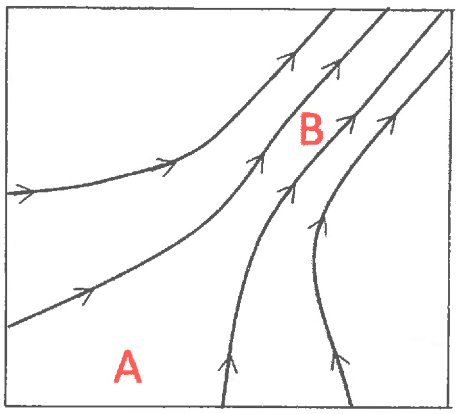
Interim exam 6A7X2 part Electricity and Magnetism
Tuesday February 26 2019, 17.30-19.30 h

It is allowed to use a (graphing) calculator

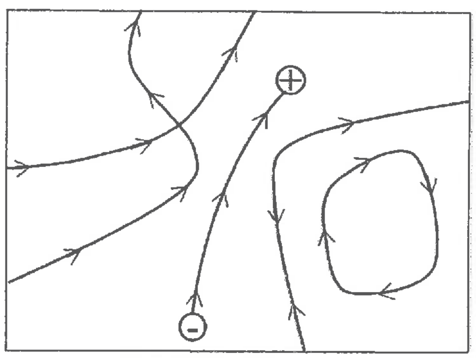
Problem 1. Electrical field lines (20 points)
Electric field lines are used to represent the static electric field. Below the electric field lines crossing part of space are shown.



a. (4 pt) Explain where the strength of the electric field is the highest : at point A or at point B ?

b. (4 pt) Explain where the electrical potential is the highest: at point A or at point B ?

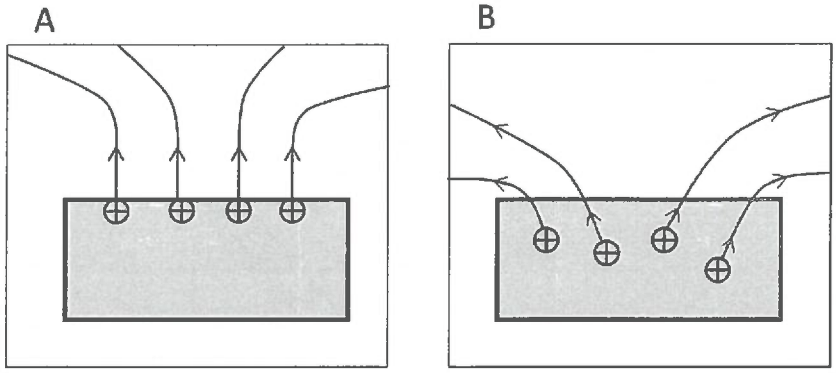
The diagram below again shows electric field lines. All lines lie in the 2-dimensional plane of the drawing. Plus and minus signs indicate positive and negative charges, respectively.



Graph with errors

c. (6 pt) The schematic diagram above contains four errors. Name the four errors and briefly explain what is wrong about them.

The two schemes A and B below show two rectangular, gray boxes representing two different materials. Both materials contain positive charge. Electric field lines are indicated. One of the materials is a metal and is electrically conducting. The other material is an electrical insulator.



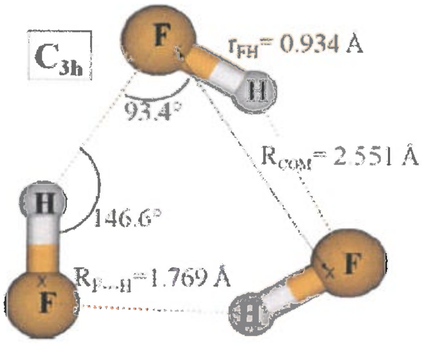
d. (6 pt) Explain which diagram (A or B) represents the metal. Support your choice with an extended argument and identify two features of the field lines shown that support your choice.

Problem 2. The hydrogen fluoride trimer (25 points)

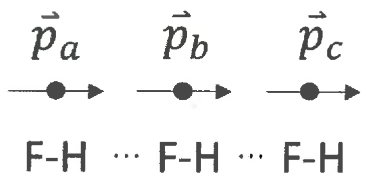
The HF molecule is electrically neutral but has a large dipole moment of 1.8 Debye. We first look at a single isolated HF molecule. Due to its dipole moment, the HF molecule is surrounded by an electric field. We draw an imaginary spherical surface around the centre of the HF molecule with a radius of 0.5 nm.

a. (5 pt) Calculate the flux of the electric field generated by the HF molecule through this imaginary surface.

In the gas phase at low temperatures, HF molecules tend to form clusters. In 2014, Asselin and coworkers, reported the following structure for $(HF)_3$:



We will now use the electrostatic dipole-dipole interaction to evaluate the stability of the cyclic structure for $(HF)_3$. To do so we first investigate the possibility of a linear structure for $(HF)_3$. The linear structure is illustrated schematically below:



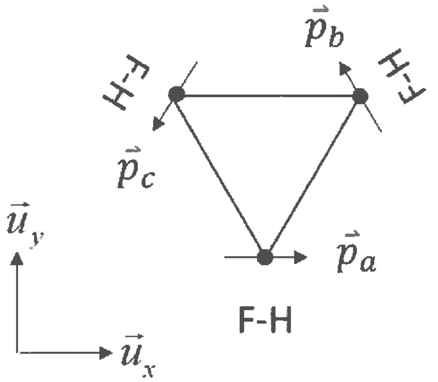
Here, $\vec{p}_a$ indicates the dipole moment of H-F molecule a. Assume that the distance r between two adjacent dipoles is 0.255 nm. We note that for a dipole moment p of 1.8 Debye, we have $\frac{-p^2}{4\,\pi\,\varepsilon_0\,r^3} = -0.122\ eV$

b. (5 pt) Calculate the electrostatic potential energy for the interaction between dipole a and dipole b in the linear trimer (U_{ab}).

The total electrostatic potential energy of the trimer is the sum of the potential energies of all possible pairs of dipoles, so here (a,b), (a,c) and (b,c).

c. (5 pt) Calculate the total electrostatic potential energy of the linear trimer making use of your results from question b. (If you do not have an answer at b), assume U_{ab} = -0.136 eV.)

We now look at the cyclic trimer structure:



The distance between dipoles in each possible pair is equal to $r = 2.55$ nm. The position and dipole vectors for the three dipole a,b and c can be expressed in x,y, and z components as:

$$\vec{r}_a = \begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix}; \vec{r}_b = r\begin{pmatrix} ½ \\ ½\sqrt{3} \\ 0 \end{pmatrix}; \vec{r}_c = r\begin{pmatrix} -½ \\ ½\sqrt{3} \\ 0 \end{pmatrix} \quad \text{and} \quad \vec{p}_a = p\begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix}; \vec{p}_b = p\begin{pmatrix} -½ \\ ½\sqrt{3} \\ 0 \end{pmatrix}; \vec{p}_c = p\begin{pmatrix} -½ \\ -½\sqrt{3} \\ 0 \end{pmatrix}$$

An important clue on the structure of the $(HF)_3$ trimer comes from the experimental observation that the orientation of the $(HF)_3$ cluster cannot be altered by application of a uniform, static electric field.

d. (5 pt) Explain why this observation is inconsistent with a linear structure for $(HF)_3$ and supports the cyclic structure shown above.

e. (5 pt) Calculate the total electrostatic potential energy for the cyclic structure. (Hint: first calculate the energy for the (a,b) pair and then use the symmetry of the cyclic structure to find the energies for the other pairs).

END.