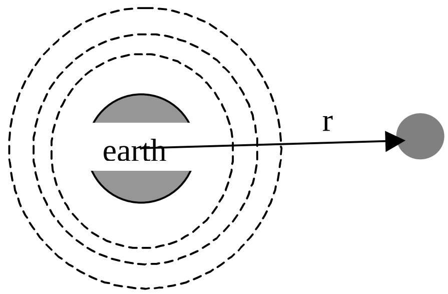
# Electric fields

<u>Action at a distance:</u> How does the Earth "know" how much for to exert on the moon? Is there something from the earth that travels to the moon, determines "r" and then applies F? Similarly if a glass rod is brought near a pith ball the reaction observed is "instantaneous". How is the distance 'determined' in this case ? Rather than say a force "flies out" from one ball to the other we say that there is a field - which <u>always</u> exists. An object at 'r' just <u>reacts</u> to this field.




Similarly a charge "q" has an "Electric field" around it - and any other charge - a "test charge" - will feel the field. Denote this field by E.

<u>Define E</u>: E is the force acting on a test charge $q_0$ divided by the test charge when it tends to 0. Since we specify a force E is a vector.

$\vec{E} = \lim_{q \to 0} \frac{\vec{F}}{q_0}$; the limit is necessary since we do not to "disturb" the existing field in the process of introducing the test charge.

Units of E: The field is measured in (Newtons/Coulomb) consistent with it's definition.

<u>Examples of "fields" and their magnitudes:</u>

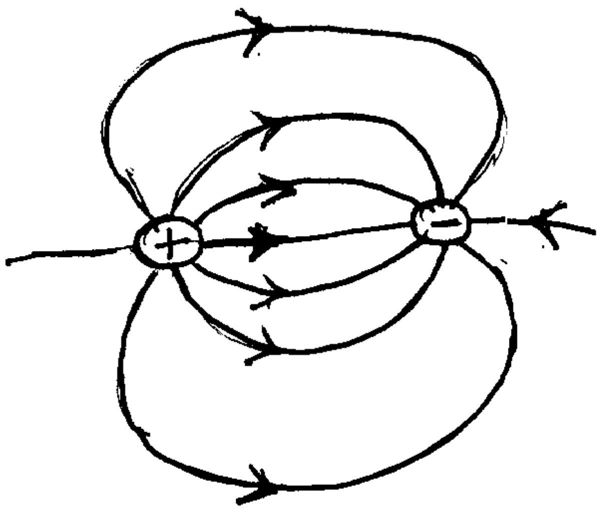
(a) Hydrogen atom: Given the radius of the atom we can calculate that the force of attraction between the electron and the proton as F = 9 x $10^{-8}$ N. Therefore the electric field that exists is $E = \frac{F}{q_0} = \frac{9.0x10^{-8}N}{1.6x10^{-19}C} = 5x10^{11}(N/C)$

(b) Electrical breakdown of dry air - for example occurs when a spark flies from the tip of your finger onto a metal desk or the lock to your car in winter. E = $10^6$ N/C

(b) We think the net charge in the universe is zero. What about the field ? In interplanetary space do the fields due to all charges cancel ? Apparently not !
$E_{space} \approx (10^{-3} - 10^{-2})$ N/C

Field due to a point charge: Consider a point charge "$q_1$". The electric field E points away from a +ve $q_1$. For a - ve charge the field points inwards.

Suppose we had both +ve & -ve - then the field lines would be



OR

we may not even know where the charges are because they are far away - we might have just field lines. A test charge $q_0$ placed anywhere within these field lines experiences a force given by

$$\vec{F} = q_0 \vec{E}$$

Given E the force is easy to calculate. It is harder to figure out what is the charge distribution (that gives rise to this E) and then calculate the force on $q_0$.

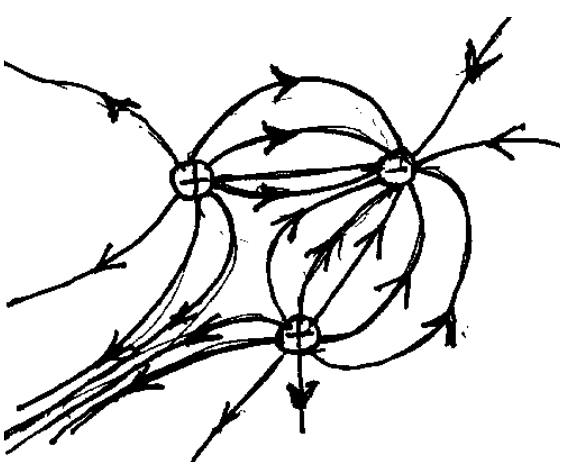
Superposition principle: We used it in the picture above with the electric dipole. The net electric field is the vector sum of the fields of individual charges, $q_i$

$$\vec{F}_{net} = \vec{F}_{01} + \vec{F}_{02} + \vec{F}_{03} + \vec{F}_{04} + \ldots = \sum_i \vec{F}_{0i}$$

Therefore $\vec{E}_{net} = \dfrac{\vec{F}_{net}}{q_0} = \dfrac{\vec{F}_{01}}{q_0} + \dfrac{\vec{F}_{02}}{q_0} + \dfrac{\vec{F}_{03}}{q_0} + .. = \sum_i \vec{E}_i = \dfrac{1}{4pe_0} \sum_i \dfrac{q_i}{r_i^2} \hat{r}_i$

Where $r_i$ is directed from $q_i$ to the point where the electric field is measured.

Electric Field Lines: In the above e.g. of a dipole we drew E-field lines intuitively. What if we add a third charge, say +q as shown in the figure below ?



What are the rules we follow in drawing the electric field lines?

1. Lines are drawn so that the tangent to the line is the direction of E

2. The density of lines specifies the "intensity" of E. Suppose we made N lines come out of +q then if the charge is increased to 2q we have 2N lines.

3. Lines cannot terminate in free space. They have

to either start at +ve or end at -ve.

4. Lines cannot intersect.

5. The area of a sphere increases as $4\pi r^2$ and the electric field falls off as $1/r^2$. This is consistent with preserving flux.

Qualitative Examples: How does one understand that there is no electric field in a circle ? For every field line originating on the circle one can draw another opposite field line thus ensuring the total field is zero.