

Workshop Tutorials for Biological and Environmental Physics

Solutions to ER4B: Electric Potential

A. Qualitative Questions:

1. Playing golf in a storm.

a. The clouds are negative with respect to the Earth, which is at zero, so the field lines go from the Earth to the clouds. See diagram opposite.

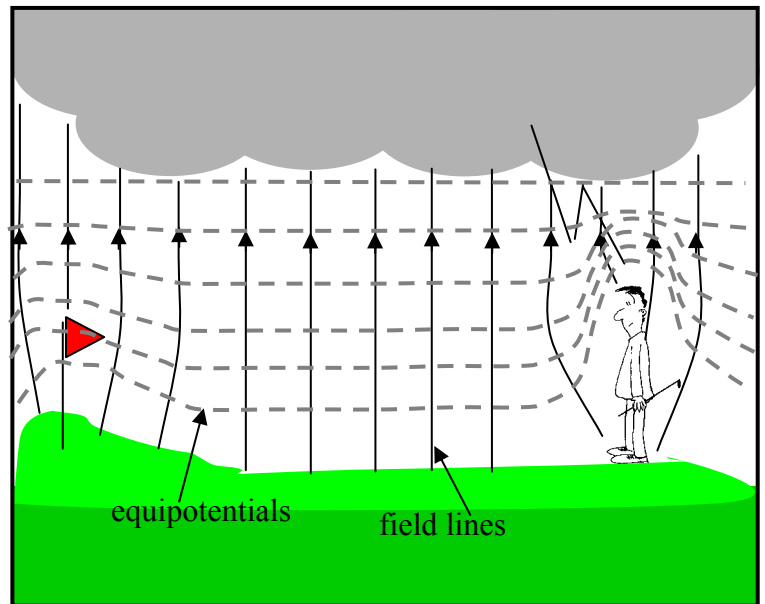
b. Bert, like all humans, is a good conductor, hence he will be at the same potential all over, from his head to his feet, and the electric field will be distorted around him.

c. There will be a very high potential difference between the air above his head and the ground at his feet, given by $\Delta V = Ed$.

d. 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.

e. Walking around and swinging a golf club in a thunderstorm is dangerous. The club could act as a lightning rod, as it is long and metallic. If there is a very large electric field then lightning could strike, and Bert's golf club, and his body, will form a path of low resistance for the current.

f. There are very few free charges in the air usually, so no current is established. Breakdown of dry air to give free charges occurs at fields around $3 \times 10^6 \text{ V.m}^{-1}$, which is much more than the fine weather field of 100 V.m^{-1} .



2. Dust precipitators.

a. See diagram opposite.

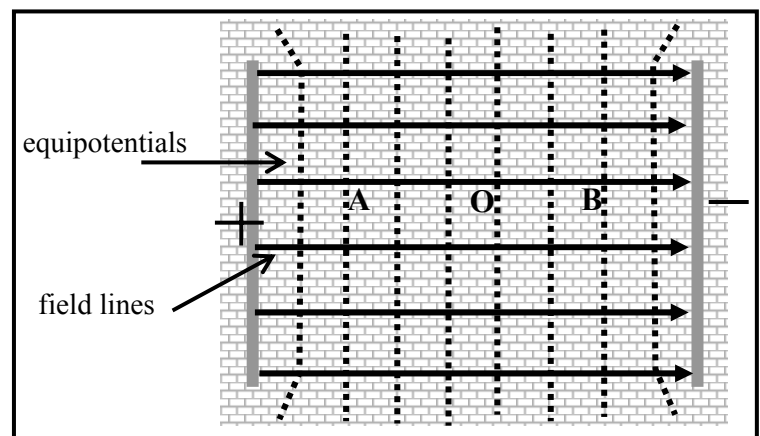
b. The dust particle in the chimney has a charge of $+1e$, hence it will be attracted to the negative plate and repelled by the positive plate, and will move towards point B.

c. The system will lose electric potential energy in doing this, 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 to negative.

f. 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. Activity Questions:

1. Equipotentials

Equipotentials are surfaces on which the electric potential is constant. Field lines represent the magnitude and direction of forces. Field lines are always perpendicular to equipotentials, so you can use equipotentials to draw field lines (or vice versa). Note that there is no work done moving a charge along an equipotential because the force is perpendicular to the displacement, and there is no change in potential energy.

2. 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".

C. Quantitative Questions:

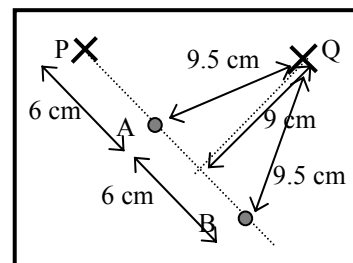
1. Membrane potential and electric field.

a. The field, if uniform, is

$$E = V/d = 90 \times 10^{-3} \text{V} / 8.0 \times 10^{-9} \text{m} = 1.1 \times 10^7 \text{V.m}^{-1}.$$

b. To move 3 Na^+ ions to a location at higher potential requires $3e\Delta V$ of energy input. But when 2 K^+ ions go the other way to a lower energy state they release energy $2e\Delta V$. That requires a net energy input of $e\Delta V$ by the pump, $W = e\Delta V = 1.6 \times 10^{-19} \text{C} \times 90 \times 10^{-3} \text{V} = 1.4 \times 10^{-20} \text{J}$ gained.

2. The charges are 6 cm apart, point P is 6 cm from charge A and point Q is 9 cm from a point half way between the charges as shown. Hence electrode P is 6 cm away from charge A and 12 cm away from charge B. Electrode Q is 9.5 cm away from both charges A and B. The charge at point A is shown is $+1.5 \times 10^{-14} \text{C}$, and that at point B is $-1.0 \times 10^{-14} \text{C}$



a. See diagram opposite.

b. The potential at point P due to charge A will be

$$V = \frac{kq}{r} = \frac{8.99 \times 10^9 \text{N.m}^2.\text{C}^{-2} \times 1.5 \times 10^{-14} \text{C}}{0.06 \text{m}} = +2.2 \text{mV}.$$

c. The potential at point P due to charge B will be

$$V = \frac{kq}{r} = \frac{8.99 \times 10^9 \text{N.m}^2.\text{C}^{-2} \times -1.0 \times 10^{-14} \text{C}}{0.06 \text{m}} = -1.5 \text{mV}.$$

d. The potential at point P will be the sum of the potentials due to the two charges, which is

$$V_P = 2.2 \text{mV} + -1.5 \text{mV} = 0.7 \text{mV}$$

e. To find the potential difference between points P and Q we first need to find the potential at Q:

$$V_Q = \frac{kq_A}{r_A} + \frac{kq_B}{r_B} = \frac{8.99 \times 10^9 \text{N.m}^2.\text{C}^{-2} \times 1.5 \times 10^{-14} \text{C}}{0.095 \text{m}} + \frac{8.99 \times 10^9 \text{N.m}^2.\text{C}^{-2} \times -1.0 \times 10^{-14} \text{C}}{0.095 \text{m}} = 0.5 \text{mV}$$

The potential difference between P and Q is therefore $V_P - V_Q = 0.7 \text{mV} - 0.5 \text{mV} = 0.2 \text{mV}$.

