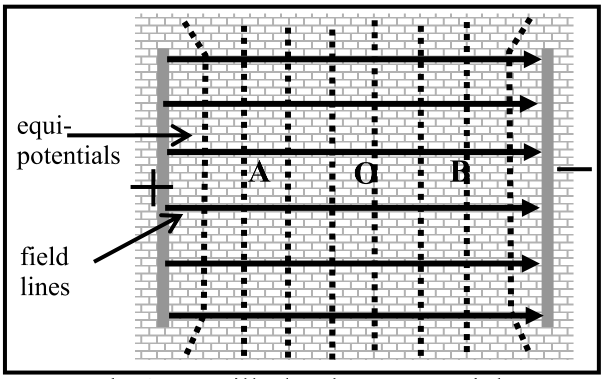
Workshop Tutorials for Technological and Applied Physics

Solutions to ER4T: **Electric Potential**

A. Qualitative Questions:

1. Electric potential and potential energy.
a. The electric potential energy of a charge at some point is the energy required or the work that must be done to move a charge from infinity to that point. The potential energy is the potential energy of the whole system of charges. For convenience we take the zero of electric potential energy to be when the charge is at infinity so we can talk about the potential energy of that particular charge due to the field produced by other charges. The potential is then the potential energy per unit charge.
b. The electric potential energy of a pair of like charges is positive because work has to be done on them to move them from infinitely far apart in towards each other. The change in potential energy is equal to the work done on the charges, hence the potential energy is positive. The opposite is true of a negative and positive charge, they do work in coming together, hence they have negative potential energy.
c. The gravitational potential energy of a pair of masses is negative, as in the case of opposite charges, they are attractive, so they do work as they approach, rather than work having to be done on them to bring them together.
d. Electric field is defined as the change in potential with distance. If the electric field is zero, then the potential is not changing with distance, i.e. it is constant, but this does not necessarily mean that it is zero.

2. Dust precipitators.
a. See diagram opposite.



b. The dust particle has a charge of $+1e$, hence it will be attracted to the negative plate and repelled by the positive plate, and will move towards point B.
c. The system will lose electric potential energy, just as when a ball falls, the ball-earth system loses gravitational potential energy. The dust particle will accelerate, gaining kinetic energy as it moves from O to B.
d. A particle with charge $-2e$ will move the opposite way, towards **A**. It will also lose potential energy and gain kinetic energy, but as its charge is twice as great it will have twice the electric potential energy as the $+1e$ particle, and twice as much electric potential energy will be converted to kinetic energy for a given distance traveled.
e. The electric potential is highest at point **A** and lowest at point **B**; it decreases as you move from positive from to negative.

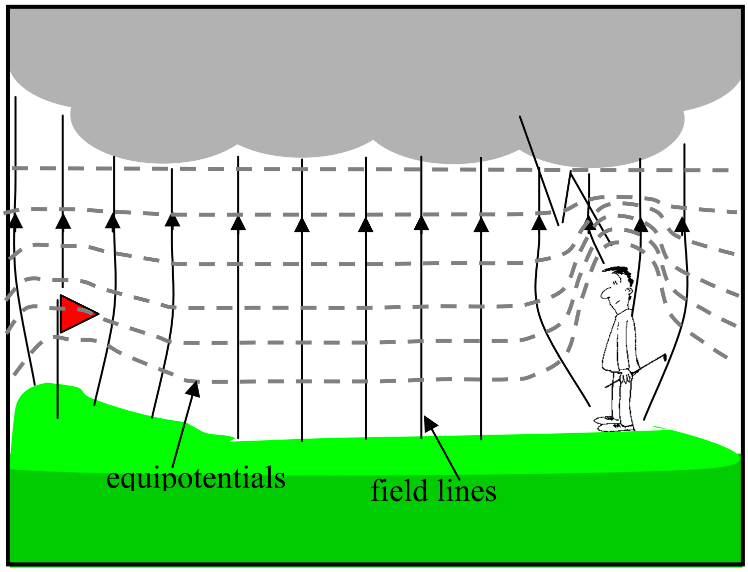
B. Activity Questions:

1. Measuring voltages
The resistance of the wire is much less than that of the resistor. Since the value of the current in both wire and resistor must be the same, using $V = IR$ we can see that the potential difference across the whole wire must be much smaller than the potential difference across the resistor. The potential difference between any two points on the wire is probably so small that you could not measure it.
To say that a voltmeter is connected "in parallel" is just a fancy way of saying that you connect its terminals to the two points for which you want to know the potential difference. Since there is usually something else like a resistor already connected between those two points people say that the voltmeter and the resistor are "in parallel".

2. Equipotentials

Equipotentials are surfaces which have the same value of electric potential and field lines represent the magnitude and direction of forces. Field lines are perpendicular to equipotentials, so you can use equipotentials to draw field lines.

C. Quantitative Questions:



The potential difference between the cloud layer 500 m overhead and the ground is probably around 10^9 V.

a. The electric field is the potential difference per unit distance,
$E = V/d = 10^9 \text{ V} / 500 \text{ m} = 2.0 \times 10^6 \text{ V.m}^{-1}$.

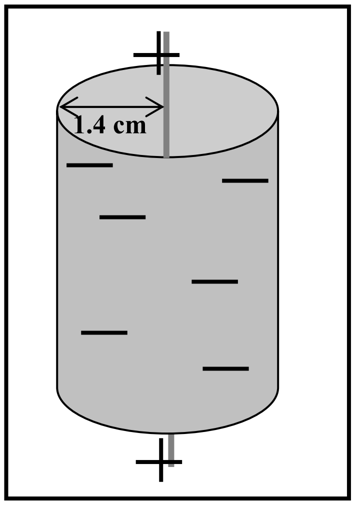
b. See diagram opposite.

c. Assuming a uniform field, the potential difference between the ground and the air at 180 cm above the ground is
$V = Ed = 2.0 \times 10^6 \text{ V.m}^{-1} \times 1.80 \text{ m}$
$= 3.6 \times 10^6 \text{ V} = 3.6 \text{ MV}$.

d. Bert, like all humans, is a good conductor, hence he will be the same potential all over, from his head to his feet, and the electric field will be distorted around him

e. Bert is standing on the ground, hence he is earthed. The earth is at zero volts, so Bert will also be at zero volts, including his head.

f. The change in electric potential energy of an electron moving from the clouds to the ground will be the change in potential × the charge of the electron, $\Delta U = Ve = 10^9 \text{ V} \times 1.6 \times 10^{-19} \text{ C} = 1.6 \times 10^{-10}\text{J}$.



2. Geiger counters are used to detect ionizing radiation. The detector part consists of positively charged wire which is mounted inside a negatively charged conducting cylinder, as shown. The radius of the central wire is 25 μm, the radius of the cylinder is 1.4 cm and the length of the tube is 16 cm. If the electric field at the cylinder's inner wall is 2.9×10^4 N.C^{-1}.

a. The field at the inner wall of the cylinder will be entirely due to the enclosed charge (Gauss' law), so we can use the expression given in the hint, $E = \frac{\lambda}{2\pi\varepsilon_0 r}$, to find the linear charge density:

$\lambda = 2\pi\varepsilon_0 rE = 2 \times \pi \times 8.85 \times 10^{-12} \text{ F.m}^{-1} \times 0.014 \text{ m} \times 2.9 \times 10^4 \text{ N.C}^{-1}$
$= 2.3 \times 10^{-8} \text{ C.m}^{-1}$.

The length, l, of the tube and wire is 16 cm, so the total excess charge on the wire is $q = \lambda \times l = 0.16 \text{ m} \times 2.3 \times 10^{-8} \text{ C.m}^{-1} = 3.6 \text{ nC}$.

b. The potential difference between the inner wire and the outer cylinder is

$$\Delta V = V_w - V_c = -\int_{r_c}^{r_w} E.dr = \int_{r_w}^{r_c} \frac{\lambda}{2\pi\varepsilon_0 r}.dr = \left[\frac{\lambda}{2\pi\varepsilon_0}\ln r\right]_{r_w}^{r_c} = \frac{\lambda}{2\pi\varepsilon_0}(\ln r_w - \ln r_c) = \frac{\lambda}{2\pi\varepsilon_0}\ln\left(\frac{r_c}{r_w}\right).$$

c. The potential difference between the wire and the cylinder is

$$\Delta V = \frac{\lambda}{2\pi\varepsilon_0}\ln\left(\frac{r_c}{r_w}\right) = \frac{2.3\times10^{8}\text{ C.m}^{-1}}{2\times\pi\times8.85\times10^{-12}\text{ F.m}^{-1}}\ln\left(\frac{0.14\text{ m}}{25\times10^{-6}\text{ m}}\right) = 3.6 \times 10^3\text{V} = 3.6 \text{ kV}.$$