CHAPTER 19: ELECTRIC POTENTIAL AND ELECTRIC FIELD

19.1 ELECTRIC POTENTIAL ENERGY: POTENTIAL DIFFERENCE

6. ***Integrated Concepts*** *(a) What is the average power output of a heart defibrillator that dissipates 400 J of energy in 10.0 ms? (b) Considering the high-power output, why doesn't the defibrillator produce serious burns?*

Solution (a) The power is the work divided by the time, so the average power is:

$$P = \frac{W}{t} = \frac{400\ \text{J}}{10.0\times 10^{-3}\ \text{s}} = \underline{4.00\times 10^{4}\ \text{W}}.$$

(b) A defibrillator does not cause serious burns because the skin conducts electricity well at high voltages, like those used in defibrillators. The gel used aids in the transfer of energy to the body, and the skin doesn't absorb the energy, but rather, lets it pass through to the heart.

19.2 ELECTRIC POTENTIAL IN A UNIFORM ELECTRIC FIELD

17. *(a) Will the electric field strength between two parallel conducting plates exceed the breakdown strength for air (*$3.0\times 10^{6}\ \text{V/m}$*) if the plates are separated by 2.00 mm and a potential difference of* $5.0\times 10^{3}\ \text{V}$ *is applied? (b) How close together can the plates be with this applied voltage?*

Solution (a) Using the equation $E = \dfrac{V_{\text{AB}}}{d}$, we can determine the electric field strength produced between two parallel plates since we know their separation distance and the potential difference across the plates:

$$E = \frac{V_{\text{AB}}}{d} = \frac{5.0\times10^{3}\ \text{V}}{2.00\times10^{-3}\ \text{m}} = \underline{2.5\times10^{6}\ \text{V/m}} < 3\times10^{6}\,\text{V/m}.$$

No, the field strength is smaller than the breakdown strength for air.

(b) Using the equation $E = \frac{V_{\text{AB}}}{d}$, we can now solve for the separation distance, given the potential difference and the maximum electric field strength:

$$d = \frac{V_{\text{AB}}}{E} = \frac{5.0\times10^{3}\ \text{V}}{3.0\times10^{6}\ \text{V/m}} = 1.67\ \times10^{-3}\ \text{m} = \underline{1.7\,\text{mm}}.$$

So, the plates must not be closer than 1.7 mm to avoid exceeding the breakdown strength of air.

23. *An electron is to be accelerated in a uniform electric field having a strength of* $2.00\times10^{6}\ \text{V/m}$. *(a) What energy in keV is given to the electron if it is accelerated through 0.400 m? (b) Over what distance would it have to be accelerated to increase its energy by 50.0 GeV?*

Solution

(a) Using the equation $\Delta\text{KE} = q\Delta V$, we can get an expression for the change in energy terms of the potential difference and its charge. Also, we know from the equation $E = \frac{V_{\text{AB}}}{d}$ that we can express the potential difference in the terms of the electric field strength and the distance traveled, so that:

$$\begin{aligned}\Delta\text{KE} &= qV_{\text{AB}} = qEd \\ &= (1.60\times10^{-19}\ \text{C})(2.00\times10^{6}\ \text{V/m})(0.400\,\text{m})\left(\frac{1\,\text{eV}}{1.60\times10^{-19}\ \text{J}}\right)\left(\frac{1\,\text{keV}}{1000\,\text{eV}}\right) \\ &= \underline{800\,\text{keV}}\end{aligned}$$

In other words, the electron would gain 800 keV of energy if accelerated over a distance of 0.400 m.

(b) Using the same expression in part (a), we can now solve for the distance traveled:

$$d = \frac{\Delta \text{KE}}{qE} = \frac{(50.0\times10^{9}\ \text{eV})}{(1.60\times10^{-19}\ \text{C})(2.00\times10^{6}\ \text{v/m})}\left(\frac{1.60\times10^{-19}\ \text{J}}{1\,\text{eV}}\right)$$
$$= 2.50\times10^{4}\ \text{m} = \underline{25.0\ \text{km}}$$

So, the electron must be accelerated over a distance of 25.0 km to gain 50.0 GeV of energy.

19.3 ELECTRIC POTENTIAL DUE TO A POINT CHARGE

29. *If the potential due to a point charge is* $5.00\times10^{2}\ \text{V}$ *at a distance of 15.0 m, what are the sign and magnitude of the charge?*

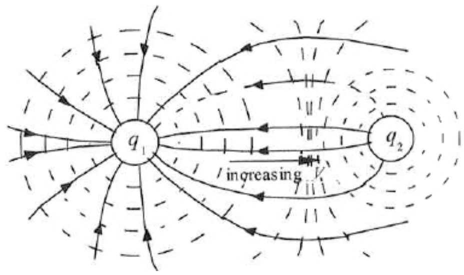
Solution Given the equation $V = \frac{kQ}{r}$, we can determine the charge given the potential and the separation distance: $Q = \frac{rV}{k} = \frac{(15.0\ \text{m})(500\ \text{V})}{9.00\times10^{9}\ \text{N}\cdot\text{m}^2/\text{C}^2} = \underline{8.33\times10^{-7}\ \text{C}}$

The charge is positive because the potential is positive.

19.4 EQUIPOTENTIAL LINES

38. *Figure 19.28 shows the electric field lines near two charges* q_1 *and* q_2*, the first having a magnitude four times that of the second. Sketch the equipotential lines for these two charges, and indicate the direction of increasing potential.*

Solution To draw the equipotential lines, remember that they are always perpendicular to electric fields lines. The potential is greatest (most positive) near the positive charge, q_2, and least (most negative) near the negative charge, q_1. In other words, the potential increases as you move out from the charge q_1, and it increases as you move towards the charge q_2.



19.5 CAPACITORS AND DIELETRICS

46. *What charge is stored in a* $180\ \mu\text{F}$ *capacitor when 120 V is applied to it?*

Solution Using the equation $Q = CV$, we can determine the charge on a capacitor, since we are given its capacitance and its voltage:

$$Q = CV = (1.80\times10^{-4}\ \text{F})(120\ \text{V}) = 2.16\times10^{-2} = \underline{21.6\ \text{mC}}$$

50. *What voltage must be applied to an 8.00 nF capacitor to store 0.160 mC of charge?*

Solution Using the equation $Q = CV$, we can determine the voltage that must be applied to a capacitor, given the charge it stores and its capacitance:

$$V = \frac{Q}{C} = \frac{1.60\times10^{-4}\ \text{C}}{8.00\times10^{-9}\ \text{F}} = 2.00\times10^{4}\ \text{V} = \underline{20.0\ \text{kV}}$$

19.6 CAPACITORS IN SERIES AND PARALLEL

59. *What total capacitances can you make by connecting a* $5.00\ \mu\text{F}$ *and an* $8.00\ \mu\text{F}$ *capacitor together?*

Solution There are two ways in which you can connect two capacitors: in parallel and in series. When connected in series, the total capacitance is given by the equation

$$\frac{1}{C_s}=\frac{1}{C_1}+\frac{1}{C_2}\Rightarrow C_s=\frac{C_1C_2}{C_1+C_2}=\frac{(5.00\ \mu\text{F})(8.00\ \mu\text{F})}{5.00\ \mu\text{F}+8.00\ \mu\text{F}}=\underline{3.08\ \mu\text{F (series)}}$$

and when connected in parallel, the total capacitance is given by the equation

$$C_p=C_1+C_2=5.00\ \mu\text{F}+8.00\ \mu\text{F}=\underline{13.0\ \mu\text{F(parallel)}}$$

19.7 ENERGY STORED IN CAPACITORS

66. *Suppose you have a 9.00 V battery, a* $2.00\ \mu\text{F}$ *capacitor, and a* $7.40\ \mu\text{F}$ *capacitor. (a) Find the charge and energy stored if the capacitors are connected to the battery in series. (b) Do the same for a parallel connection.*

Solution (a) If the capacitors are connected in series, their total capacitance is:

$$\frac{1}{C_s}=\frac{1}{C_1}+\frac{1}{C_2}\Rightarrow C_s=\frac{C_1C_2}{C_1+C_2}=\frac{(2.00\ \mu\text{F})(7.40\ \mu\text{F})}{9.40\ \mu\text{F}}=1.575\ \mu\text{F}.$$

Then, since we know the capacitance and the voltage of the battery, we can use the equation $Q=CV$ to determine the charge stored in the capacitors:

$$Q=C_sV=(1.574\times10^{-6}\ \text{F})(9.00\ \text{V})=\underline{1.42\times10^{-5}\ \text{C}}$$

Then determine the energy stored in the capacitors, using the equation

$$E_{\text{cap}}=\frac{C_sV^2}{2}=\frac{(1.574\times10^{-6}\ \text{F})(9.00\ \text{V})^2}{2}=\underline{6.38\times10^{-5}\ \text{J}}.$$

Note: by using the form of this equation $E=\dfrac{CV^2}{2}$ involving capacitance and voltage, we can avoid using one of the parameters that we calculated, minimizing our change of propagating an error.

(b) If the capacitors are connected in parallel, their total capacitance is given by the equation $C_{\mathrm{p}} = C_1 + C_2 = 2.00\ \mu\mathrm{F} + 7.40\ \mu\mathrm{F} = 9.40\ \mu\mathrm{F}$

Again, we use the equation $Q = CV$ to determine the charge stored in the capacitors: $Q = C_{\mathrm{p}}V = (9.40\times10^{-6}\ \mathrm{F})(9.00\ \mathrm{V}) = \underline{8.46\times10^{-5}\ \mathrm{C}}$

And finally, using the following equation again, we can determine the energy stored in the capacitors:

$$E_{\mathrm{cap}} = \frac{C_{\mathrm{p}}V^2}{2} = \frac{(9.40\times10^{-6}\ \mathrm{F})(9.00\ \mathrm{V})^2}{2} = \underline{3.81\times10^{-4}\ \mathrm{J}}$$