ANSWERS - AP Physics Multiple Choice Practice – Electrostatics

	Solution	Answer
1.	By definition	B
2.	Since charge is free to move around on/in a conductor, excess charges will repel each other to the outer surface	E
3.	When the battery is disconnected, Q remains constant. Since C decreases when d increases and $Q = CV$, V will increase	E
4.	$E = kQ/r^2$	D
5.	$V = kQ/r$	C
6.	$W = qV$	C
7.	Since both charges are positive, the electric field vectors point in opposite directions at points between the two. At point A, the magnitudes of the electric field vectors are equal and therefore cancel out, making $E = 0$ at point A	A
8.	$V = \Sigma kQ/r$ and since both charges are positive, the largest potential is at the closest point to the two charges (it is more mathematically complex than that, but this reasoning works for the choices given)	A
9.	$C = \varepsilon_0 A/d$; if $A \times 2$, $C \times 2$ and if $d \times 2$, $C \div 2$ so the net effect is C is unchanged	C
10.	The net charge on the two spheres is $+Q$ so when they touch and separate, the charge on each sphere (divided equally) is $\frac{1}{2} Q$. $F \propto Q_1 Q_2$ so before contact $F \propto (2Q)(Q) = 2Q^2$ and after contact $F \propto (\frac{1}{2} Q)(\frac{1}{2} Q) = \frac{1}{4} Q^2$ or 1/8 of the original force	E
11.	$C = \varepsilon_0 A/d$ and changing Q or V has no effect on the capacitance	C
12.	By definition	A
13.	$E = F/q$	E
14.	$\Delta v = at$ where $a = F/m$. So we have $\Delta v = 10^{-14} \times 10^{-9} \div 10^{-30} = 10^{(-14 + -9 - (-30))}$	D
15.	Inside the metal sphere $E = 0$. Once outside the sphere E decreases as you move away so the strongest field will be the closest point to the *outside* of the sphere	C
16.	Newton's third law	C
17.	Where E is zero must be closer to the smaller charge to make up for the weaker field. The vectors point in opposite directions when outside the two opposite charges. These two criteria eliminate 4 of the choices.	A
18.	Charges flow when there is a difference in potential. Analyzing the other choices: A is wrong because the charge resides on the surface. For B, $E = 0$ in a charged conducting sphere. $E = kQ/r^2$ eliminates choice C. And for D, charge separation will occur, but the object will not acquire any charge.	E
19.	E is uniform between charged parallel plates therefore the force on a charge is also uniform between the plates	B
20.	$F_g = Gm_1 m_2/r^2$ and $F_E = kq_1 q_2/r^2$. The nuclear force does not have a similar relationship.	C
21.	$E \propto 1/r^2$ so if $r \times 2$, $E \div 4$	B
22.	While the charges may separate, the forces on the opposite charges are in opposite directions, canceling out	A

23. $V = kQ/r$ so the smaller sphere is at the lower potential (more negative = lower) Negative charge flows from low to high potential so the charge will flow from the smaller sphere to the larger. The flow of charge ceases when there is no difference in potential.　　E

24. $E = V/d$ so if $V \times 2$, $E \times 2$ and if $d \div 5$, $E \times 5$ so the net effect is $E \times 10$　　E

25. The electric field vectors from the two charges point down and to the left (away from the charges) so the resultant field points down and left　　C

26. The potential energy of a particle at a location is the potential at that location times the charge. In this case, the potential is $kQ/d + kQ/d = (2kQ/d)$　　D

27. If the battery remains connected, the potential remains constant. C decreases as the separation increases soothe charge $Q = CV$ will also decrease　　B

28. $U_C = \frac{1}{2} CV^2$　　E

29. In metals under electrostatic conditions, the electric field is zero everywhere inside.　　A

30. The electric field vector from the $+Q$ charge points down and from the $-Q$ charge points to the right so the resultant field points down and right　　D

31. The two vectors, each of magnitude $E = kQ/d^2$, point at right angles to each other so the resultant field is $\sqrt{2}E$　　D

32. Since the electron and the proton have equal charge, the forces on them are equal. Since they have different masses, the accelerations, speeds and displacements will not be equal.　　E

33. The electric field between charged parallel plates is uniform, which means the potential changes uniformly with distance. For a change of 8 V over 4 cm means the change of potential with position (and the electric field strength) is 2 V/cm, which gives the potential 1 cm away from the 2 V plate as 4 V　　D

34. $E = V/d$　　D

35. $W = \Delta K = QV$ (mass doesn't have an effect on the kinetic energy, just on the speed in this case)　　D

36. The field lines point away from Y and toward Z making Y positive and Z negative.　　D

37. $E = kQ/r^2$　　A

38. $C = \varepsilon_0 A/d$; $\varepsilon_0(2A)/(2d) = \varepsilon_0 A/d$　　C

39. Charges arrange themselves on conductors so there is no electric field inside, and no electric field component along the surface　　A

40. By symmetry $V_R = V_S$ so $\Delta V_{RS} = 0$ and $W = q\Delta V$　　D

41. The force on the upper charge is to the left and twice the magnitude of the force on the bottom charge, which is to the right. This makes the net force to the left and the torque on the rod to be counterclockwise.　　B

42. Compared to the $+Q$ charge at the center, the charge on the outer surface of the outer cylinder has twice the magnitude and is of opposite sign (so it is $-2Q$). There is also an equal and opposite charge induced on the inner surface of the outer cylinder making the total charge on the outer cylinder $-2Q + -Q$　　E

43. Since the capacitor is isolated, Q remains constant. Filling the place with oil (a dielectric) will increase the capacitance, causing the potential ($V = Q/C$) to decrease.　　B

44. $F_E \propto q_1 q_2 / r^2$; if q_1 and $q_2 \times 2$; $F \times 4$ and if $r \div 2$, $F \times 4$ making the net effect $F \times 4 \times 4$　　E

45. Since there is no component of the electric field along a conducting surface under electrostatic conditions, no work is done moving the charge around the surface, meaning no differences in potential   E

46. Regardless of velocity, the force on a charge in an electric field is parallel to the field ($\mathbf{F} = q\mathbf{E}$)   D

47. $W = Fd = qEd$ A

48. E points away from + charges and toward – charges. Use symmetry.   A

49. D and E are not symmetric so the field will not point at the midpoint of any side. The field in choice B points *at* the bottom charge.   C

50. $C_1/C_2 = (\varepsilon_0 A_1/d_1)/(\varepsilon_0 A_2/d_2) = A_1 d_2/A_2 d_1 = s^2(2d)/[(2s)^2 d] = \frac{1}{2}$ B

51. Since the capacitor is isolated, Q remains constant. Filling the place with oil (a dielectric) will increase the capacitance, causing the potential ($V = Q/C$) to decrease.   B

52. $V = kQ/r$ so the smaller sphere (Y) is at the higher potential. Negative charge flows from low to high potential so the charge will flow from X to Y.   A

53. Once inside a uniform sphere of charge, the electric field is zero. Since $E = 0$ the potential does not change within the sphere (meaning it is the same value as the surface)   A

54. Outside a uniform sphere of charge, it behaves as a point charge.   D

55. $\mathbf{E} = \mathbf{F}/q$. The vector nature of the equation allows one to find the direction of F and the equation itself allows one to find the ratio F/q, but not q specifically   C

56. Outside a uniform sphere of charge, it behaves as a point charge. $E = kQ/r^2$ E

57. By symmetry, the force on an electron at the center from the top half will be straight down and the force from the bottom half will also be straight down   B

58. E is a vector so all the individual E field vectors from the four charges will cancel. V is a scalar and will add since they are all positive charges.   D

59. The points where $V = 0$ must lie closer to the smaller charge. Unlike electric field vectors which also require the individual vectors point in opposite directions, there are a locus of points (in this case in a ring surrounding the +Q charge) where $V = 0$ as the two charges are opposite in sign and V is a scalar. So the other point on the x axis is between the two charges, but closer to the +Q charge. This must be a value between 1.5 D and 2 D   D

60. When inside a uniform shell of charge, there is an electric field due to the shell. When outside a uniform shell of charge, the electric field is as if the shell was a point charge.   A

61. The potential difference between the plates is 4 V and the right side is the positive plate. We need the batteries pointing in the same direction with the positive terminal on the right.   D

62. The electron experiences a force toward the positive plate of magnitude $F = Eq$. $E = V/d$ and cannot be calculated without knowing d.   D

63. While spheres X and Y are in contact, electrons will repel away from the rod out of sphere X into sphere Y.   D

64. The capacitor with the largest capacitance will store the most charge. $C = \kappa\varepsilon_0 A/d$ where $\kappa_{glass} > \kappa_{air}$ and κ_{vacuum} E

65. $K = q\Delta V$. To find ΔV we use $Q = CV$ (V is ΔV in this case) which gives $K = e(Q/C)$ and if we use $C = \varepsilon_0 A/d$ we have $K = e(Qd/\varepsilon_0 A)$ A

66. While spheres 1 and 2 are in contact, electrons will repel away from the rod out of sphere 1 into sphere 2.   C

67. The force vectors from the two $+Q$ charges point down and to the left (away from the charges) so the resultant force points down and left   E

68. The two vectors, each of magnitude F, point at right angles to each other so the resultant field is $\sqrt{2}F$ D

69. Where E is zero must be closer to the smaller charge to make up for the weaker field. The vectors point in opposite directions when between the two like charges. These two criteria eliminate 4 of the choices   C

70. Since both charges are positive and V is a scalar equal to $\Sigma kQ/r$, the potential will never be zero in the vicinity of these two charges.   E

71. $W = q\Delta V$ C

72. The electric field (and hence, the electric force on a charge) is greatest where the potential changes most rapidly with position (the greatest gradient) since $E = V/d$. On this graph, this would be the point where the slope is the greatest   D

73. $F_E = F_C$ and $q_1 = q_2 = e$ so we have $ke^2/R^2 = mv^2/R$ and we multiply both sides by ½ R so the right side becomes $\frac{1}{2} mv^2$ (the kinetic energy). Choices C and E could have been eliminated because they are negative, and kinetic energy cannot be negative. Choices A & D are dimensionally incorrect (D has the units of a force, not energy, and A has the units of electric potential)   B

74. If F is constant and $F = ma$, the acceleration is also constant. Negative charges experience forces opposite in direction to electric field lines.   A

75. By symmetry, $E = 0$ at the midpoint and goes to infinity near each charge ($E = kQ/r^2$)   A

76. If no work is done by the field and there is a field present, the motion must be perpendicular to the field, along an equipotential line, making the force perpendicular to the displacement of the charge (a requirement for zero work). Along an equipotential line, $\Delta V = 0$ and $W = q\Delta V$.   D

77. Inside the sphere, $E = 0$ which means the potential does not change with position and is the same value as the surface, which is kQ/R. At point P, the potential is kQ/r. $W = q\Delta V = q(kQ/R - kQ/r)$ E

78. $E = V/d$ B

79. If the battery is disconnected, Q remains constant. If a dielectric is inserted between the plates, the capacitance increases and since $Q = CV$, the potential difference decreases.   A

80. Conductors under electrostatic conditions will arrange their changes so no electric field exists inside (other than those created by charges placed inside the empty cavity). Fields from external charges will not penetrate into conducting enclosures.   A

81. $U_C = \frac{1}{2} CV^2$ B

82. $W = K = q\Delta V$ and $K = \frac{1}{2} mv^2$ C

83. At point P, the field due to charge Q points up and to the right and the field due to charge $-4Q$ is larger in magnitude and points down and to the right. Due to the asymmetry, no components will cancel.   E

84. Where E is zero must be closer to the smaller charge to make up for the weaker field. The vectors point in opposite directions outside the two opposite charges. These two criteria eliminate 3 of the choices. For the magnitudes of the electric fields to be zero the ratios Q/r^2 must be equal giving (in units along the x axis) $Q/r^2 = 4Q/(r + 4 \text{ units})^2$ giving $r = 4$ units   A

85. Since $E = \Delta V/d$, E represents the slope of the line on the graph which could be choice C or D. since $V \propto 1/r$ the slope is proportional to $\Delta V/r = (1/r)/r = 1/r^2$ which is choice C   C

86. By symmetry, all the vectors cancel   A

87. $W = q\Delta V = +Q(V_{center} - V_{\infty}) = +QV_{center}$ where $V_{center} = \Sigma V = \Sigma kQ/r = 6kQ/R$ D

88. E points from high potential to low potential, perpendicular to equipotential lines (the direction of the force on a positive charge)   A

89. E is greatest in magnitude where V changes most rapidly with position (the largest gradient) which is where the lines are closest together.   B

90. $\Delta V_{CE} = V_E - V_C = 10$ V. The amount of work, $W = q\Delta V = 1$ μC $\times$ 10 V = 10 μC. Since the external force must push against the negative charge to keep it from accelerating and bring it to rest at point E, the work done by the external force must be negative.   B

91. $C = K\varepsilon_0 A/d$. Only changes in the geometry of the capacitor will change the capacitance, not changes to the battery or resistor.   D

92. For charge to be distributed *throughout* a material, it must be non-conducting   E

93. Advanced question (not exactly in the B curriculum, but interesting). Like gravity inside a uniform sphere of mass, the field is directly proportional to r when inside the sphere (and proportional to $1/r^2$ when outside)   D

94. In I, charge separation occurs (negative charges repel to the leaves). The whole process describes charging by induction, where the electrons leave the electroscope to ground (the finger) and once contact with ground is broken, the electroscope is left with a positive charge (III)   D

95. Charged objects attract object with an opposite charge, but also neutral objects by separation of charges.   E

96. If E = 0, the field vectors point in opposite directions, making q positive. In magnitude we can find q by $(+4$ μC$)/(0.2$ m$)^2 = q/(0.3$ m$)^2$ A

97. If V = 0 and $V = \Sigma kQ/r$ then q must be negative and $(+4$ μC$)/(0.2$ m$) = q/(0.3$ m$)$ D

98. by definition of conductors under electrostatic conditions   D

99. Since the electrostatic force pushes the charge to the right, with the field line, it is a positive charge. $\Sigma F_y = 0$ gives $T \cos\theta = mg$ and $\Sigma F_x = 0$ gives $T \sin\theta = F_E = qE$. Divide the two expressions to eliminate T.   B

100. V is constant inside and on the surface of a charged conductor and is proportional to 1/r outside a charged conducting sphere.   A

101. If the battery is disconnected, the charge on the plates remains constant. If the separation increases, C decreases $(C = \varepsilon_0 A/d)$. Since Q = CV, V must increase.   E

102. $W = q\Delta V$ (motion along an equipotential line requires no work so only ΔV matters, not the path)   E

103. $F \propto 1/r^2$ A

104. In a later topic, you will learn magnetic field are created by *moving* charges. Electric field lines point toward negative charges.   C

105. Charges flow when there is a difference in potential.   E

106. The distance between the +q charge and each charge is d. The force on the +q charge from each charge is in the same direction, making the net force $kq^2/d^2 + k(3q^2)/d^2$ B

107. $W = Fd = qEd$ E

108. E is zero inside a charged conductor and is proportional to $1/r^2$ outside a charged conducting sphere.   D

109. Electric field lines point in the direction of the force on a positive charge (away from positive charges and toward negative charges) — A

110. The rod will attract the same charge from each sphere to the side closer to the rod. — B

111. Since the plates are insulated, the charge remains constant. If the distance is increased, the capacitance will decrease ($C \propto A/d$) and since $Q = CV$, the potential difference must increase by the same factor that the distance increases. This means $E = V/d$ remains the same. — C

112. $F \propto 1/r^2$; if $r \times 4$, $F \div 16$ — E

113. If the leaves are positive, further separation means they are becoming more positive, which implies electrons are leaving the leaves, attracted to the top plate of the electroscope. This will occur if the object is positively charged. — A

114. Vector addition. Since all the charges are positive, the forces due to charges 2 and 4 point in opposite directions, making the magnitude of the net force along the x axis 2 N. Combine this with a net force along the y axis of 6 N using the Pythagorean theorem — A

115. $Q = CV$ and $V = Ed$ and using $C = \varepsilon_0 A/d$ gives $E = Q/\varepsilon_0 A$ — A

116. The greatest potential energy would be where the charge is at the point with the greatest potential since $U_E = qV$ (at a point). This is closest to the positive plate. — E

117. $W = Fd = qEd$ — E

118. Charged objects attract neutral objects by separating the charges within the neutral object. — D

119. An alpha particle has twice the charge and four times the mass of a proton. Twice the charge means twice the electric force. This, combined with four times the mass gives half the acceleration. — E

120. $Q = CV$ and $C = \varepsilon_0 A/d$ which gives $V = Qd/\varepsilon_0 A$ — C

121. At a point midway between the charges $E = kq/(d/2)^2$ from each charge. Since they are opposite charges, the field vectors between the charges point in the same direction. — E

122. For the E field vectors to point in opposite directions, point P must lie outside the two charges. For the magnitudes of E due to each charge to cancel, Point P must be closer to the smaller charge. — C

123. The extra kinetic energy gained by the electron is $W = K = q\Delta V$, where ΔV is the potential difference between the midway line and the upper plate, which is 200 V. This makes the additional kinetic energy 200 eV. Kinetic energy is a scalar so the total KE of the electron is now 300 eV + 200 eV — C

124. If a positive rod attracts ball A, it is either negative or neutral. For ball B to also attract ball A means ball B can be charged positive or negative (if ball A is neutral) or neutral (if ball A is positive) — E

125. $F = Eq$ and $E = V/d$ giving $d = qV/F$ — D

126. Since the battery is removed, the charge remains constant. If the distance is decreased, the capacitance will increase ($C \propto A/d$) and since $Q = CV$, the potential difference must decrease by the same factor that the distance decreases. — B

127. Since the spherical shell is conducting, a charge of $-Q$ is induced on the inner surface. This gives a charge of $+Q$ on the outer surface since the spherical shell is neutral. As $E = 0$ inside the conducting shell, the potential inside is constant and the same as on the surface, which is kQ/r — C

128. $F \propto 1/r^2$; if $r \times 0.4$ then $F \div 0.4^2$ — B

129. The oil drop experiment not only found the charge of the electron, but also the fact that charge was quantized.　　　　E

130. The force vectors from each charge and their relative magnitude are drawn below　　　　B
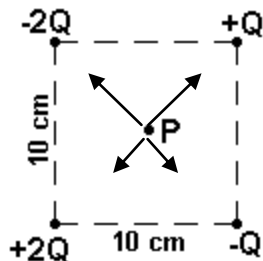
131. Using $F = ma = qE$ and $E = V/d$ gives $a = qV/md$　　　　E

132. Since the battery is disconnected, Q remains constant. $U_C = Q^2/2C$ so $U_{new}/U_{old} = C_{old}/C_{new} = (\varepsilon_0 A/d)/(\kappa\varepsilon_0 A/d) = 1/\kappa$　　　　B

133. Since the spherical shell is conducting, a charge of $-Q$ is induced on the inner surface. This gives a charge of $+Q$ on the outer surface since the spherical shell is neutral and the field outside the shell is as if the shell was a point charge.　　　　B

134. $U_E = kq_1q_2/r$　　　　A

135. The process described is charging by induction which gives the electroscope in this case a net negative charge. Bringing a negative charge near the top of the electroscope will cause electrons to repel to the leaves. Since the leaves are already negative, this will cause them to separate further.　　　　B

136. The charge density is Q/area which is $Q/4\pi r^2$ so for the inner surface it is $Q_{inner}/4\pi a^2$ and for the outer surface it is $Q_{outer}/16\pi a^2$. For these to be equal Q_{outer} must be $4Q_{inner}$. Because of the $+Q$ charge inside, there is a charge of $-Q$ induced on the inner surface, which means the outer surface must have charge $-4Q$. Thus the *total* charge on the shell is $-5Q$　　　　A

137. The force on a positive charge is in the direction of the electric field at that location.　　　　C

138. Conductors under electrostatic conditions will arrange their changes so no electric field exists inside (other than those created by charges placed inside the empty cavity). Fields from external sources will not penetrate into conducting enclosures.　　　　D

139. Once inside a uniform sphere of charge, the electric field is zero. Since $E = 0$ the potential does not change within the sphere (meaning it is the same value as the surface). $V \propto 1/r$ outside the sphere.　　　　E

140. Negative potential energy means the system is bound. This means energy input is required to break the system apart.　　　　A

141. $F \propto 1/r^2$　　　　A

142. Newton's third law requires the forces be equal and opposite. This eliminates choices A, B and C. Since they both positive, the force is repulsive.　　　　D

143. q_2/q_1 = lines on q_2/lines on q_1 and since the lines point toward q_2 and away from q_1 they are oppositely charged, making the ratio negative.　　　　B

144. The points where $V = 0$ must lie closer to the smaller charge. Unlike electric field vectors which also require the individual vectors point in opposite directions, there are a locus of points (in this case in a ring surrounding the $-Q$ charge) where $V = 0$ as the two charges are opposite in sign and V is a scalar.　　　　E

145. For E to be zero, the electric field vectors from each charge must point in opposite directions and must therefore occur at a point outside the charges. For the electric field vectors from each charge to be equal in magnitude so they can cancel, it must also occur at a point closer to the smaller charge to make up for the weaker field.   B

146. Since the battery remains connected, V remains constant. C decreases as d increases ($C \propto 1/d$) and $U_C = \frac{1}{2} CV^2$ D

147. Only electrons are transferred in static charging processes.   C

148. Any charge will experience a net force of zero where the electric field is zero. This must be where the fields from each charge point in opposite directions and also closer to the smaller charge, which is to the left of the +Q charge (the answer will be to the left of –1 m). Let the distances to the +Q and the –2Q charge be x and (X + 2), respectively. This gives $E_1 = E_2$ and $kQ/x^2 = k(2Q)/(x + 2)^2$. Solve for x and add the extra 1 m to the origin.   A

149. Since the battery is removed, the charge remains constant. If the distance is increased, the capacitance will decrease ($C \propto A/d$) and since Q = CV, the potential difference must increase by the same factor that the distance increases and $U_C = \frac{1}{2} QV$ D

150. $U_E = \Sigma kq_1q_2/r$ where we are summing *each pair* of charges. Computing U_E gives a total potential energy that is negative. This means negative work must have been done by an outside agent to keep the charges from colliding into each other and stop them in their respective locations. The net field and the potential at the center is zero due to symmetry.   E

151. $F \propto q_1q_2/r^2$; the original force $F \propto 100Q^2/d^2$. The new charges are 15Q and 5Q making the new force $F \propto 75Q^2/(2d)^2 = 19Q^2/d^2$ A

152. Assuming C remains constant and $U_C = \frac{1}{2} CV^2$, for U_C to double V must increase by $\sqrt{2}$ C

153. When one sphere is touched, the charged divides equally ($\frac{1}{2}$ Q each). When this sphere is then touched to the second sphere, the net charge (3/2 Q) is divided equally ($\frac{3}{4}$ Q each). Since $F \propto q_1q_2$, the original force is proportional to Q^2 and the new force is then proportional to ($\frac{1}{2}$ Q)($\frac{3}{4}$ Q) = 3/8 Q^2 D

154. Q = CV   D

155. $W = K = q\Delta V$ so $\Delta V \propto v^2$ and for v to double, ΔV must increase by 4   B

156. Adding the force vectors shown (each 15 N) with x components that cancel and y components that equal 15 N cos 30° gives F = 2 × 15 N cos 30° = 26 N   B
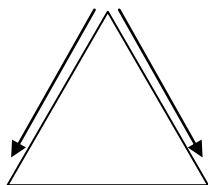
157. Once outside the spheres, they act as point charges and their difference in size is irrelevant   E

158. When connected, the potentials become equal. This gives $kQ_X/r_X = kQ_Y/r_Y$ and since $E = kQ/r^2$, dividing the potentials by their respective radii gives $kQ_X/(r_X)^2 < kQ_Y/(r_Y)^2$ D

159. 1.5×10^{12} excess electrons is a charge of magnitude $(1.5 \times 10^{12}) \times (1.6 \times 10^{-19}) = 2.4 \times 10^{-7}$ C. Use Q = CV   E

160. The field is zero everywhere inside a metal sphere.   C

161. $\Delta V = Ed$ A

162. The force on Q_2 from Q_1 points downward and the force from Q_3 points at right angles to the left. Compute each force using $F = kq_1q_2/r^2$ and use the Pythagorean theorem.   D

163. The field at the center due to Q_1 and Q_3 cancels. The only contribution to the field then is that due to Q_2. $E = kQ/r^2$ where $r^2 = 0.3^2 + 0.4^2$ A

164. E inside = 0 and outside $E \propto 1/r^2$ E

165. Initially, when B is removed, A and C are equally and oppositely charged and B is neutral. Touching B to A gives B ½ the charge of A (split equally). The charge on B is then ½ that of C and oppositely charged. When B and C touch, the total charge between them is ½ the charge of C and the same sign as C. Each sphere then has ¼ of the charge of C after contact is made. This makes the end result that the charge on sphere B is ¼ the original charge of A and the same sign as sphere C, which is opposite that of A   C

166. Advanced question (not exactly in the B curriculum, but interesting). Like gravity inside a uniform sphere of mass, the field is directly proportional to r when inside the sphere (and proportional to $1/r^2$ when outside)   D

167. The field due to the two +3q charges cancel. The –q in the upper right counters –q from the lower left, leaving the net contribution to the field a –q from the lower left.   B

168. With equal charge, the forces are the same. The potential energy of the charges is equal in magnitude, but positive for the proton and negative for the electron. For scalars, positive numbers are higher than negative numbers.   B

169. The charge Q in the middle will induce a charge –Q on the inner surface of the shell. For the net charge of the shell to be –q, the outer surface must have the rest of the charge such that $q_{outer} + q_{inner} = -q$ so $q_{outer} = -q - q_{inner} = -q - (-Q) = Q - q$ C

170. The potential inside the shell is the same as the potential at the surface of the shell since E = 0 inside the shell. $V = kq_{outer}/b$ E

171. Charges flow when there is a difference in potential.   B

172. $V = \Sigma kQ/r$ E

173. The electric field cancels from symmetry all but +Q remaining in the upper right corner and $E = kQ/r^2$ B

174. Since the plates are insulated, the charge remains constant. If the distance is increased, the capacitance will decrease ($C \propto A/d$) and since Q = CV, the potential difference must increase by the same factor that the distance increases. $U_C = ½ QV$ B

175. If the E fields are the same, that means $kQ_X/r_X^2 = kQ_Y/r_Y^2$, or $Q_X/Q_Y = r_X^2/r_Y^2$ A

176. $U_E \propto 1/r$ D

177. $\Sigma F = 0$ so we have $T + k(q)(q)/d^2 - Mg = 0$ giving $T = Mg - kq^2/d^2$ E

178. When lowered inside, the charged sphere induces a negative charge on the inner surface of the cup. The outer surface remains neutral since it is grounded. When the grounding wire is removed, the cup has a net negative charge, which when the sphere is removed, will move to the outer surface of the cup.   B

179. $K = q\Delta V$ so $K_1/K_2 = q_1/q_2$ E

180. The field is zero where the fields from each charge point in opposite directions and also closer to the smaller charge, which is to the left of the –Q charge   A

181. $E = \Delta V/d$ B

182.   E fields point from high potential to low potential, perpendicular to the equipotential lines.   A

183.   For a sphere, $E = kQ/r^2$ and $V = kQ/r$ C

184.   Combining two droplets doubles the charge. The volume is doubled, which means the radius is   C
       multiplied by $\sqrt[3]{2}$. This gives $V = kQ/r = k(2Q)/(\sqrt[3]{2}r)$

185.   The work to assemble the charges is the potential energy of the system, which is the sum of the   B
       potential energies of each pair of charges $U_E = -ke^2/a - ke^2/a + ke^2/2a$

186. $E = kQ/r^2$ C