7.10: Electric Potential (Answer)

Check Your Understanding

7.1. $K = \frac{1}{2}mv^2, v = \sqrt{2\frac{K}{m}} = \sqrt{2\frac{4.5 \times 10^{-7} J}{4.00 \times 10^{-9} kg}} = 15 m/s$

7.2. It has kinetic energy of $4.5 \times 10^{-7} J$ at point r_2 and potential energy of $9.0 \times 10^{-7} J$J, which means that as **Q** approaches infinity, its kinetic energy totals three times the kinetic energy at r_2, since all of the potential energy gets converted to kinetic.

7.3. positive, negative, and these quantities are the same as the work you would need to do to bring the charges in from infinity

7.4. $\Delta U = q\Delta V = (100C)(1.5V) = 150J$

7.5. –2.00 C, $n_e = 1.25 \times 10^{19} electronsne$

7.6. It would be going in the opposite direction, with no effect on the calculations as presented.

7.7. Given a fixed maximum electric field strength, the potential at which a strike occurs increases with increasing height above the ground. Hence, each electron will carry more energy. Determining if there is an effect on the total number of electrons lies in the future.

7.8. $V = k\frac{q}{r} = (8.99 \times 10^9 N \cdot m^2/C^2)(\frac{-3.00 \times 10^{-9} C}{5.00 \times 10^{-3} m}) = -5390V$; recall that the electric field inside a conductor is zero. Hence, any path from a point on the surface to any point in the interior will have an integrand of zero when calculating the change in potential, and thus the potential in the interior of the sphere is identical to that on the surface.

7.9. The **x**-axis the potential is zero, due to the equal and opposite charges the same distance from it. On the **z**-axis, we may superimpose the two potentials; we will find that for $z >> d$, again the potential goes to zero due to cancellation.

7.10. It will be zero, as at all points on the axis, there are equal and opposite charges equidistant from the point of interest. Note that this distribution will, in fact, have a dipole moment.

7.11. Any, but cylindrical is closest to the symmetry of a dipole.

7.12. infinite cylinders of constant radius, with the line charge as the axis

Conceptual Questions

1. No. We can only define potential energies for conservative fields.

3. No, though certain orderings may be simpler to compute.

5. The electric field strength is zero because electric potential differences are directly related to the field strength. If the potential difference is zero, then the field strength must also be zero.

7. Potential difference is more descriptive because it indicates that it is the difference between the electric potential of two points.

9. They are very similar, but potential difference is a feature of the system; when a charge is introduced to the system, it will have a potential energy which may be calculated by multiplying the magnitude of the charge by the potential difference.

11. An electron-volt is a volt multiplied by the charge of an electron. Volts measure potential difference, electron-volts are a unit of energy.

13. The second has 1/4 the dipole moment of the first.

15. The region outside of the sphere will have a potential indistinguishable from a point charge; the interior of the sphere will have a different potential.

17. No. It will be constant, but not necessarily zero.

19. no

21. No; it might not be at electrostatic equilibrium.

23. Yes. It depends on where the zero reference for potential is. (Though this might be unusual.)

25. So that lightning striking them goes into the ground instead of the television equipment.

27. They both make use of static electricity to stick small particles to another surface. However, the precipitator has to charge a wide variety of particles, and is not designed to make sure they land in a particular place.

Problems

29. a. $U = 3.4 J$;

b. $\frac{1}{2}mv^2 = kQ_1Q_2(\frac{1}{r_i} - \frac{1}{r_f}) \to v = 750 m/s$

31. $U = 4.36 \times 10^{-18} J$

33. $\frac{1}{2}m_e v_e^2 = qV$, $\frac{1}{2}m_H v_H^2 = qV$, so that $\frac{m_e v_e^2}{m_H v_H^2} = 1$ or $\frac{v_e}{v_H} = 42.8$.

35. $1V = 1J/C; 1J = 1N \cdot m \to 1V/m = 1N/C$

37. a. $V_{AB} = 3.00 kV$;

b. $V_{AB} = 7.50 kV$

39. a. $V_{AB} = Ed \to E = 5.63 kV/m$;

b. $V_{AB} = 563 V$

41. a. $\Delta K = q\Delta V$ and $V_{AB} = Ed$,so that $\Delta K = 800 keV$;

b. $d = 25.0 km$

43. One possibility is to stay at constant radius and go along the arc from P_1 to P_2, which will have zero potential due to the path being perpendicular to the electric field. Then integrate from a to b: $V_{ab} = \alpha ln(\frac{b}{a})$

45. $V = 144 V$

47. $V = \frac{kQ}{r} \to Q = 8.33 \times 10^{-7} C$; The charge is positive because the potential is positive.

49. a. $V = 45.0 MV$;

b. $V = \frac{kQ}{r} \to r = 45.0 m$;

c. $\Delta U = 132 MeV$

51. $V = kQ/r$; a. Relative to origin, find the potential at each point and then calculate the difference. $\Delta V = 135 \times 10^3 V$;

b. To double the potential difference, move the point from 20 cm to infinity; the potential at 20 cm is halfway between zero and that at 10 cm.

53. a. $V_{P1} = 7.4 \times 10^5 V$ and $V_{P2} = 6.9 \times 10^3 V$;

b. $V_{P1} = 6.9 \times 10^5 V$ and $V_{P2} = 6.9 \times 10^3 V$

55. The problem is describing a uniform field, so $E = 200 V/m$ in the **–z**-direction.

57. Apply $vecE = -\vec{\nabla} V$ with $\vec{\nabla} = \hat{r}\frac{\partial}{\partial r} + \hat{\varphi}\frac{1}{r}\frac{\partial}{\partial \varphi} + \hat{z}\frac{\partial}{\partial z}$ to the potential calculated earlier, $V = -2k\lambda lns : \vec{E} = 2k\lambda\frac{1}{r}\hat{r}$ as expected.

59. a. increases; the constant (negative) electric field has this effect, the reference point only matters for magnitude; b. they are planes parallel to the sheet; c. 0.006 m

61. a. from the previous chapter, the electric field has magnitude $\frac{\sigma}{\varepsilon_0}$ in the region between the plates and zero outside; defining the negatively charged plate to be at the origin and zero potential, with the positively charged plate located at **+5mm** in the **z**-direction, V=1.7×104VV=1.7×104Vso the potential is 0 for $z<0, 1.7\times 10^4 V(\frac{z}{5mm})$ for $0\leq z\leq 5mm, 1.7\times 10^4 V$ for $z>5mm$;

b. $qV=\frac{1}{2}mv^2\rightarrow v=7.7\times 10^7 m/s$

63. $V=85V$

65. In the region $a\leq r\leq b, \vec{E}=\frac{kQ}{r^2}\hat{r}$, and **E** is zero elsewhere; hence, the potential difference is $V=kQ(\frac{1}{a}-\frac{1}{b})$.

67. From previous results $V_P-V_R=-2k\lambda ln\frac{s_P}{s_R}$., note that b is a very convenient location to define the zero level of potential: $\Delta V=-2k\frac{Q}{L}ln\frac{a}{b}$.

69. a. $F=5.58\times 10^{-11} N/C$;The electric field is towards the surface of Earth.

b. The coulomb force is much stronger than gravity.

71. We know from the Gauss's law chapter that the electric field for an infinite line charge is $\vec{E}_P=2k\lambda\frac{1}{s}\hat{s}$, and from earlier in this chapter that the potential of a wire-cylinder system of this sort is $V_P=-2k\lambda ln\frac{s_P}{R}$ by integration. We are not given λ, but we are given a fixed V_0; thus, we know that $V_0=-2k\lambda ln\frac{a}{R}$ and hence $\lambda=-\frac{V_0}{2kln(\frac{a}{R})}$. We may substitute this back in to find a. $\vec{E}_P=-\frac{V_0}{ln(\frac{a}{R})}\frac{1}{s}\hat{s}$;

b. $V_P=V_0\frac{ln(\frac{s_P}{R})}{ln(\frac{a}{R})}$;

c. $4.74\times 10^4 N/C$

73. a. $U_1=7.68\times 10^{-18}J, U_2=5.76\times 10^{-18}J$;

b. $U_1+U_2=-1.34\times 10^{-17}J$

75. a. \(\displaystyle U=2.30×10^{−16}J;

b. $\overline{K}=\frac{3}{2}kT\rightarrow T=1.11\times 10^7$

77. a. $1.9\times 10^6 m/s$;

b. $4.2\times 10^6 m/s$;

c. $5.9\times 10^6 m/s$;

d. $7.3\times 10^6 m/s$;

e. $8.4\times 10^6 m/s$

79. a. $E=2.5\times 10^6 V/m<3\times 10^6 V/m$ No, the field strength is smaller than the breakdown strength for air.

b. $d=1.7mm$

81. $K_f=qV_{AB}=qEd\rightarrow E=8.00\times 10^5 V/m$

83. a. Energy=$2.00\times 10^9 J$;

b. $Q=m(c\Delta T+L_{\nabla})\ m=766kg$;

c. The expansion of the steam upon boiling can literally blow the tree apart.

85. a. $V=\frac{kQ}{r}\rightarrow r=1.80km$;

b. A 1-C charge is a very large amount of charge; a sphere of 1.80 km is impractical.

87. The alpha particle approaches the gold nucleus until its original energy is converted to potential energy. $5.00MeV = 8.00 \times 10^{-13}J$, so $E_0 = \frac{qkQ}{r} \rightarrow r = 4.54 \times 10^{-14}m$

(Size of gold nucleus is about $7 \times 10^{-15}m$).

Additional Problems

89. $E_{tot} = 4.67 \times 10^7 J$ $E_{tot} = qV \rightarrow q = \frac{E_{tot}}{V} = 3.89 \times 10^6 C$

91. $V_P = k\frac{q_{tot}}{\sqrt{z^2+R^2}} \rightarrow q_{tot} = -3.5 \times 10^{-11} C$

93. $V_P = -2.2GV$

95. Recall from the previous chapter that the electric field $E_P = \frac{\sigma_0}{2\varepsilon_0}$ is uniform throughout space, and that for uniform fields we have $E = -\frac{\Delta V}{\Delta z}$ for the relation. Thus, we get $\frac{\sigma}{2\varepsilon_0} = \frac{\Delta V}{\Delta z} \rightarrow \Delta z = 0.22m$ for the distance between 25-V equipotentials.

97. a. Take the result from Example 7.13, divide both the numerator and the denominator by x, take the limit of that, and then apply a Taylor expansion to the resulting log to get: $V_P \approx k\lambda\frac{L}{x}$;

b. which is the result we expect, because at great distances, this should look like a point charge of $q = \lambda L$

99. a. $V = 9.0 \times 10^3 V$;

b. $-9.0 \times 10^3 V(\frac{1.25cm}{2.0cm}) = -5.7 \times 10^3 V$

101. a. $E = \frac{KQ}{r^2} \rightarrow Q = -6.76 \times 10^5 C$;

b. $F = ma = qE \rightarrow a = \frac{qE}{m} = 2.63 \times 10^{13} m/s^2 (upwards)$;

c. $F = -mg = qE \rightarrow m = \frac{-qE}{g} = 2.45 \times 10^{-18} kg$

103. If the electric field is zero ¼ from the way of q_1 and q_2, then we know from $E = k\frac{Q}{r^2}$ that $|E_1| = |E_2| \rightarrow \frac{Kq_1}{x^2} = \frac{Kq^2}{(3x)^2}$ so that $\frac{q_2}{q_1} = \frac{(3x)^2}{x^2} = 9$; the charge q_2 is 9 times larger than q_1.

105. a. The field is in the direction of the electron's initial velocity.

b. $v^2 = v_0^2 + 2ax \rightarrow x = -\frac{v_0^2}{2a}(v=0)$. Also, $F = ma = qE \rightarrow a = \frac{qE}{m}$,$x = 3.56 \times 10^{-4} m$;

c. $v_2 = v_0 + at \rightarrow t = -\frac{v_0 m}{qE}(v=0), \therefore t = 1.42 \times 10^{-10} s$;

d. $v = -(\frac{2qEx}{m})^{1/2} - 5.00 \times 10^6 m/s$ (opposite its initial velocity)

Challenge Problems

107. Answers will vary. This appears to be proprietary information, and ridiculously difficult to find. Speeds will be 20 m/s or less, and there are claims of 10^{-7} grams for the mass of a drop.

109. Apply $\vec{E} = -\vec{\nabla} V$ with $\vec{\nabla} = \hat{r}\frac{\partial}{\partial r} + \hat{\theta}\frac{1}{r}\frac{\partial}{\partial\theta} + \hat{\varphi}\frac{1}{r sin\theta}\frac{\partial}{\partial\varphi}$ to the potential calculated earlier, $V_P = k\frac{\vec{p}\cdot\hat{r}}{r^2}$ with $\vec{p} = q\vec{d}$, and assume that the axis of the dipole is aligned with the **z**-axis of the coordinate system. Thus, the potential is

$$V_P = k\frac{q\vec{d}\cdot\hat{r}}{r^2} = k\frac{qdcos\theta}{r^2}\ .$$

$$\vec{E} = 2kqd(\frac{cos\theta}{r^3})\hat{r} + kqd(\frac{sin\theta}{r^3})\hat{\theta}$$
