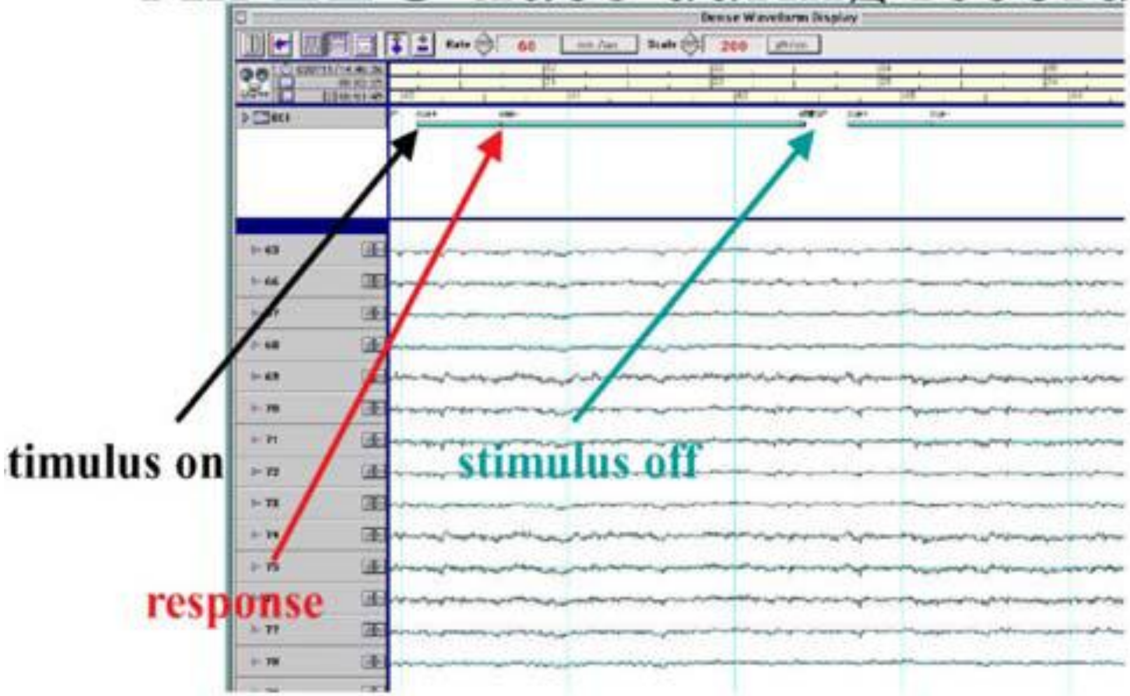
Dr. Hans Berger, an Austrian psychiatrist was the **first to record electroencephalographs from humans**. **Berger found the regular waves at about 10 cycles per second** that he named the **Alpha waves** because they were the first waveforms he isolated in the human EEG. **Berger published a paper in 1929** based on the research he had done five years earlier with his son Klaus as a subject. He made 73 recordings, which became the **first published EEGs of humans**.



20 equally spaced electrodes are pasted to the surface of the scalp (standard positions adopted by the International Federation of EEG) , and is called the 10/20 system.

Standard placements of electrodes on the human scalp: A, auricle; C, central; F, frontal; Fp, frontal pole; O, occipital; P, parietal; T, temporal.

An EEG trace during recording

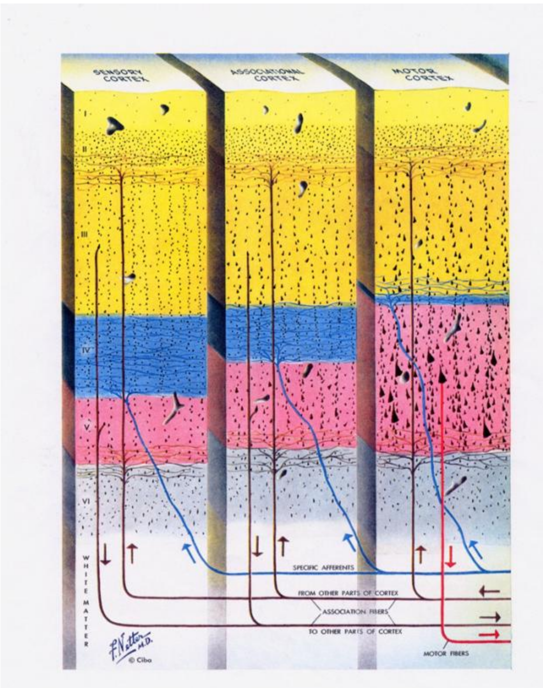


The Basis of EEG

For brain electrical activity to be detectable through skull,
The signal must be strong enough
To achieve this : All neurons must generate signals at the same time and they must be oriented in the same direction so negative and positive don’t cancel each other out when summed

Synchronized neuronal activity from hundreds of thousands or millions of neurons acting together form the electrical patterns on the surface of the brain (brain waves).
Neurons responsible of EEG signals are the pyramidal cells.

Pyramidal Cell Orientation in Cortex



-Pyramidal cells extend through all layers of cortex , are vertically oriented and paralell to each other (closely packed – several hundred cells, each pack receives similar input)

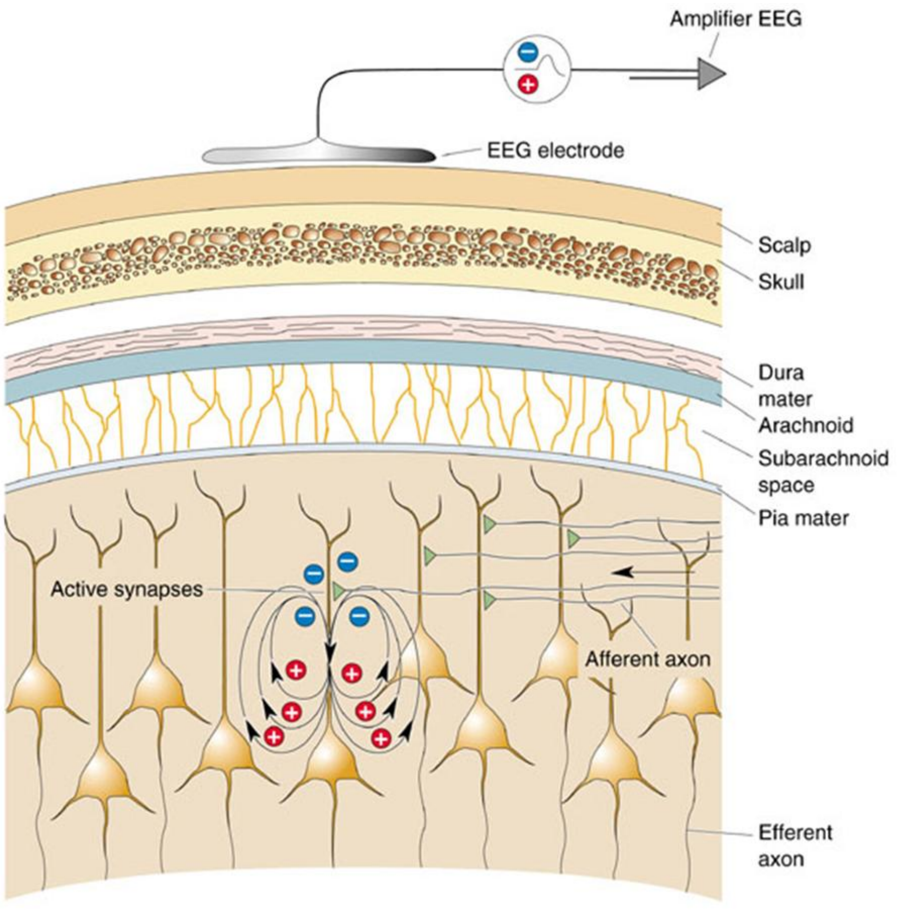
- one afferent axon may contact thousands of cortical neurons)

 so that the potential they create sums up (= spatial summation)

-A single pyramidal cell receives about 30,000 excitatory inputs and 1700 inhibitory inputs.

-The current generated by these neurons sum up in the extracellular space and form the EEG signals.

The electrical signals in EEG arise mainly from cortical nerve cells. Thousands of pyramidal cell inhibitory or excitatory postsynaptic potential act in synchrony and form the EEG signal.



Dipoles of the cell

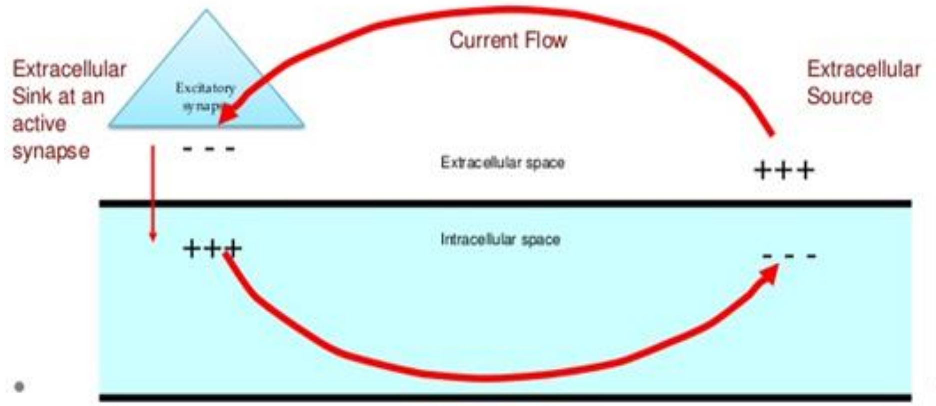
Ionic flow across the mebrane results in current flow from source to sink

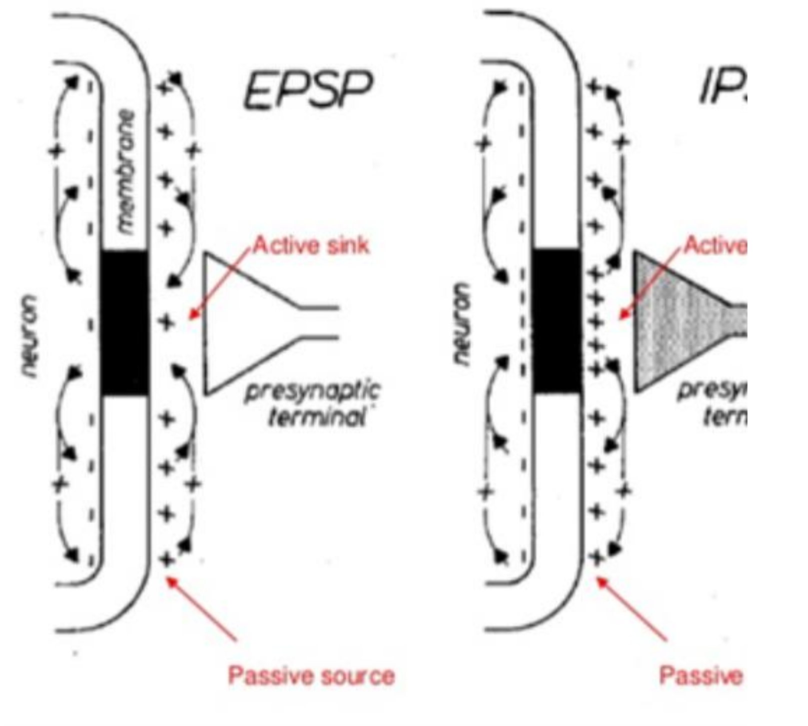
Source is area of positive charge

Sink is the area of negative charge

Active source result from changes in potential at the synapse

Passive source result from potential changes at a distance.





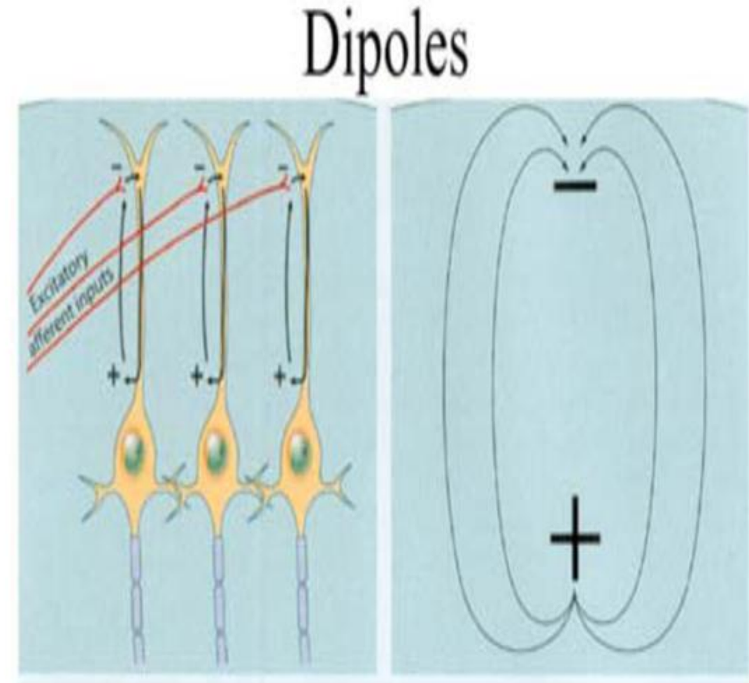
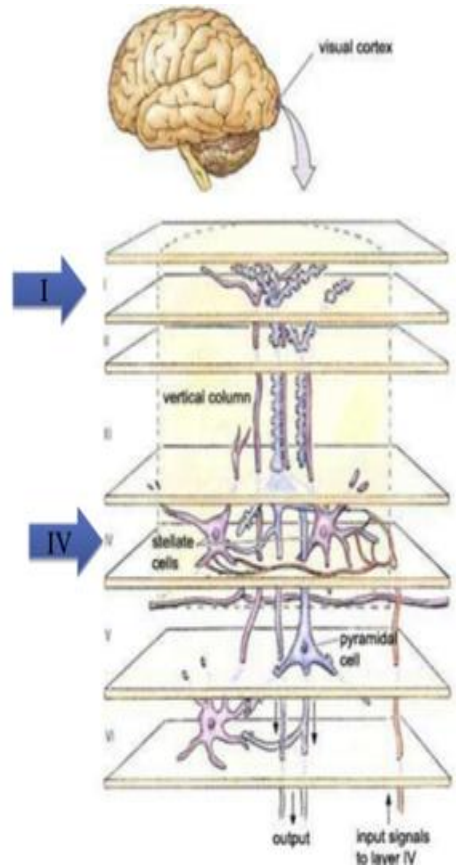


Figure 3.36 Gazzaniga et al 1998

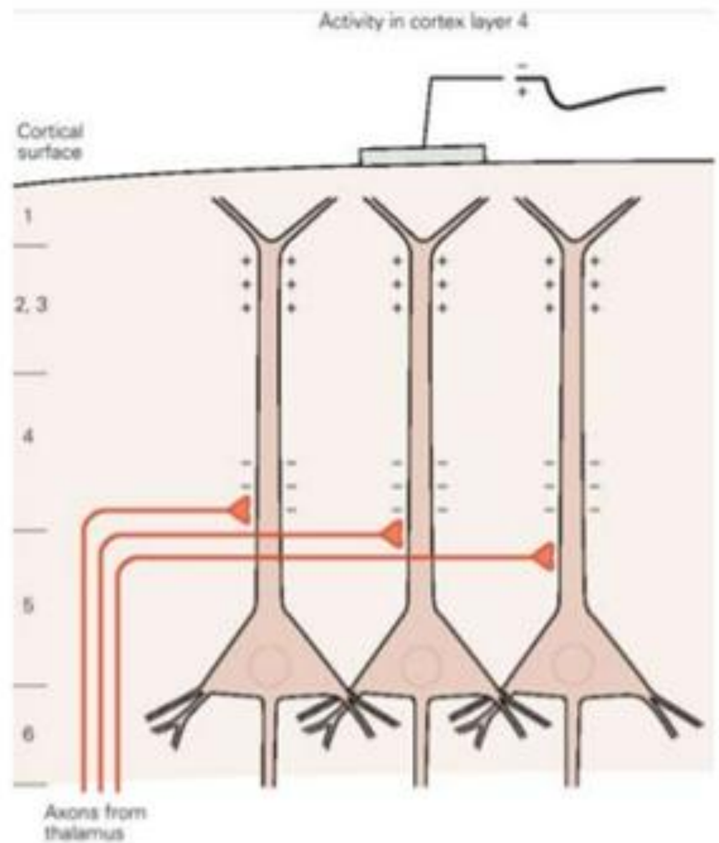
The resting potential of cortical neurons fluctuate as a result of impulses arriving from other neurons' axons to the soma or to the dentrites. According to the neurotransmitter released from the incoming axon postsynaptic potential can be excitatory (Na+ influx) or inhibitory (Cl- influx).

- Afferent signals enter in upper layer 1 and lower layer 4.
- Apical (1) and basal (4) dendrites of pyramidal cells.
- Sources and sinks dominate at apical or basal locations.
- The large distance between source and sink results in a current dipole.



Extracelluar Current Flow

Excitatory thalamic input to basal dendrites in layer IV results in EPSP and an extracellular sink.
A passive source is generated at the apical dendrites and current flows toward cell body.
This generates positive potential at the surface.

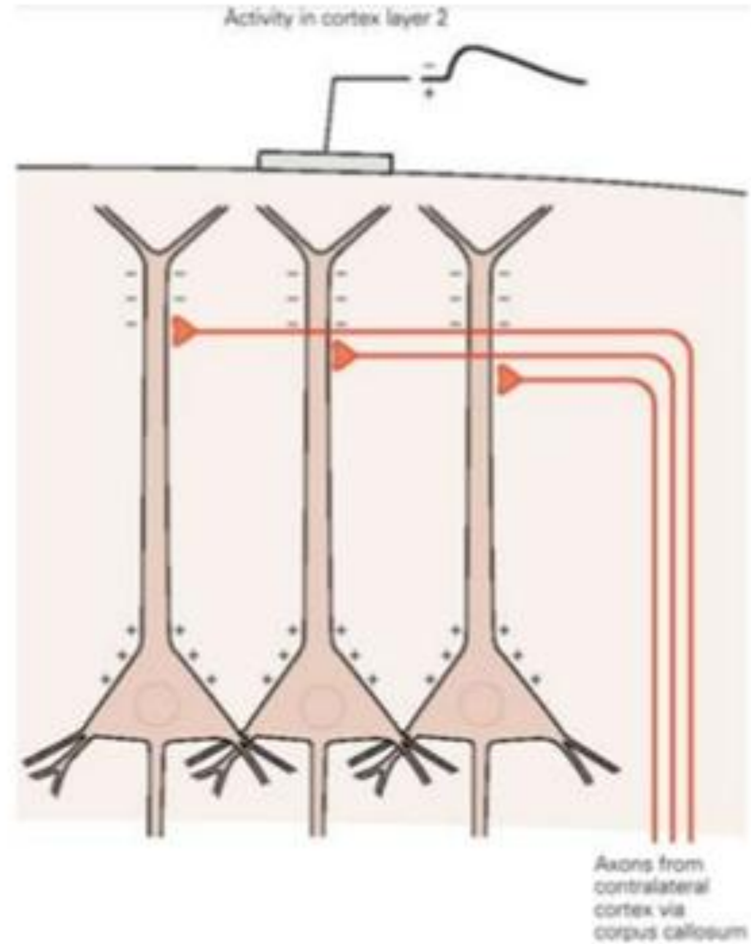


Extracelluar Current Flow

Excitatory input to layer I generates an EPSP in apical dendrites and an active sink.

A passive source is generated at the soma resulting in current flowing toward layer I.

This results in the EEG recording a negative potential at the location above the neurons.



The amplitude of the EEG signal depends on how synchronous the activity of neurons are.

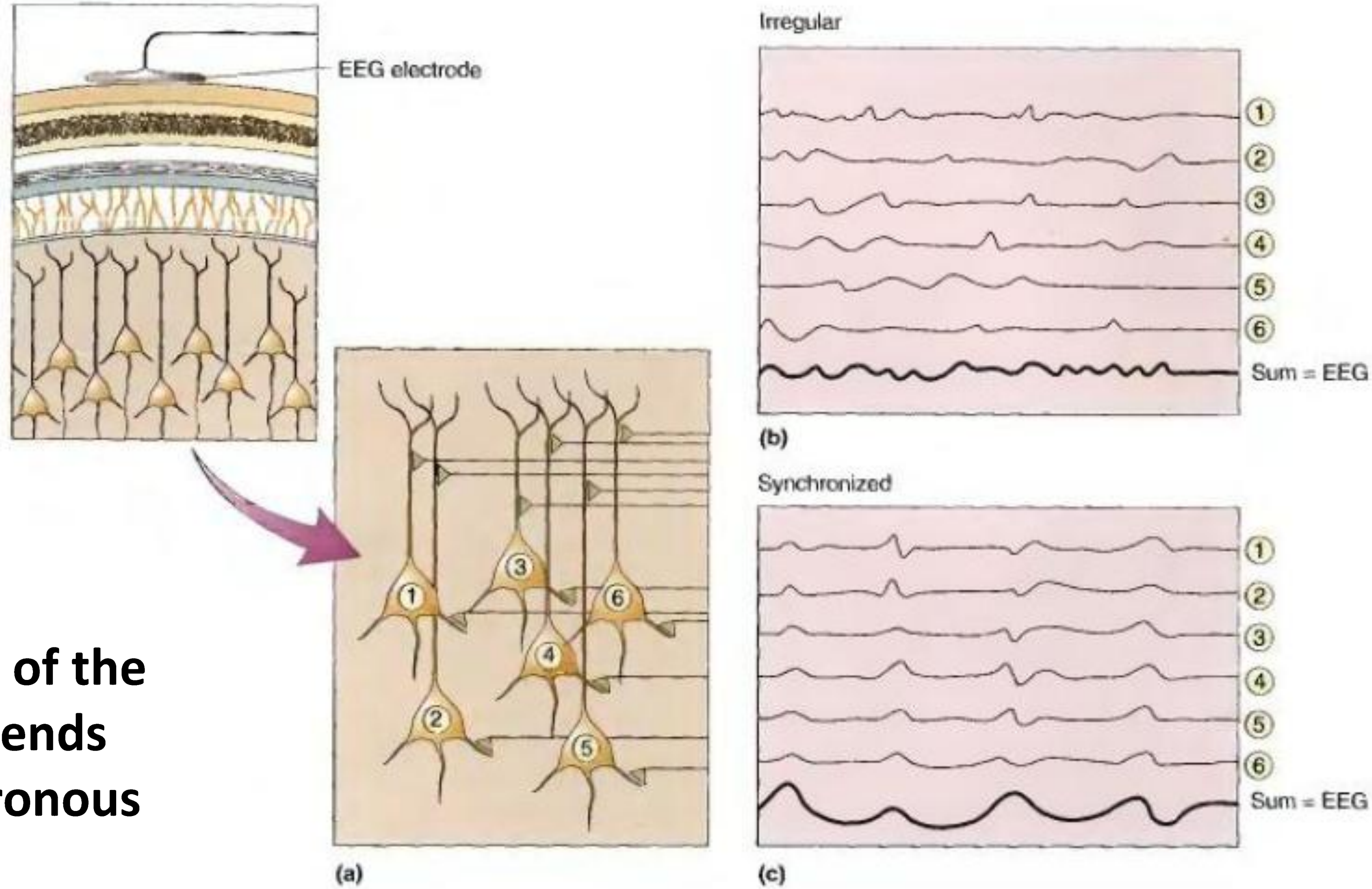


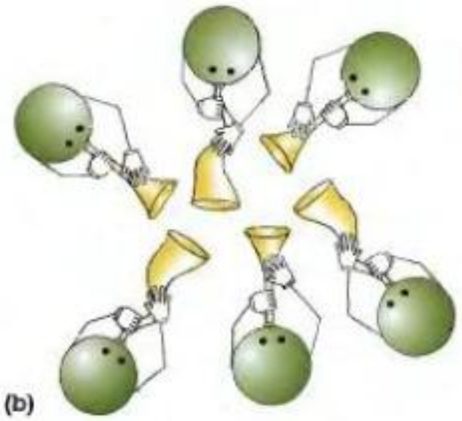
FIGURE 19.4

The generation of large EEG signals by synchronous activity. (a) In a population of pyramidal cells located under an EEG electrode, each neuron receives many synaptic inputs. **(b)** If the inputs fire at irregular intervals, the pyramidal cell responses are not synchronized, and the summed activity detected by the electrode has a small amplitude. **(c)** If the same number of inputs fire within a narrow time window so the pyramidal cell responses are synchronized, the resulting EEG is much larger.

Expect irregular wave recording but rythmic waves are observed.
Rhytmicity

Rhytmic, synchronous activity in the brain is formed by a combination of a pacemaker which is the thalamus and/ or collective behavior of cortical neurons.
Thalamic neurons can generate rhythmic action potentials which are relayed to the cortical neurons by thalamocortical axons.
Excitatory or inhibitory interconnections of neurons result in coordinated synchronous activity which can be localized or spread to larger regions.
Slow frequency repetitive stimulation of thalamus produces rythmical cortical activity.
The cortex produces a synchronous output in response to thalamic input.

(a)



(b)

FIGURE 19.7

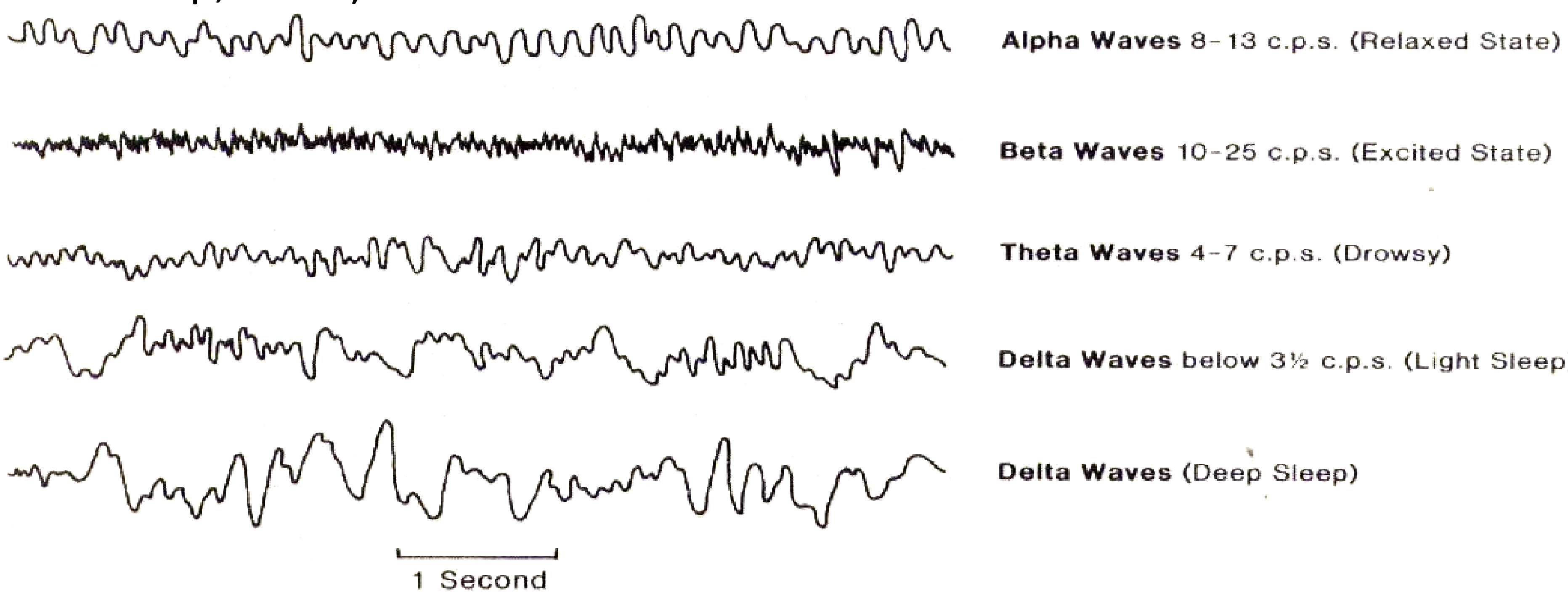
Two mechanisms of synchronous rhythms. Synchronous rhythms can **(a)** be led by a pacemaker or **(b)** arise from the collective behavior of all participants.

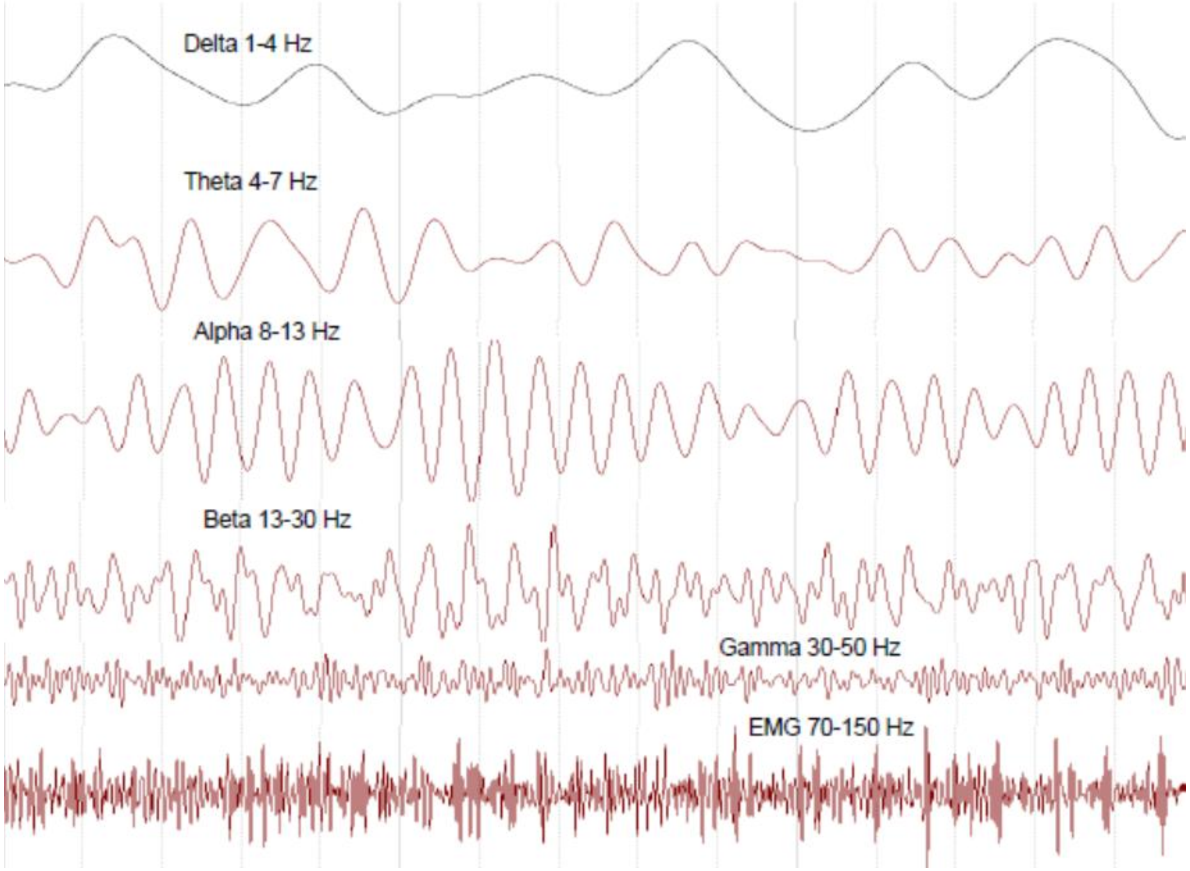
Rhythms occur in distinct frequency ranges:

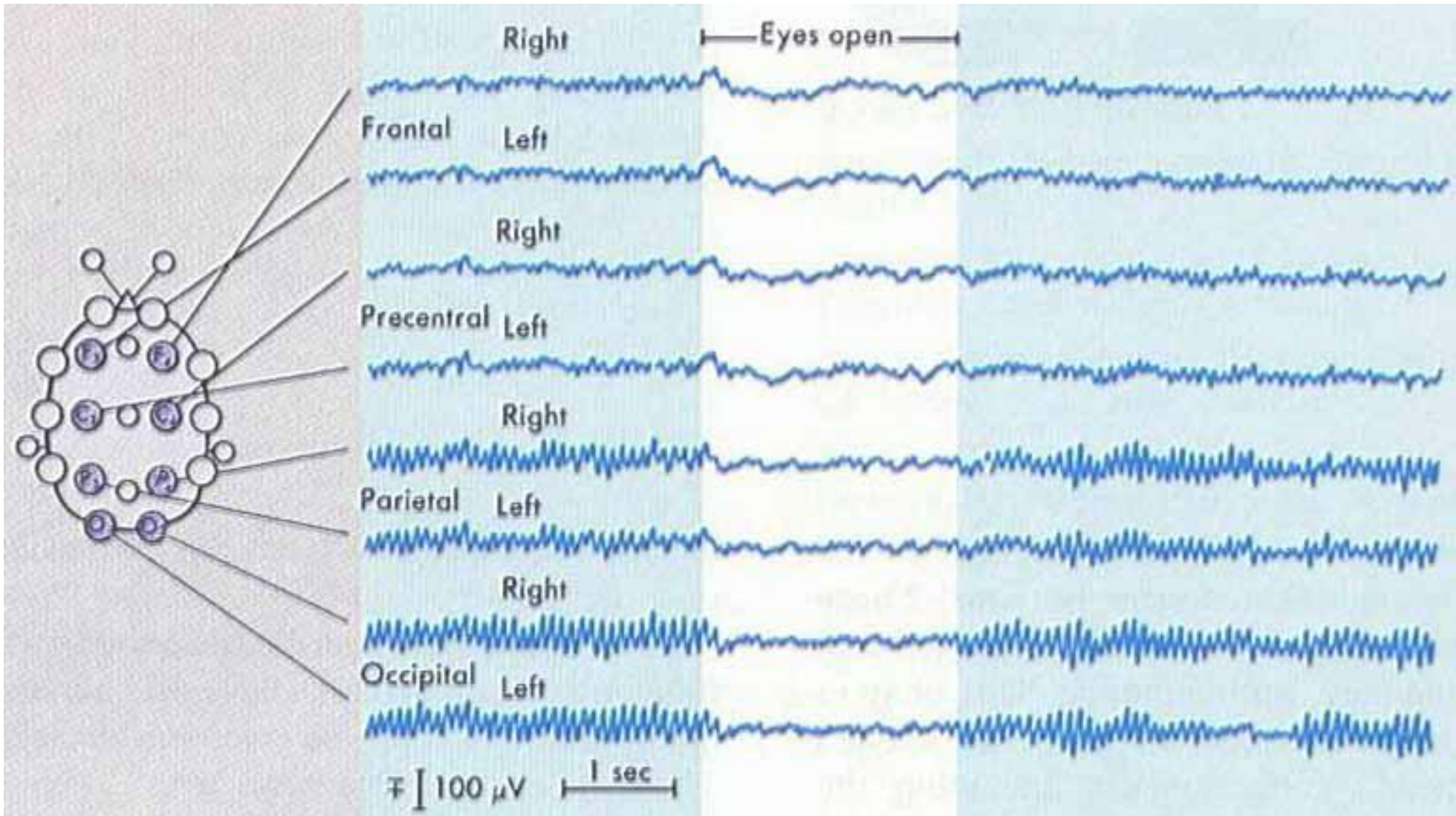
Gamma:	20-60 Hz ("cognitive" frequency band)
Beta:	14-20 Hz (activated cortex)
Alpha:	8-13 Hz (quiet waking)
Theta:	4-7 Hz (sleep stages)
Delta:	less than 4 Hz (sleep stages, especially "deep sleep")

Higher frequencies: active processing, relatively de-synchronized activity (alert wakefulness, dream sleep).

Lower frequencies: strongly synchronized activity (nondreaming sleep, coma).

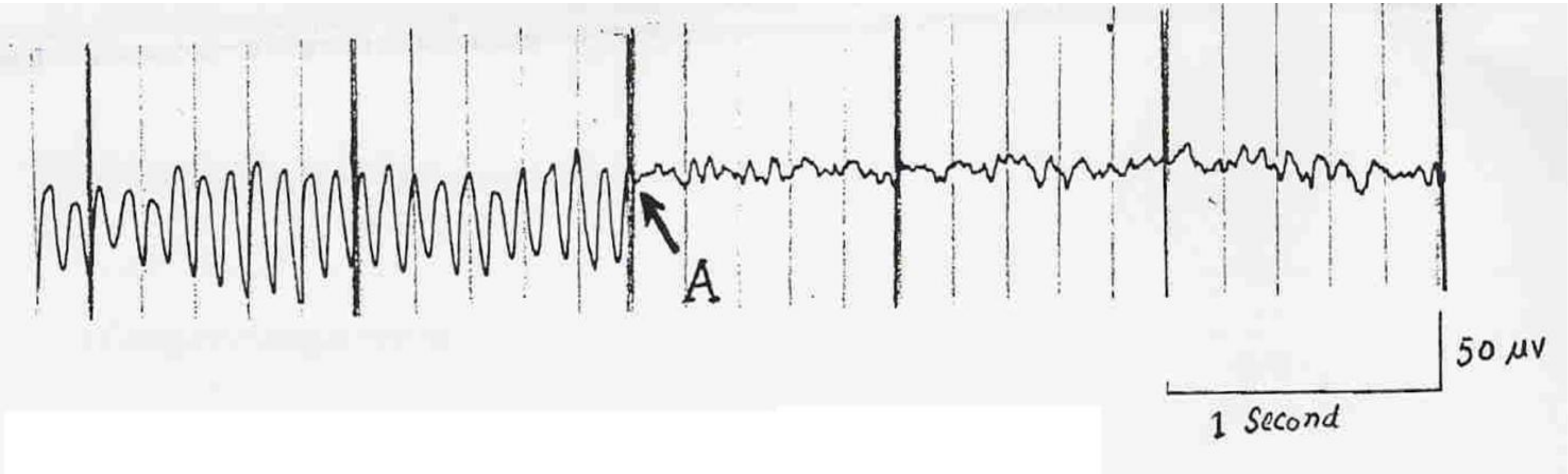



Delta 1-4 Hz
Theta 4-7 Hz
Alpha 8-13 Hz
Beta 13-30 Hz
Gamma 30-50 Hz
EMG 70-150 Hz



Here you can see **“alpha block”** or desynchronization of alpha waves

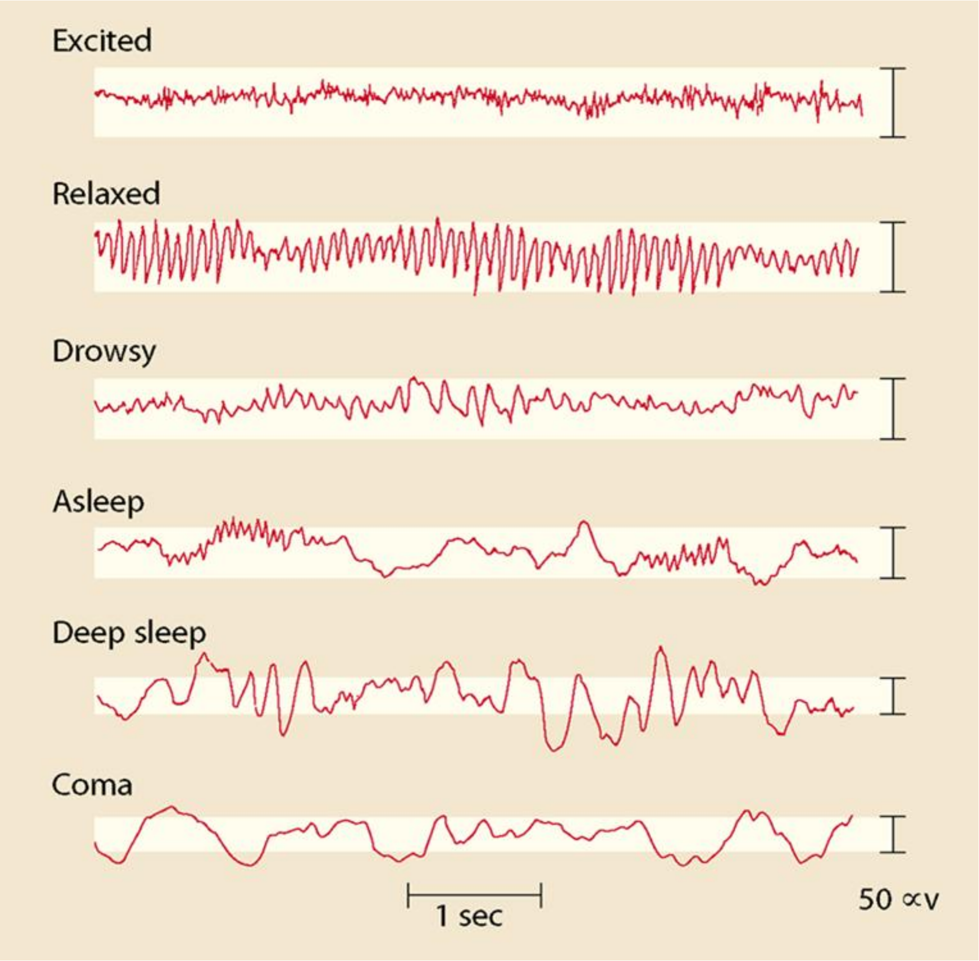
Desynchronization or Alpha block



Cause:

Eyes opening (after closure)
Thinking by the subject (mathematical calculation)
Sound (clapping)

characteristic EEG rhythms during several states of consciousness.
During deep sleep, you see delta waves.
When someone's drowsy, you see theta waves.
Alpha is characteristic of a relaxed but alert state with eyes closed.
And beta is characteristic of a more excited, or actively attentive state.



ALPHA WAVES represent a relaxed awareness in the mind. Alpha is usually best detected in the frontal regions of the head, on each side of the brain. Alpha is the major rhythm seen in normal relaxed adults and is regarded as the common relaxation mode beyond the age of 13. Alpha has been linked to extroversion (introverts show less), creativity (creative subjects show alpha when listening and coming to a solution for creative problems), and mental work. When your alpha is within normal ranges we tend to also experience good moods, see the world truthfully, and have a sense of calmness. Alpha is one of the brain's most important frequency to learn and use information taught in the classroom and on the job.

THETA WAVES can indicate drowsiness, daydreaming, the first stage of sleep or 'indirect' imagination/thinking. Theta activity is not often seen in awake adults (unless engaged in a meditative practice), but is perfectly normal in alert children up to 13 years and in most sleep.Theta is believed to reflect activity from the limbic system and hippocampal regions. Theta is observed in anxiety, behavioral activation and behavioral inhibition. When the theta rhythm appears to function normally it mediates and/or promotes adaptive, complex behaviors such as learning and memory.

DELTA WAVES reveals deep sleep or slow-wave 'background' thinking.

the highest in amplitude and the slowest waves. Certain frequencies, in the delta range, have been shown to trigger the body's healing and growth mechanisms. Delta is the dominant rhythm in infants up to one year, as well as stages 3 and 4 of dreamless sleep.

We increase Delta waves in order to decrease our awareness of the physical world. We also access information in our unconscious mind through Delta. Peak performers decrease Delta waves when high focus and peak performance are required. The inappropriate Delta response often severely restricts the ability to focus and maintain attention. It is as if the brain is locked into a perpetual drowsy state.

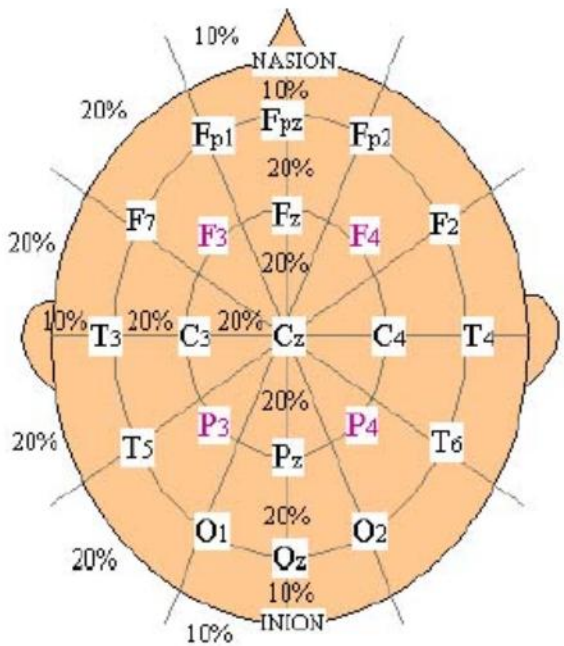
BETA WAVES are characteristic of an engaged mind, which is highly alert and well focused.

Beta activity dominates the normal waking state of consciousness when attention is directed towards the outside world. Typically detected in the **frontal lobes** on both sides of the brain. It may be absent or reduced in areas of brain damage. Tends to be the dominant rhythm in those who are alert, anxious or have their eyes open.e.g. converstaion that needs full attention, public speaking, teaching!!, complex problem solving

Band	Frequency (Hz)	Location	Normally	Pathologically
Delta	up to 4	frontally in adults, posteriorly in children; high-amplitude waves	• adult slow wave sleep • in babies • Has been found during some continuous-attention tasks	• subcortical lesions • diffuse lesions • metabolic encephalopathy hydrocephalus • deep midline lesions
Theta	4 – 7	Found in locations not related to task at hand	• young children • drowsiness or arousal in older children and adults • idling • Associated with inhibition of elicited responses (has been found to spike in situations where a person is actively trying to repress a response or action).[39]	• focal subcortical lesions • metabolic encephalopathy • deep midline disorders • some instances of hydrocephalus
Alpha	7 - 14	posterior regions of head, both sides, higher in amplitude on non-dominant side. Central sites (c3-c4) at rest	• relaxed/reflecting • closing the eyes • Also associated with inhibition control, seemingly with the purpose of timing inhibitory activity in different locations across the brain.	• coma
Beta	15 - 30	both sides, symmetrical distribution, most evident frontally; low-amplitude waves	• alert, eyes open • active, busy, or anxious thinking, active concentration	• benzodiazepins
Gamma	30 – 100+	Somatosensory cortex	• Displays during cross-modal sensory processing (perception that combines two different senses, such as sound and sight) • Also is shown during short-term memory matching of recognized objects, sounds, or tactile sensations	• A decrease in gamma-band activity may be associated with cognitive decline, especially when related to the theta band; however not proven for use as a clinical diagnostic measurement

EEG Recording

EEG is recorded using electrodes (diameter 0.4 to 1.0 cm) held in place on the scalp with special pastes, caps or nets. In clinical applications 19 recording electrodes are placed uniformly over the scalp (the **International 10-20 System**). In addition, one or two reference electrodes (often placed on ear lobes) and a ground electrode (often placed on the nose) to provide amplifiers with reference voltages are required.



The head is divided into proportional distances from prominent skull landmarks (nasion, preauricular points, inion) to provide adequate coverage of all regions of the brain. Label 10-20 designates proportional distance in percents between ears and nose where points for electrodes are chosen.

. Electrode placements are labelled according adjacent brain areas: F (frontal), C (central), T (temporal), P (posterior), and O (occipital). The letters are accompanied by odd numbers at the left side of the head and with even numbers on the right side

In **referential recordings**, potentials between each recording electrode and a fixed reference are measured over time. The reference should not pick up signals which are not intended to be recorded, like heart activity. Reference electrodes are placed at some distance from recording electrode (the ear-lobes, the nose, or the mastoids (i.e. the bone behind the ears).
With multi-channel recordings (e.g. >32 channels), it is common to compute the "average reference", i.e. to subtract the average over all electrodes from each electrodes for each time point.

Bipolar recordings measure potential differences between adjacent scalp electrodes.
Electrode placements and the different ways of combining electrode pairs to measure potential differences on the head constitute the **electrode montage**.

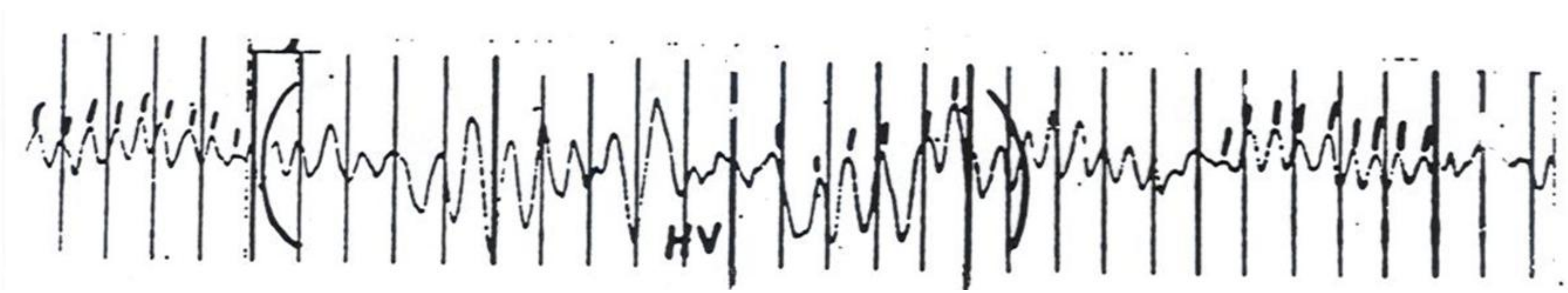
Provocation test

Intermittent photic stimulation

Increase rate & decrease amplitude

Hyperventilation

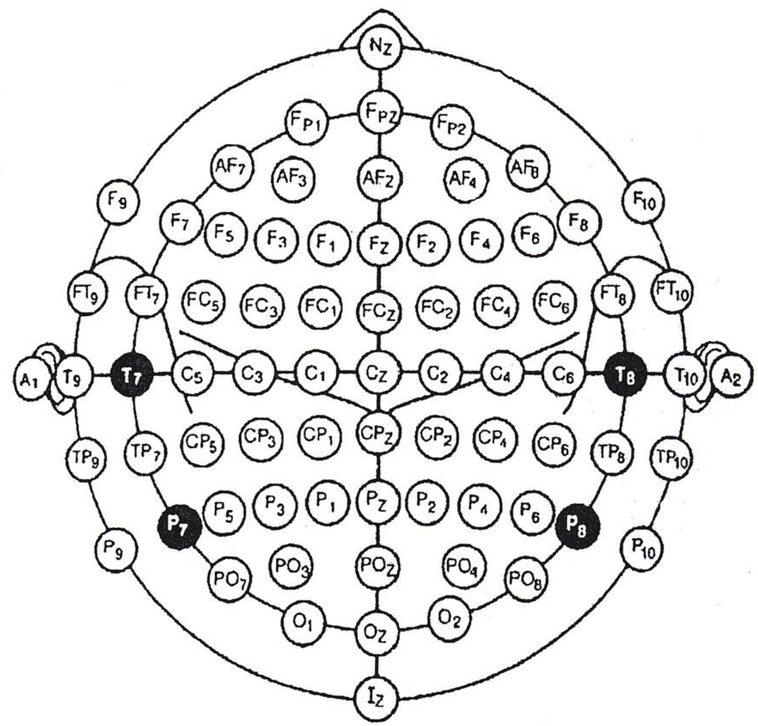
Decrease rate & increase in amplitude

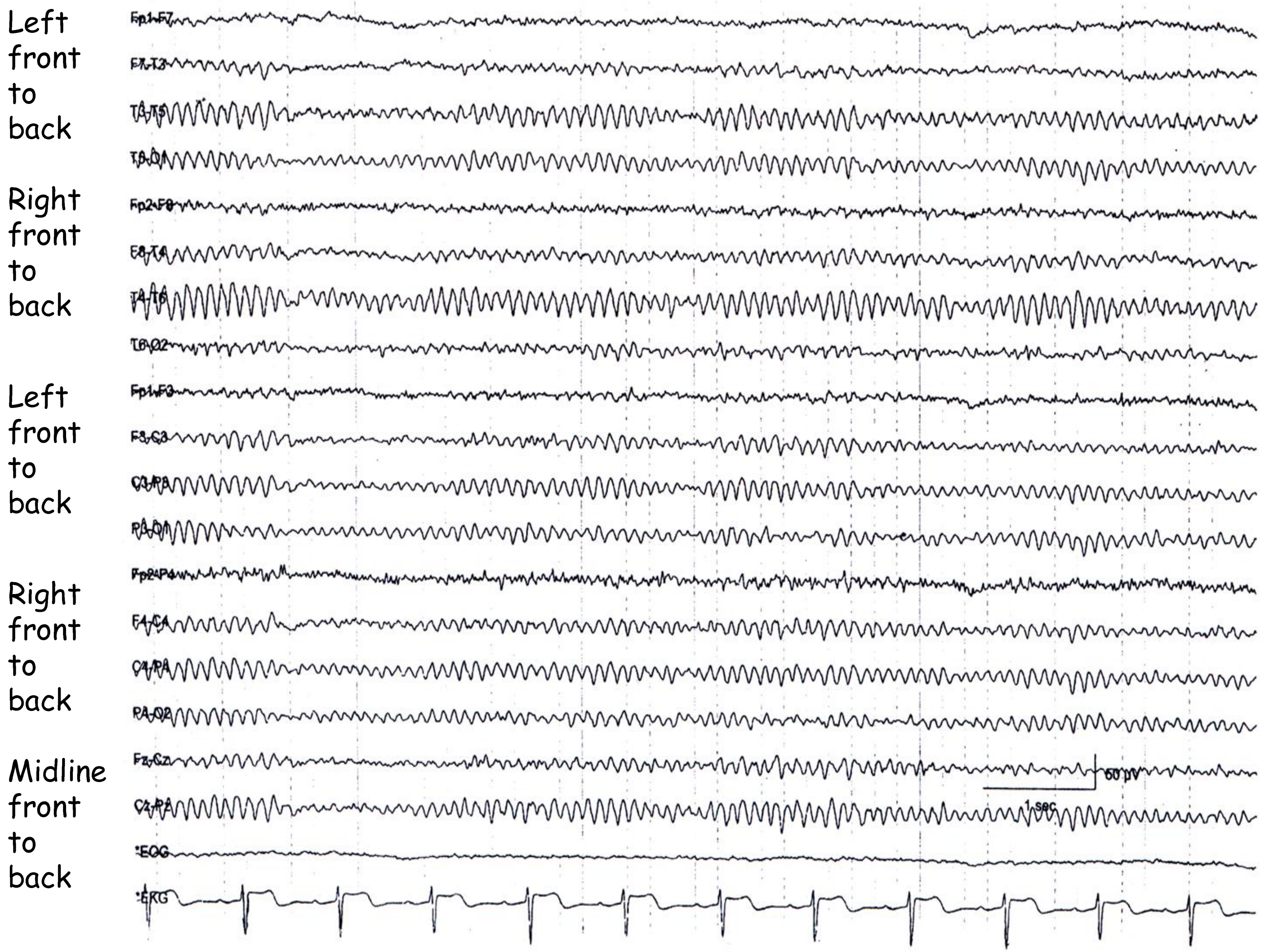


often 64 to 131 recording electrodes or more are used in research.

When large numbers of electrodes are employed, potential at each location may be measured with respect to the average of all potentials (the ***common average reference***),

"10 - 10" Electrode Location Naming Convention
(Sharbrough et al, 1991)





A-1 Normal adult. This is a 55-year-old man who is awake with eyes closed. There is a well-developed alpha rhythm at 10 Hz, prominent in the posterior head regions. The sinusoidal waves constitute the major and nearly only finding in this record. Little if any beta activity is present.

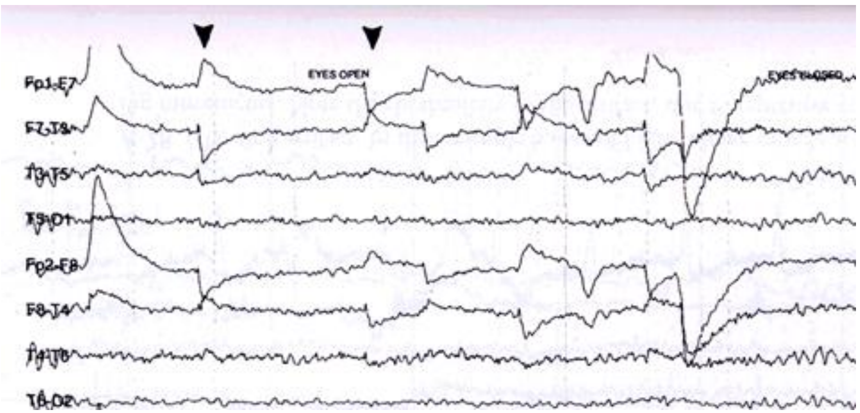
Factor influencing EEG

Age

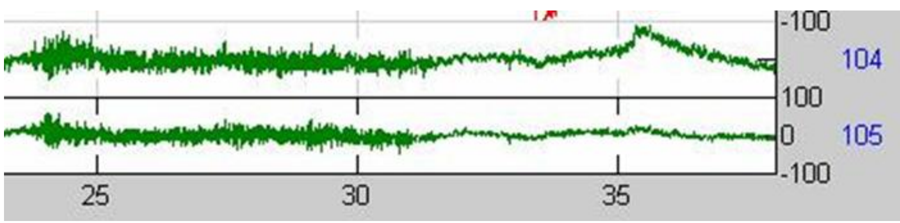
Infancy – theta, delta wave
Child – alpha formation.
Adult – all four waves.

Level of consciousness (sleep)
Hypocapnia(hyperventilation) slow & high amplitude waves.
Hypoglycemia
Hypothermia
Low glucocorticoids

Artifacts



Lateral eye movement artifact

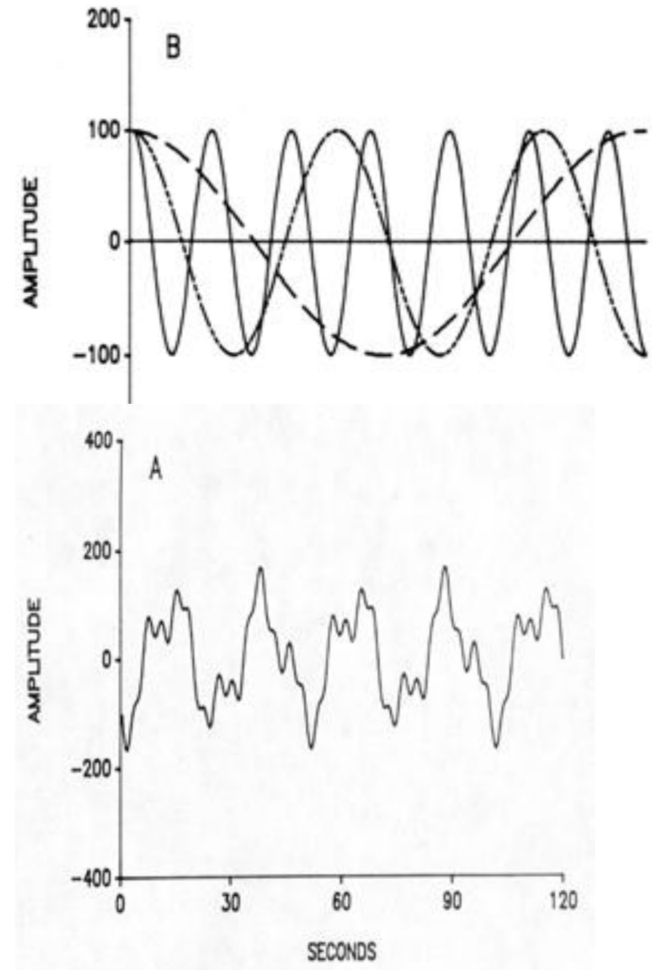


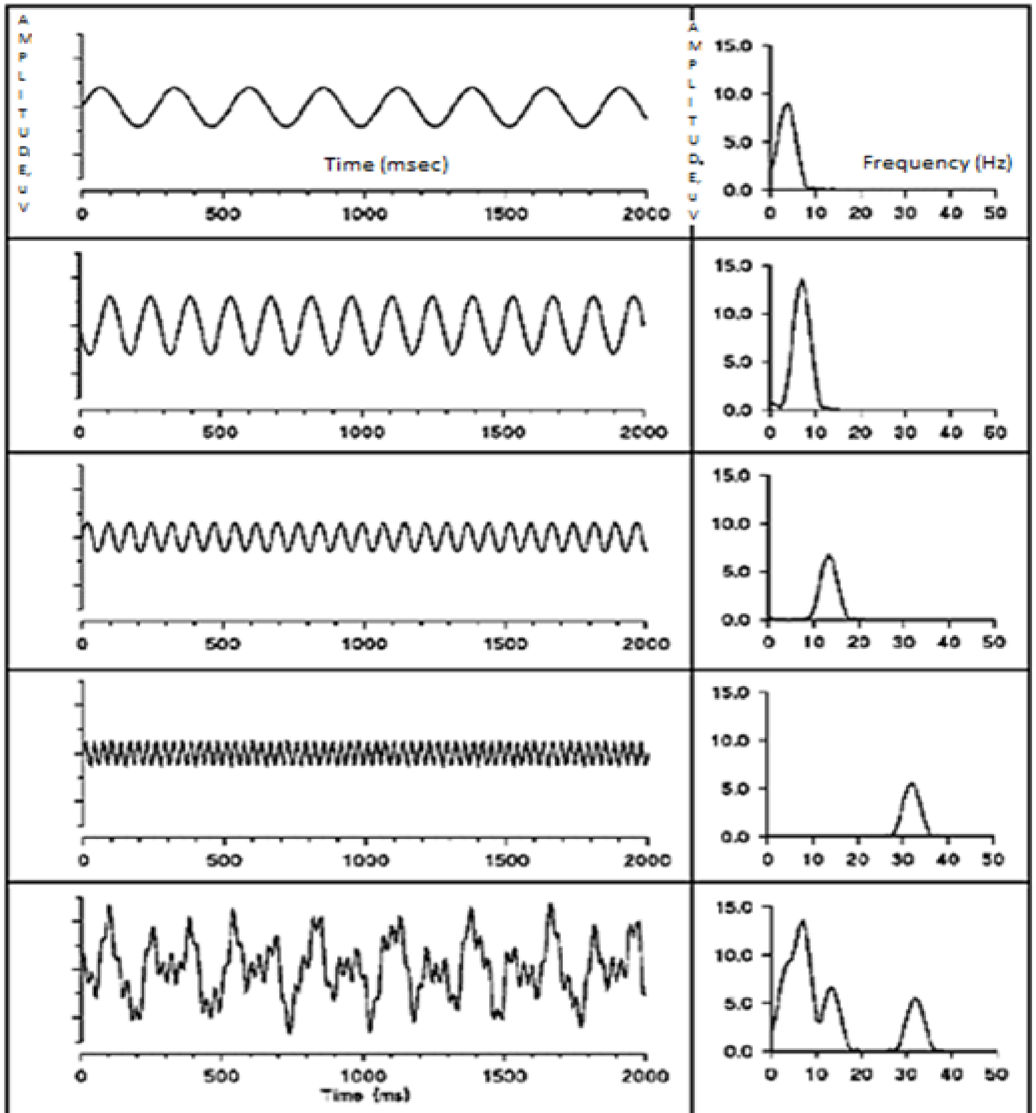
Muscle artifacts (greater amplitude)

Signal Processing

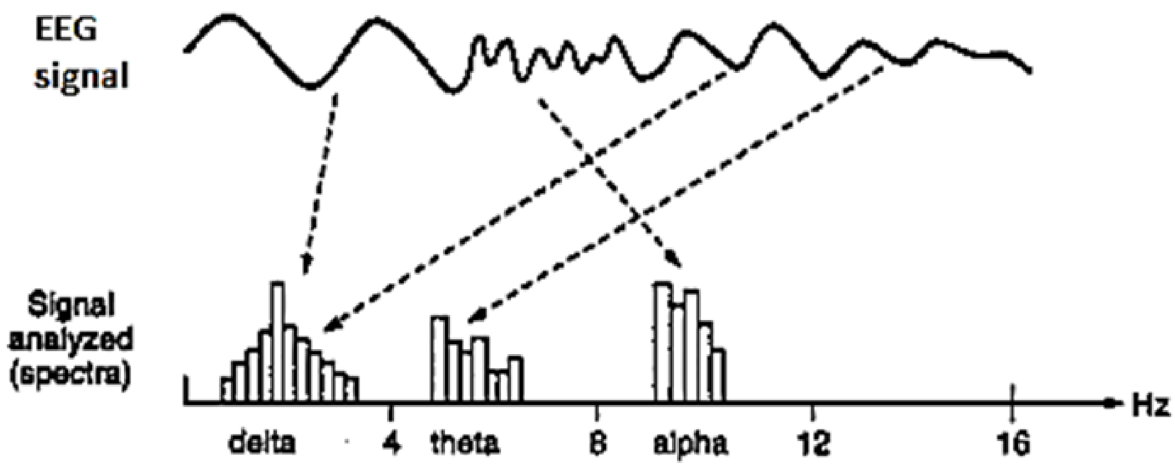
Frequency analysis.

Frequency analysis is one of the most common methods of analyzing the EEG. It
depends upon the Fourier transform,.
Fourier analysis : every complex wave can be broken down into a series of simpler sine waves.
Frequency : number of cycles within one second (1 Hz = 1 cycle/second).





Fourier transform
take a wave form shown on left with time on the x axis and amplitude in microvolts on the y axis, and determine how much amplitude is in every frequency?
So the fourier transform takes this amplitude versus time on the left and transforms it into amplitude versus frequency (or “**amplitude spectrum**”) on the right. These first four waves are just simple sine waves so you get amplitude spectra with just one peak on the right.
This last signal is a real EEG signal, and you can see how it is a more complex wave with multiple frequency components.



EEG wave broken down into an amplitude spectrum, where you have the slower waves transformed into its delta, theta, and alpha components.
, where
delta is 0 to 4 Hz, theta is 4 to 8 Hz, and alpha is 8 to 12 Hz.

Sleep studies

The EEG is frequently used in the investigation of sleep disorders especially sleep apnoea.

Polysomnography : EEG activity together with

heart rate,
airflow,
respiration,
oxygen saturation and
limb movement

Sleep patterns of EEG

There are two different kinds of sleep:

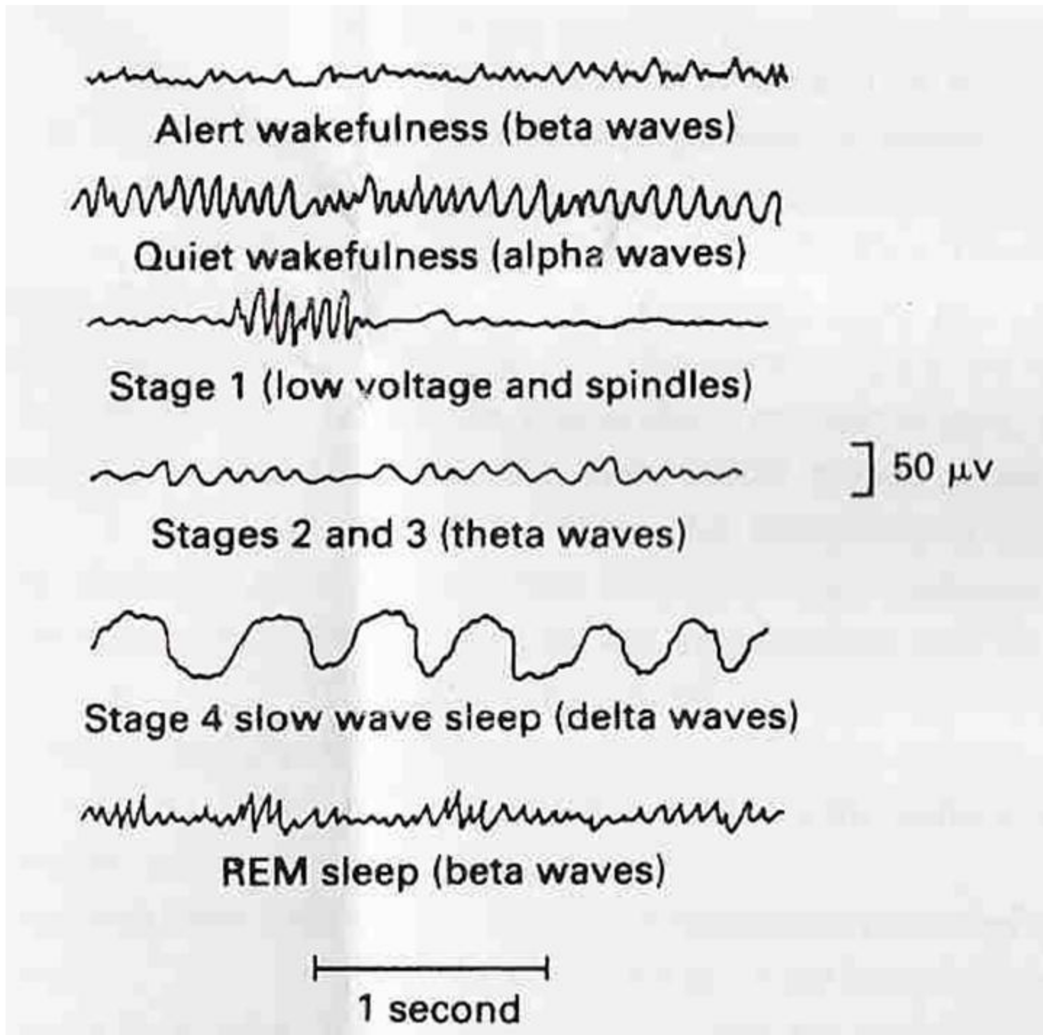
- Rapid eye movement sleep (REM-Sleep)
- Non-REM sleep (NREM sleep)/ slow wave sleep

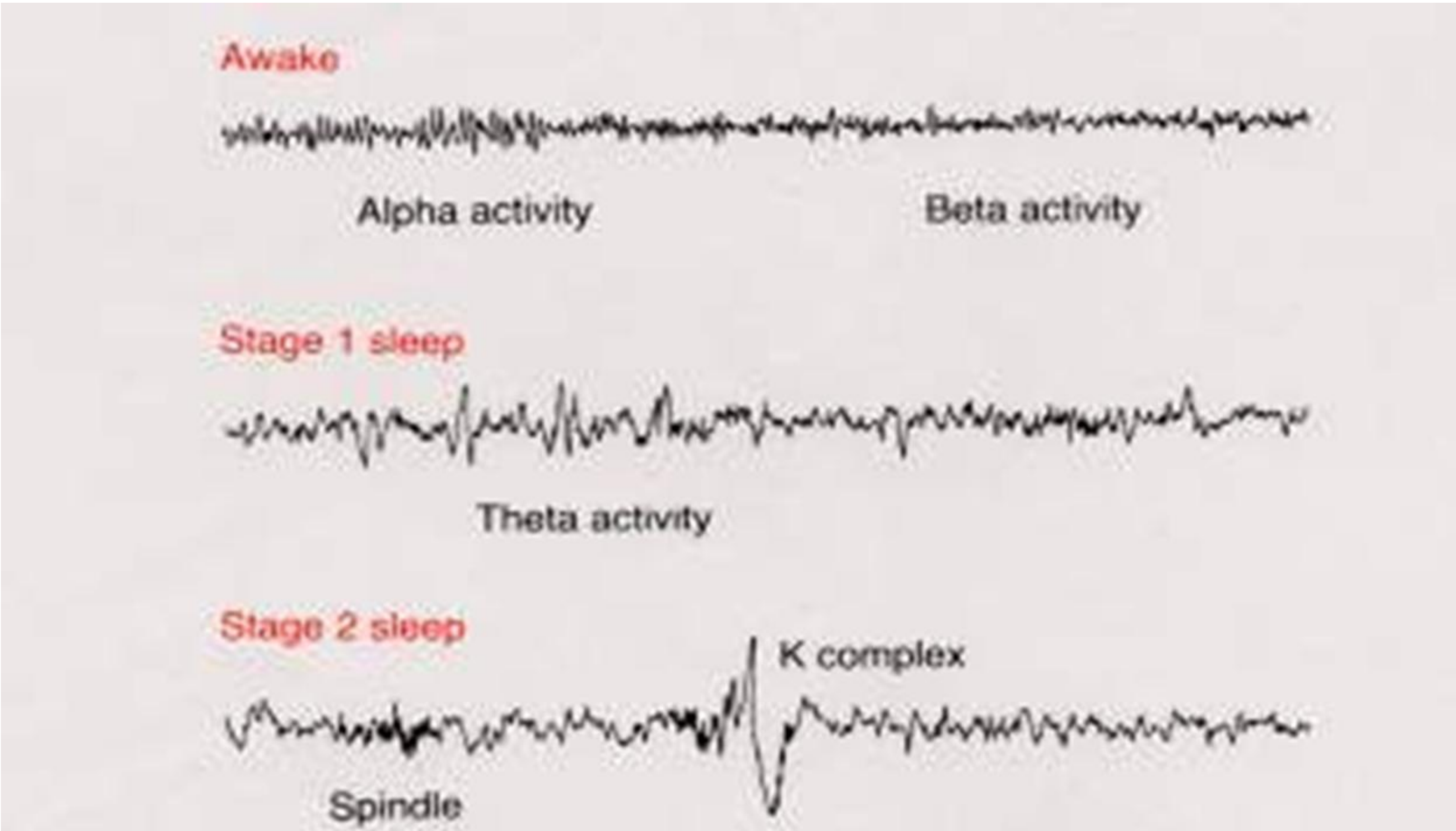
NREM sleep is again divided into 4 stages (I to IV). The EEG pattern in sleep is given in the following table:

Stages of sleep	**EEG pattern**	**Somatic or Behavioral changes**
Alert	Alpha activity on eye closed Desynchronization on eye opening	Respond to verbal commands
I (Drowsiness)	Alpha dropout & appearance of vertex waves & theta.	Reduced HR & RR
II (Light sleep)	Sleep spindles, vertex sharp waves & K-complexes	Reduced HR & RR
III (Deep Sleep)	Much slow background K-complexes	Reduced HR & RR

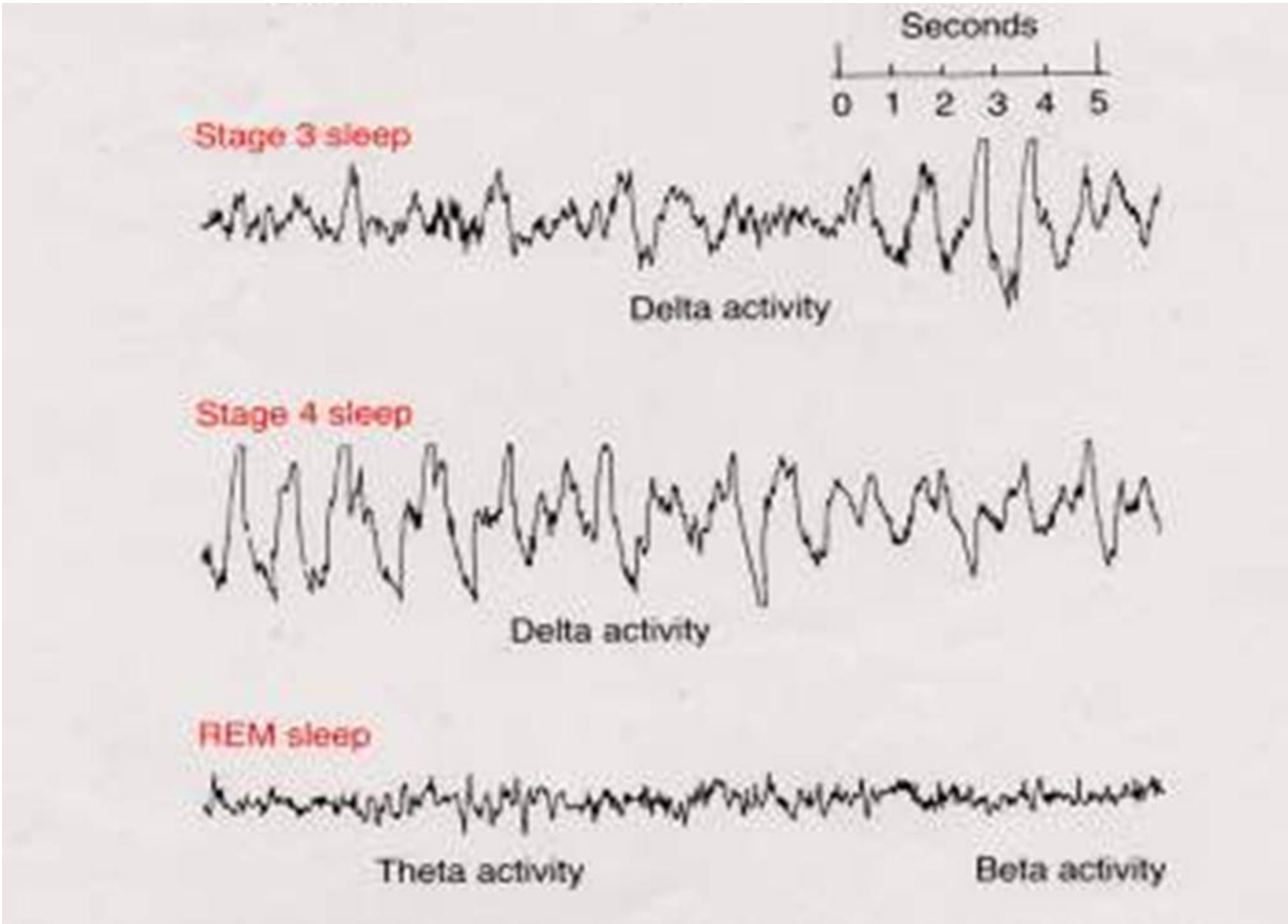
IV (very deep sleep)	Synchronous delta waves, some K-complexes	Reduced HR & RR
REM sleep (paradoxical sleep)	Desynchronization with faster frequencies	HR, BP & RR irregular Marked hypotonia Rapid eye movement 50 – 60 /min. Dreaming threshold of arousal

Changes in brain waves during different stages of sleep & wakefulness





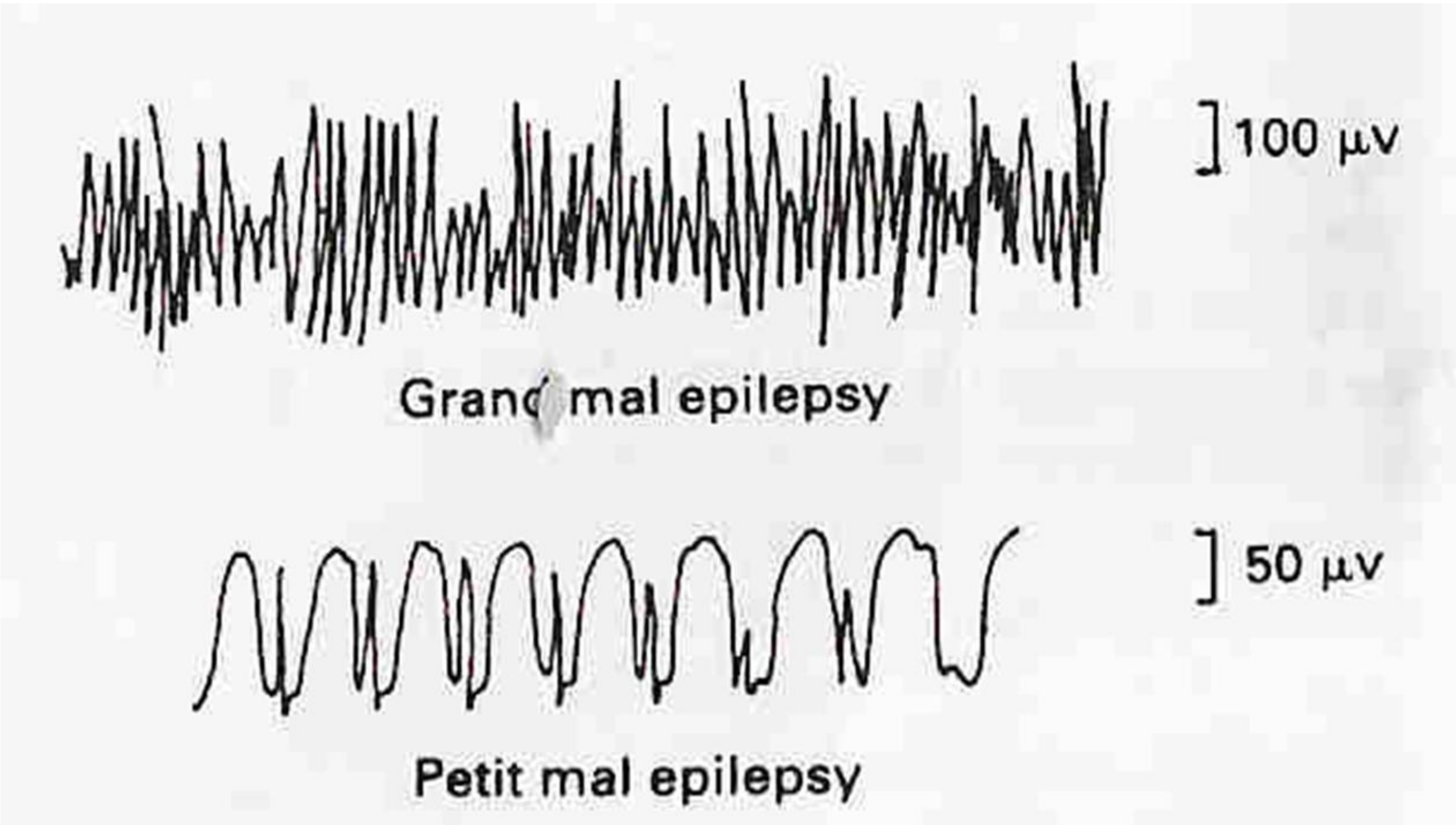
Awake
Alpha activity
Beta activity
Stage 1 sleep
Theta activity
Stage 2 sleep
K complex
Spindle


Seconds
0 1 2 3 4 5
Stage 3 sleep
Delta activity
Stage 4 sleep
Delta activity
REM sleep
Theta activity
Beta activity

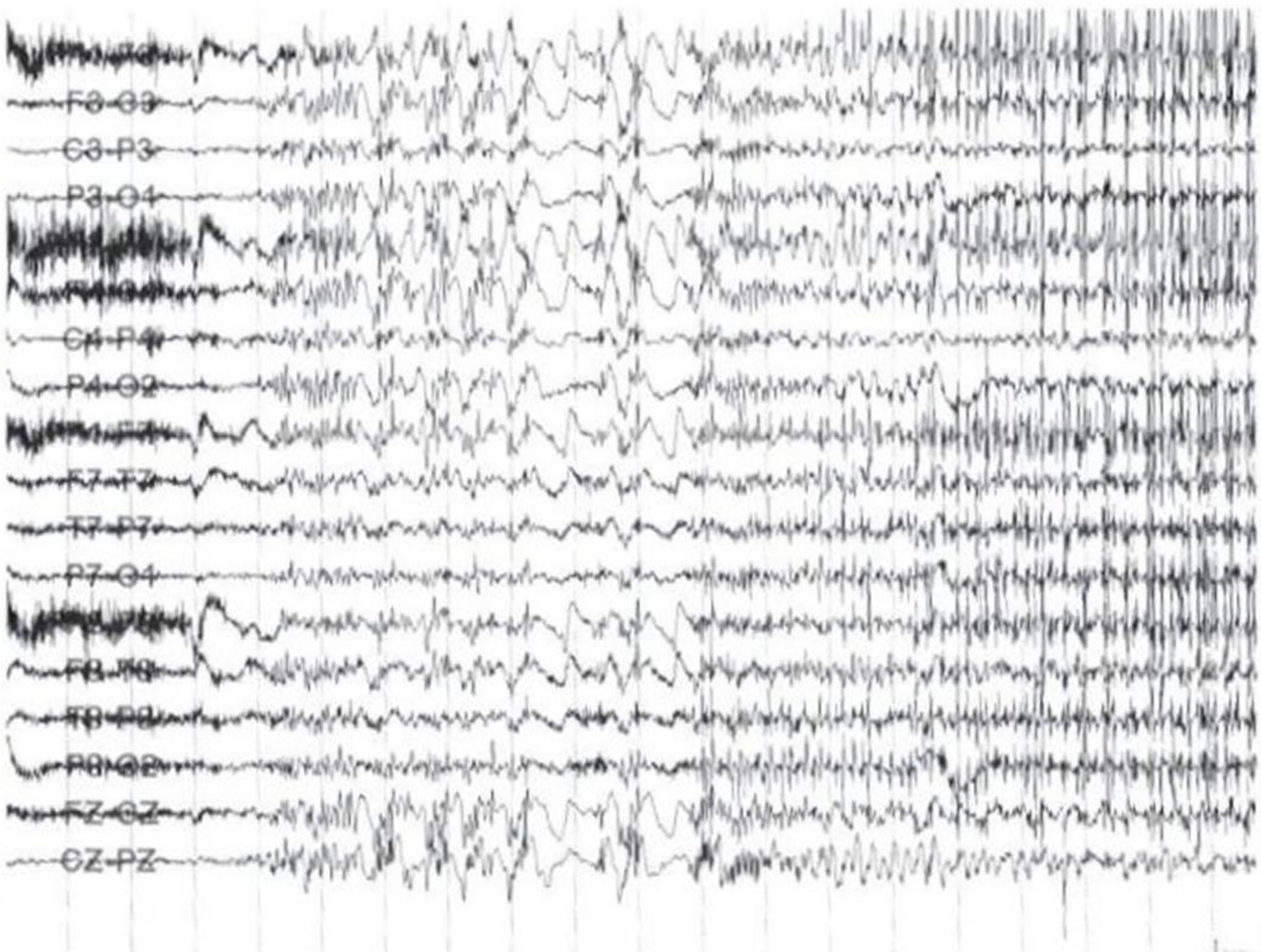
Epilepsy

Generalized (grandmal) seizures.
Absence (petitmal) seizures.

EEG in different types of epilepsy



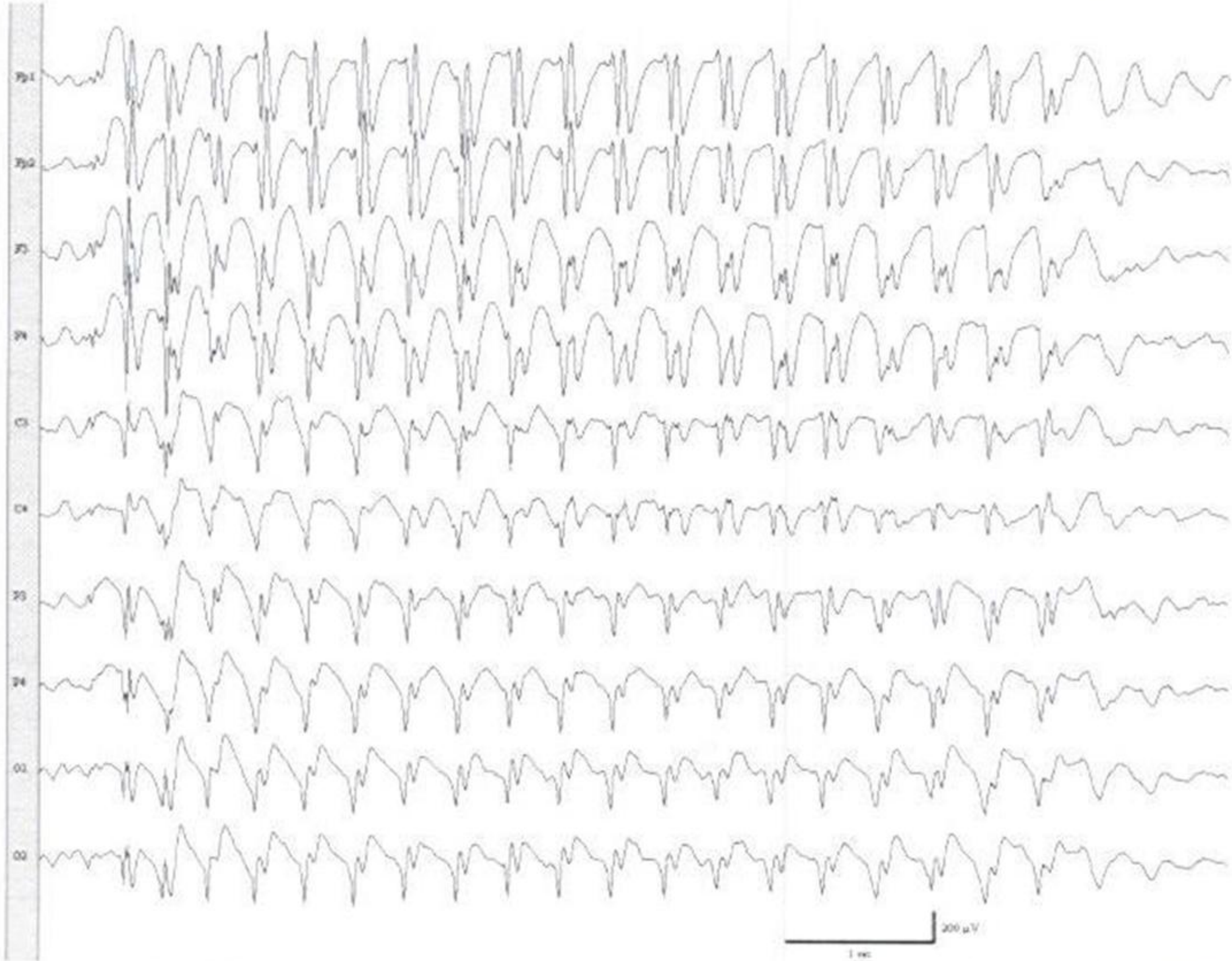
Generalized tonic-clonic seizure onset



Montage = LB

Note that EEG changes at onset are generalized, with 10 Hz rhythmic activity, without focal features. The EEG is dominated by muscle artifact as of the following page.

Generalized absence seizure



Montage = Linked ear ref.

Note that the frequency of generalized spike-and-wave activity is about 3 Hz at onset and 2.5 Hz at termination.

Evoked Potential   Event Related Potential

An **evoked potential** or **evoked response** is a potential recorded in response to a stimulus
It is distinct from spontaneous potentials

Evoked potential amplitudes are low (less than microvolt to several microvoltes)

[EEG amplitude : tens of microvolt, EMG amplitude millivolte, EECG amplitude nearly 1 volt]]

Event-related potentials (ERPs) are very small voltages generated in the brain in response to specific events or stimuli.
Event-related potentials can be elicited by a wide variety of sensory, cognitive or motor events

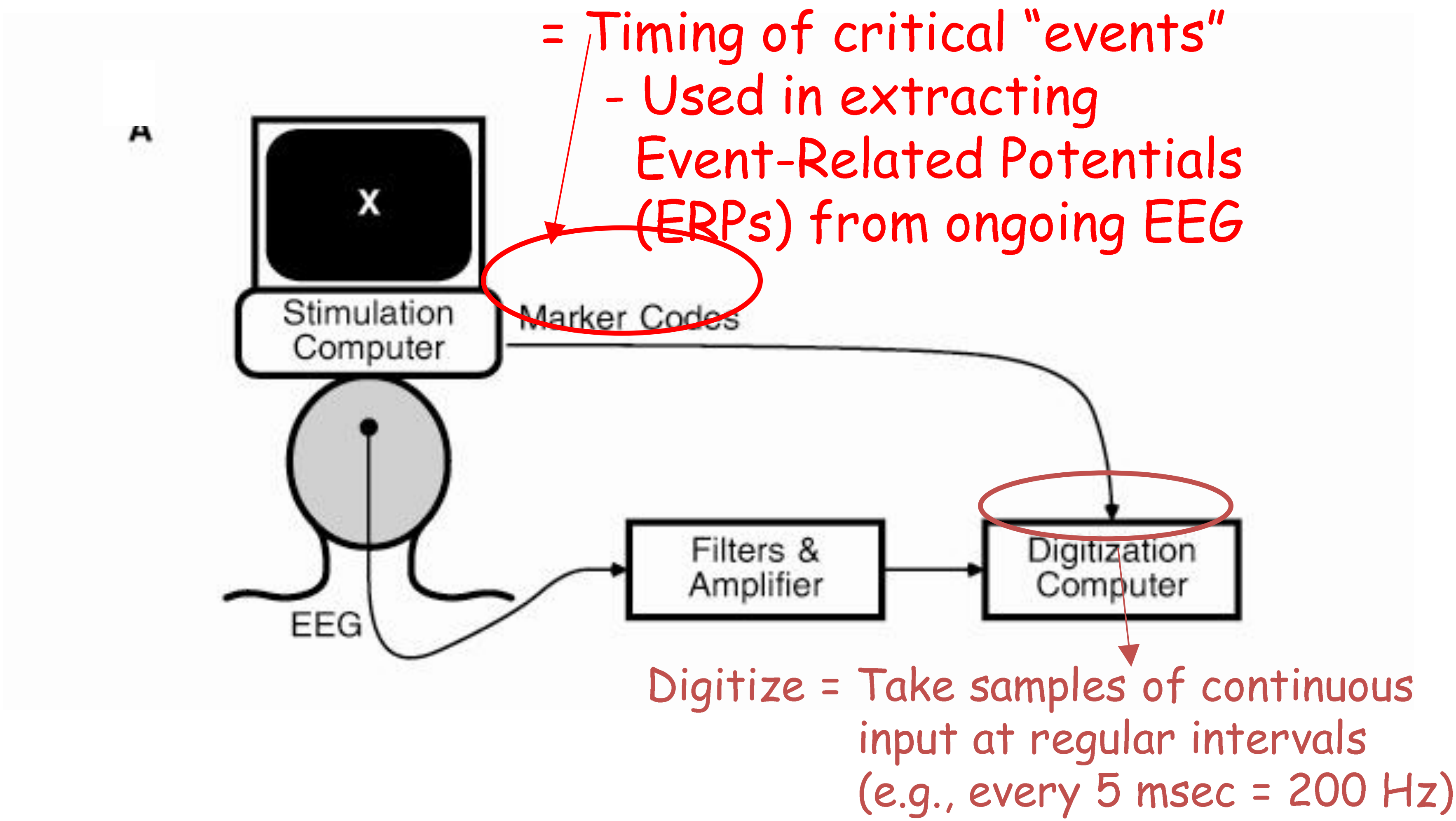
ERPs are used extensively in neuroscience, cognitive psychology, and pscho-physiological research

They are thought to reflect the summed activity of postsynaptic potentials produced when a large number of similarly oriented cortical pyramidal neurons (in the order of thousands or millions) fire in synchrony while processing information. These include dense local interactions involving excitatory pyramidal neurons and inhibitory interneurons, as well as long-range interactions mediated by axonal pathways in the white matter.

ERPs are measured with EEG

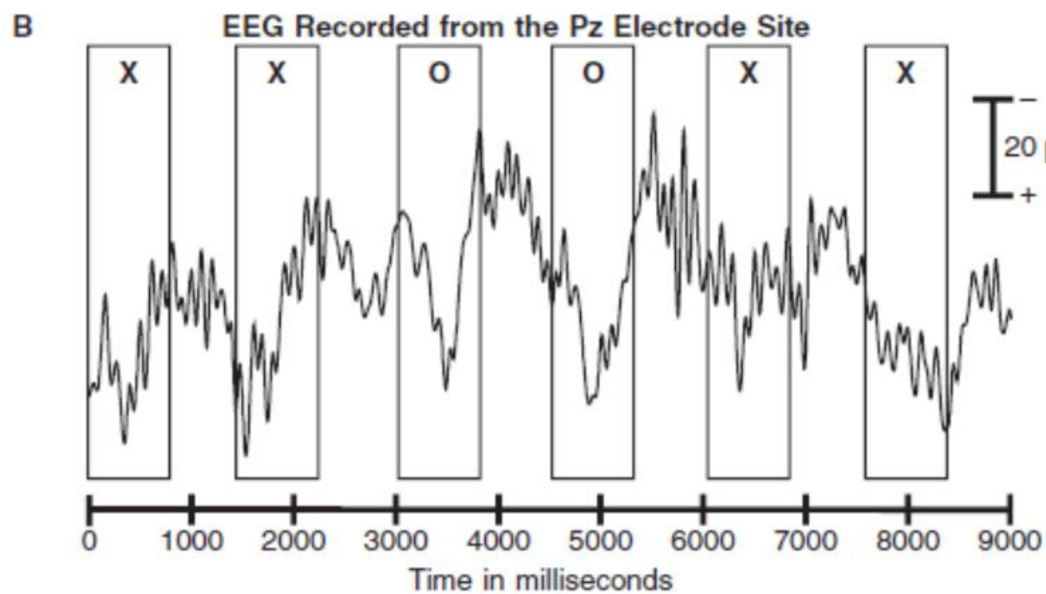
The signal is time-locked to the stimulus .

i.e time locked to sensory, motor or cognitive events.



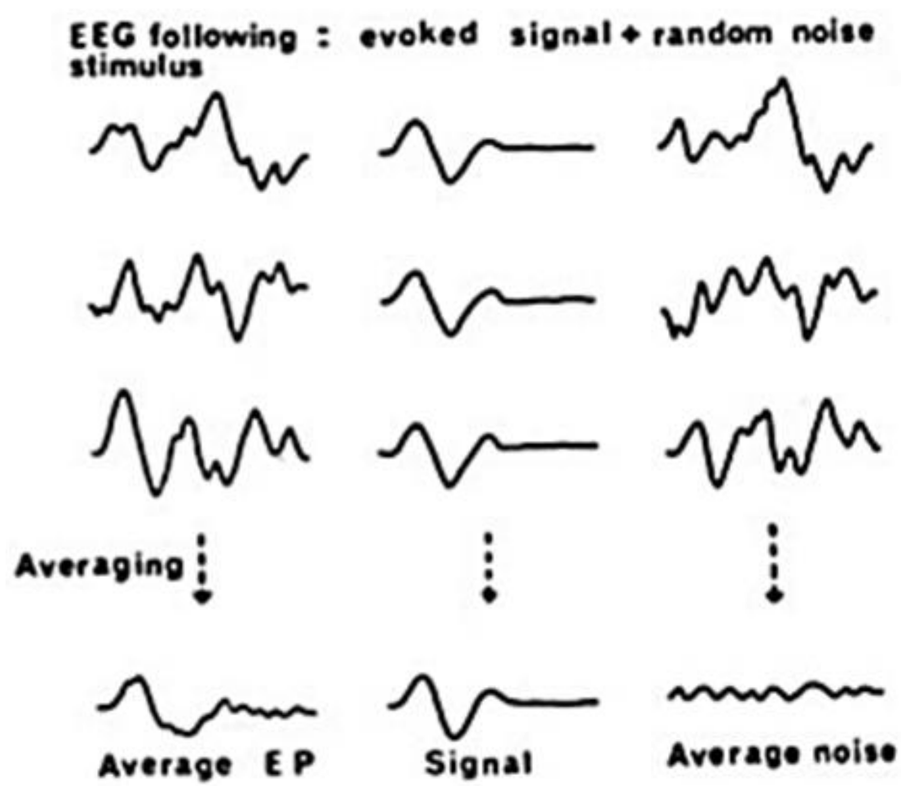
A Simple Example Experiment (by Steven J. Luck "An Introduction to Event Related Technique"

Subjects viewed sequences consisting of 80 %t Xs and 20 % Os, and they pressed one button for the Xs and another button for the Os. Each letter was presented on a video monitor for 100 ms, followed by a 1,400 ms blank interstimulus interval.
Figure 1.1B shows the EEG that was recorded at one electrode site (Pz, on the midline over the parietal lobes) from one of the subjects over a period of nine seconds.



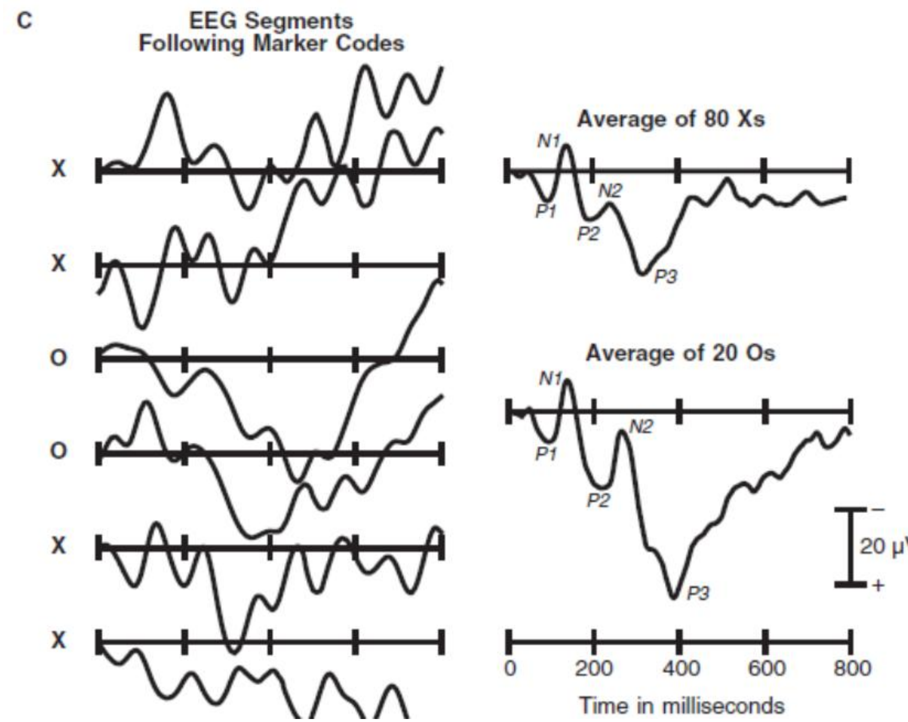
At the end of each session, a simple signal averaging procedure was made to extract the ERPs elicited by the Xs and the Os

Specifically, we extracted the segment of EEG surrounding each X and each O and lined up these EEG segments w.r.t the marker codes creating averaged ERP waveforms for the X and the O at each electrode site.



The resulting averaged ERP waveforms consist of a sequence of positive and negative voltage deflections, which are called peaks, waves, or components. In fig. the peaks are labeled P1, N1, P2, N2, and P3.

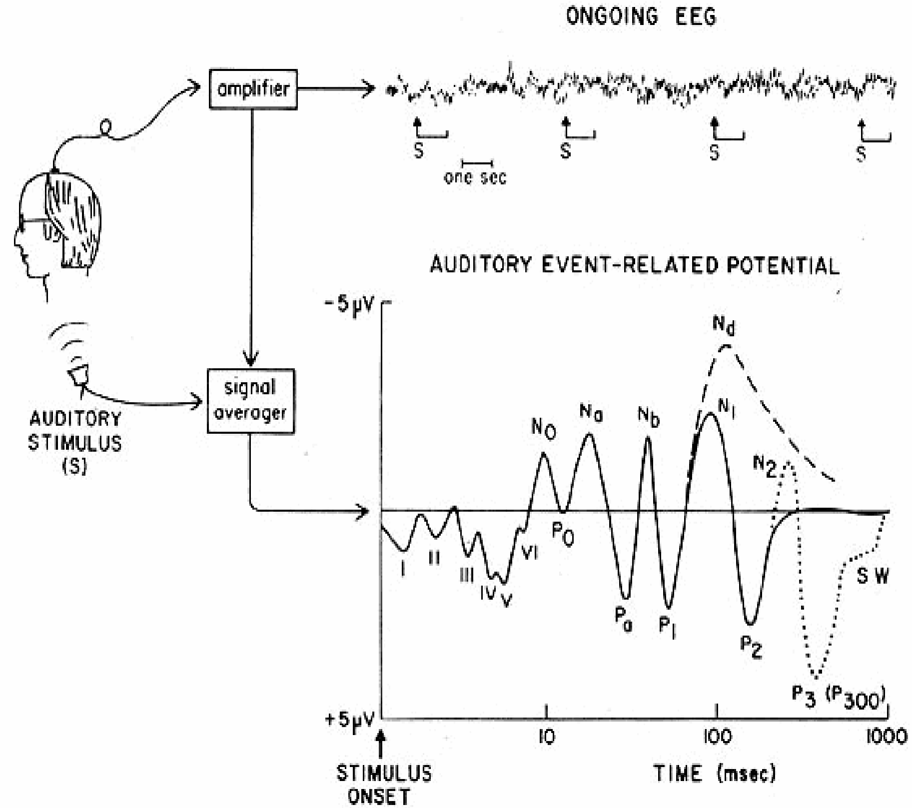
They are classically labelled according to their polarity (positive/negative) at specific recording sites and the typical latency of their occurrence (e.g. N100 refers to a negative potential around 100ms, similarly for P300, N400 etc.).



Oddball" Paradigm = 1 stimulus appears more often (X) than another (O)

Typically see large "P3 (P300)" in response to "oddball" stimulus

ERPs in humans can be divided into 2 categories.
The early waves, peaking roughly within the first 100 milliseconds after stimulus, are termed ‘sensory’ or ‘exogenous’. They depend largely on the physical parameters of the stimulus. In contrast, ERPs generated in later parts (the P300 peak) reflect the manner in which the subject evaluates the stimulus and are termed ‘cognitive’ or ‘endogenous’ ERPs as they examine information processing.



Sensory components from different stimuli that are given the same label are not usually related in any functional manner: They just have the same polarity and ordinal position in the waveform. For example, the auditory P1 and N1 components bear no particular relationship to the visual P1 and N1 components.

Some ERP Peaks Related to Language

N400 = ERP "component" related to meaning
- Bigger when word's meaning doesn't fit context
- Bigger for unfamiliar words
- May reflect amount of work required to integrate with context

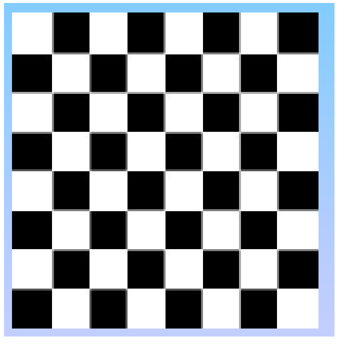
P600 = ERP "component" related to form
- Bigger when word not of expected type position in a sentence
- May be a type of P300

Visual evoked potential

Commonly used visual stimuli are flashing lights, or checkerboards on a video screen that flicker between black on white to white on black (invert contrast).

Visual evoked potentials are very useful in detecting blindness in patients that cannot communicate, such as babies or animals.

Other applications include the diagnosis of optic neuritis, which causes the signal to be delayed. Such a delay is also a classic finding in Multiple Sclerosis.

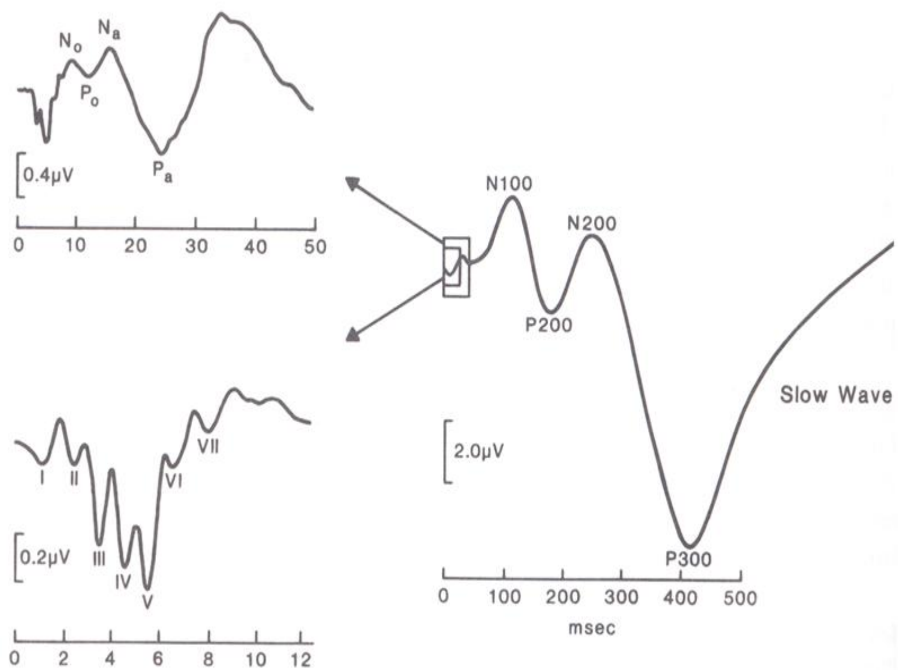


Diagnosis of multiple sclerosis, compression of optic nerve, optic chiasm (tumor of pituitary gland or optic nerve glioma)

Auditory evoked potential can be used to trace the signal generated by a sound, from the cochlear nerve, through the lateral lemniscus, to the medial geniculate nucleus, and to the cortex.

- For the brain auditory evoked potential (BAEP), the stimulus is supplied through headphones. The ear that is being tested receives a clicking sound.

- diagnostic analysis of middle ear, cochlear and retrocochlear lesion



Idealized Auditory ERPs

Magnetoencephalography

MEG

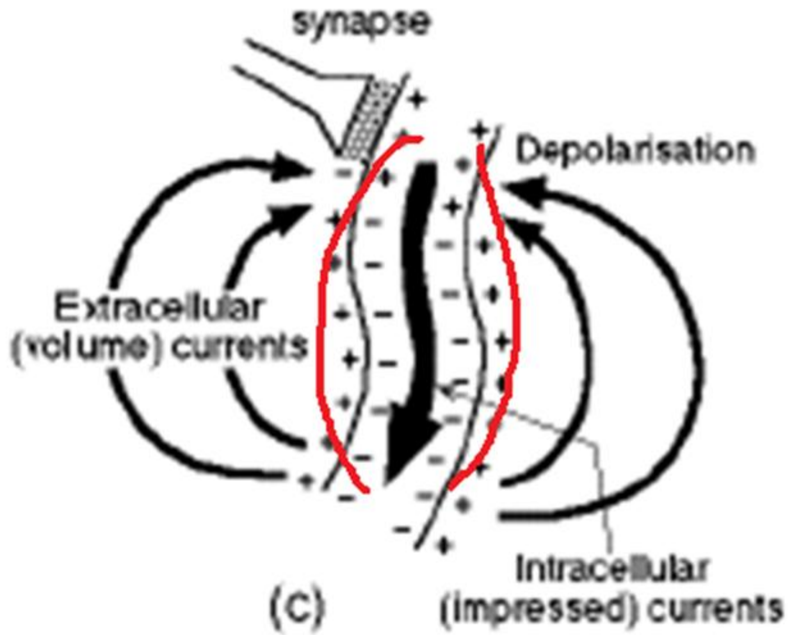
Measures changes in magnetic fields that accompany electrical activity.

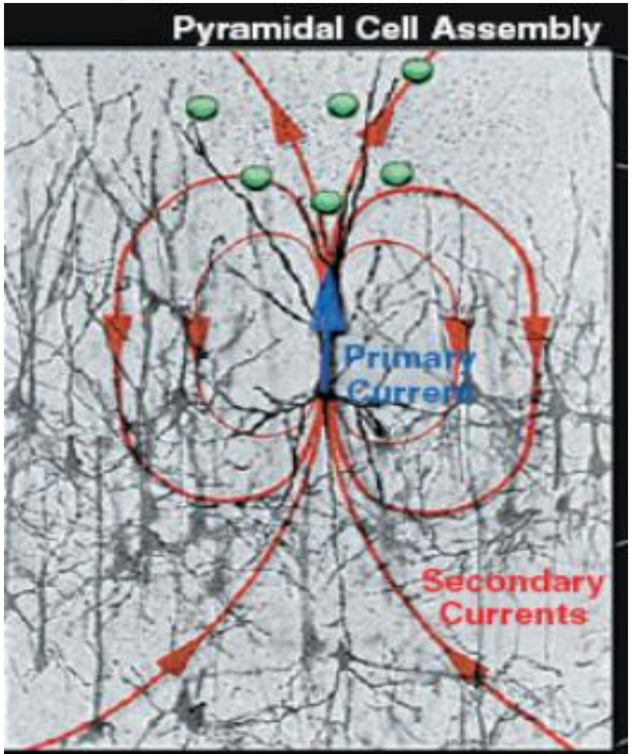
The MEG laboratory

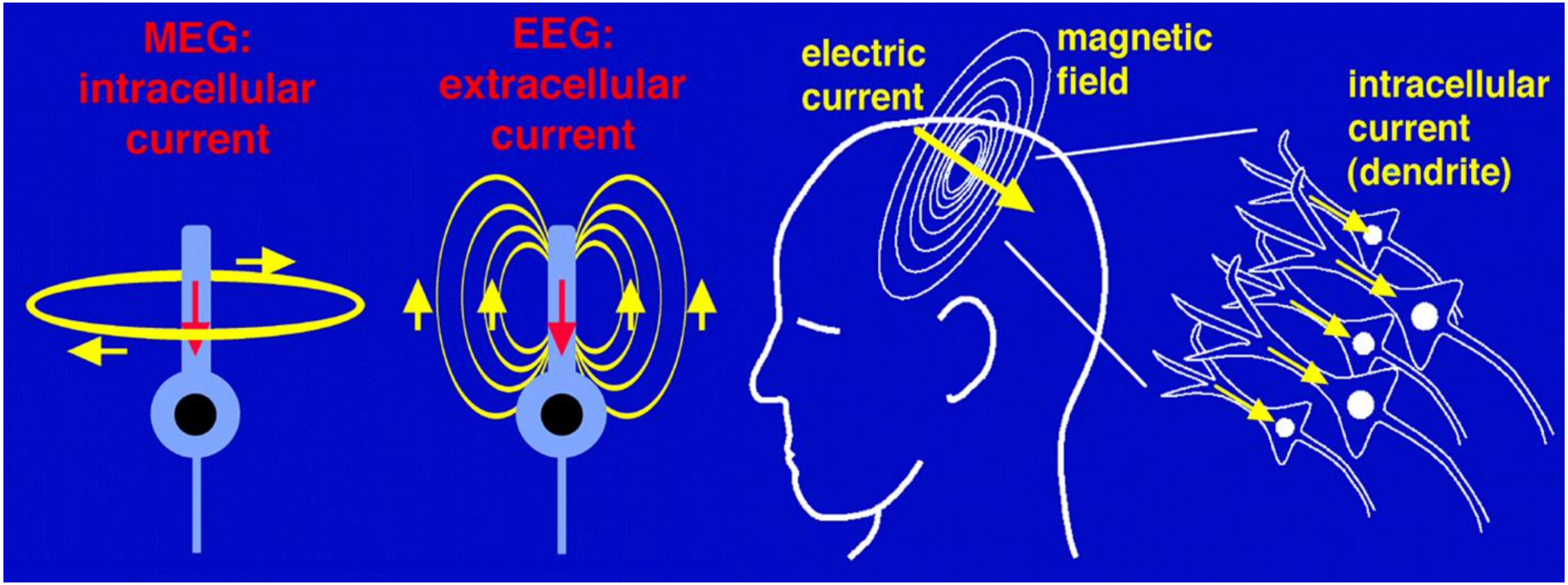
Postsynaptic potential generate intracellular currents (primary currents) and extracellular currents (secondary currents)

MEG measures magnetic fields induced mainly by primary currents

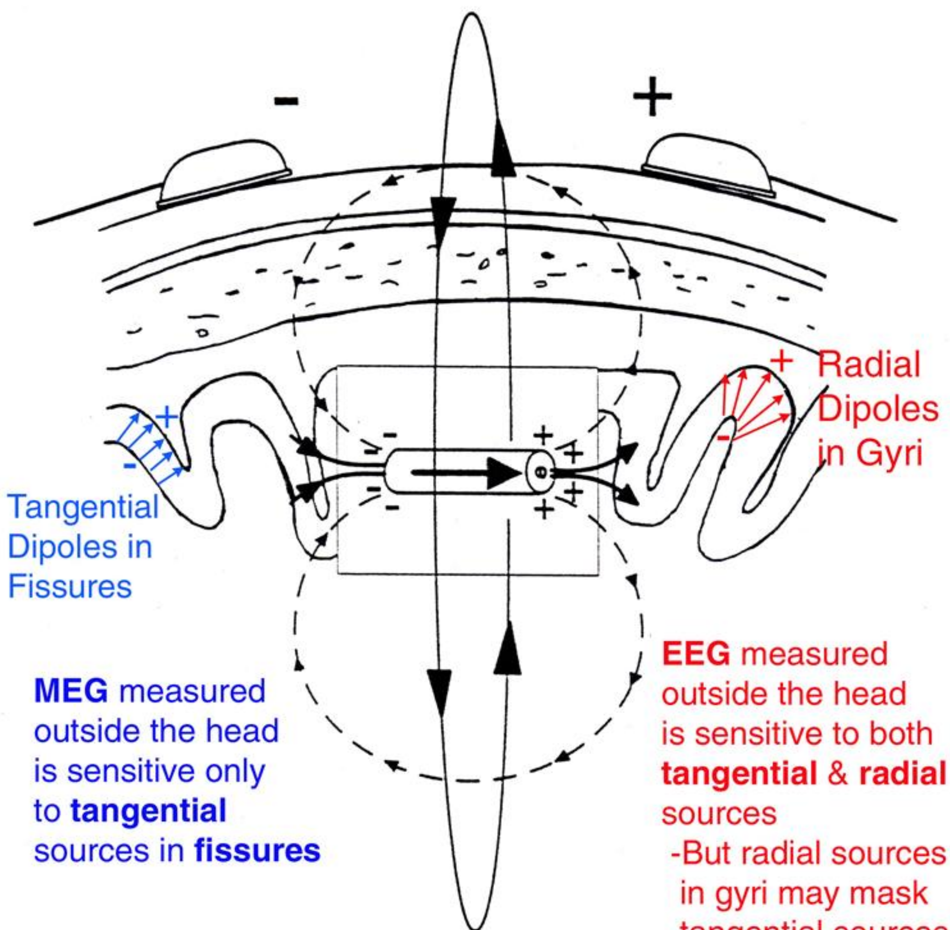
Cummulative summation of postsynaptic primary currents of millions apical dendrites of pyramidal cells in one cortical area generates a magnetic field that is measurable by MEG






MEG:
intracellular
current
EEG:
extracellular
current
electric
current
magnetic
field
intracellular
current
(dendrite)

Sources of EEG & MEG

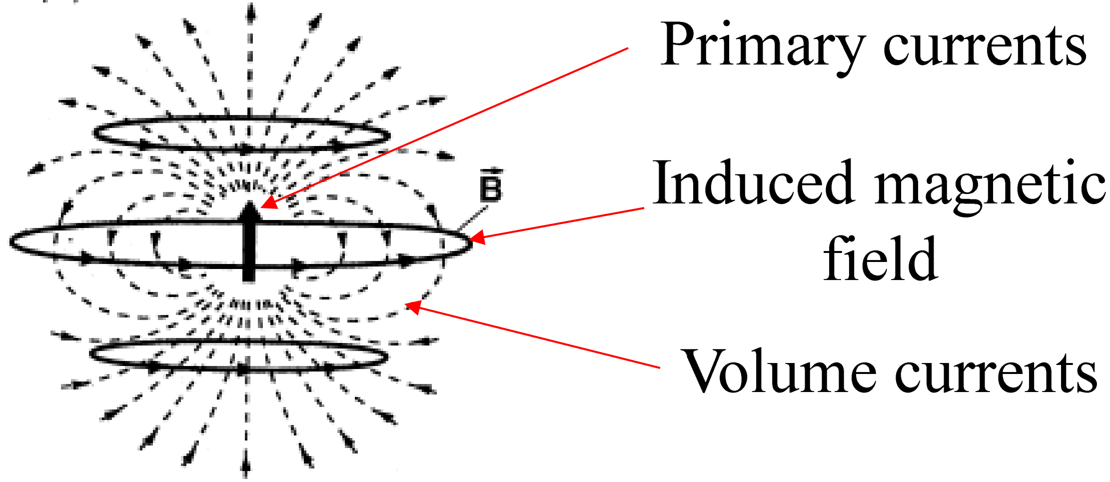


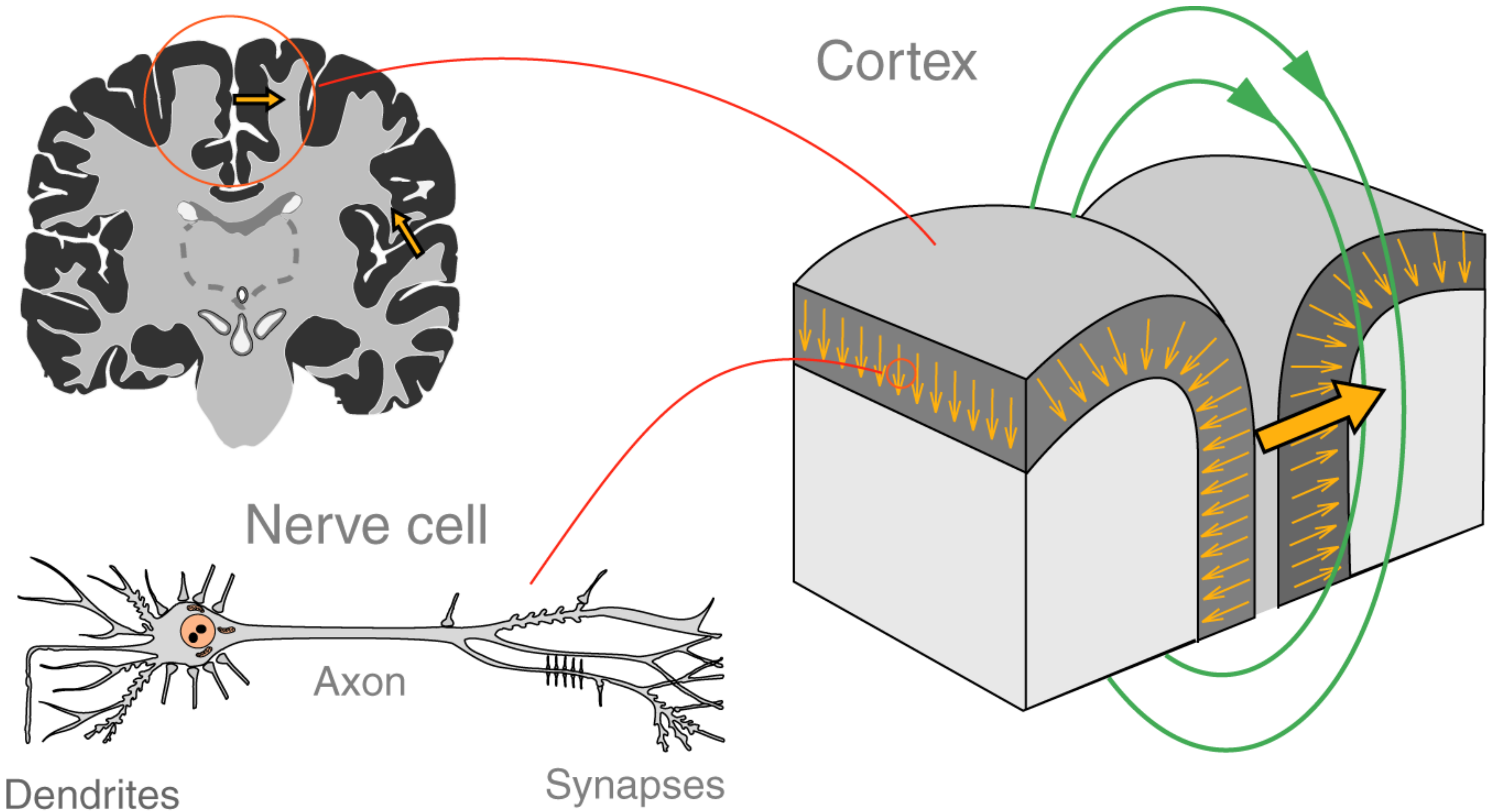
MEG measured outside the head is sensitive only to **tangential** sources in **fissures**

EEG measured outside the head is sensitive to both **tangential** & **radial** sources

-But radial sources in gyri may mask tangential sources in fissures

"Right Hand Law"

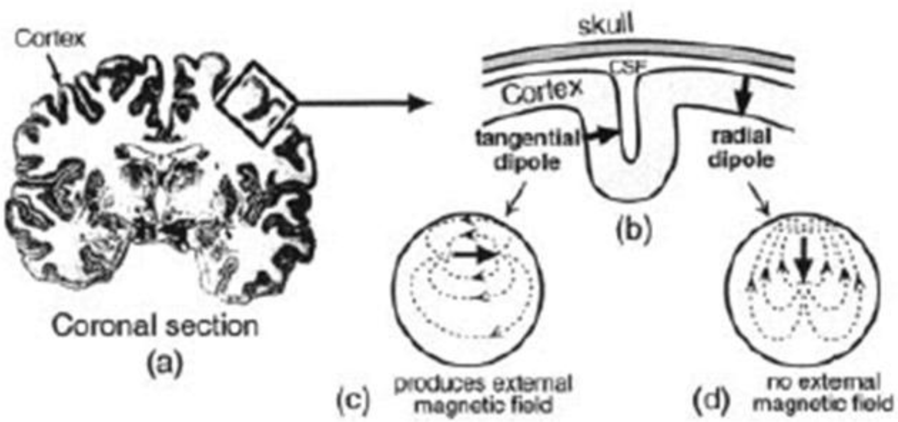


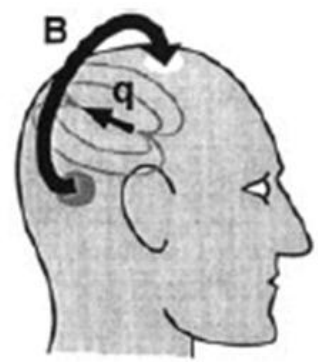


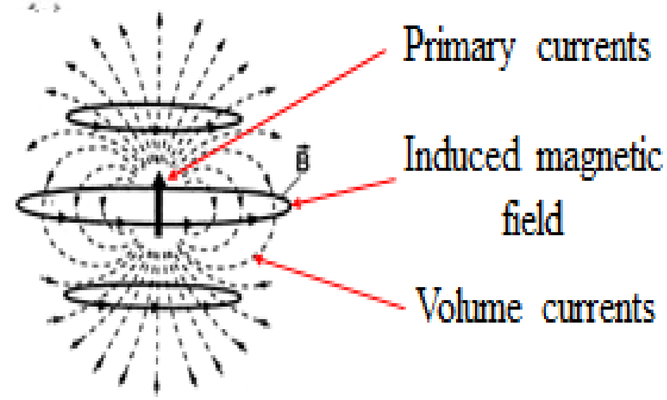
Tangential currents will produce magnetic fields that are observable outside the head

Radial currents will not produce magnetic fields outside the head

MEG only detects tangential currents







MEG measures the fluctuations of frequency (Hz) and amplitude (T) of the brain magnetic signal 10 fT (10^{-15}) to about several pT (10^{-12})

Earth 's magnetic field is about 0.5 mT

Urban magnetic noise is about 1 nT to 1 µT

Moving vehicules, moving elevators, radio, TV, powerlines, etc.

The electrical activity of the heart, eye blinks also generate a field 2 to 3 order of magnitude larger than the signal from the brain

Noise is about a factor of 10^3 to 10^6 larger than the MEG signal

We need very sensitive MEG sensors
to pick up the brain magnetic fields

MEG measurements need noise cancellation with extraordinary accuracy:

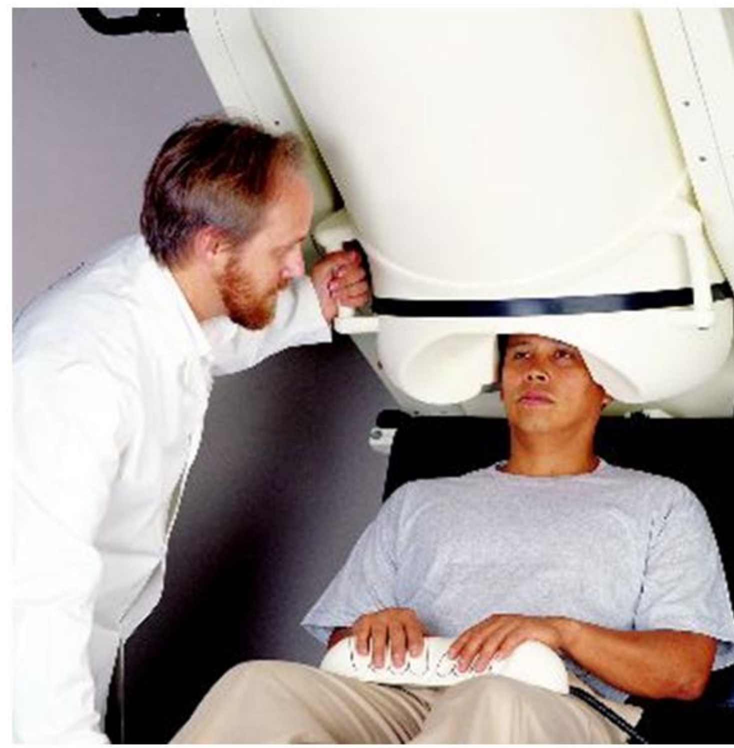
Design of the SQUID
Magnetic shielded room
Hardware and software
And averaging

Superconducting QUantum Interference Device
SQUIDs are sensitive to very low magnetic fields

To have their superconductive properties,
the SQUIDs need to be maintained at-269 °C (in liquid Helium)

With MEG, you can make (as in EEG) :

- Continuous acquisition of brain signals and study some events that appear « randomly » (Epileptic abnormalities, etc.)
- Evoked response: averaged MEG signals that are synchronous with an external stimulus or voluntary motor event



THANK YOU