Health Informatics, semester 1
Foundations of Science

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Homework for Unit 3:
Electrodynamics and Wave Phenomena

Problem 8: Gravitational vs. Coulomb force

Given are two homogeneous iron balls with 5 cm and 10 cm diameter. Their centers are at rest and separated by 10 cm.

a) Calculate their masses, the gravitational force between them and the acceleration of both balls.

b) Now, both balls are charged positively with a charge of +200 nC. Calculate the Coulomb force between both balls.

c) Calculate the net acceleration of both balls due to gravitational *and* electrostatic forces.

d) How long does it take until both balls hit? Neglect friction.

e) How many electrons do you need to strip from both iron balls to balance electrostatic and gravitational forces? How does this number relate to the number of atoms in the smaller ball?

Hints: The mass density of iron is 7.874 g/cm³, an iron atom weights $9.272 \cdot 10^{-26}$ kg and the volume of a ball is $4\pi/3 \cdot r^3$.

Problem 9: Serial and parallel circuits

Consider Kirchhoff's rules for current and voltage to derive formulae for the serial and parallel combination of

a) two resistors

b) two capacitors

c) two inductors.

Hints: For b) consider how the total electrical change is distributed over the capacitors in each situation. For c) consider the temporal derivative of the currents in each situation.

Problem 10: Electro- and magnetoencephalography

Electroencephalography (EEG) and magnetoencephalography (MEG) are techniques to detect neuronal activity of the brain by measuring electrical and magnetic fields on the scalp, respectively. Consider neurons as electrical dipole and current sources oriented perpendicular to the gyrified human brain surface, see Fig. 1.

a) Qualitatively draw the field lines of the electrical field of an electrostatic dipole. How is the field's main orientation and how does field strength depend on distance?

b) Qualitatively draw the field lines of the magnetic field of an electric current. How is the field's main orientation and how does field strength depend on distance?

c) In which directions can one measure the electrical and magnetic fields best on the surface of the scalp? Which field decays faster?

d) Are EEG and MEG equally sensitive to dipoles and current sources on gyri and sulci of the brain?

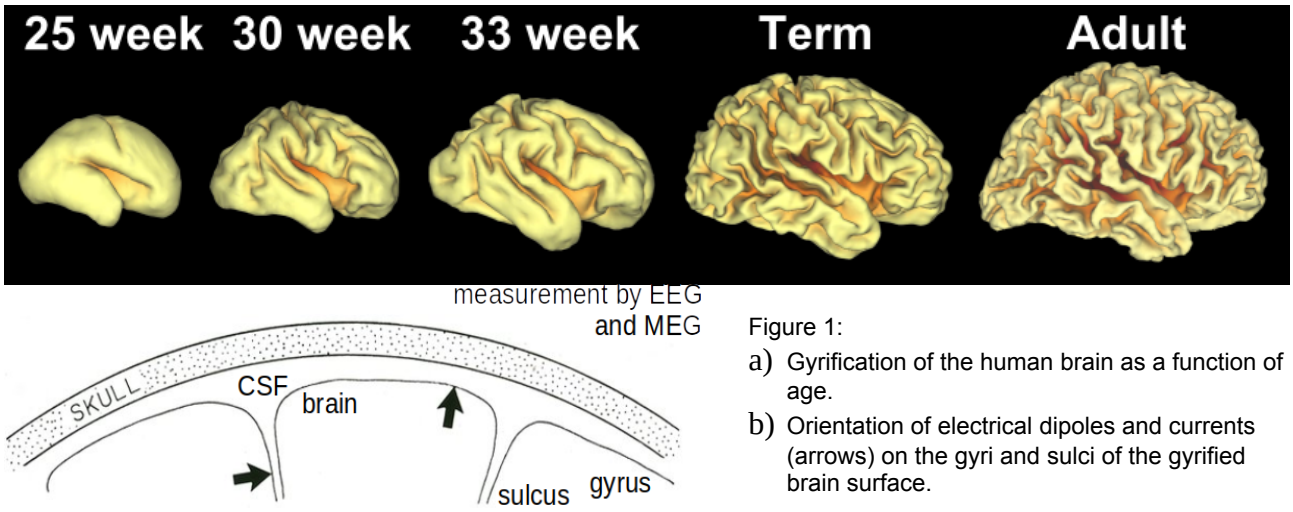

Figure 1:
a) Gyrification of the human brain as a function of age.
b) Orientation of electrical dipoles and currents (arrows) on the gyri and sulci of the gyrified brain surface.

Problem 11: Refraction and reflection

A light ray impinges onto an interface between air (light speed $c_{air} = 2.997 \cdot 10^8$ m/s) and water (light speed $c_{water} = 2.248 \cdot 10^8$ m/s). The incident angle is 30°.

a) Calculate the reflection and refraction angles for the transition air → water.

b) Calculate the reflection and refraction angles for the transition water → air.

c) In which situation can we have total reflection (i.e. a refraction angle of 90°)? At which incident angle does it occur?