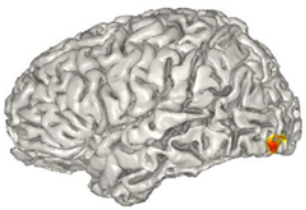
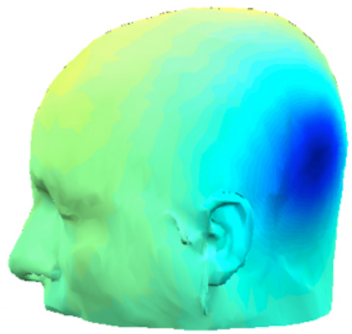
Next two meetings

- Relation between neuroelectric activity in the brain and EEG on the scalp.
- Overview of EEG/ ERP methods and issues





COGNITIVE PROCESSING TAKES PLACE IN THE BRAIN

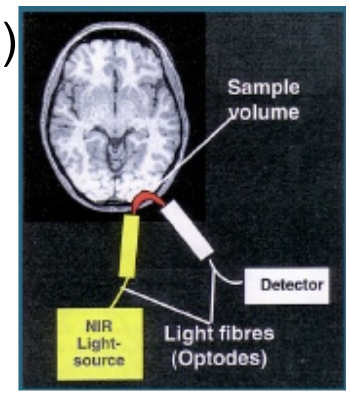
There are many different methods – strengths & weaknesses

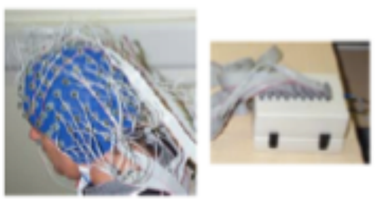
- individuals with brain damage (neuropsychology)
- individuals with epilepsy (single unit, intracranial recordings)

- positron emission tomography (PET)
- functional magnetic resonance imaging (fMRI)
- optical imaging, near infra-red spectroscopy (NIRS)

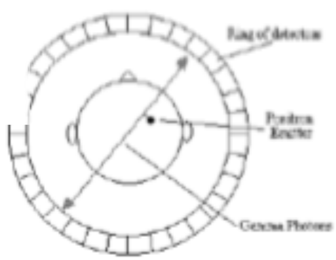
- transcranial magnetic stimulation (TMS)

- electrical recordings (EEG, EP, ERP, ERD)
- magnetoencephalogram (MEG)

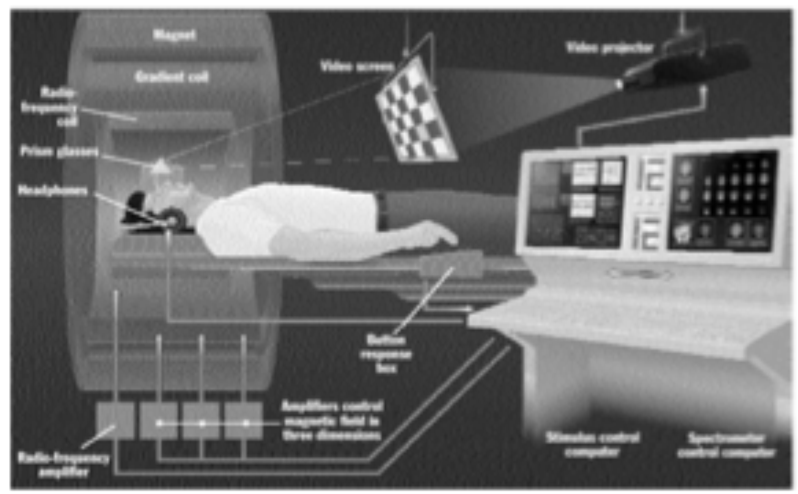




EEG



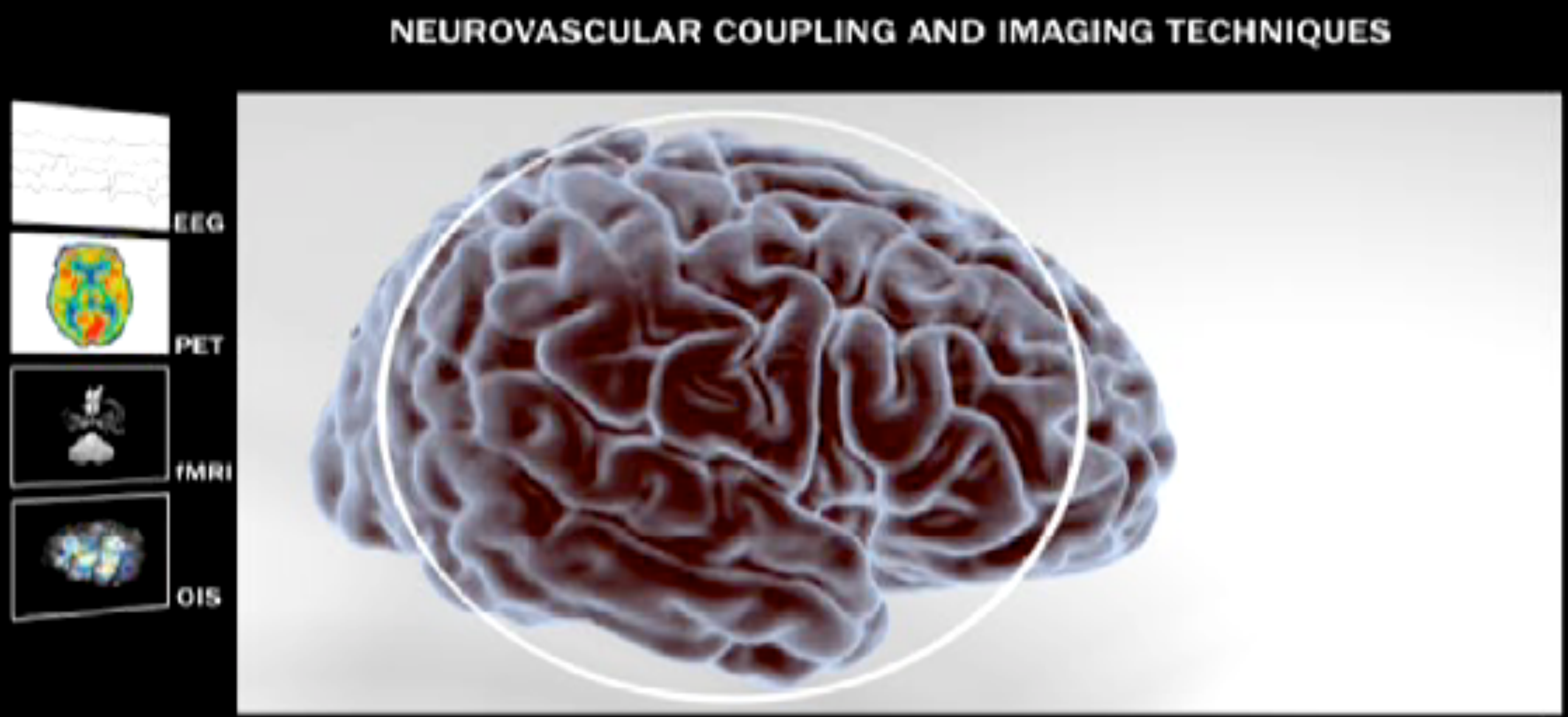
Gamma Photon Detection



Brain imaging methods

Used by permission Dr. Arthur W. Toga, Laboraory of Neuroimaging (LONI) at UCLA

Brain imaging methods



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Neuroimaging Summary

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- Brain activity = electrochemical signalling between groups of neurons.

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- PET & fMRI track blood flow / oxygenation with good spatial resolution (mm) and poor temporal resolution (seconds)

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Neuroimaging Summary

- Brain activity = electrochemical signalling between groups of neurons.
- PET & fMRI track blood flow / oxygenation with good spatial resolution (mm) and poor temporal resolution (seconds)
- Optical imaging tracks blood flow / oxygenation with good spatial and temporal resolution
- EEG and MEG track changing electromagnetic fields generated as neurons signal with poor spatial resolution (best = cm, worst = unknown) and good temporal resolution (milliseconds).

Matching measure to question

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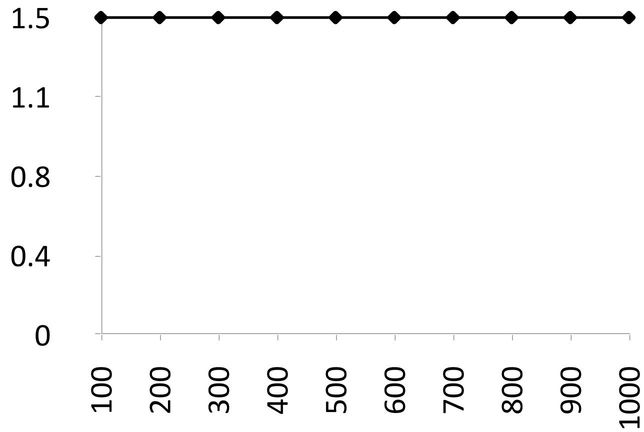
- We have lots of experimental measures ... which one do we use?

Matching measure to question

- We have lots of experimental measures ... which one do we use?
- Depends what you want to learn about

[redacted]

Battery voltage readings over time ... flat



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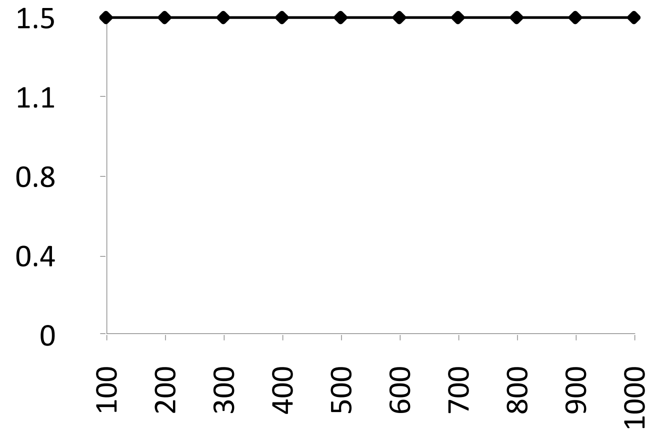

Human scalp voltage readings … not so

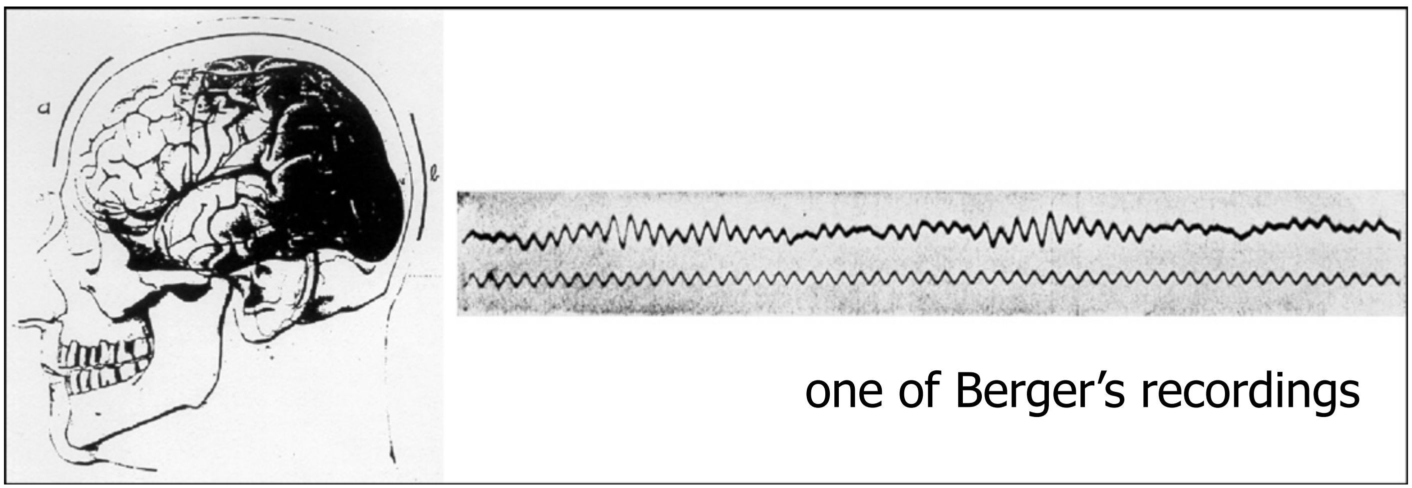

Figure 1. One of the first recordings of an electroencephalogram (EEG). Left panel: schematic illustration of the localization of lead plate electrodes: Right panel, upper trace: EEG of Hans Berger's son Klaus (15 years). Right panel, lower trace: time marker, sine wave 10 Hz. From "U¨ ber das Elektrenkephalogramm des Menschen, 1. Mitteilung," by H. Berger, 1929, *Archiv fur Psychiatrie*, *87*, p. 553.

NEURAL COMMUNICATION IS ELECTROCHEMICAL

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Signaling between *neurons* is the essence of brain activity and these interactions consist of *current flow* – the movement of charged ions – across cell membranes, such that the direction and magnitude of current flow in one neuron depends on the neurons it communicates with.

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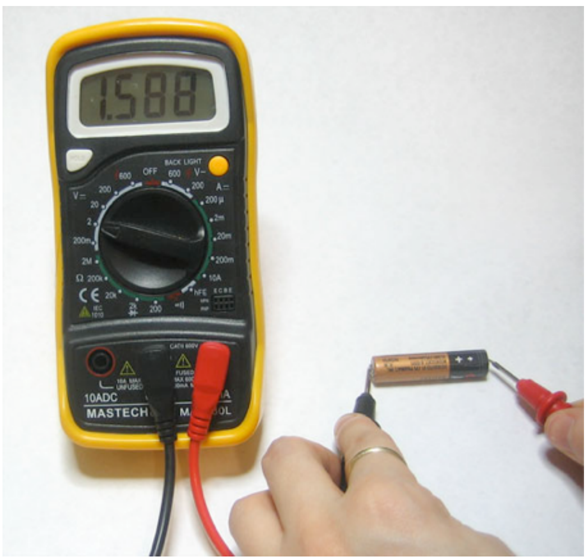
The net flow of current across the neural membrane generates an electric potential in the conductive media both inside and outside the cells.

It is this *electric potential* that forms the basis for the *electrophysiological recordings* made by electrodes *inside* or *outside* the brain.

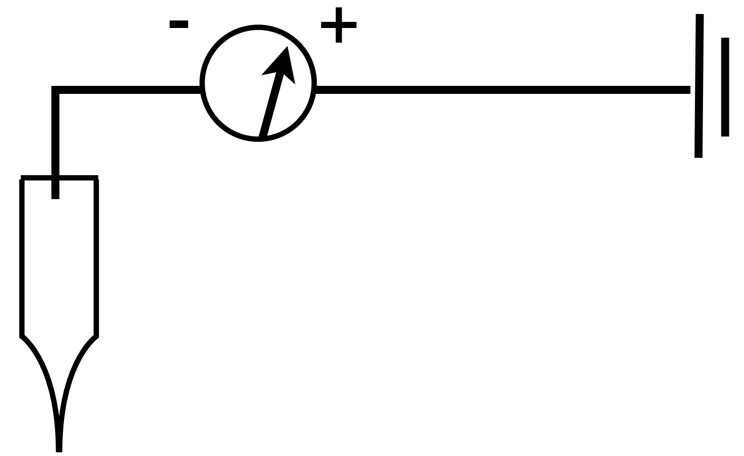
Electric potentials are measured in Volts

A fresh flashlight battery is about 1.5 Volts



voltmeter
(2 probes)

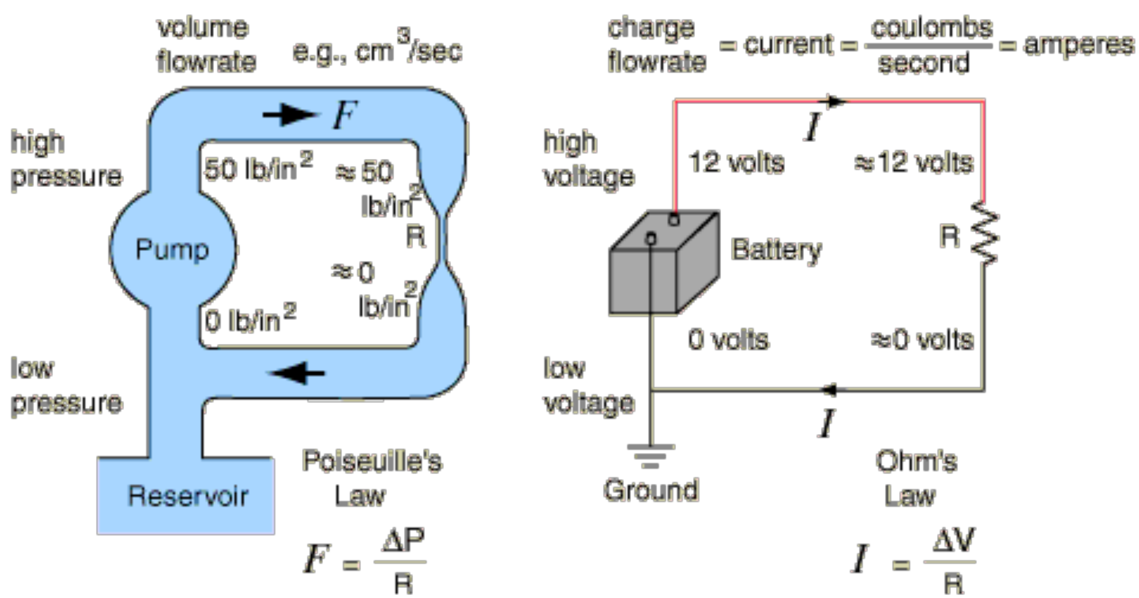
Brain potentials range from millivolts (10^{-3}V) measured in the brain tissue to microvolts (10^{-6}V) measured at the scalp



voltmeter
(also 2 probes)

Recall: Electricity and water analogy

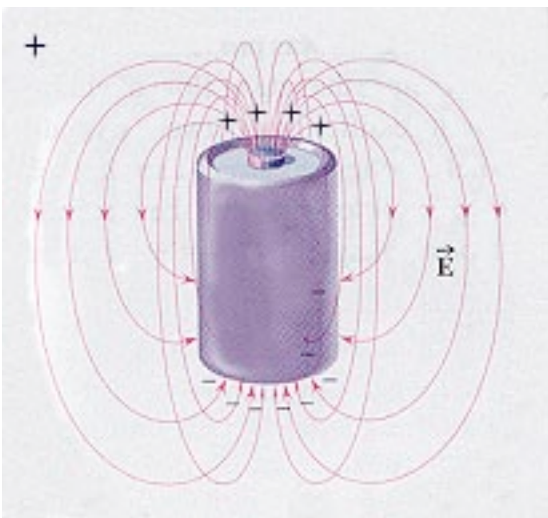
- V = electrical potential (Volts) … “pressure”
- *I* = current (Amps) … “flow”
- R = resistance (Ohms) … “constriction”

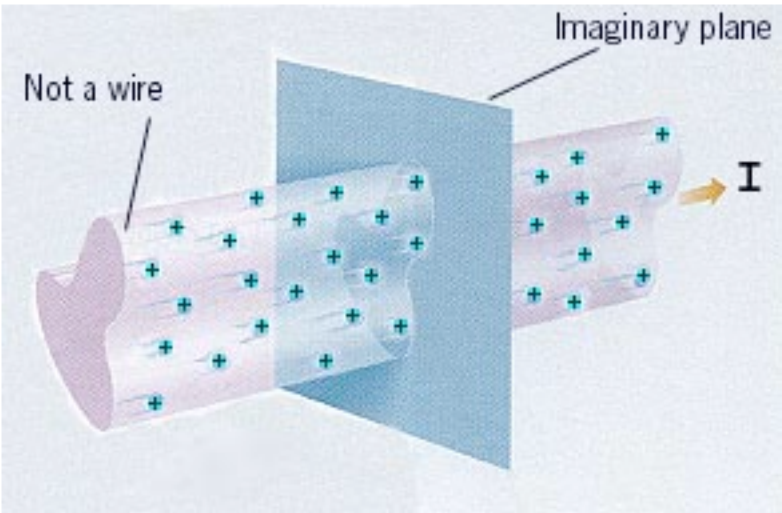


http://hyperphysics.phy-astr.gsu.edu/hbase/electric/watcir.html

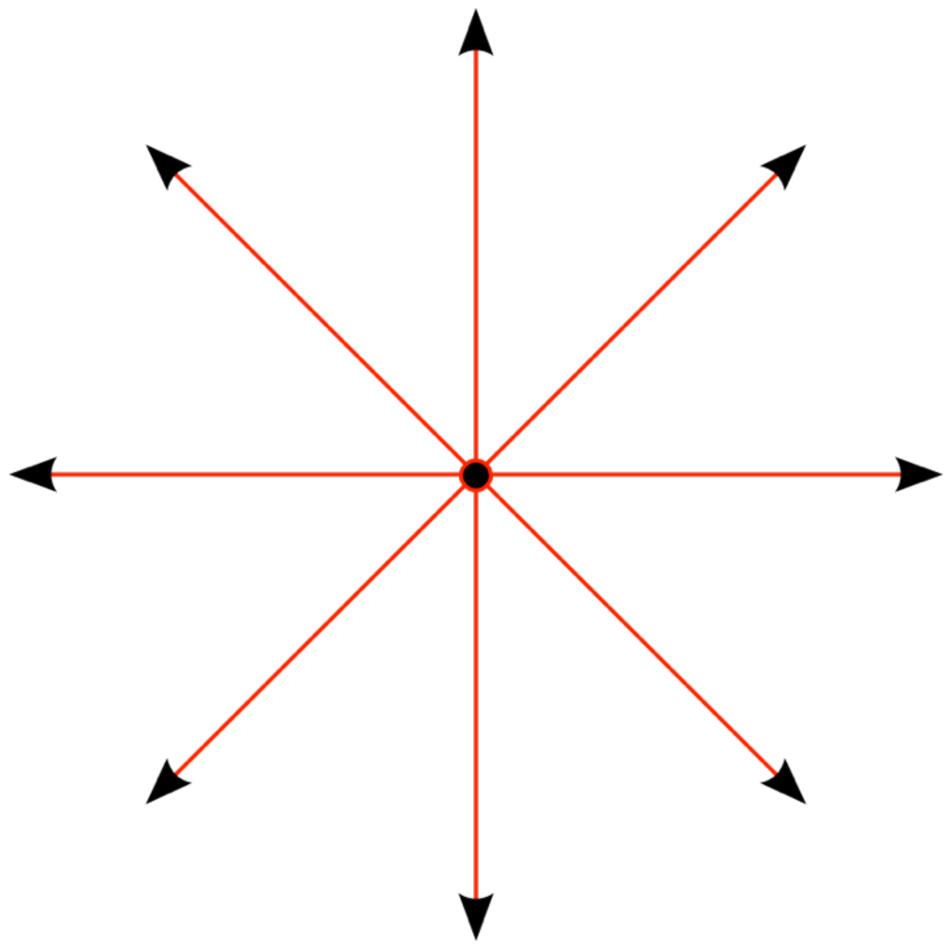
But what if there is no wire ...
Na^+ and Cl^- ions in salt water?

Charged particles are free to move about the volume of the conducting material



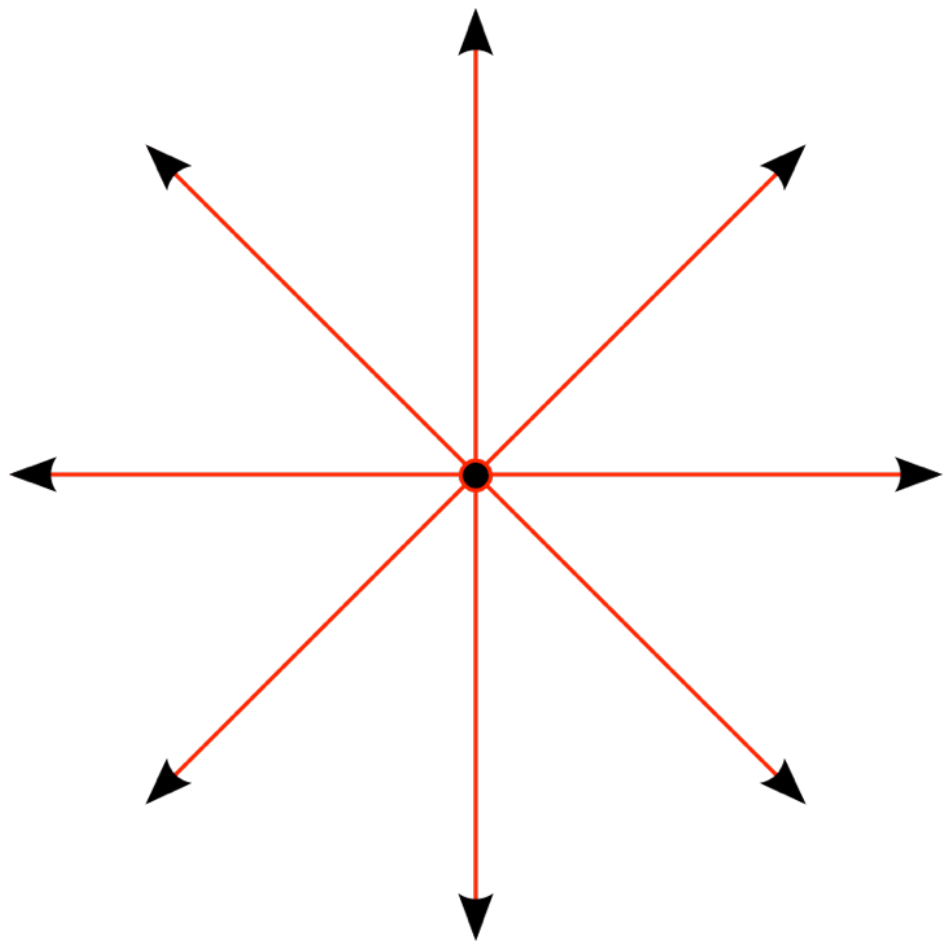


Point source in volume conductor (infinite, homogeneous)



Point source in volume conductor (infinite, homogeneous)

What is happening ...



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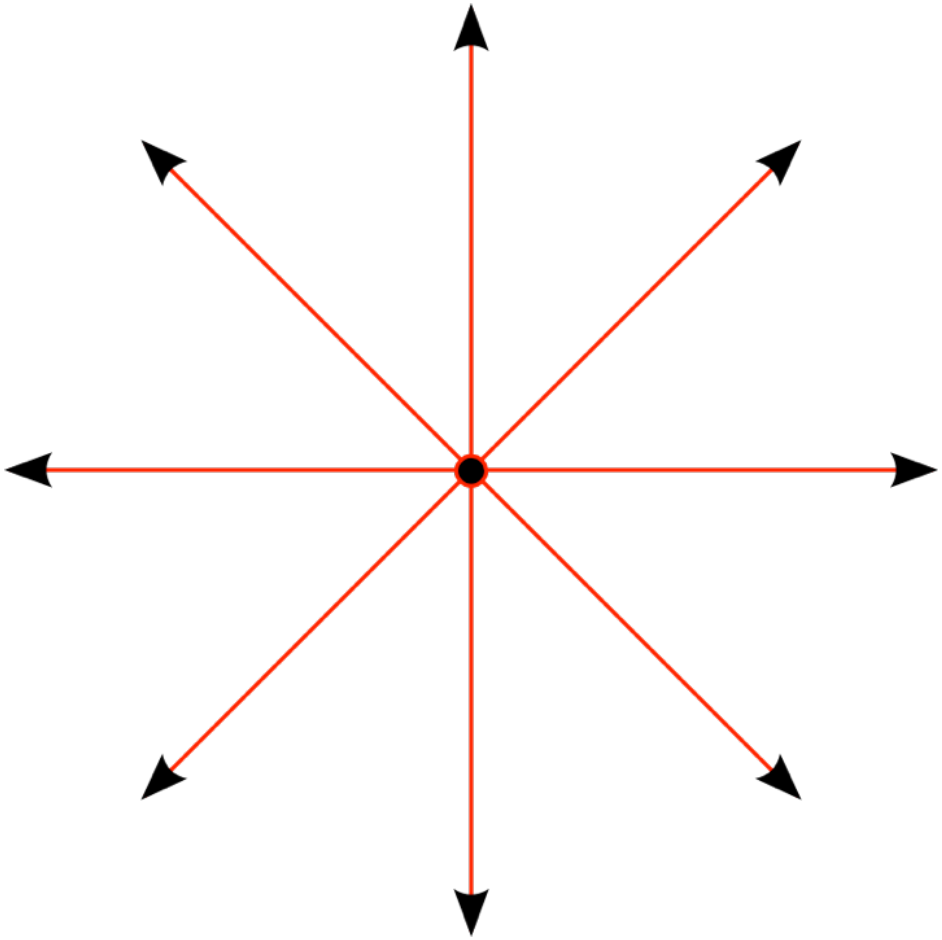

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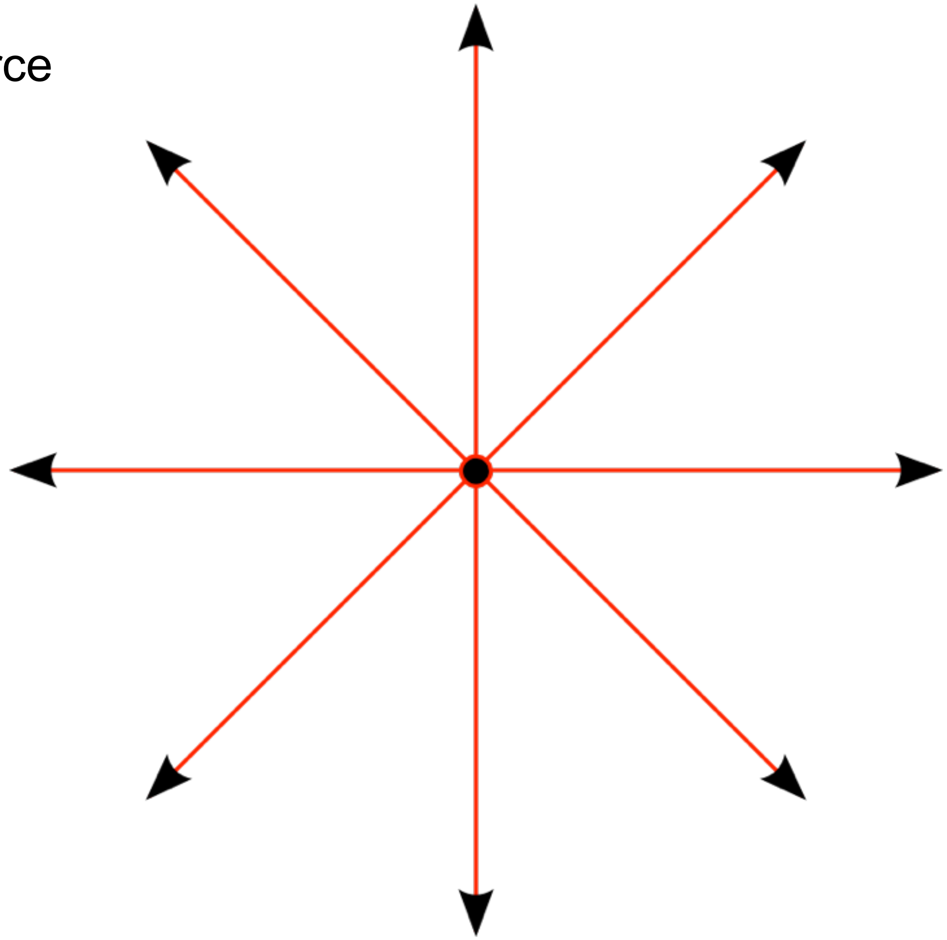

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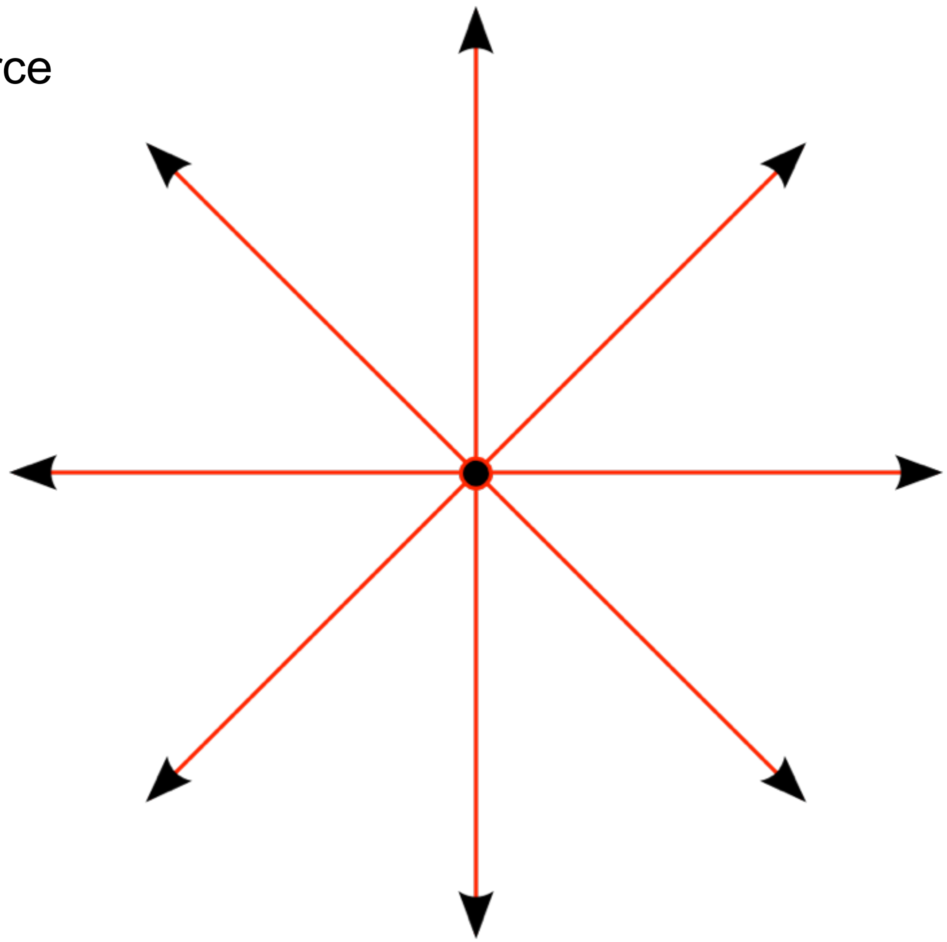
potential *("push")* in Volts



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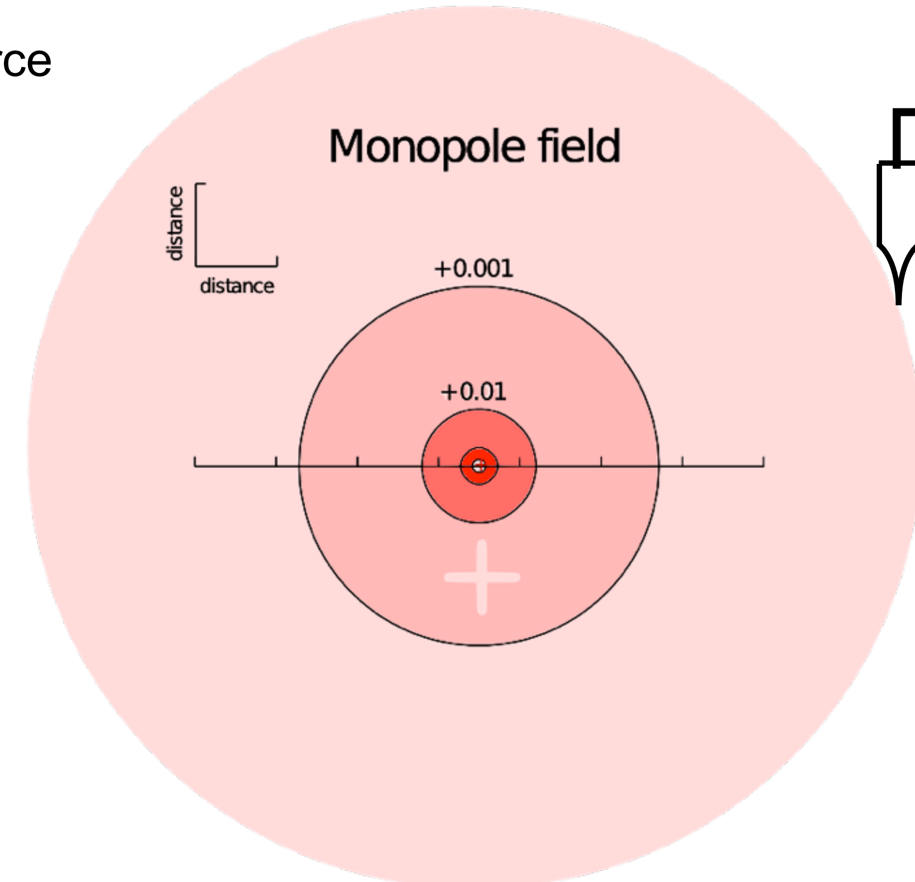

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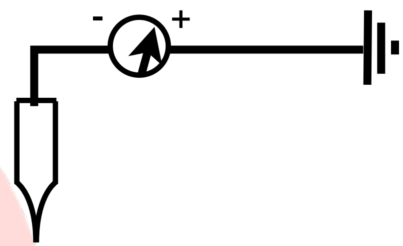

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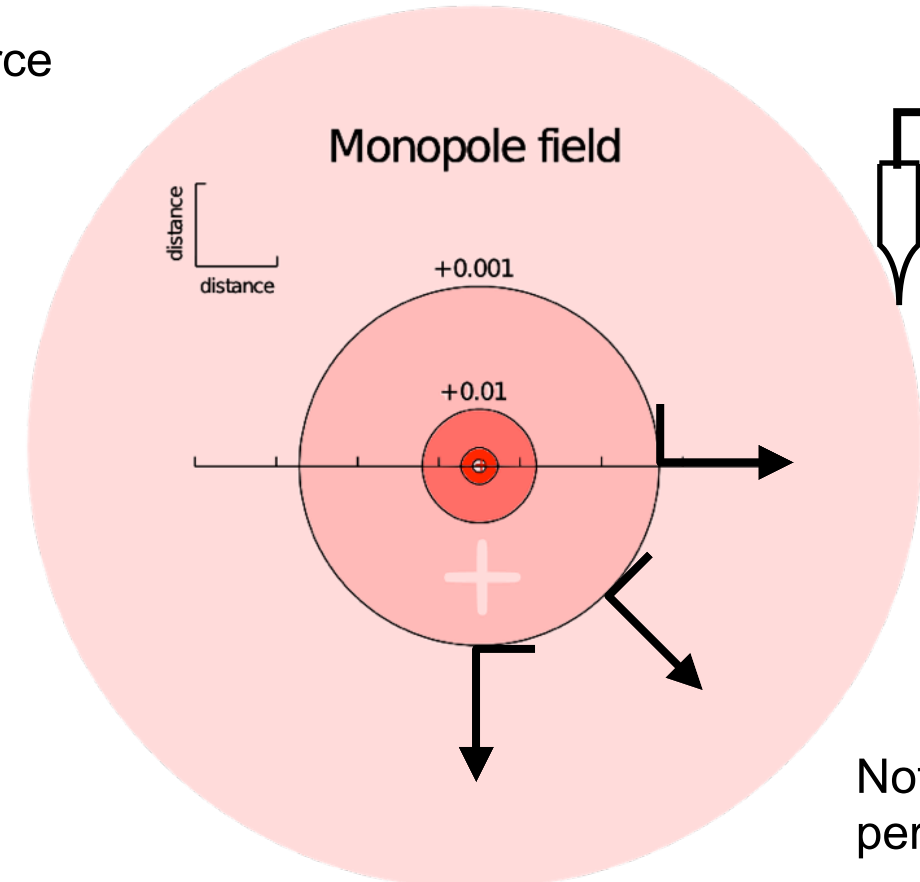
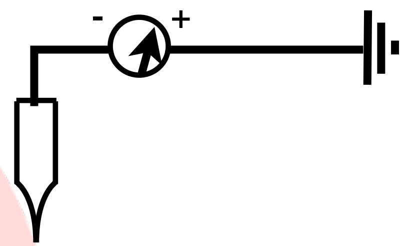




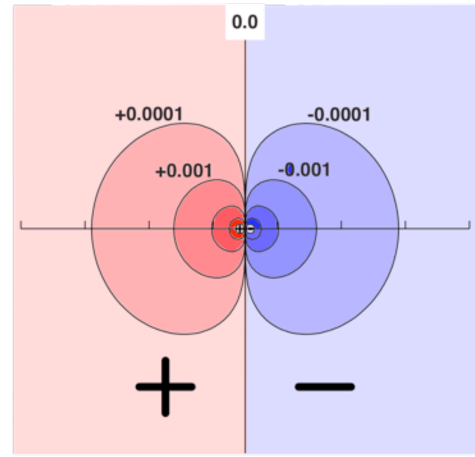
Note:isopotential lines are perpendicular to current

Current and potentials in a volume conductor

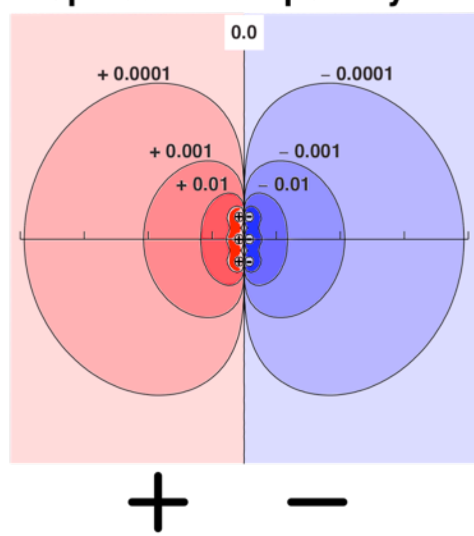
- ***Direction:*** Current flow is conventionally from ***source*** (+) to ***sink*** (-) in volume conductors
- ***Speed:*** Fields propagate virtually instantaneously
- ***Intensity:*** More current generates bigger potentials
- ***Distance:*** Fields get smaller farther from the source
- ***Linearity:*** Potential fields generated separately by multiple sources and sinks simply add up each point in space

Dipole = paired current source and sink

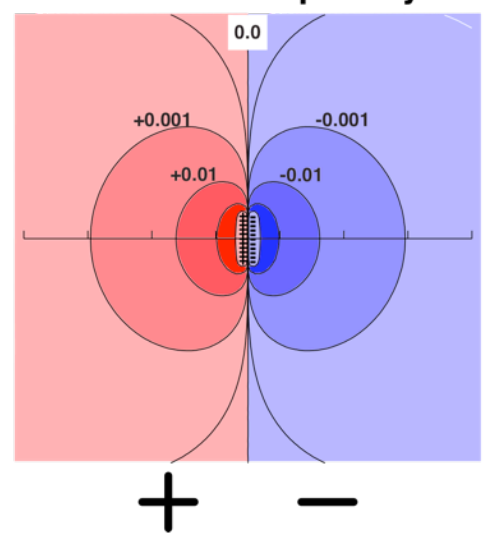
Single dipole field



Sparse three dipole layer

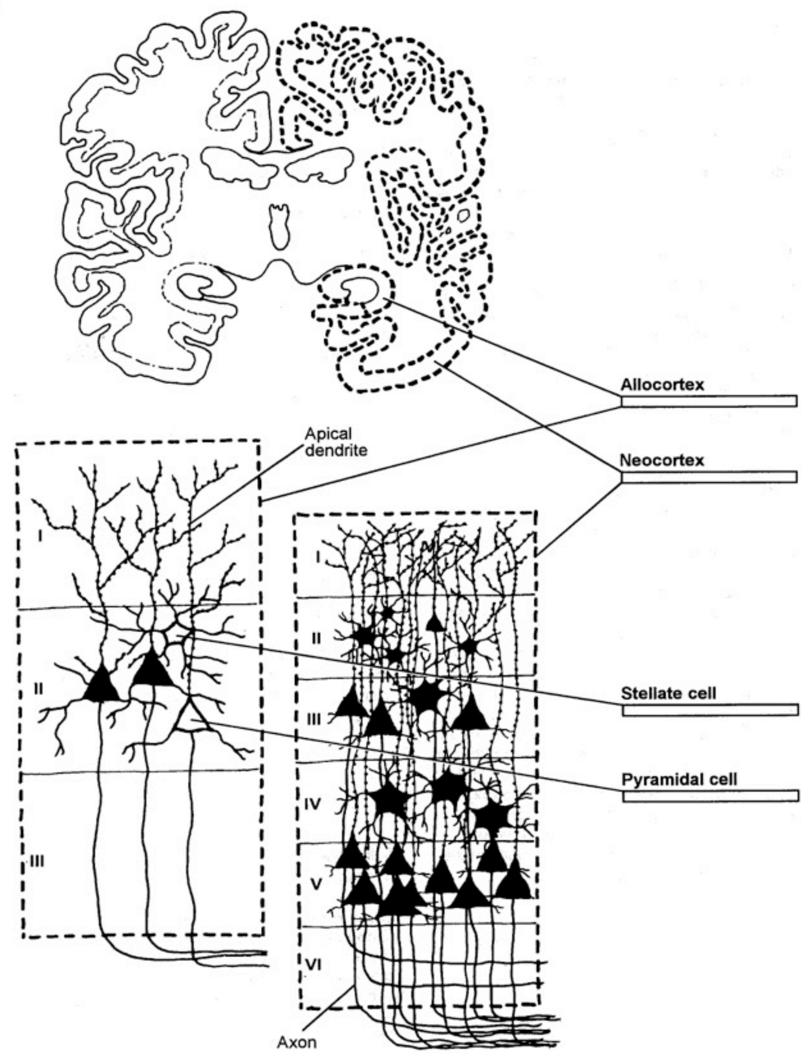


Dense eleven dipole layer

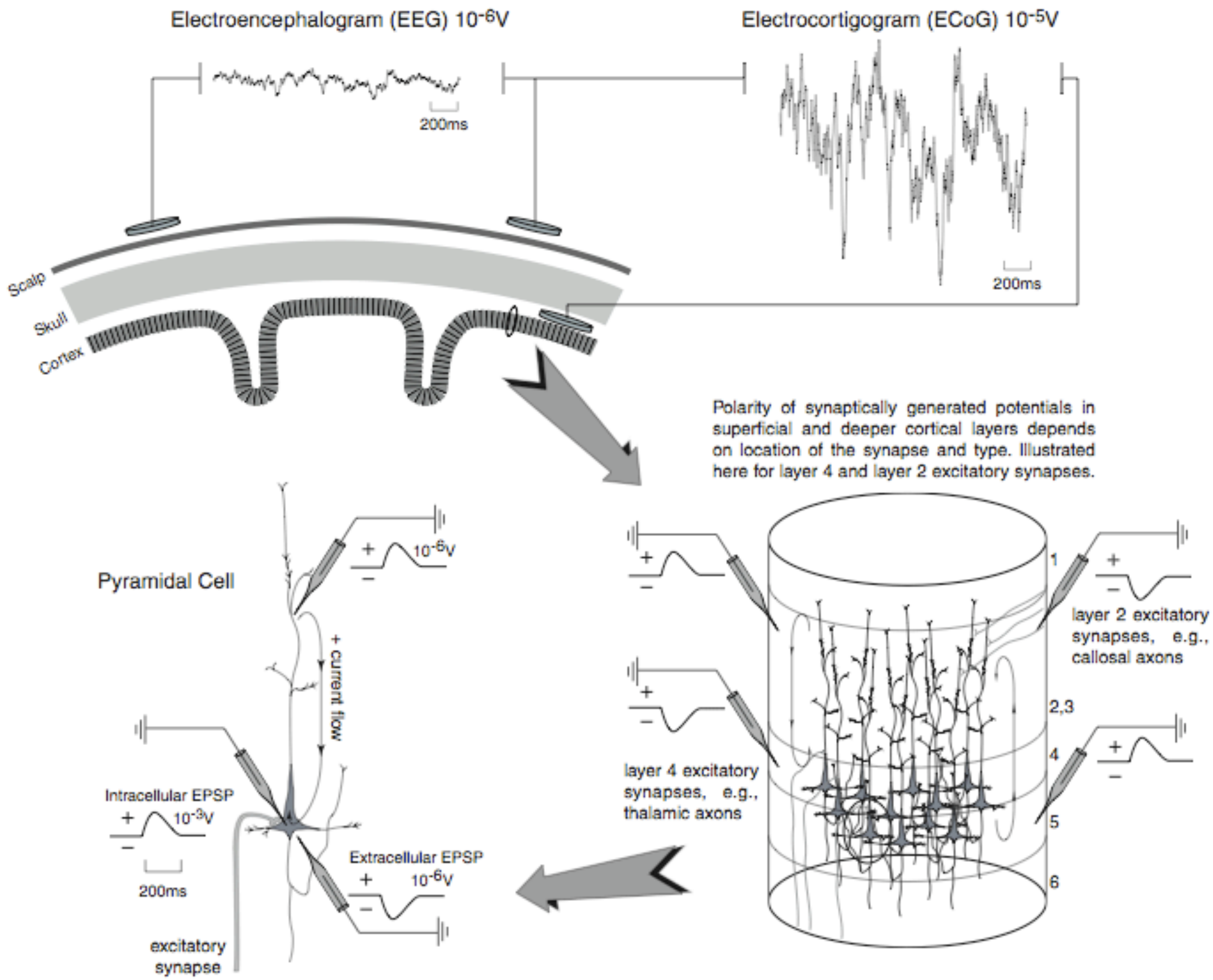


Neurons and the cortex

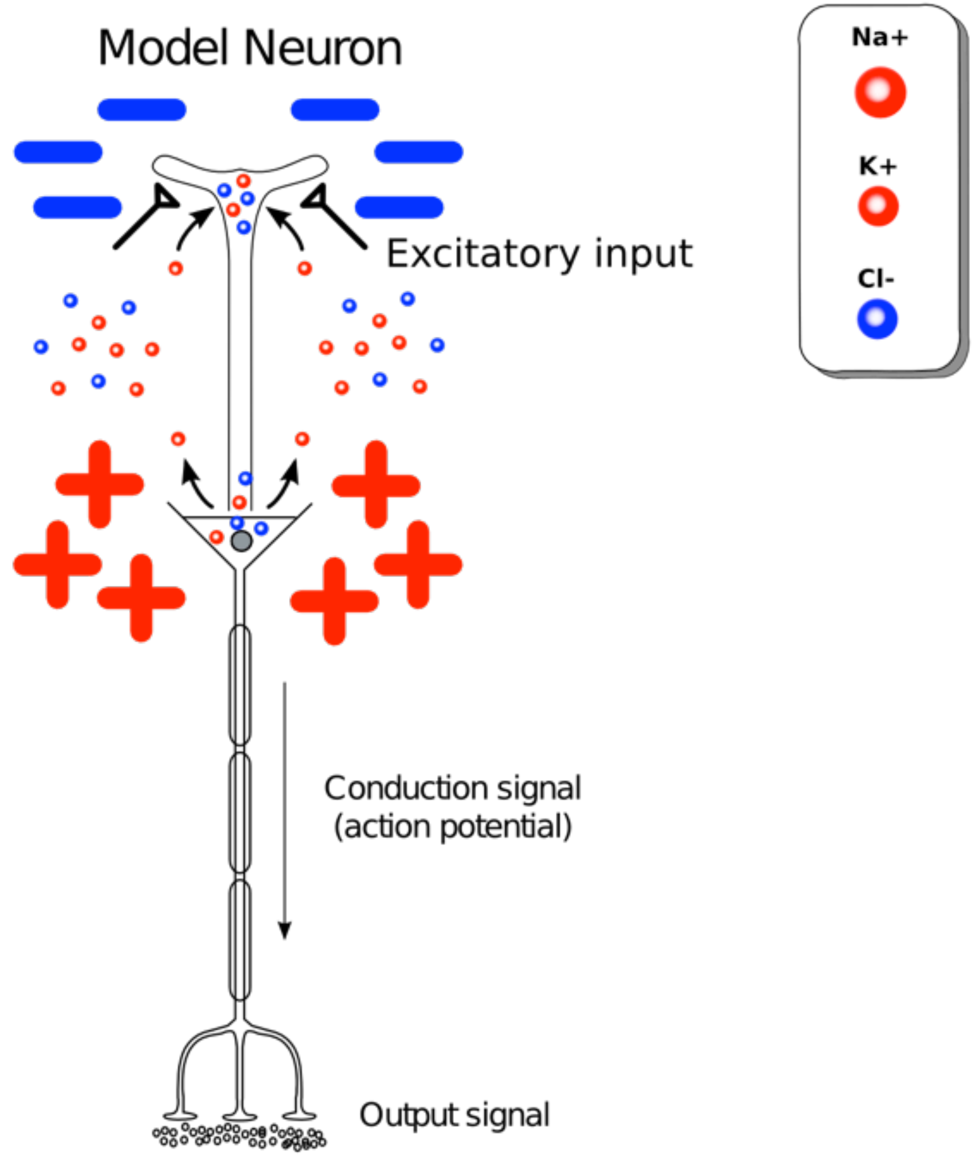
- Cortex
  - layers
  - folded
  - pyramdial cells oriented perpendicular to the surface
- Pyramidal neurons
  - excitatory
  - project axons to other areas of brain and spinal cord
- Stellate neurons:
  - inhibitory
  - local projections



Electrogenesis of the EEG



1. EPSPs: Excitatory (depolarizing) postsynaptic potentials
2. IPSPs: Inhibitory (hyperpolarizing) postsynaptic potentials
3. Integrated input exceeds neuron's threshold and triggers action potential
4. Action potential propagates along the axon
5. Neurotransmitter released into where dendrites synapse on other neurons, opening ion channels in postsynaptic membrane.
6. Rinse, lather, repeat



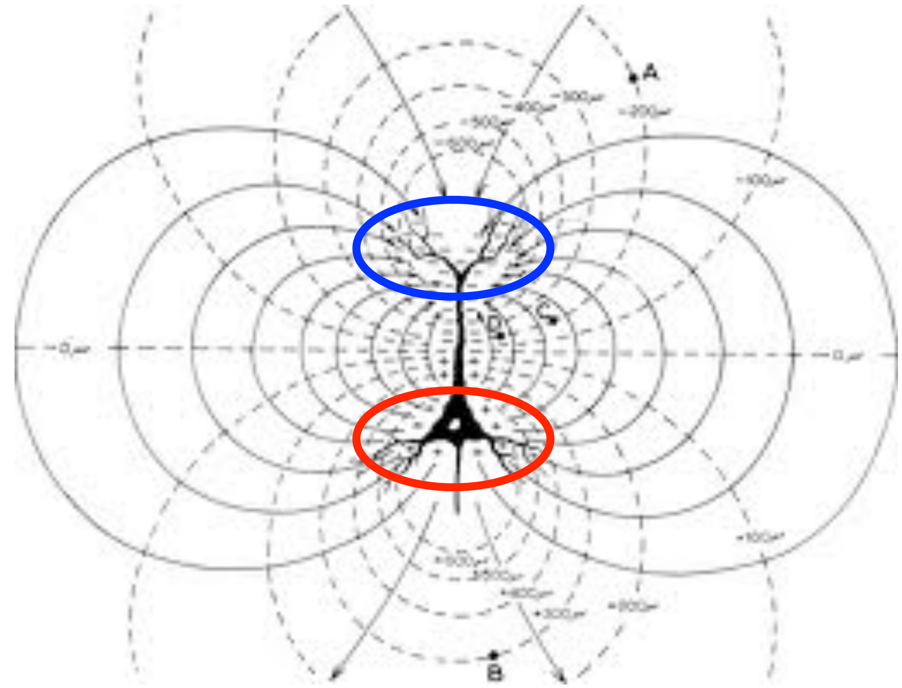
Neuron as source/sink pair: dipole

1. Net inward current flow across the cell membrane (often called a current "sink") is associated with a *negative* potential in adjacent regions of the extracellular space.

2. Net outward current flow (often called a current "source") is associated with a *positive* potential in adjacent regions of the extracellular space.

3. Current flow into the active region of the cell is balanced by an equal current flow out of passive regions of the cell.

4. The density of current flow is large in the immediate vicinity of the depolarized region, but decreases rapidly with distance. Since the potential at any point

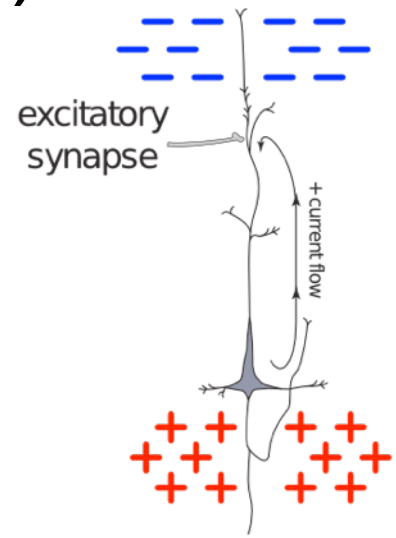


solid arrows = current flow

dotted lines = isopotentials

Post-Synaptic Potentials (PSPs)

- When transmitter binds to receptor, ion channels open ions rush into/out of postsynaptic cell

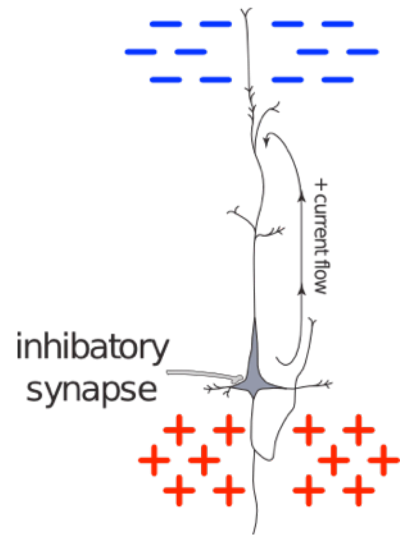


- **Excitatory Post-Synaptic Potentials (EPSPs)**

  current sink: positive ions flow into cell

- **Inhibitory Post-Synaptic Potentials (IPSPs)**

  current source: negative ions flow into cell



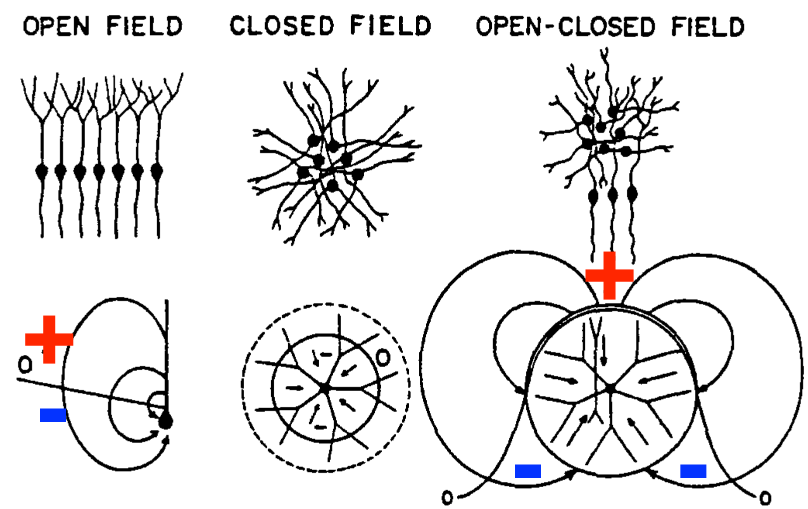
  - Field is approximately dipolar at distances large compared sink/ source separation

Potentials from multiple neurons add up (possibly to nothing)

5. According to Helmholtz's principle of superposition, potentials associated with transmembrane currents of different neurons summate at all locations in the extracellular space. Therefore, potentials of sim-

6. Even in a "simple" recording situation like that depicted in Figure 1-1, ERP morphology and latency are complex functions of electrode and source locations, as well as other factors. In the first column of

7. The specific potential recorded under a given set of conditions (or, indeed, whether any net potential is recorded) depends both upon the location of the recording electrodes and the location of the active tissue at any instant in time. In Figure 1-1, for example, the



To see the neurally generated potentials at the scalp, the neurons must:

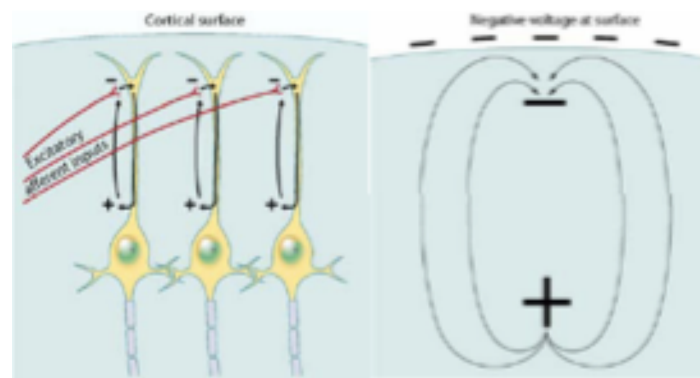
(1) be physically arranged so that their potentials add (open field) configuration; fields generated by parallel dipoles add up and can be seen at a distance; fields from non-parallel dipoles tend to cancel (closed fields) and are negligible at a distance.

(2) be active in relative synchrony.

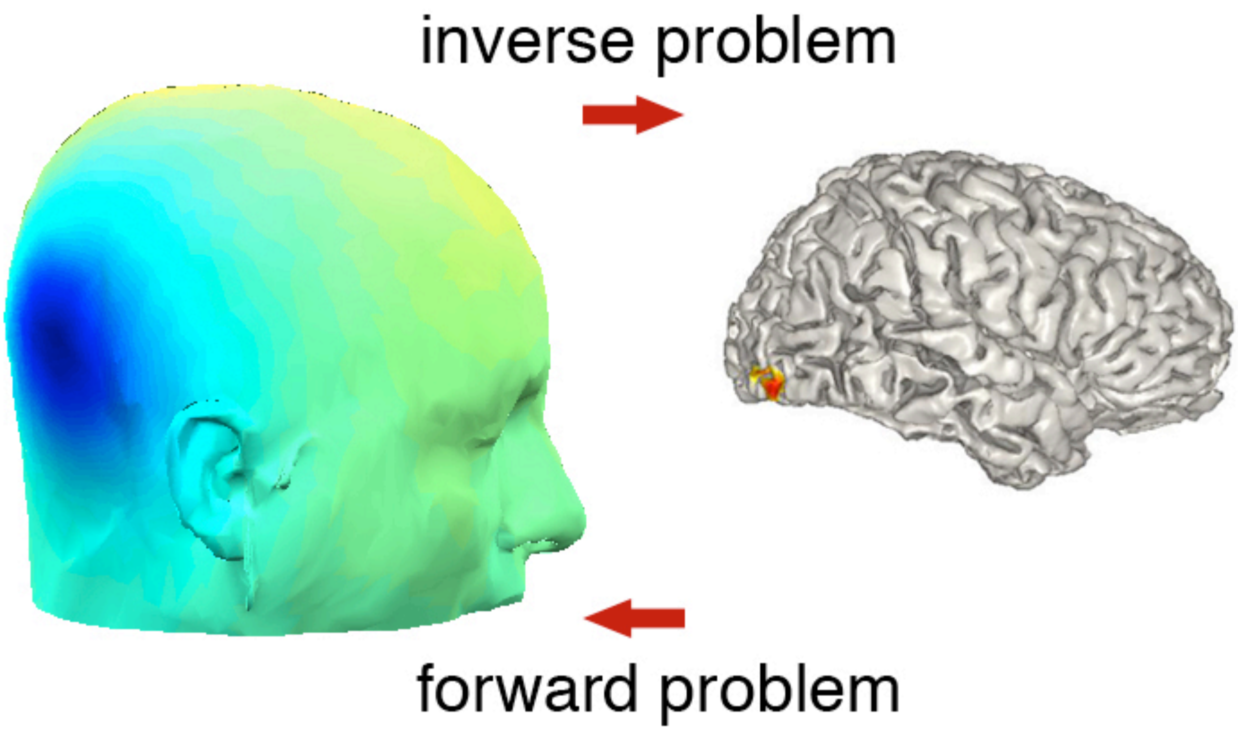
(3)for an ERP, be active in a consistent temporal relationship with the stimulus.

Action potentials generally **make little or no** contribution to scalp EEG.

EEG likely reflects the **summed PSPs** of large populations of pyramidal neurons.



Mapping between sources and surface fields: Forward and inverse problem

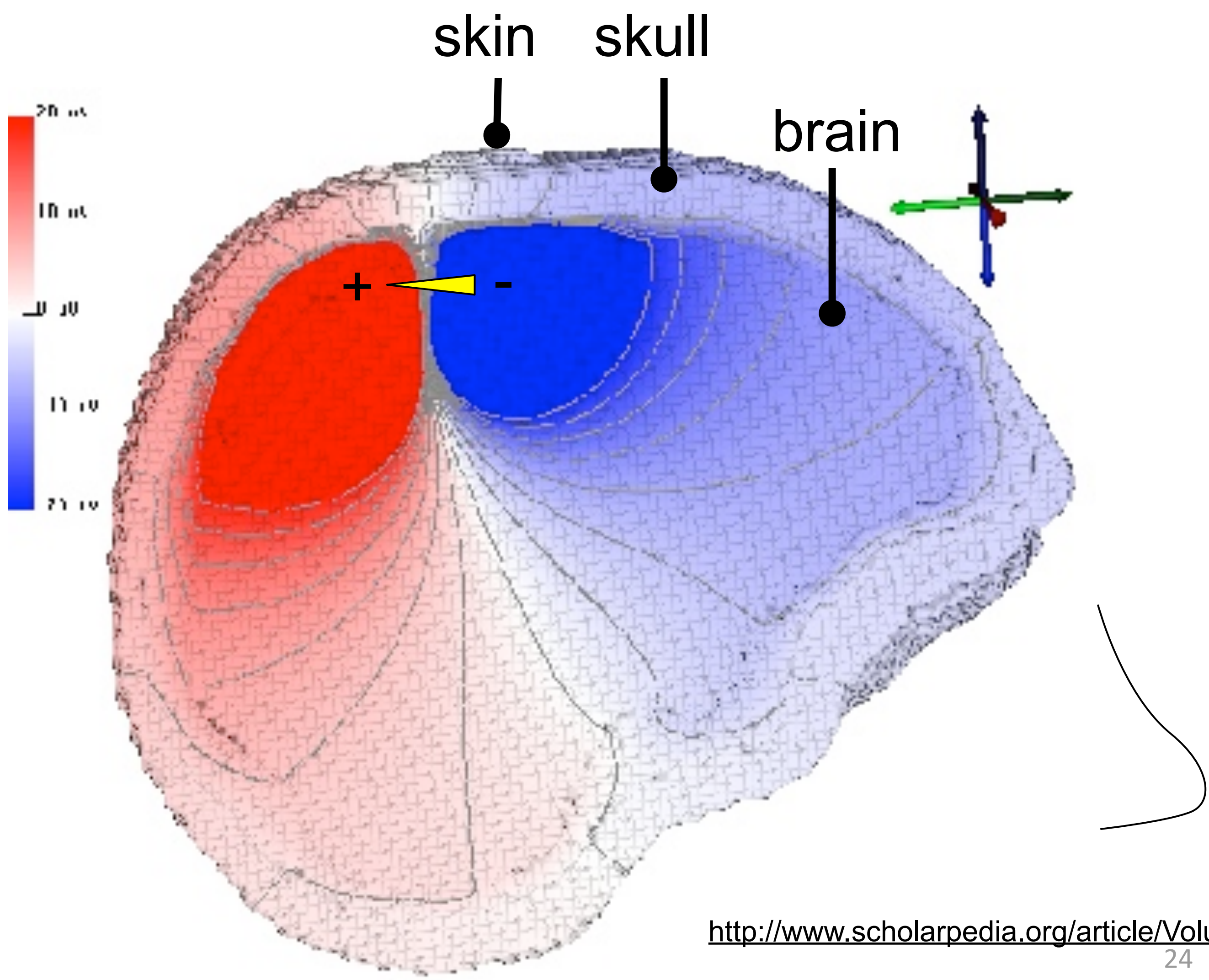


Rey R. Ramírez (2008), Scholarpedia, 3(11):1733
www.scholarpedia.org/article/Source_localization

The forward problem

- Given a set of current sources and sinks in a volume conductor, what field will they generate at the surface
- Compare: what do 3, -6, and 7 add up to?
- Solution: Calculate the fields generated by each and add them up.
- Tricky … volume conduction depends on the type of media and its shape: cerbrospinal fluid, skull, scalp, and air have different resistivities. White matter is anisotropic. Bone conducts poorly and air not at all for practical purposes.
- But … possible in principle and approximations can be computed in practice. Structural MRI can provide geometry in real heads.

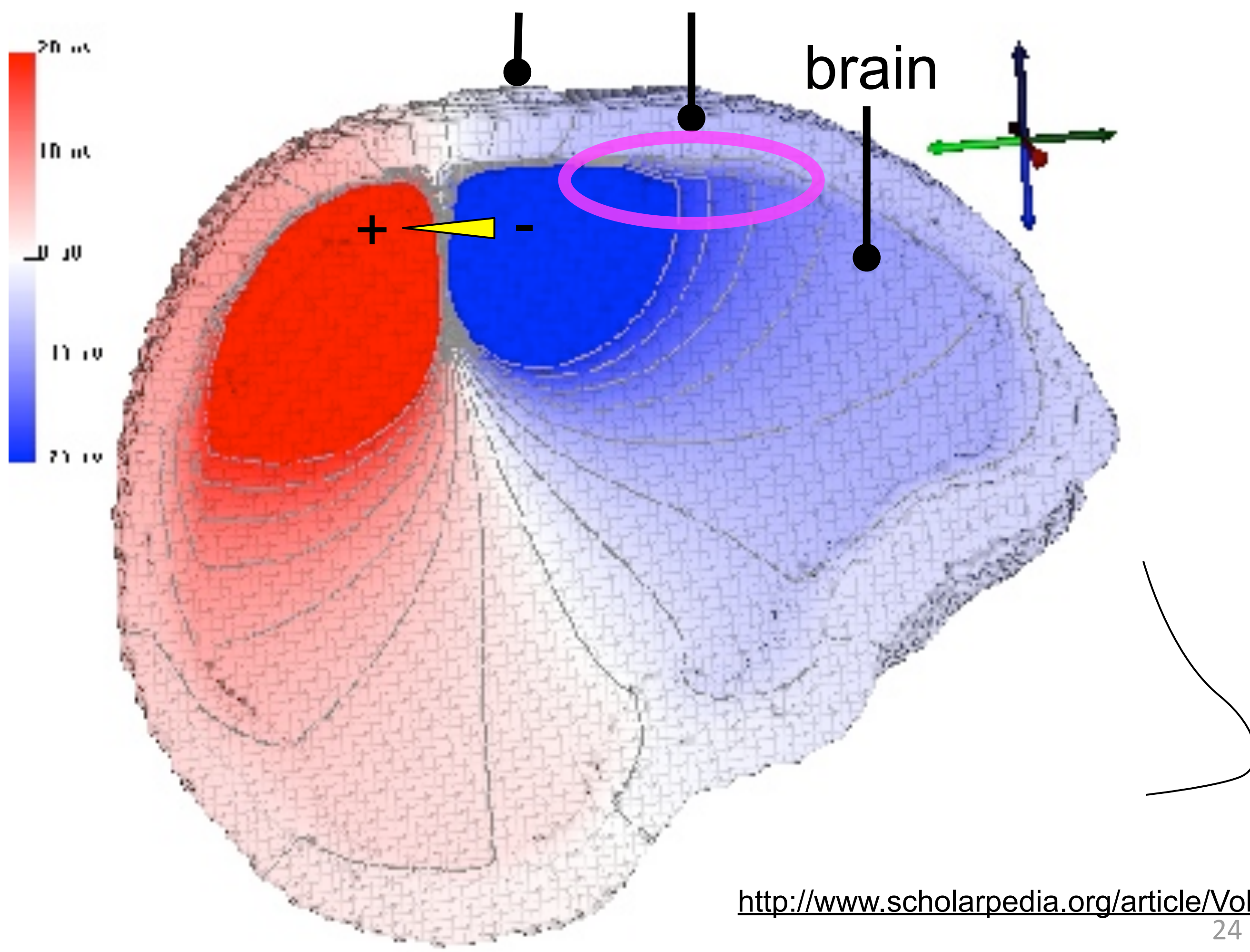
Potentials generated by dipolar source in 3-compartment hexahedral finite element head model



http://www.scholarpedia.org/article/Volume_conduction

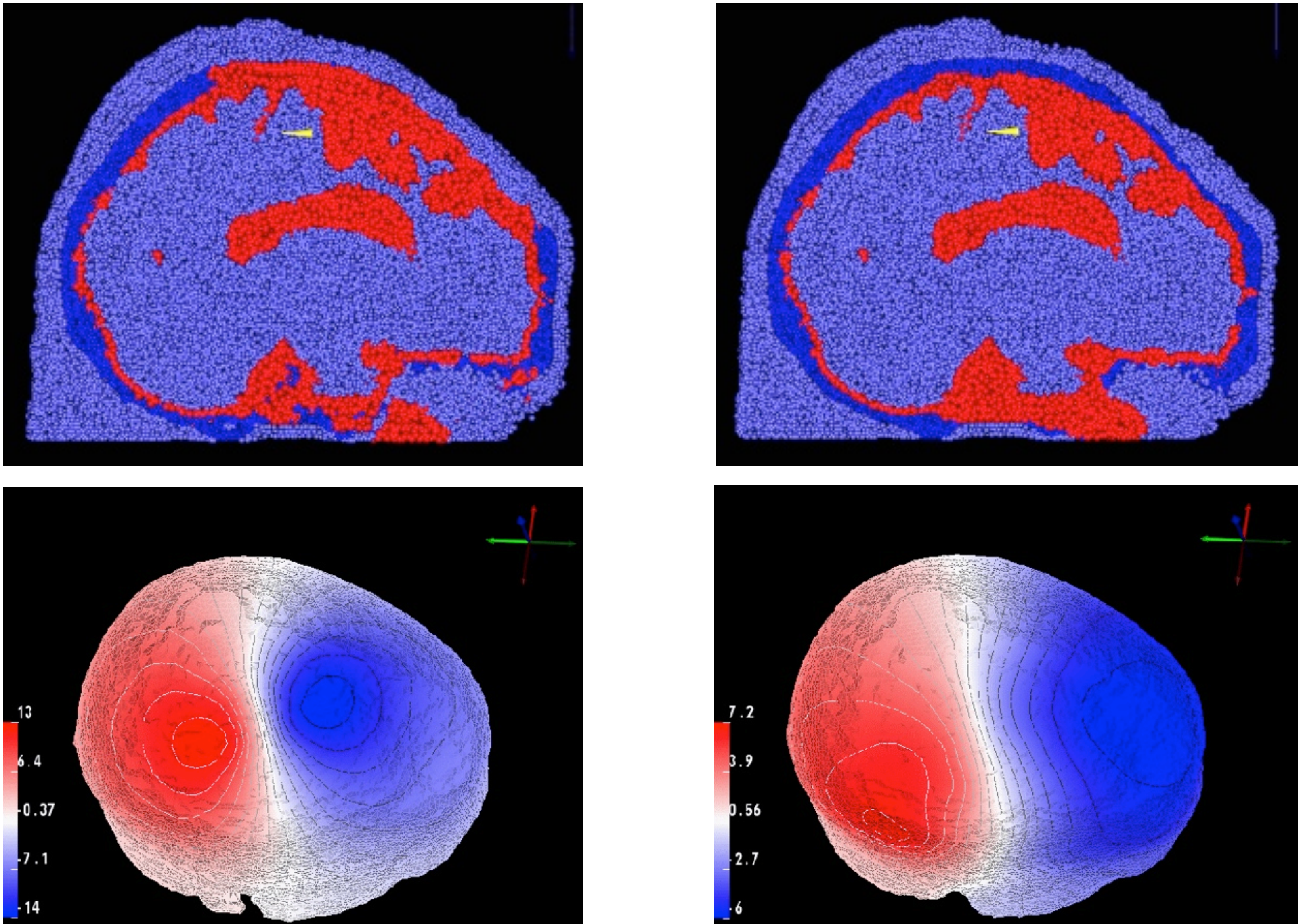
Potentials generated by dipolar source in 3-compartment hexahedral finite element head model

Note attentuation and “blurring” of potential field by skull at brain boundary



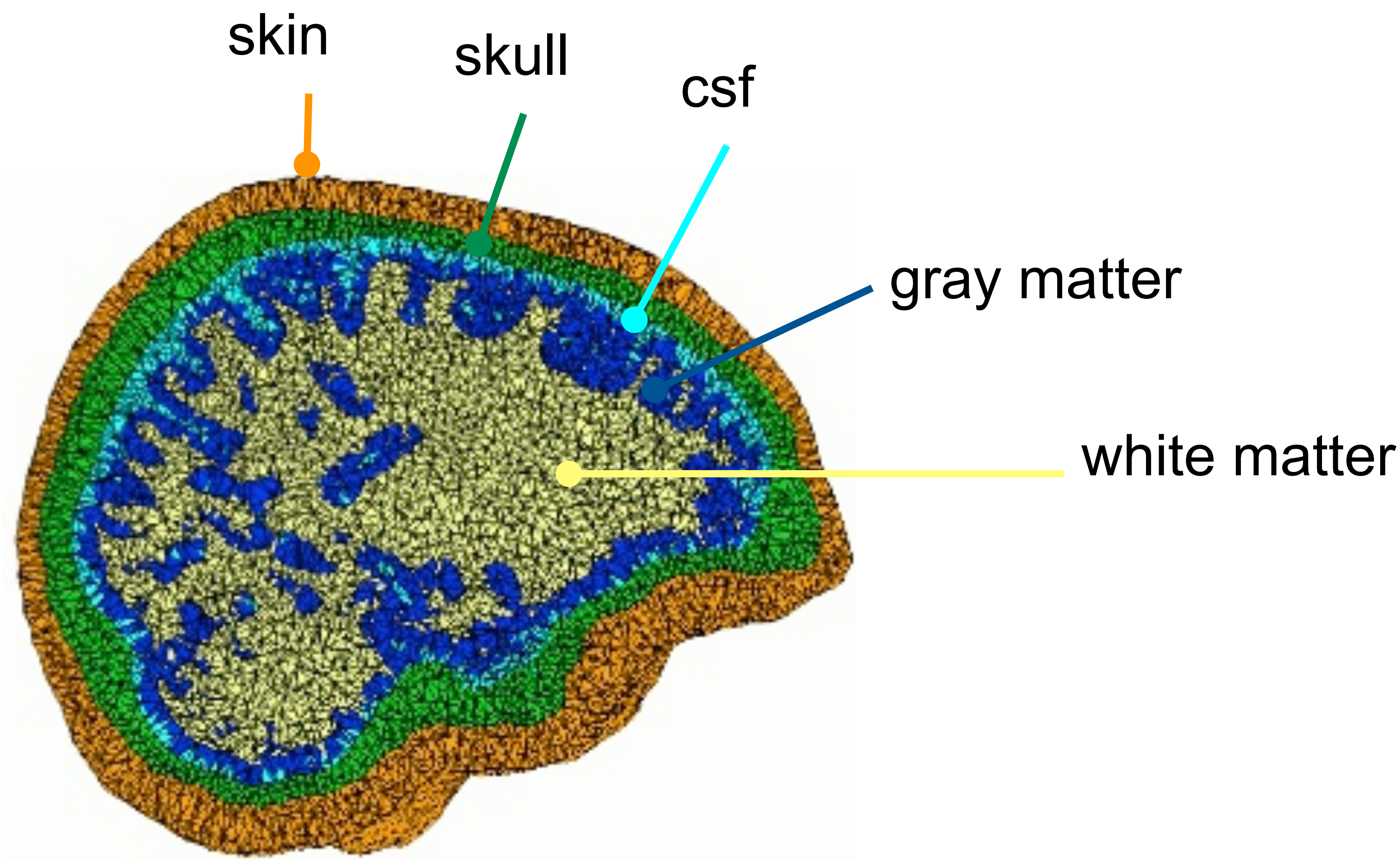
http://www.scholarpedia.org/article/Volume_conduction

Simulated dipole source with and without skull trepanation (surgical hole). Four tissue model: skin, skull, csf, brain



http://www.scholarpedia.org/article/Volume_conduction

More detailed models differentiate gray matter, white matter, CSF, and their electrical properties, e.g., anisotropy.



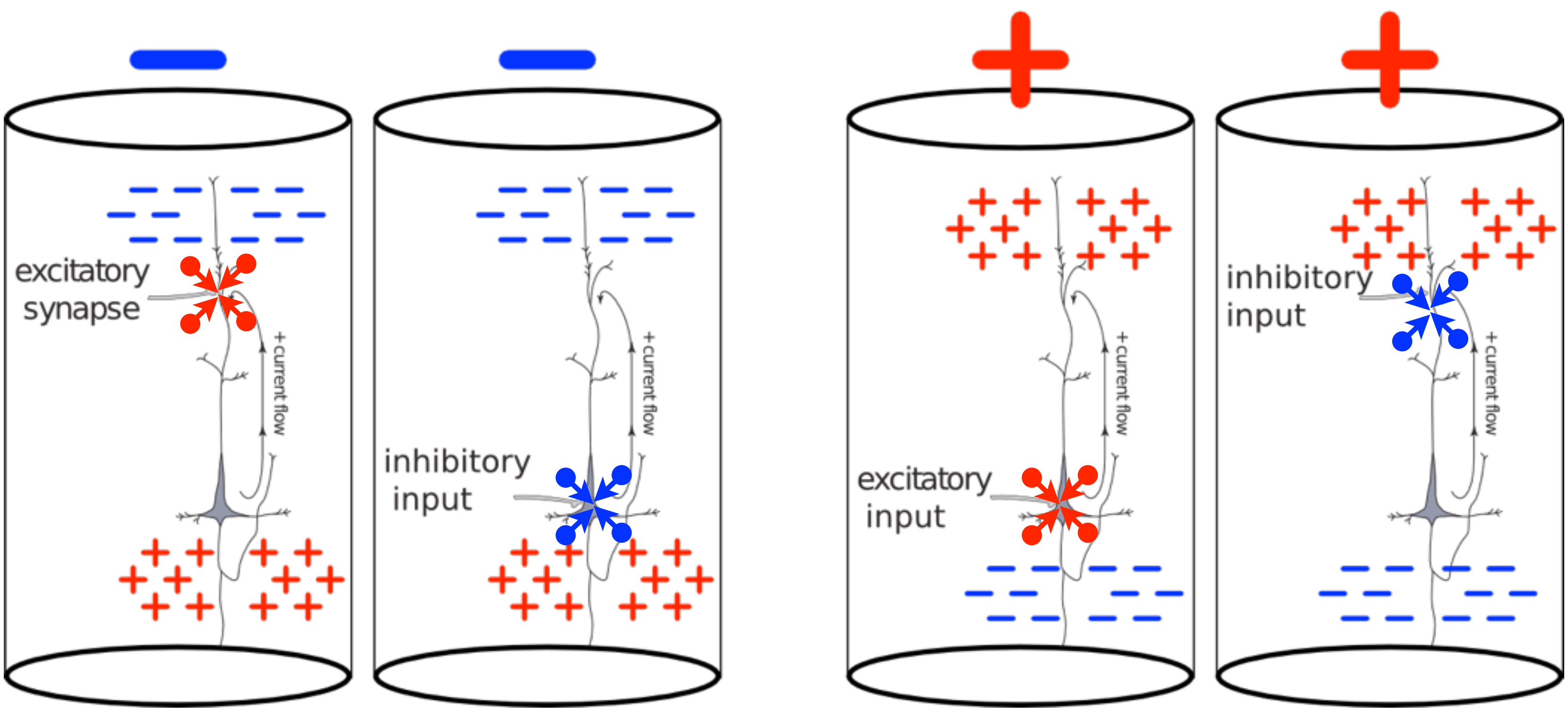
http://www.scholarpedia.org/article/Volume_conduction

The inverse problem is a problem

- *Given a pattern of potentials on the surface of a volume conductor, where are the current sources are generating it?*
- Compare: what numbers add up to make 7?
- No unique solution: In a volume conductor, e.g., head, different combinations of sources and sinks can give exactly the same potential at the surface.
- Special case solutions of the inverse problem are possible if further constraints are added
  - requiring the sources to be a small number of dipoles (BESA)
  - forcing the location of the sources to be in plausible locations, e.g., visual cortex for visual response

7. The specific potential recorded under a given set of conditions (or, indeed, whether any net potential is recorded) depends both upon the location of the recording electrodes and the location of the active tissue at any instant in time. In Figure 1-1, for example, the

Surface potential



Surface polarity depends on location and type of PSP

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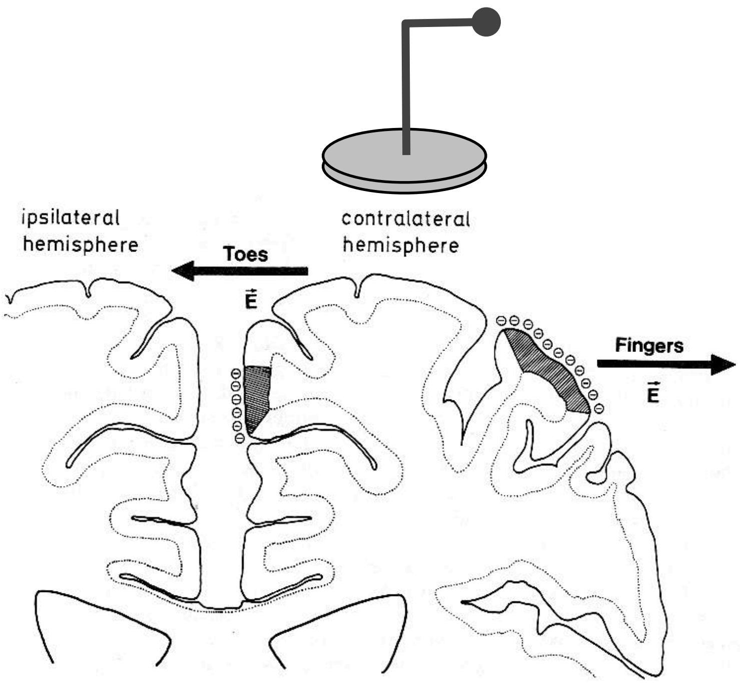

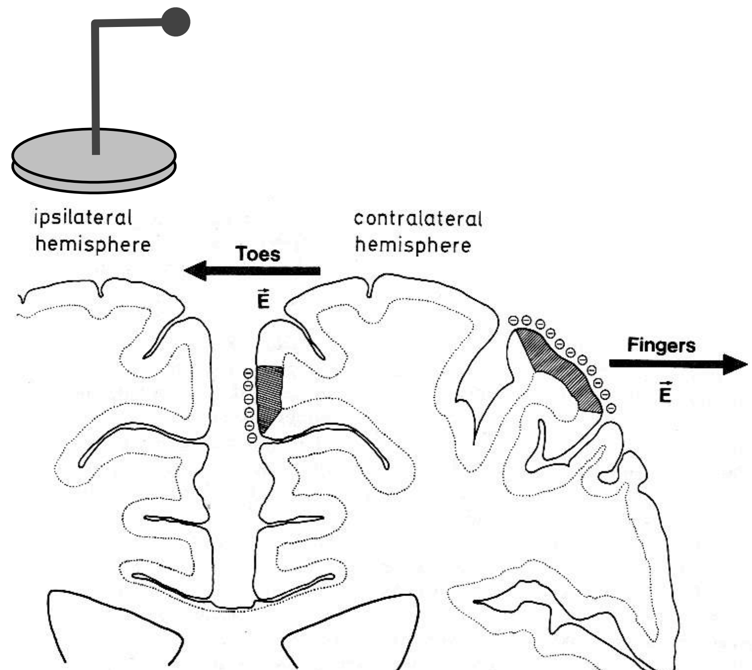

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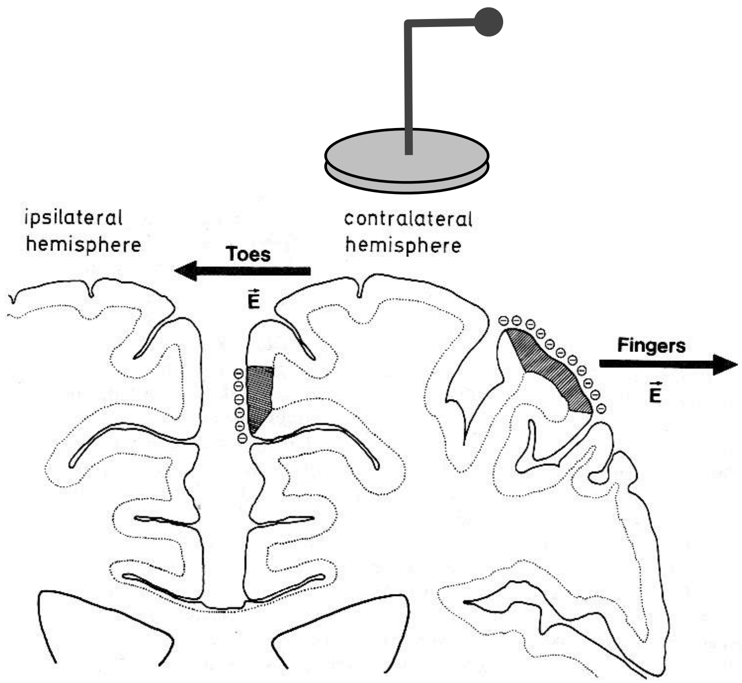
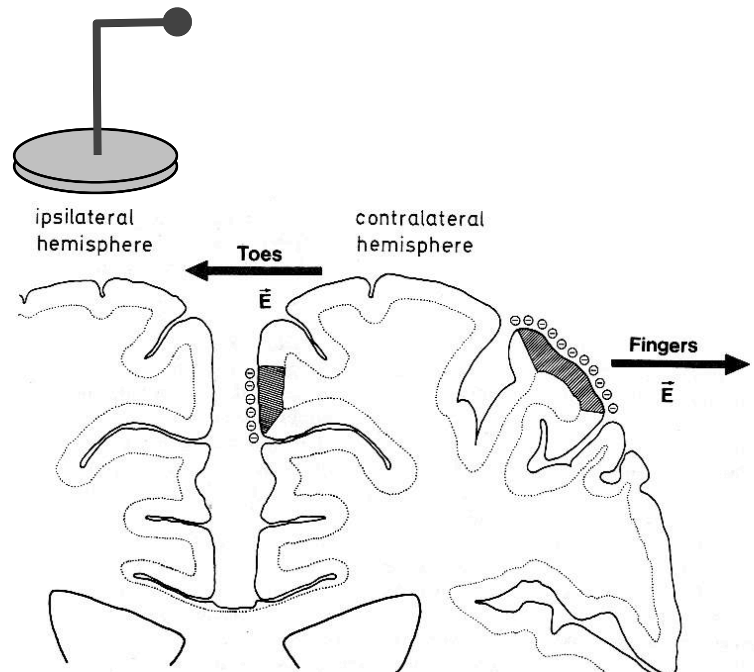
Finger movement





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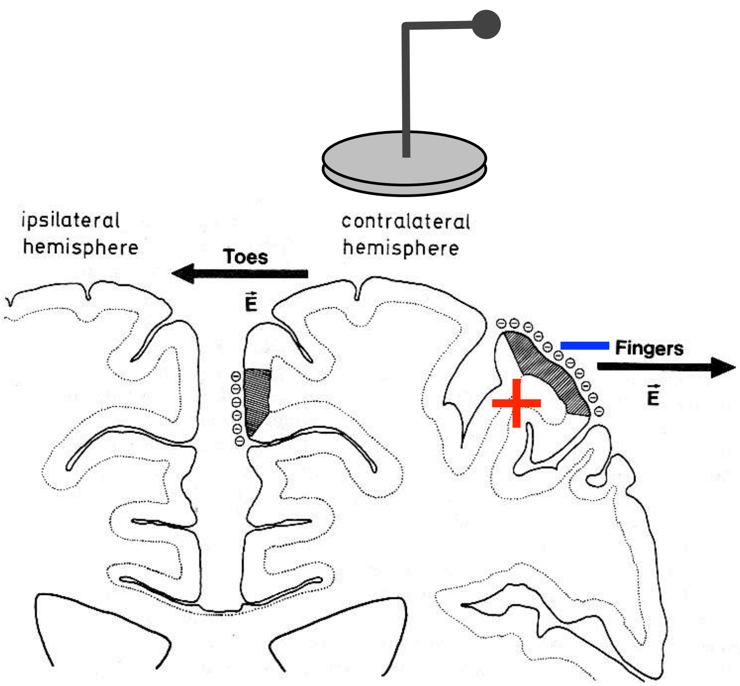

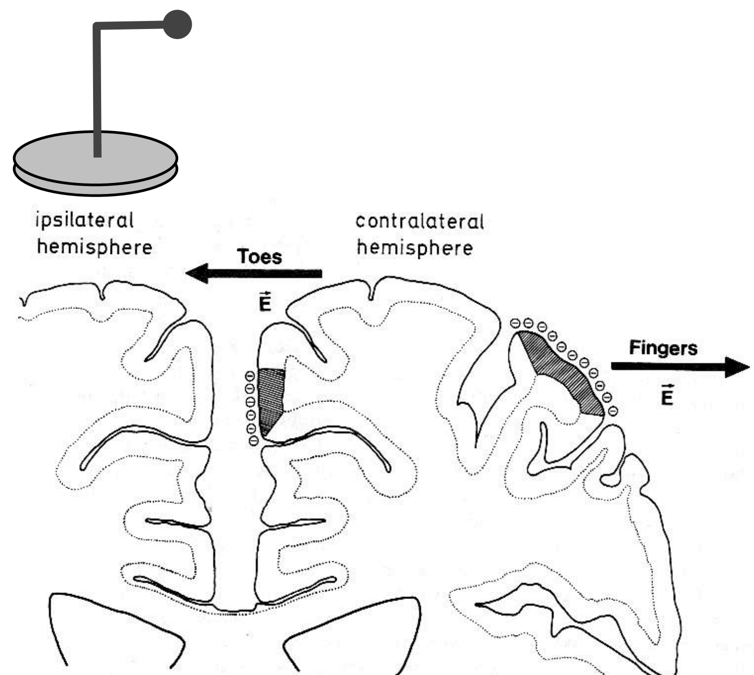

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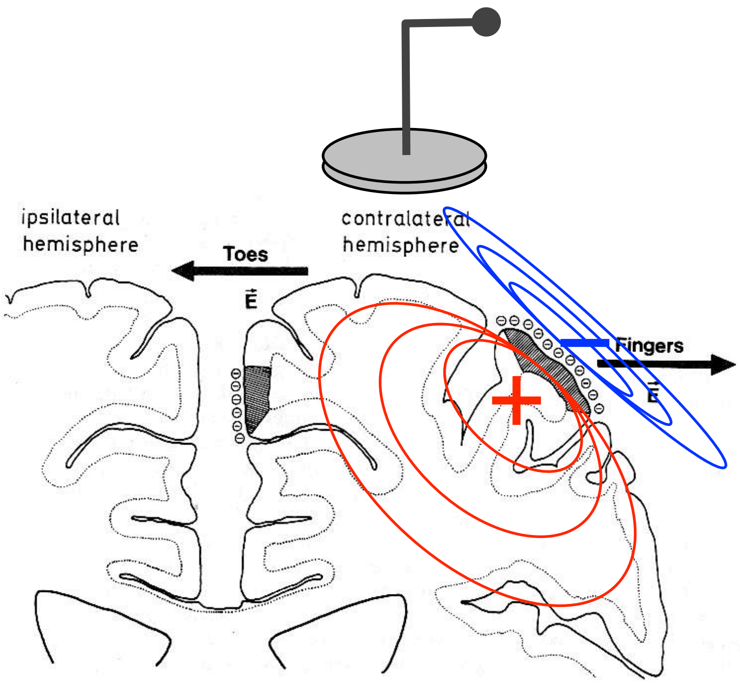
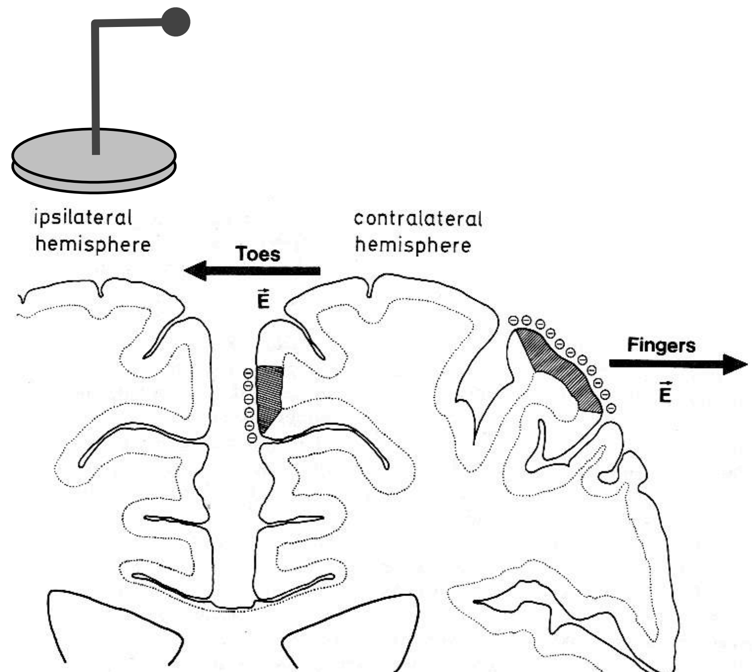
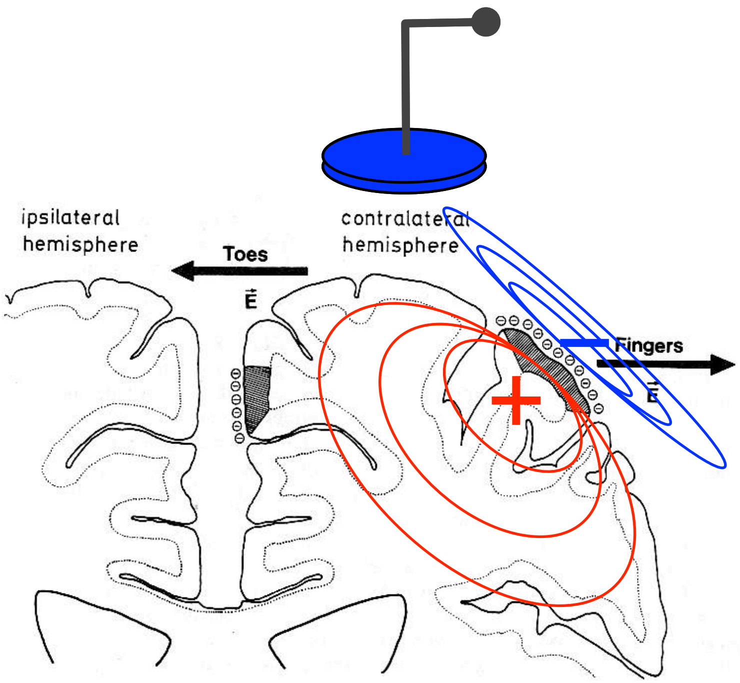
Finger movement

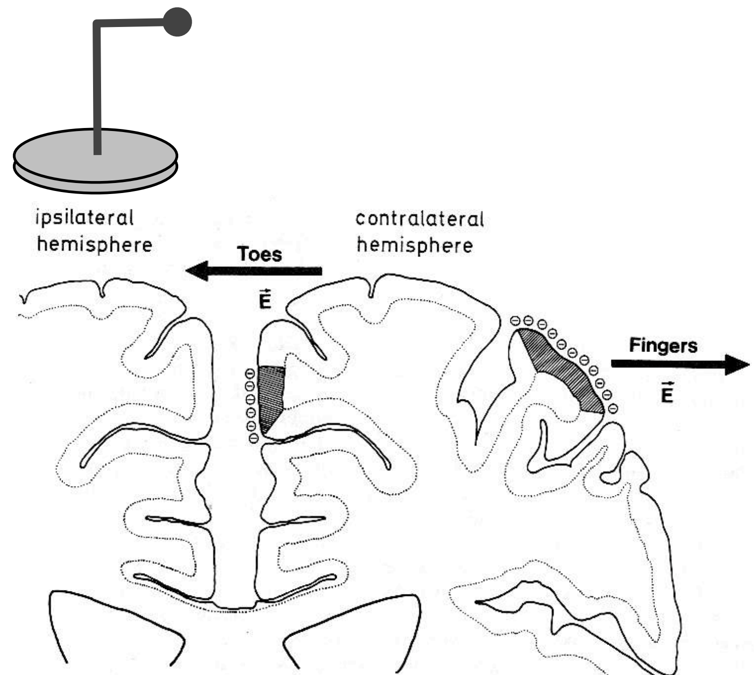




7. The specific potential recorded under a given set of conditions (or, indeed, whether any net potential is recorded) depends both upon the location of the recording electrodes and the location of the active tissue at any instant in time. In Figure 1-1, for example, the

Finger movement





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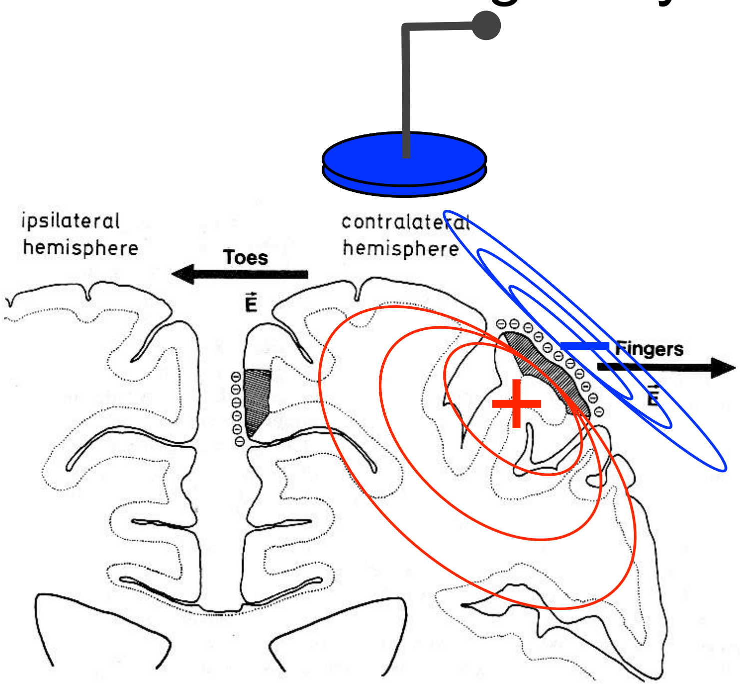
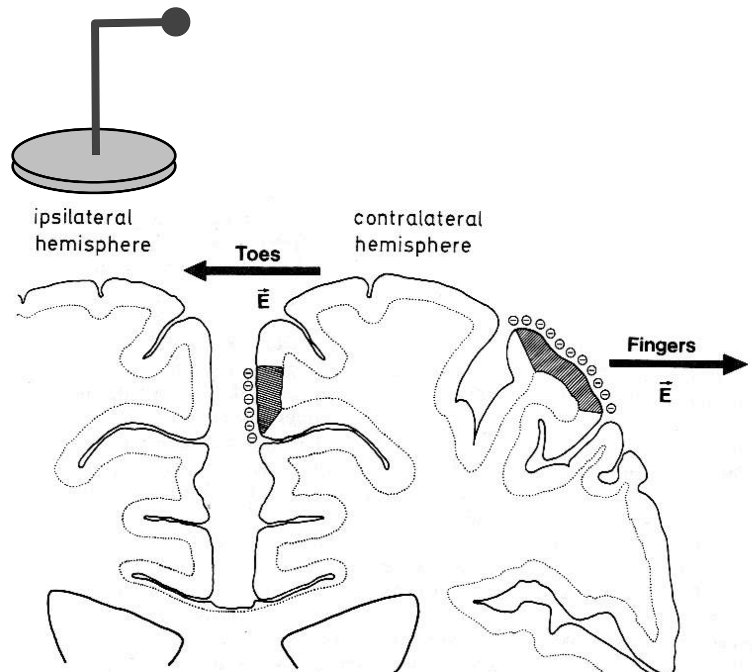
Finger movement

***contra*lateral** surface negativity





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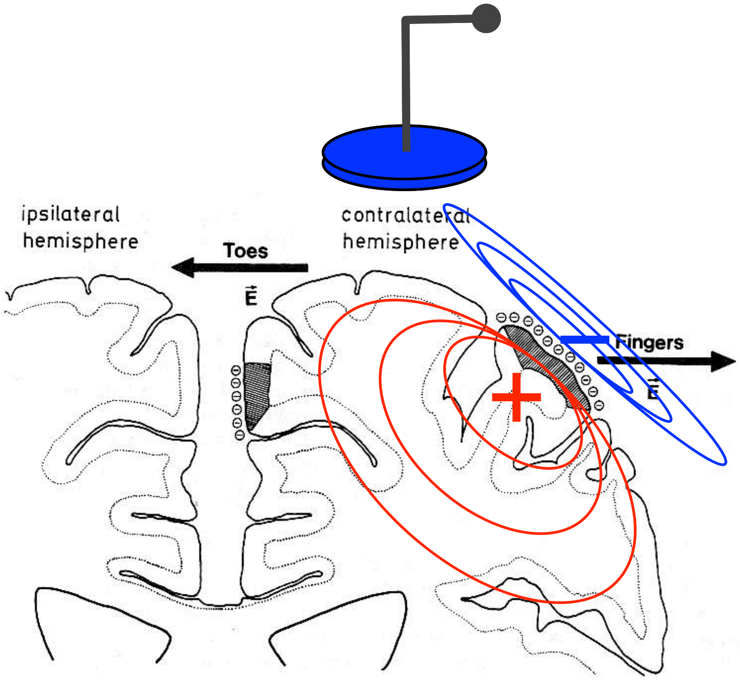
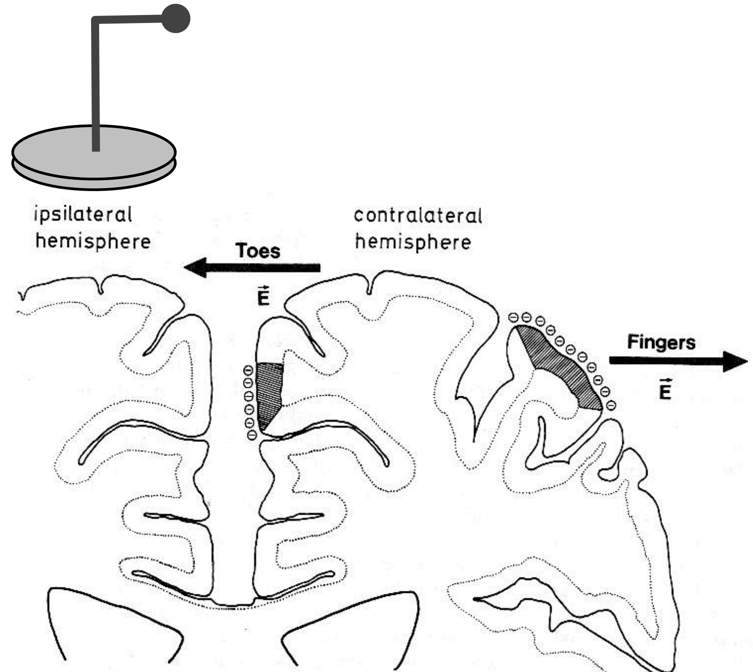
Finger movement

Toe movement

***contra**lateral*

surface negativity





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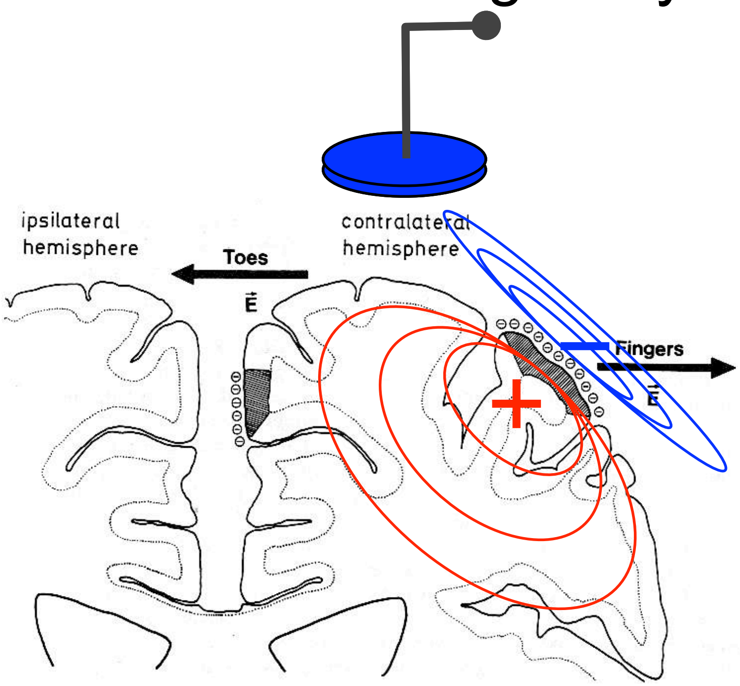
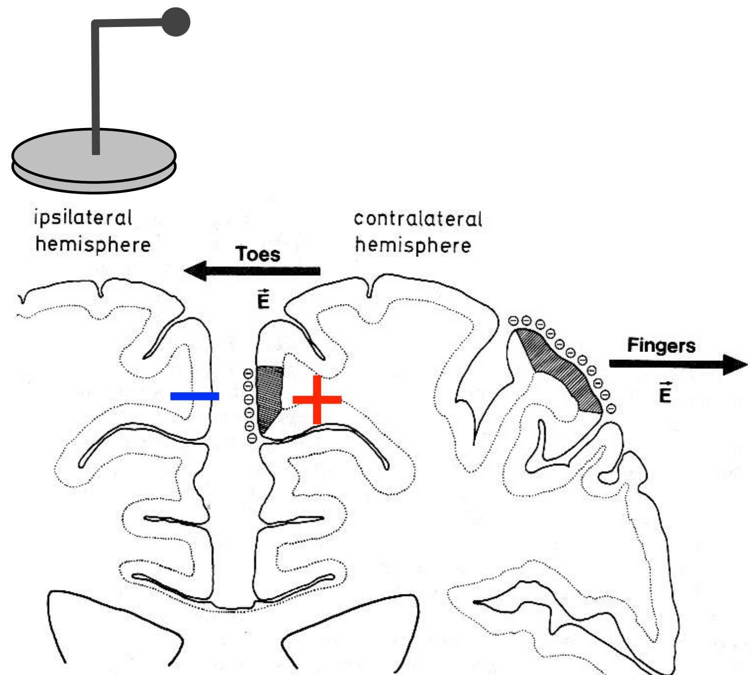
Finger movement

Toe movement

***contra*lateral**
surface negativity





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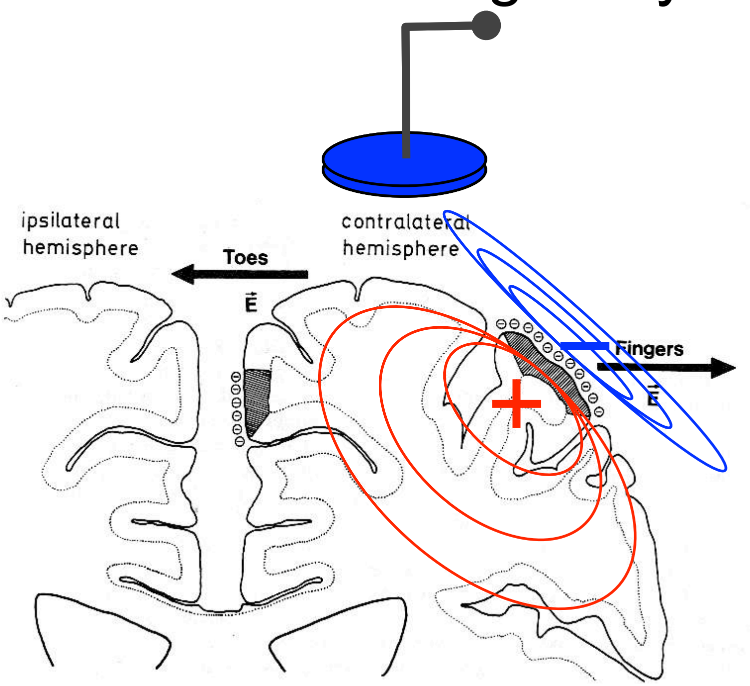
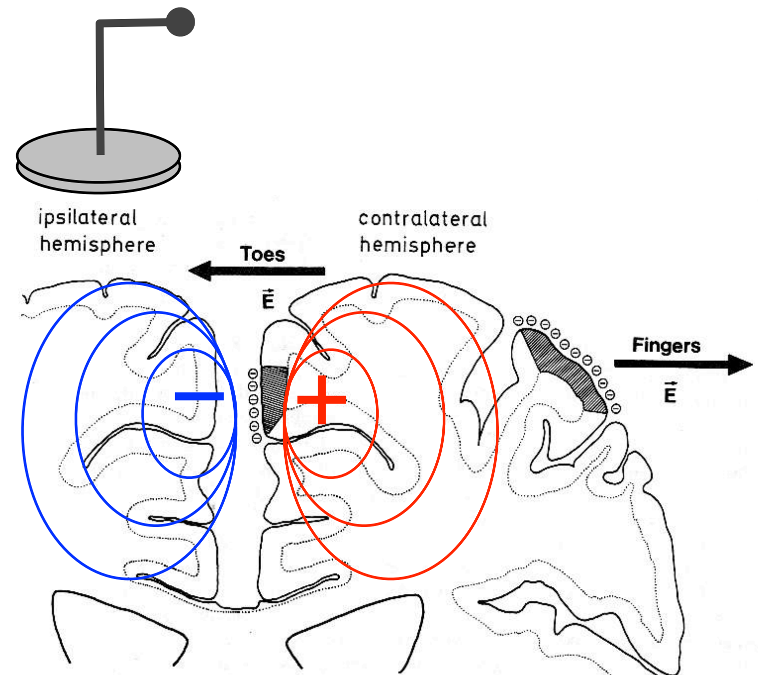
Finger movement

contralateral
surface negativity



Toe movement



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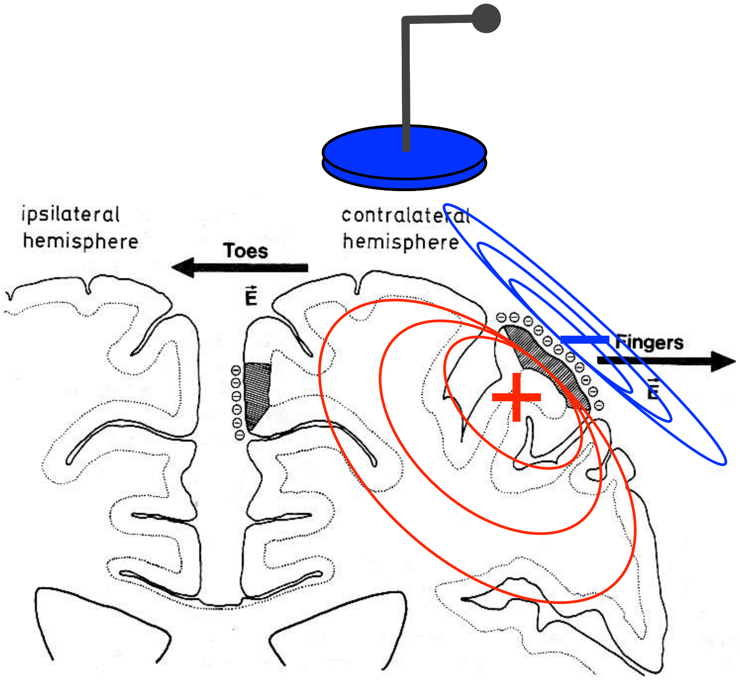
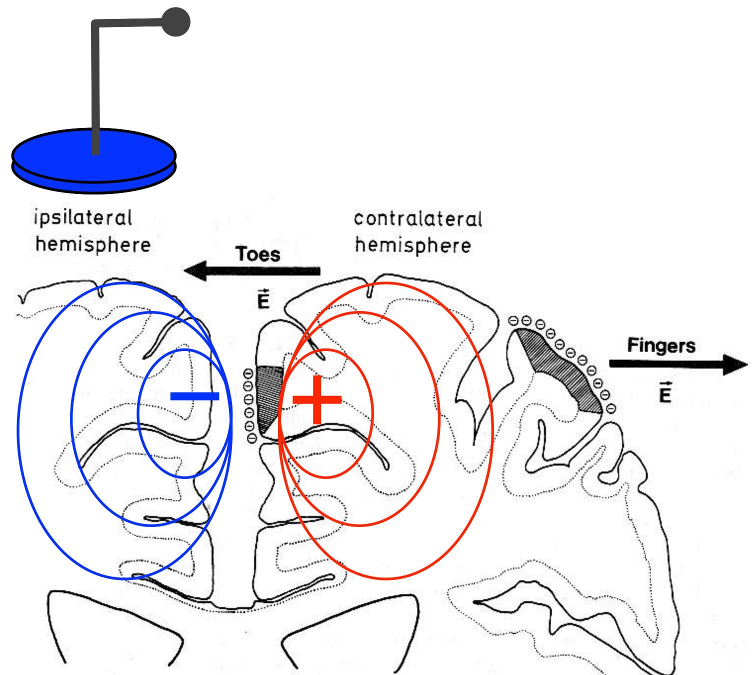
Finger movement

***contra**lateral*
surface negativity



Toe movement



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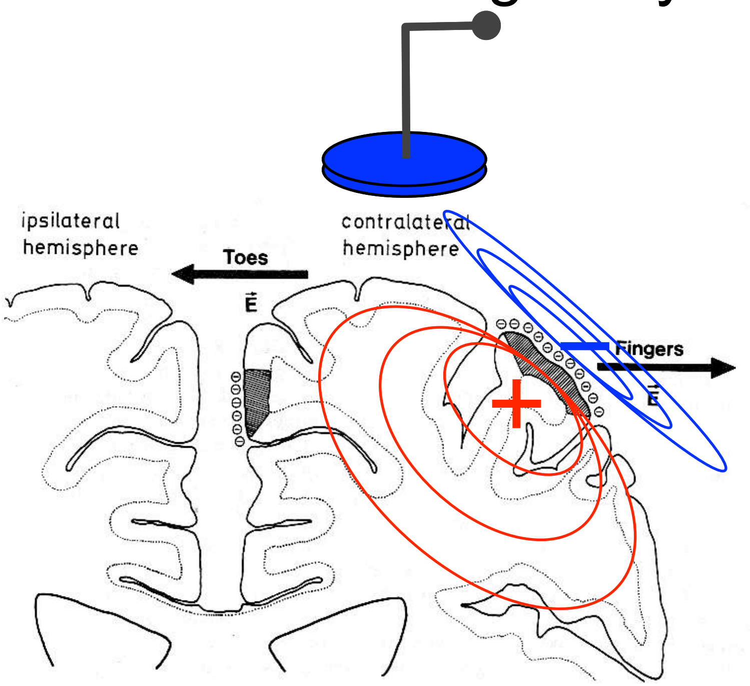
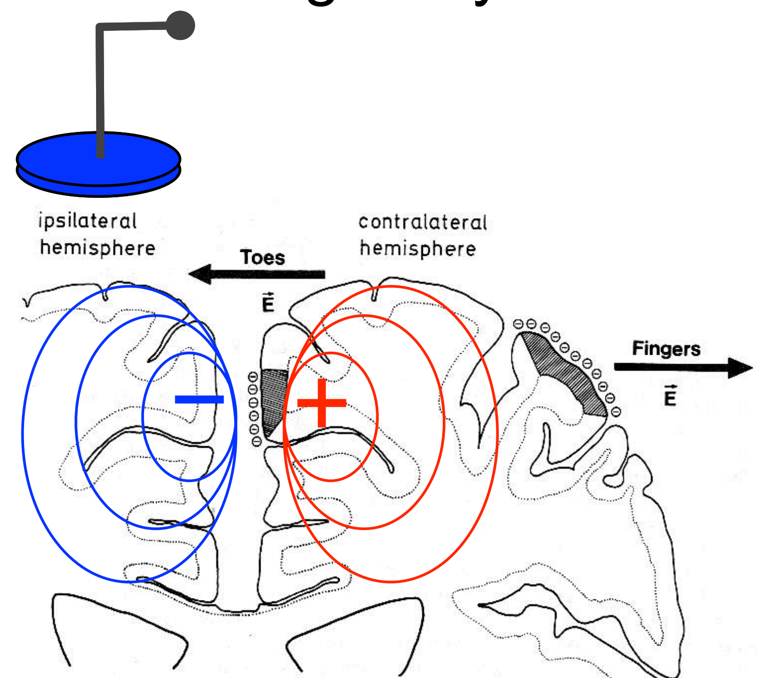
Finger movement

***contra*lateral**
surface negativity

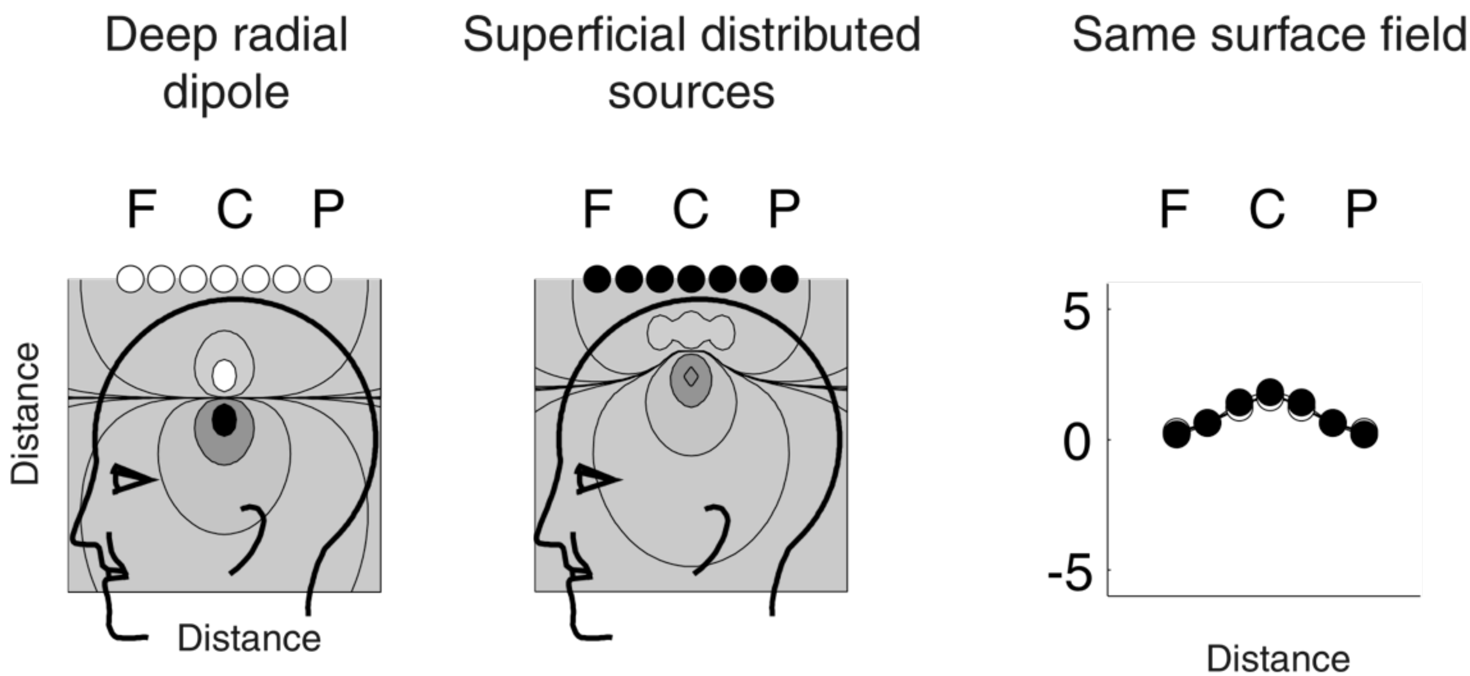


Toe movement

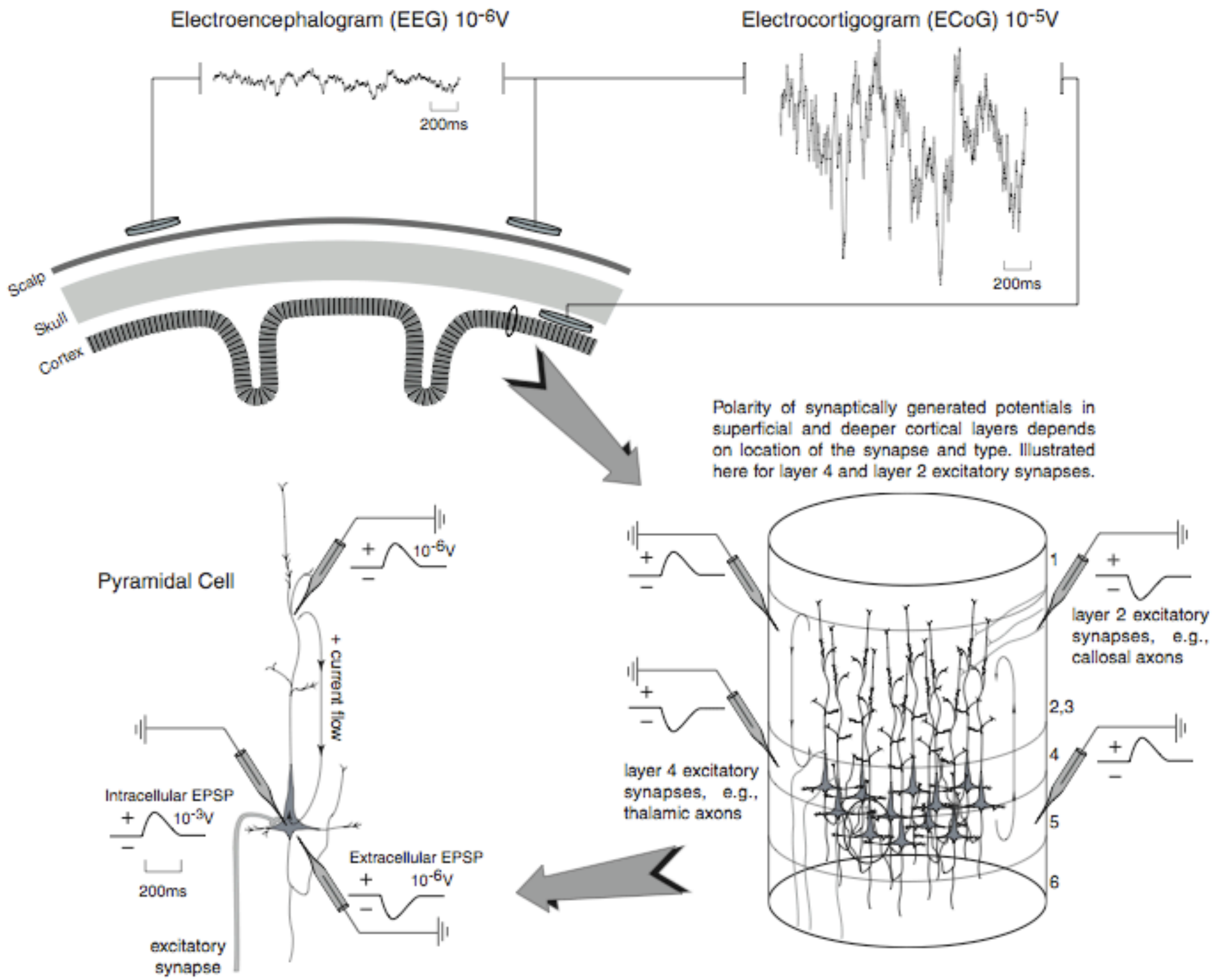
***ipsi*lateral**
surface negativity



In principle different sources may give the same surface field

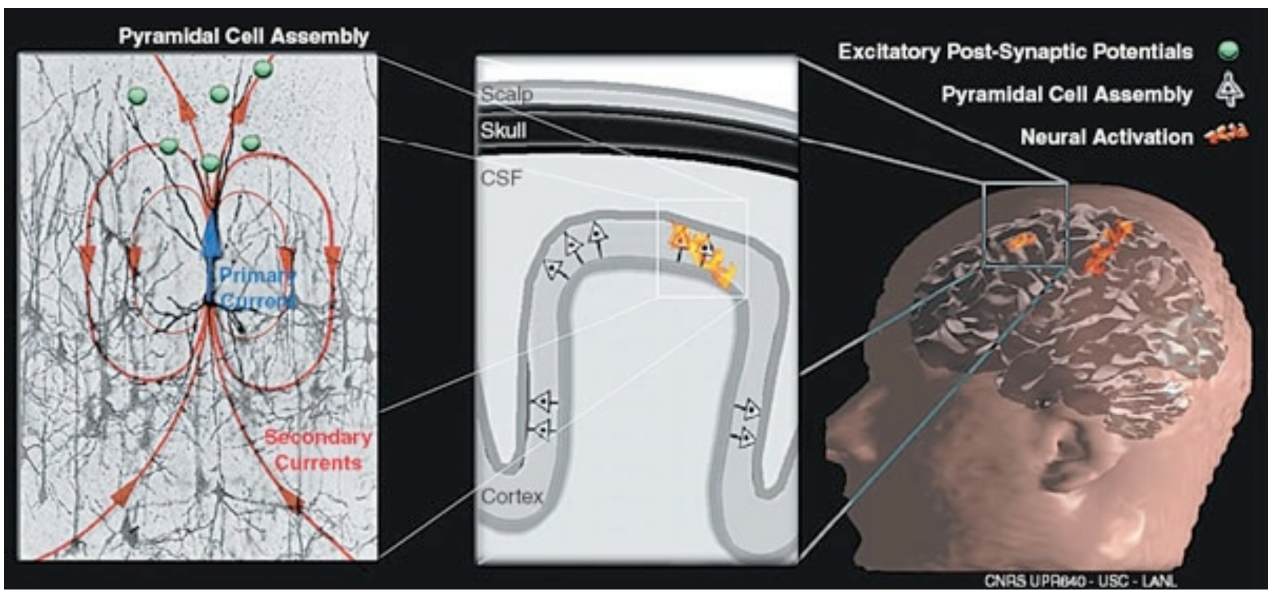


Electrogenesis of the EEG



Requirements for seeing electrical activity at scalp

- Sufficient numbers (1000-10,000+) neurons with proper orientation (parallel)
- Firing synchronously
- With electric fields that sum rather than cancel (i.e., open field configuration neurons with dendritic trees all oriented on one side and axons on the other)



Aside: electrical vs. magnetic fields

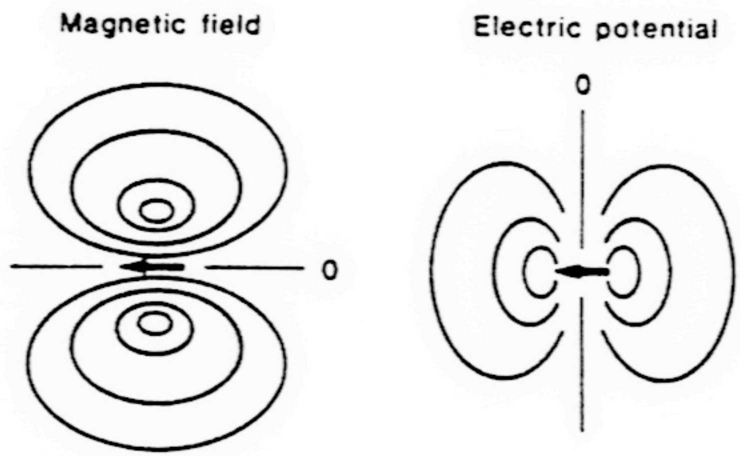


FIG. 2. Magnetic and electric field profiles generated by a current dipole. Note the orthogonality of the patterns.

Electrogenesis: EEG and MEG

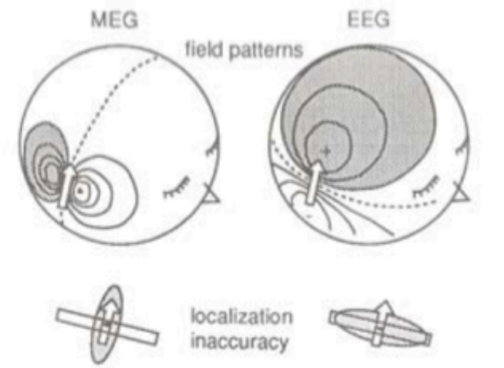
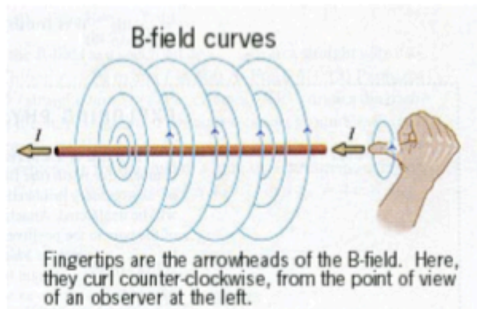
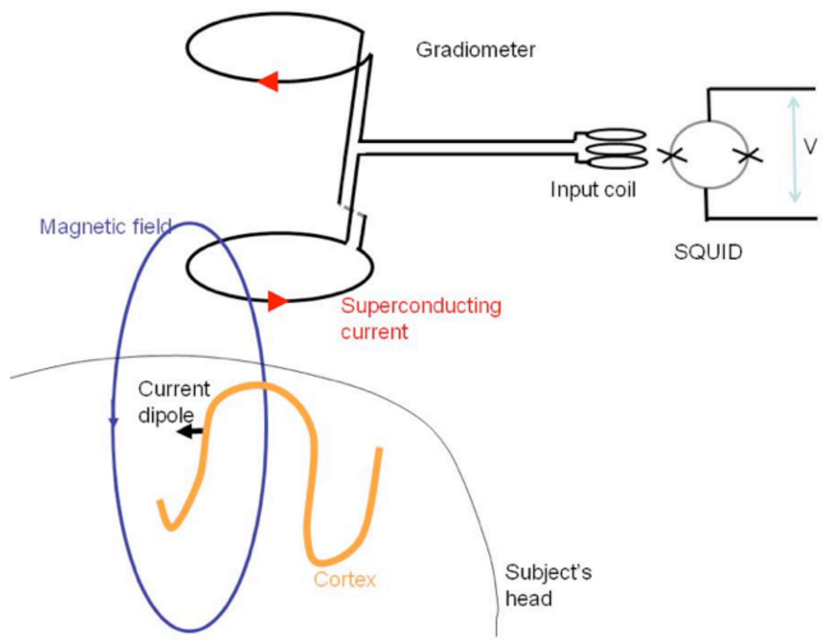


Figure 58.1. MEG and EEG field patterns over a concentric 4-layer sphere when a tangential current dipole (shown by the arrow) has been activated in an area approximating the second somatosensory cortex in the upper lip of the Sylvian fissure. The shadowed areas indicate the magnetic flux out of the head and positive potential. The lower part of the figure illustrates schematically, with shadowed ellipsoids, the inaccuracy region of the dipole location when determined "backwards" from the signals on the surface. The dipole is assumed to be in a wall of a cortical fissure.





Electrogenesis: EEG and MEG

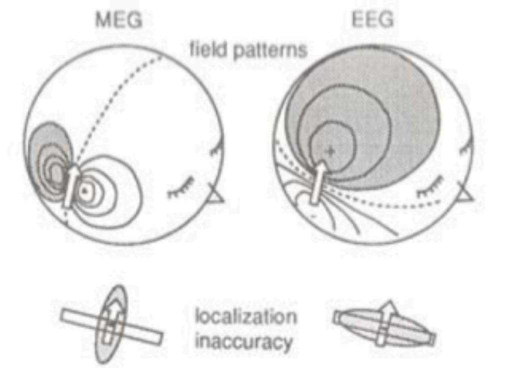
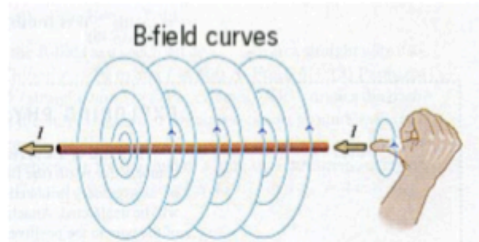


Figure 58.1. MEG and EEG field patterns over a concentric 4-layer sphere when a tangential current dipole (shown by the arrow) has been activated in an area approximating the second somatosensory cortex in the upper lip of the Sylvian fissure. The shadowed areas indicate the magnetic flux out of the head and positive potential. The lower part of the figure illustrates schematically, with shadowed ellipsoids, the inaccuracy region of the dipole location when determined "backwards" from the signals on the surface. The dipole is assumed to be in a wall of a cortical fissure.



Fingertips are the arrowheads of the B-field. Here, they curl counter-clockwise, from the point of view of an observer at the left.

MEG:
- no blurring from skull
- picks up tangential dipoles