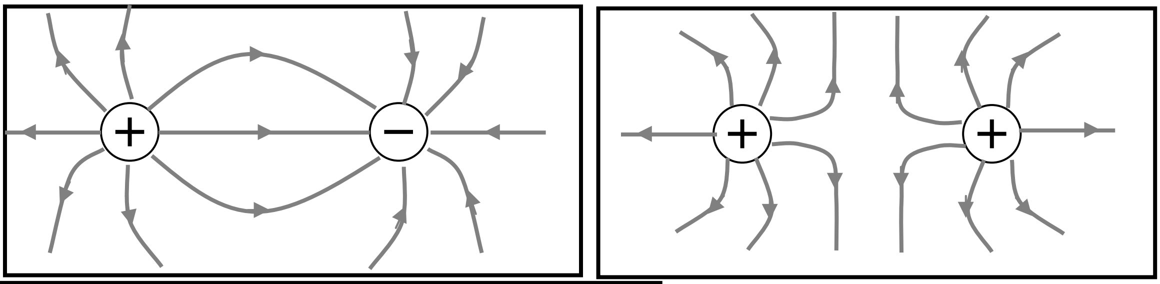
Workshop Tutorials for Technological and Applied Physics

Solutions to ER2T: **Electric Fields**

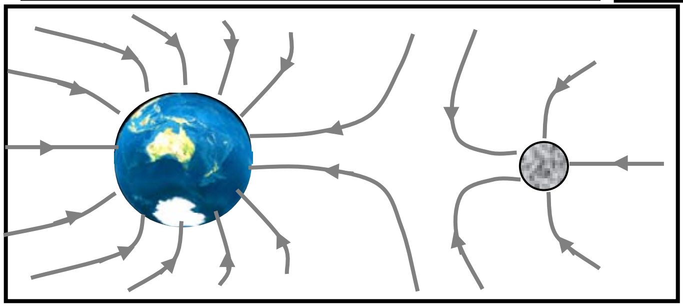
A. Qualitative Questions:

1.

a.



b.



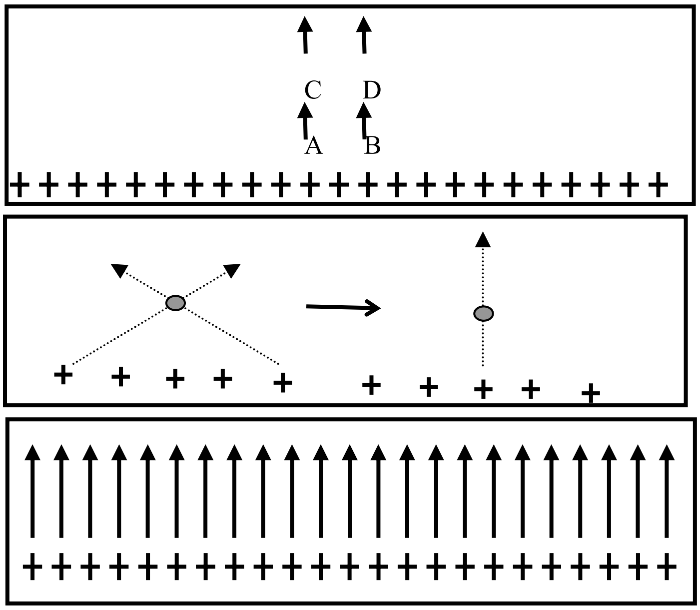
Use the force on a point charge, or in the case of a gravitational field, a point mass to define the field lines. In **b,** the force, and hence the field, is zero where the test mass is equally attracted to both Earth and moon.

c. Both gravitational and electric fields are defined in terms of force on a point object (charge or mass), and both obey a $1/r^2$ law. In gravity there is only one type of "charge", which is mass. In electrostatics there are two types, positive and negative. Like gravitational "charges" attract each other, but like electric charges repel each other and opposite charges attract. However the field lines are similar for a pair of positives for both gravitational and electric fields. Note that the direction of the field lines is different, they go into a mass, and out from a positive charge.

2. A sheet of charge.

a. The field lines all point away from the sheet of positive charge. See opposite.

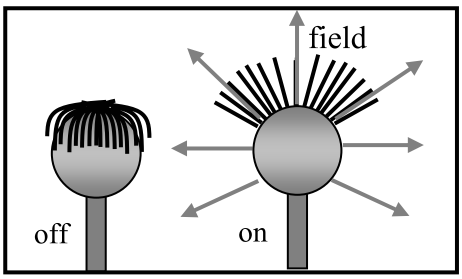
b. Brent is wrong. The net force is perpendicular and away from the sheet. Components of the forces acting in any other direction cancel each other out. As long as the sheet in infinite, there is always a pair of charges at the same distance away in either direction from the points shown. All the field vectors have the same magnitude, and are parallel. Hence the density of field lines is not changing as we move away from the sheet, so the magnitude of the field is constant.



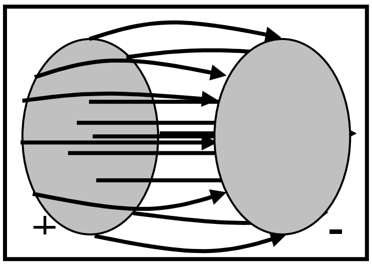
B. Activity Questions:

1. van de Graaff generator and wig

The hairs of the wig stand up because they are charged by the generator. Usually the dome becomes positive, so negative charges move from the wig to the dome, leaving it positively charged. The hair stands up because the charges exert a repulsive force on each other, the hairs try to get as far away from each other as possible and are light enough to stand up and move apart. The hairs also line up along the field lines. When a person touches the dome their hair will also stand up if enough charge is transferred.



2. Ball in a capacitor

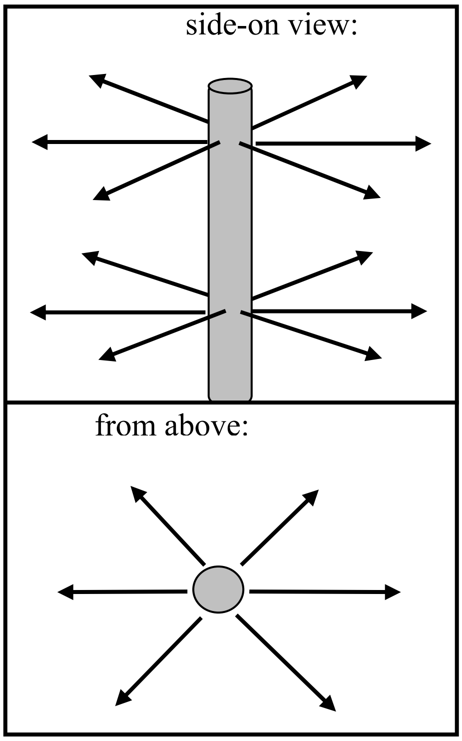


A ping-pong ball bounces continuously in between the two charged plates of a capacitor. When it contacts with one plate it picks up sufficient charge to accelerate towards the oppositely charged plate. If the foil is removed the ball still bounces, but much more slowly because it takes longer to charge. The field lines are shown opposite. The lines point from the positive plate to the negative plate, they are parallel near the middle of the plates and curve outwards near the edges of the plates

3. Confused bubbles

The bubbles are initially neutral. The positively charged dome of the van de Graaf generator attracts negative charges which move around to the side of the bubble facing the dome. This bubble will now be attracted to the dome. The other side of the bubble will be positively charged and if the bubble bursts, those behind it may be splashed with this excess positive charge and become positively charged and be repelled by the dome.

<u>**C. Quantitative Questions:**</u>



1. A photocopier corona wire typically has a radius of around 50 μm and charged to a potential of around +7kV, giving the wire a linear charge density of 40 $nC.m^{-1}$.

a. See diagram opposite. The field spreads radially outwards from the wire.

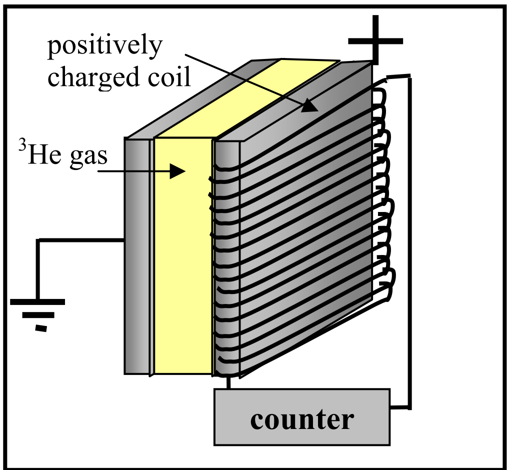
b. The field of a point charge varies as $1/r^2$, whereas the field from a line charge falls off as $1/r$. Hence the field of the point charge falls away to zero more quickly. The field produced by a sheet of charge is uniform and does not vary with *r*. (Note, this is assuming an infinite sheet! – a situation we can use as an approximation when the dimensions of the sheet are many times the distance *r* from the sheet.

c. The field at some distance *r* from the wire is given by the expression

$E = \lambda/2\pi\varepsilon_o r$, where λ is the linear charge density.

d. $E = \lambda/2\pi\varepsilon_o r = \dfrac{40\times10^{-9}\text{ C.m}^{-1}}{2\times3.142\times8.5\times10^{-12}\text{ N.m}^{-2}.\text{C}^{-2}\times1.0\times10^{-3}\text{ m}}$

$= 750 \text{ kV.m}^{-1}$.



2. The electron accelerates vertically because of the gravitational field and horizontally because of the electric field. If the electron is to hit the plate the time taken to fall 8cm must be no less than the time taken to move 2.5cm to the positive plate under the action of the electric field. In the limiting case we take the time to fall 8 cm equal to the time to move 2.5 cm horizontally.

Using $\Delta y = v_o t + ½\, a_y t^2$ where $a_y = g$ and $v_o = 0$ gives

$t^2 = 2\Delta y/g$.

In the horizontal direction , $\Delta x = v_o t + 1/2\, a_x t^2$,

where $a_x = eE/m$ and $v_o = 0$,

so $eE/m = a_x = 2\Delta x/t^2 = 2\Delta x\, g/2\Delta y$.

Thus $E = \Delta x\, gm/\Delta y\, e = 2.5 \times 10^{-2}\text{ m} \times 9.11 \times 10^{-31}\text{ kg} \times 9.8\text{m.s}^{-2}/1.6 \times 10^{-19}\text{ C} \times 8.0\times 10^{-2}\text{ m}$

$E = 1.7 \times 10^{-11}\text{N.C}^{-1}$.