

The logo for the MRC Cognition and Brain Sciences Unit, featuring the letters 'MRC' in a bold, white, sans-serif font on a dark grey rectangular background.

MRC

Cognition and  
Brain Sciences Unit

# A Brief History of Timing

**Olaf Hauk**

**MRC Cognition and Brain Sciences Unit**

*olaf.hauk@mrc-cbu.cam.ac.uk*

A dramatic photograph of a lightning storm at night. Multiple bright, jagged lightning bolts strike down from a dark, stormy sky. The background shows a cityscape with illuminated buildings and power lines under a deep blue twilight sky.

# Ancient Times

## Ancient Egypt, 2750 BC:

Electric Fish (“Thunderer of the Nile”)  
Some Roman writers mention electric shocks as an ailment for headaches (~ 0 AC)...



## Ancient Greece, 600 BC:

Thales describes static electricity  
“electron”  $\leftrightarrow$  “amber”



# Ancient Times

**Greece/India/China ~500 BC:**  
Magnetism of lodestone described



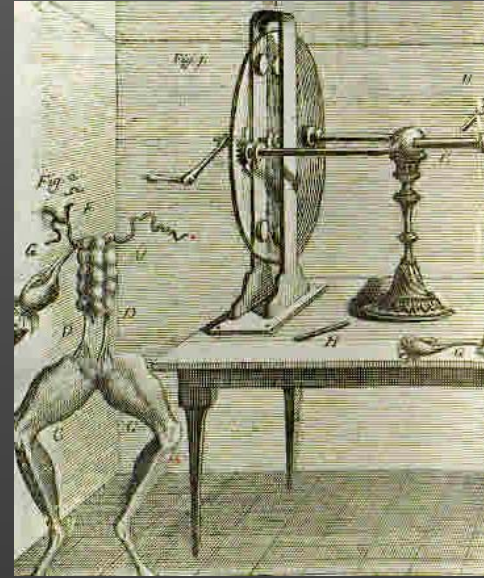
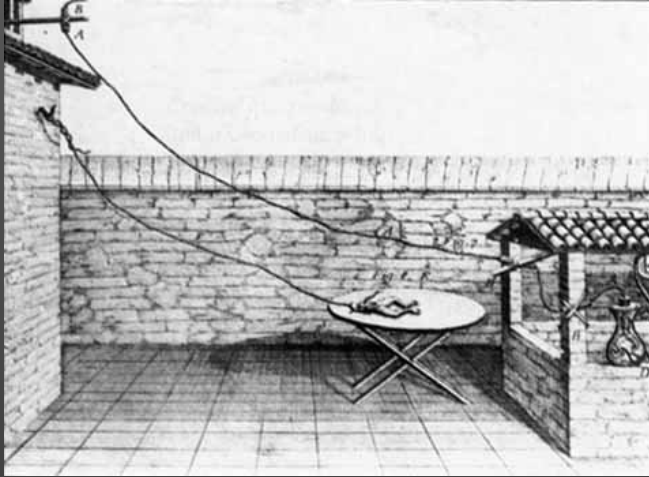
**China, ~1000 AD:**  
Compass for navigation



# Early Science

1771

Luigi Galvani, Bologna, "animal electricity"



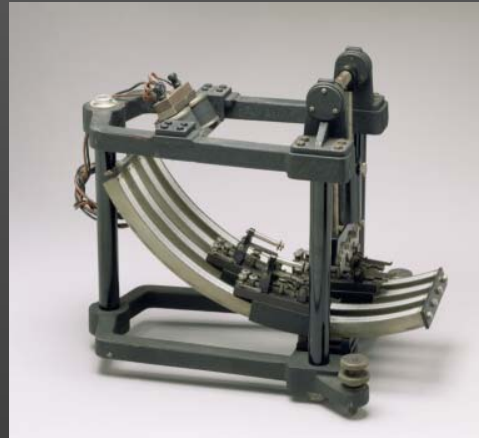
## Electric shocks to chickens:

1775 Abildgaard: "With a shock to the head, the animal was rendered lifeless, and arose with a second shock to the chest; however, after the experiment was repeated rather often, the hen was completely stunned, walked with some difficulty, and did not eat for a day and night; then later it was very well and even laid an egg."

[http://en.ecgpedia.org/wiki/A\\_Concise\\_History\\_of\\_the\\_ECG](http://en.ecgpedia.org/wiki/A_Concise_History_of_the_ECG)

# Early Electrophysiology

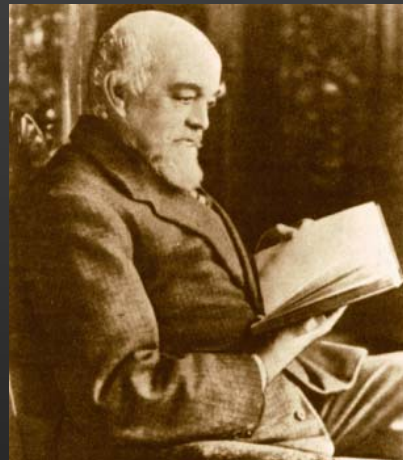
1842: Du Bois-Reymond, Berlin  
nerve action potentials  
neurons



1852: Helmholtz, Berlin  
speed of action potentials in frogs  
neurons

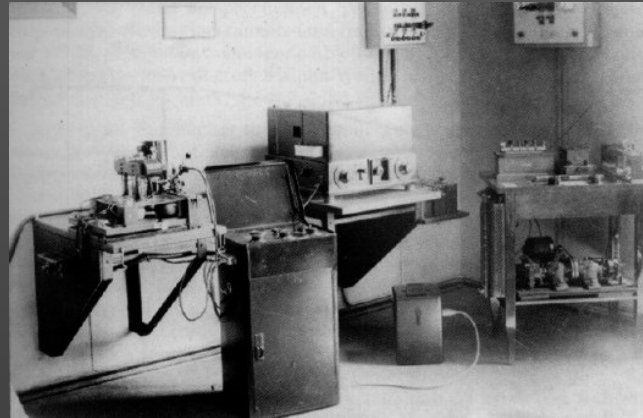
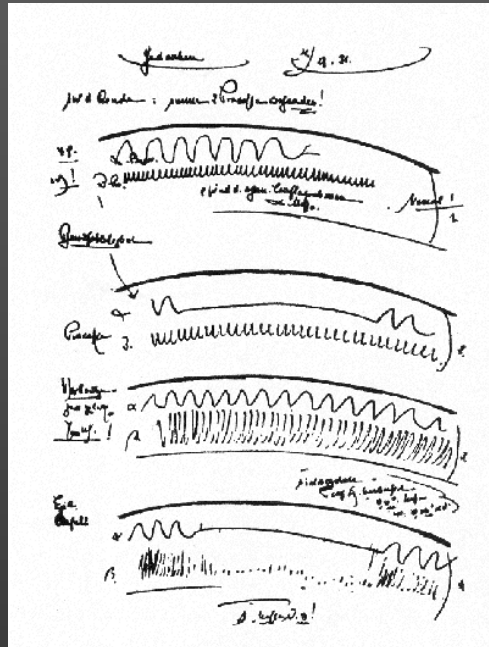


1875: Richard Caton, Liverpool  
first "ECoG" from animals

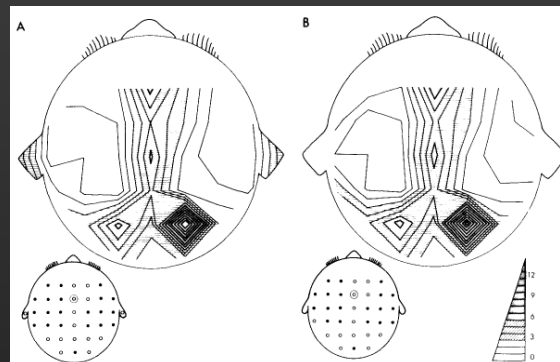


# Early EEG

Hans Berger, Jena 1924



1969/70: 32/48-channel EEG, "generators"



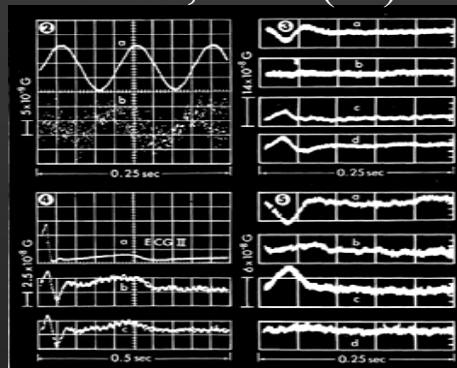
Lehmann, 1971

# First MEG: Pre-SQUID age

MEG pioneers  
MIT

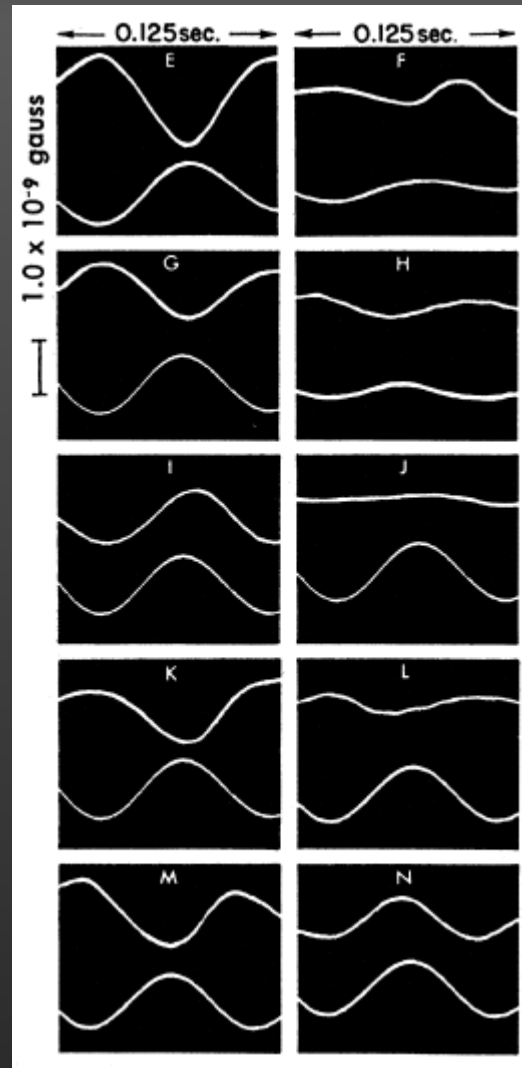


MCG, 1967/(63)



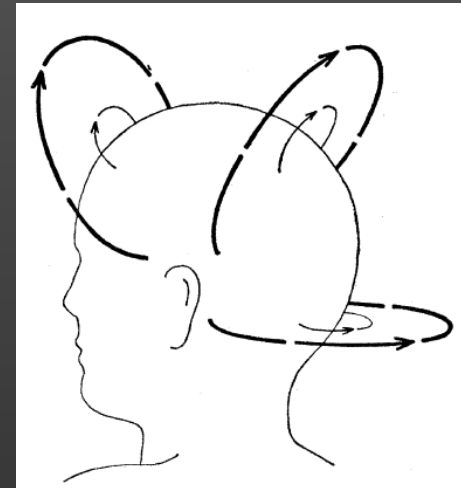
Cohen, Science 1967

MEG, 1968



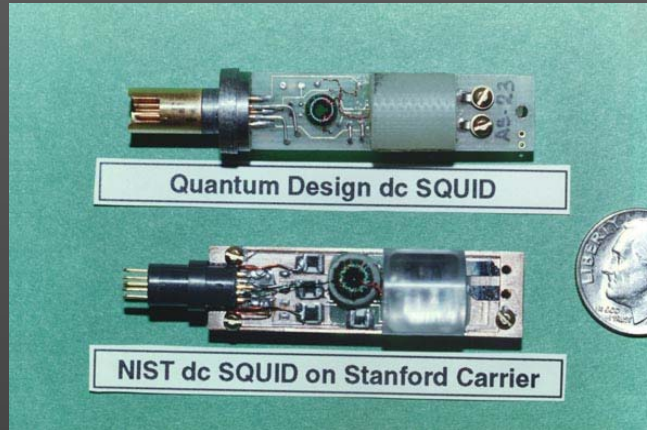
Cohen, Science 1968

Alpha Rhythm



# Early MEG: SQUIDS

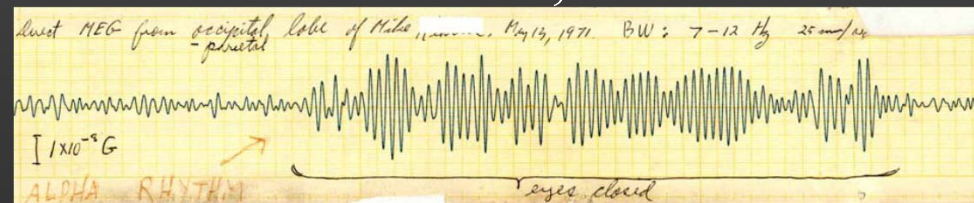
“Josephson Junction” first in 1963 (Bell Labs), first SQUID 1964 Ford Research Labs, cheaper RF SQUID 1965



## First MCG, 1969



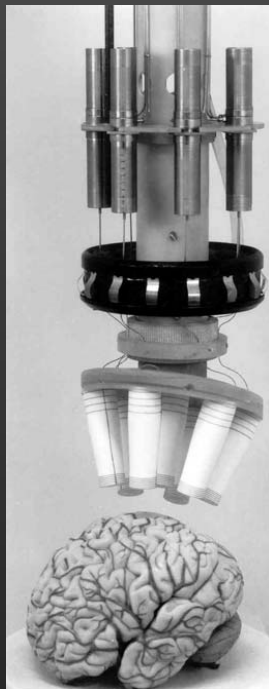
## First MEG, 1971





# The 80s...

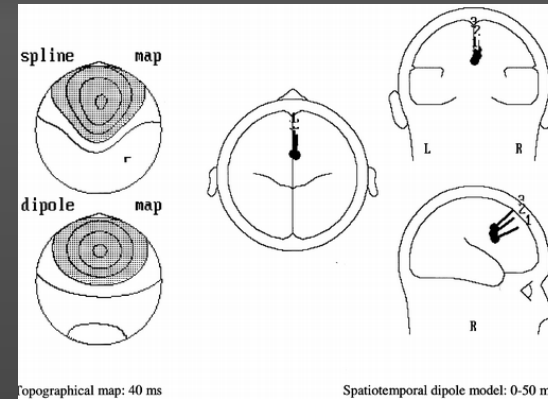
## Multi-channel systems



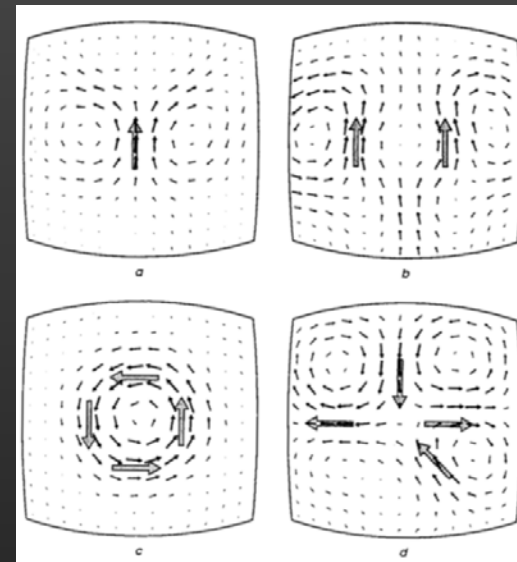
## Neuromag:

- 1983: 4 channels
- 1984: 5 channels
- 1986: 7 channels
- 1989: 24 channels

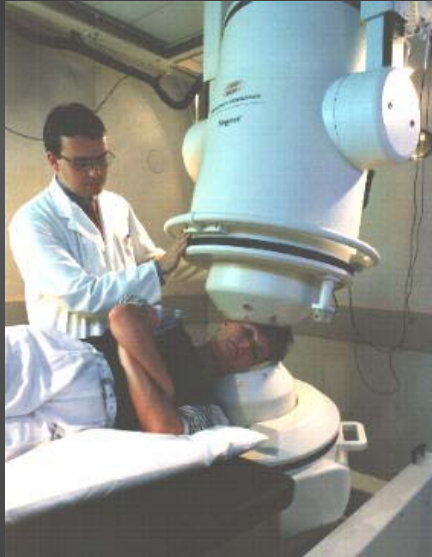
## Dipole Modelling



## 1984: Minimum Norm

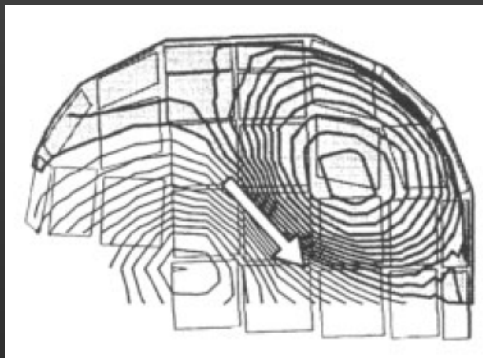


# The 90s...



## Early 90s:

~30/40-channel systems (Philips, Siemens, BTI)  
Neuromag 122 (1993)



## Mid-Late 90s:

Establishment of whole-head systems  
Neuromag 122 system  
Biomag 148 system  
CTF 151  
And others

# The Naughtyies...

## New generation of whole-head systems:

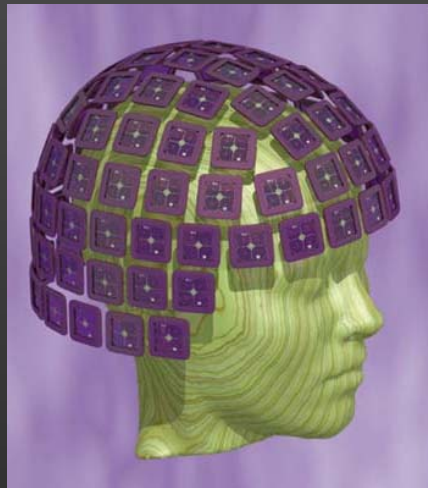
Neuromag 306

Biomag 248

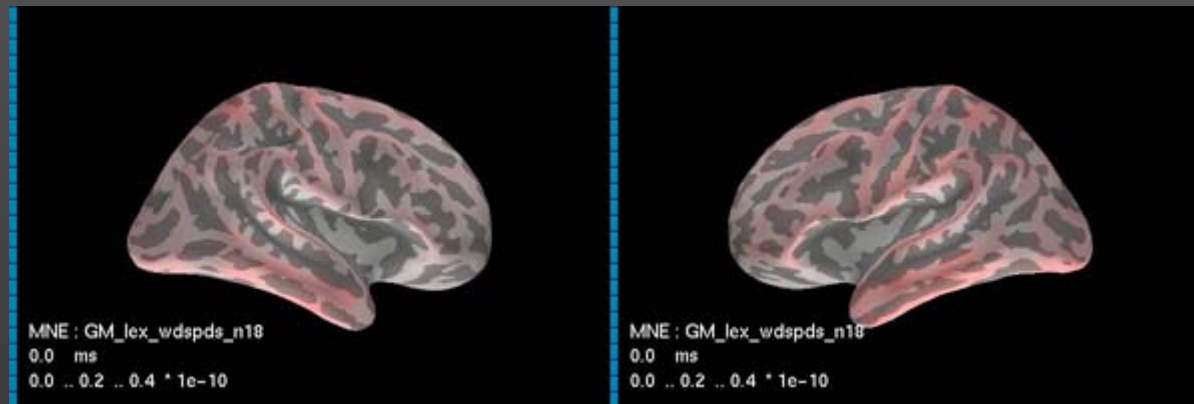
CTF 256

KIT 160 channels (64 channels for kids (not to play with...))

And others



# Word Recognition is Fast



## Wise Words...

“The mistakes in electroencephalography can fairly be attributed to ignorance of the theory underlying either the behaviour of the material or the equipment used to study it.”

*W.G. Walter & G. Parr (1950).*

“Enthusiasm for MEG (relative to EEG) has been boosted by both genuine scientific considerations and poorly justified commercial pressures.”

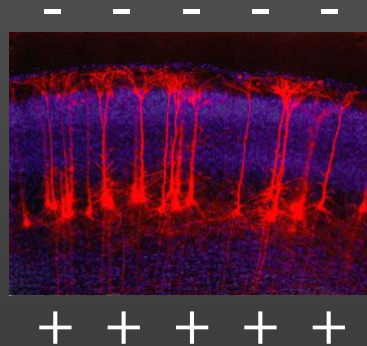
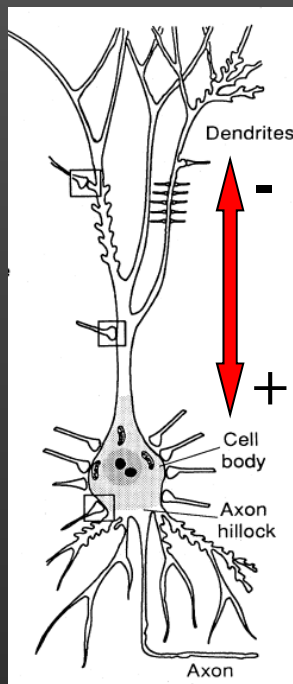
*Nunez&Srinivasan (2006), Electric Fields of the Brain, p. 84*

“No matter how enmeshed a commander becomes in the elaboration of his own thoughts, it is sometimes necessary to take the enemy into account.”

*Winston Churchill*

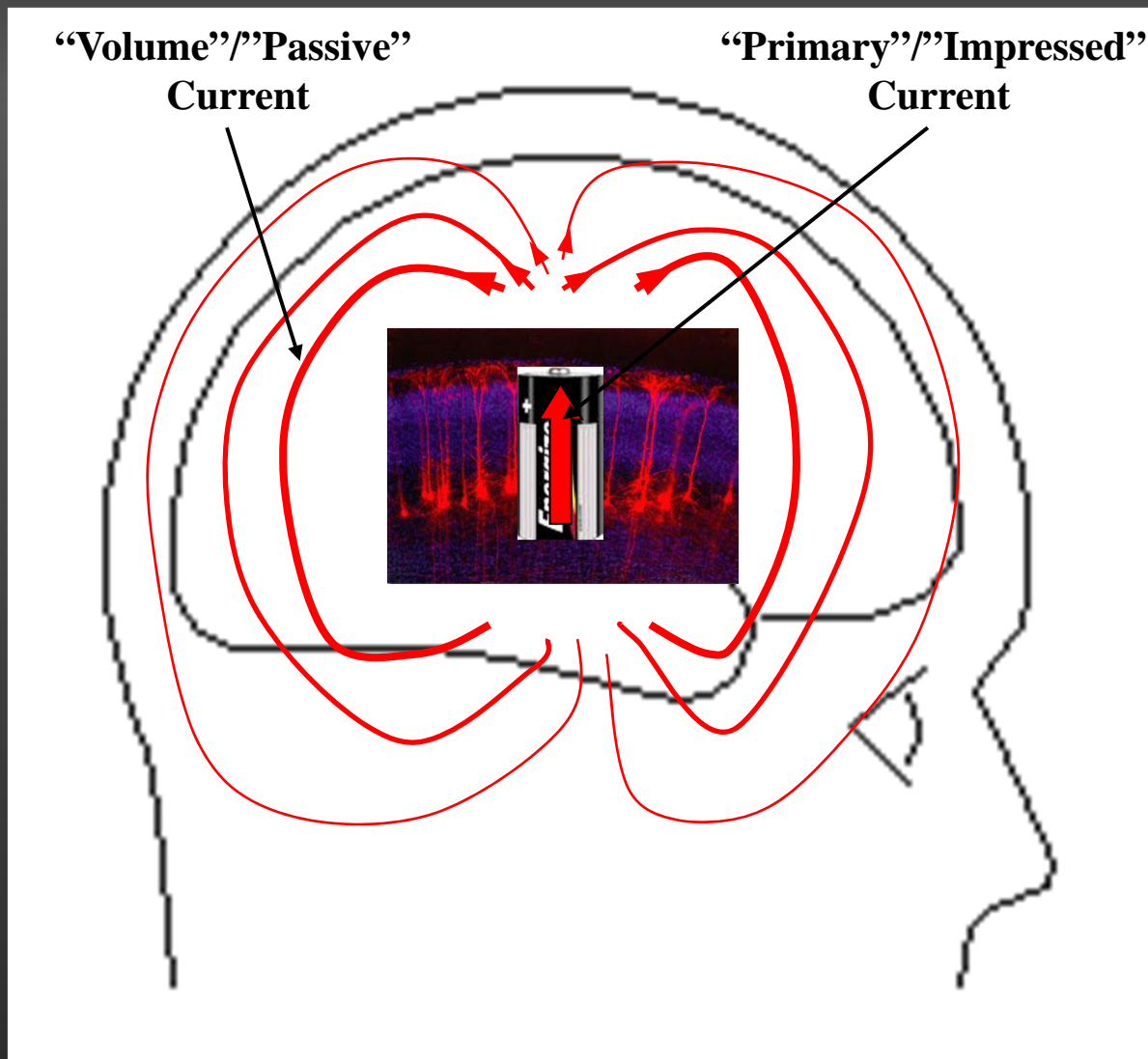
# Main Generators of Electrical Activity in the Brain

- Apical dendrites of pyramidal cells
- NOT action potentials
- EEG/MEG: same generators, different sensitivity

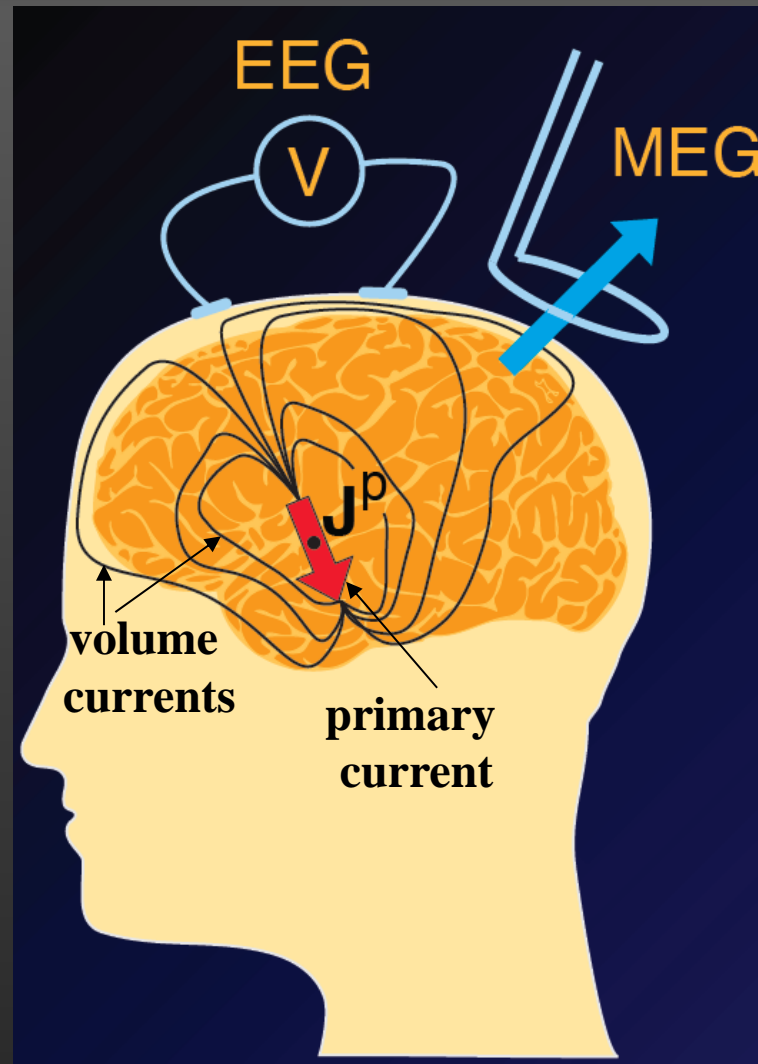


- ~ 1 Million synapses needed to activate simultaneously
  - Luckily: ~10000 cells per  $\text{mm}^2$ , ~ 1000 synapses per cell
- => several  $\text{mm}^2$  can produce measurable signal

# Current Flow in the Head



# EEG/MEG Measurements

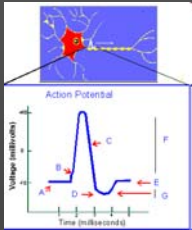




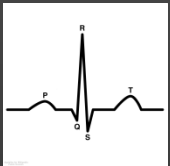
# Voltage



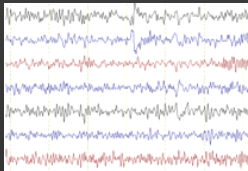
Household Batteries  $\sim 1\text{-}12\text{ V}$



Cell Membrane Potentials  $\sim 70\text{ mV}$



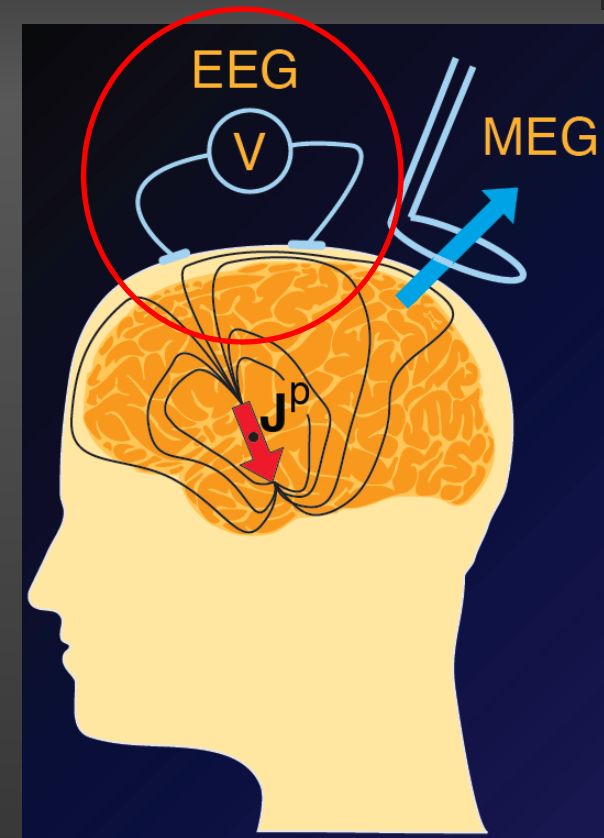
ECG:  $\sim 1\text{ mV}$



Raw EEG:  $\sim 30\ \mu\text{V}$ ; Eye blinks:  $> 100\ \mu\text{V}$



ERPs:  $\sim 1\text{-}10\ \mu\text{V}$



<http://www.nmr.mgh.harvard.edu/meg/pdfs/talks/>

# Magnetic Field



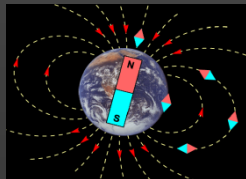
Strongest Conventional Magnetic Fields:  $< 2 \text{ T}$



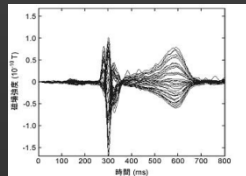
Demagnetisers:  $\sim 0.2 \text{ T}$



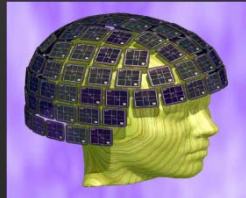
Small Bar Magnet:  $\sim 10 \text{ mT}$



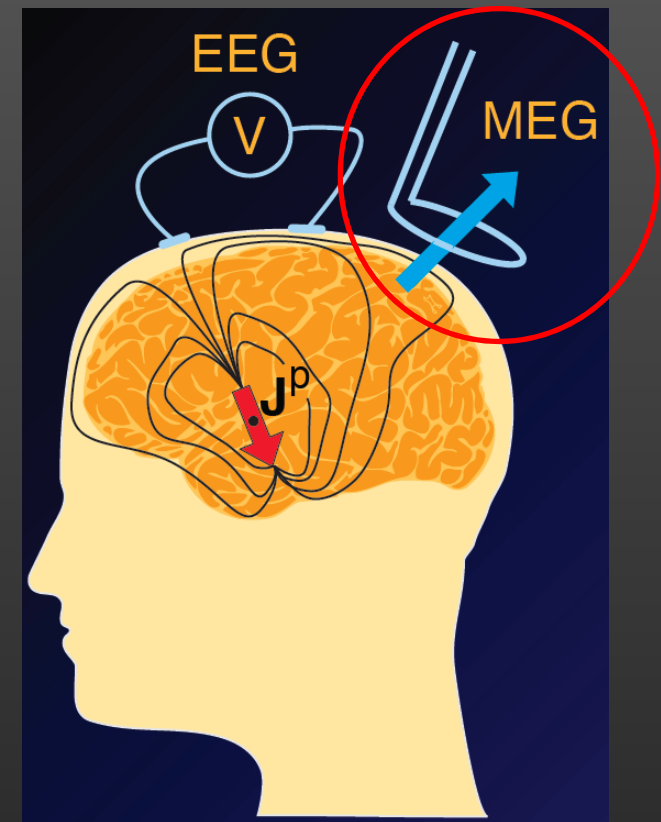
Earth:  $\sim 50 \mu\text{T}$



Heart:  $\sim 50 \text{ pikoT } (10^{-12})$

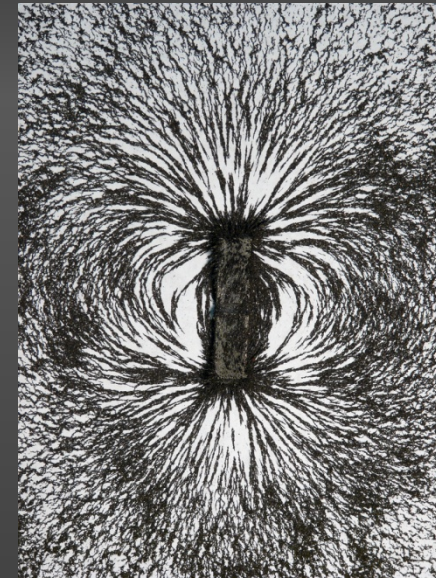
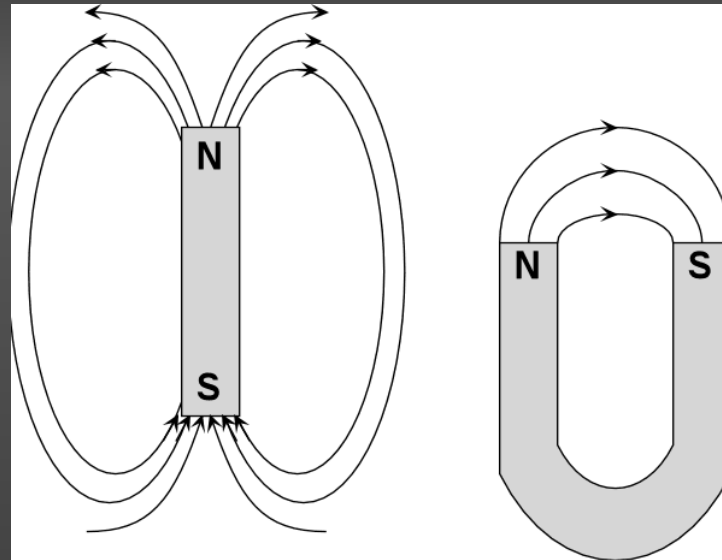


Brain:  $\sim 10 \text{ femtoT } (10^{-15})$



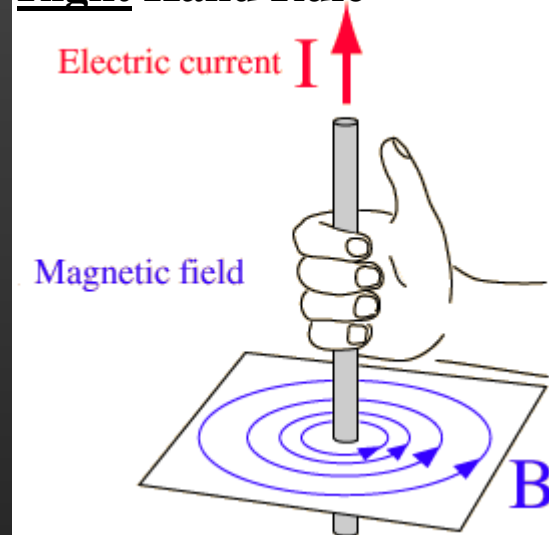
# Magnetic Fields

Most common:  
Bar magnets



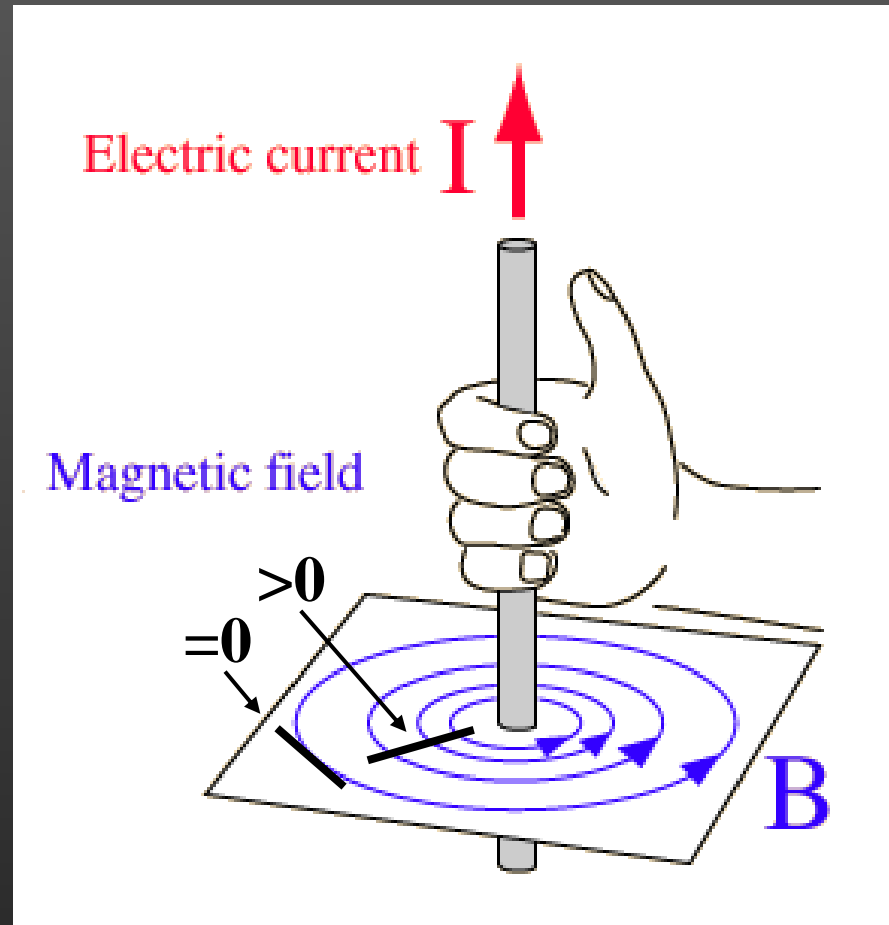
In the brain:  
Currents

## Right Hand Rule

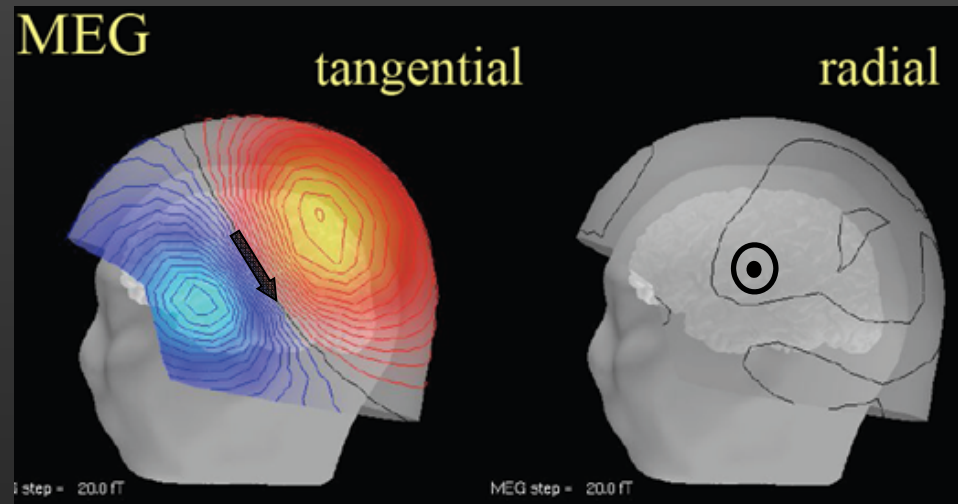
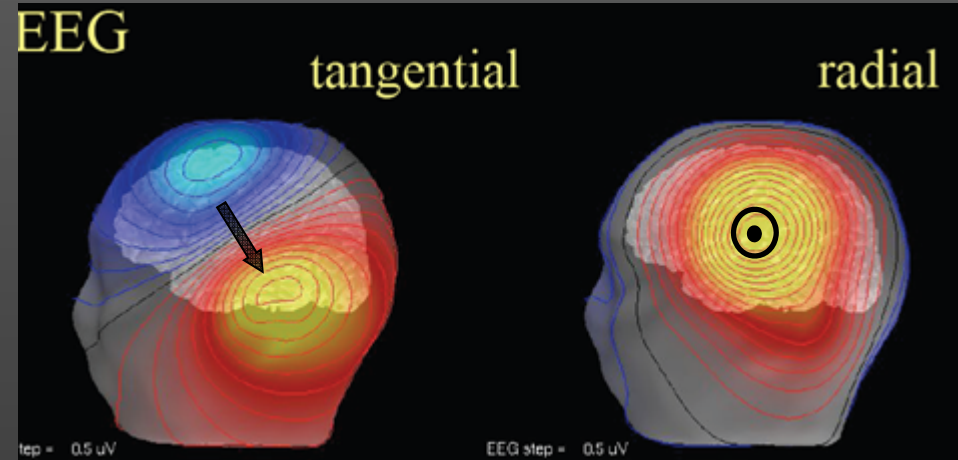


# Magnetic Fields

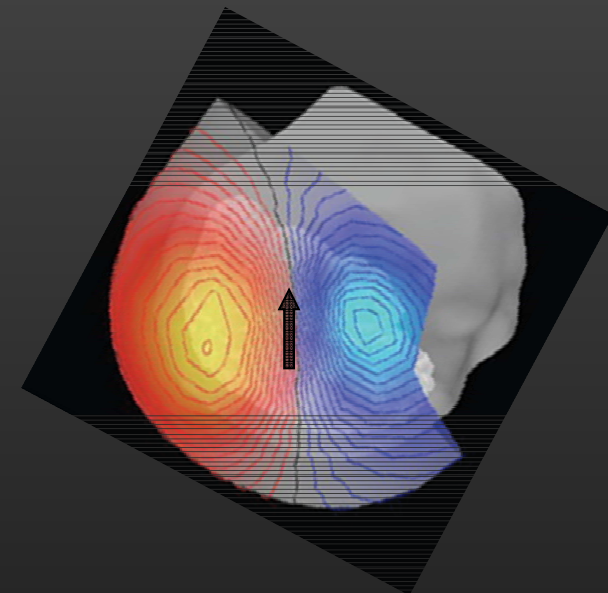
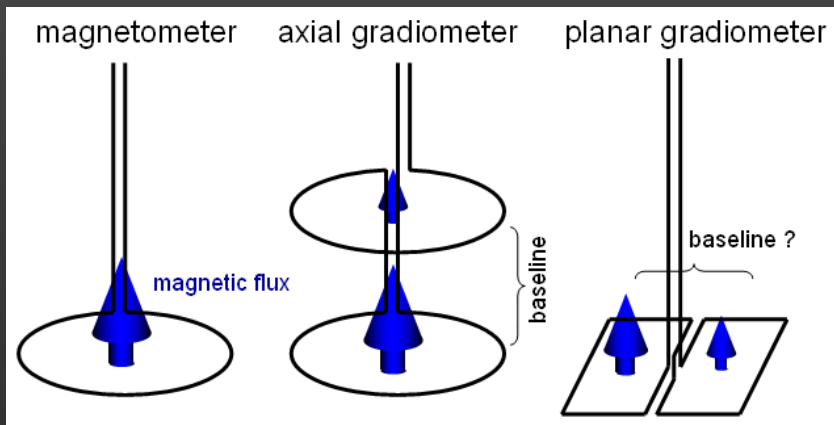
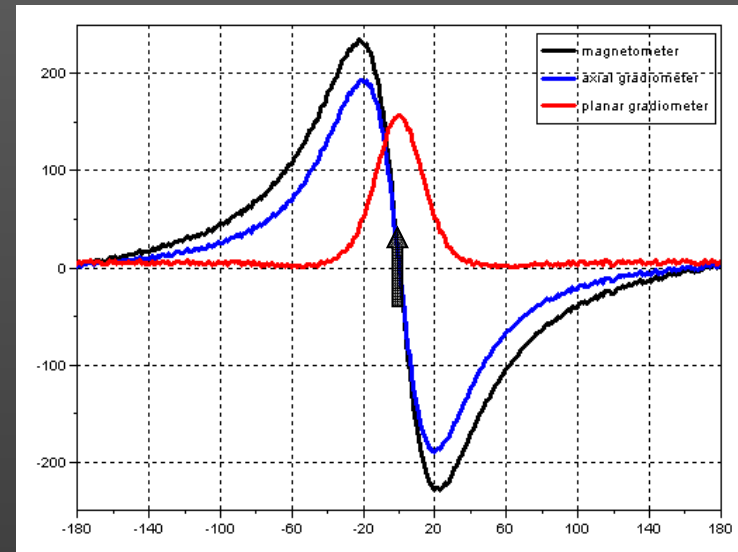
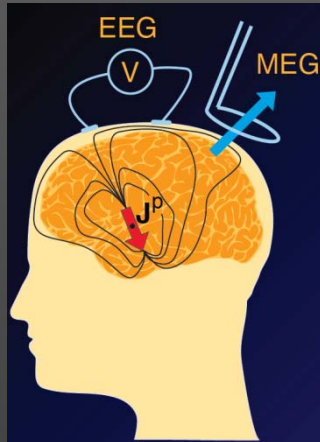
Magnetic Fields have a direction – Potentials don't



# Topographies

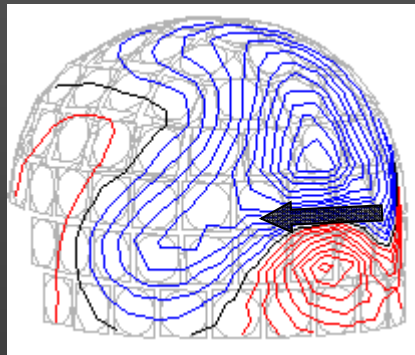


# Gradiometers and Magnetometers

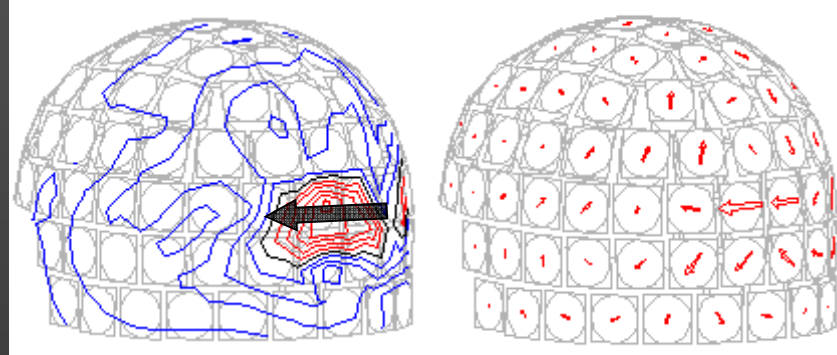


# Gradiometers and Magnetometers

Visually Evoked Fields, 90 ms

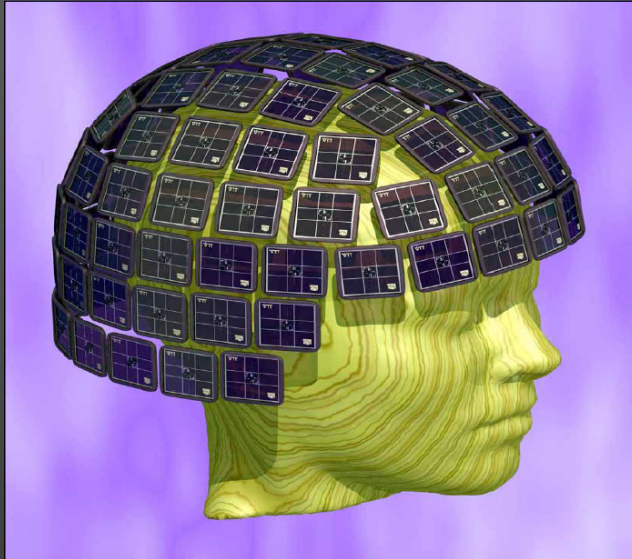


Magnetometers

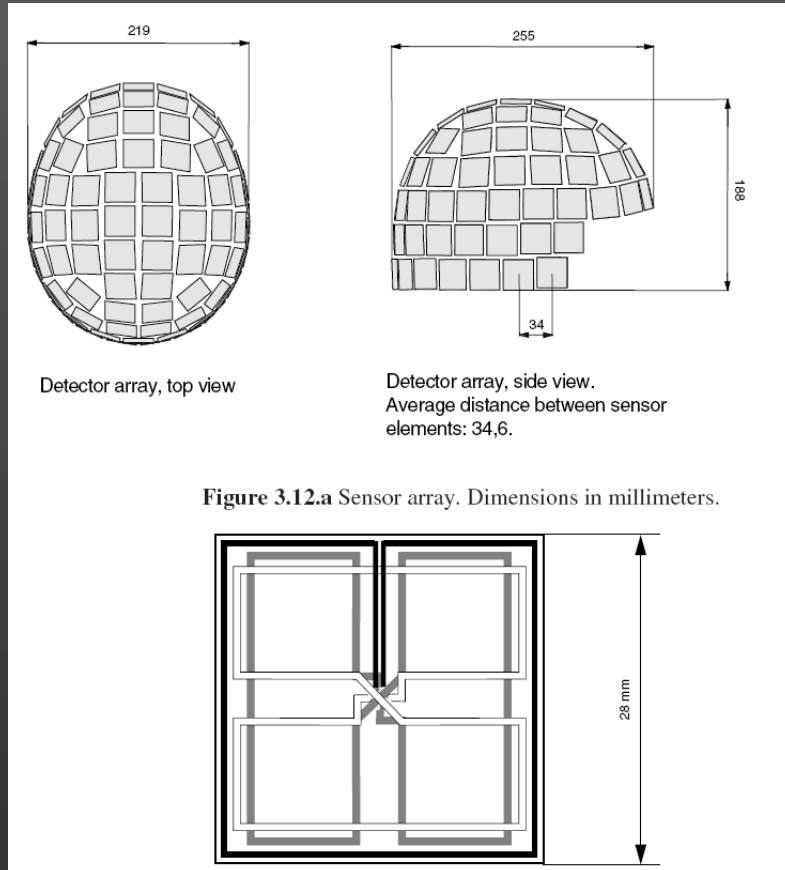


Gradiometers

# Elekta Neuromag Vectorview



102 Magnetometers  
204 Planar Gradiometers  
70/120 Electrodes



Each sensor element contains two planar gradiometers and one magnetometer:  
=>  
3 sources of independent information at each location (orthogonal “leadfields”)