AP Physics C: Electricity and Magnetism
2001 Scoring Guidelines

General Notes about 2001 AP Physics Solutions

1. The solutions contain the most common method(s) of solving the free-response questions, and the allocation of points for these solutions. Other methods of solution also receive appropriate credit for correct work.
2. Generally, double penalty for errors is avoided. For example, if an incorrect answer to part (a) is correctly substituted into an otherwise correct solution to part (b), full credit will usually be awarded.
3. An exception to this may be cases when the numerical answer to a later part should be easily recognized as wrong, e.g., a speed faster than the speed of light in vacuum.
4. Implicit statements of concepts normally receive credit. For example, if use of the equation expressing a particular concept is worth one point, and a solution contains the application of the equation to the problem but does not separately list the basic equation, the point is still awarded.

Question 1

15 points total

1. (a) **4 points** — **Distribution of Points**

For a correct formula for determining the electric field — **1 point**

$$\mathbf{E} = \sum \frac{kQ}{r^2}\,\hat{\mathbf{r}} \quad \text{or} \quad \mathbf{E} = \frac{kQ}{r^2}\,\hat{\mathbf{r}}$$

Summing the contributions to the field from the four charges, letting fields directed upward be positive and fields directed downward be negative (full credit also given for using opposite convention as long as answers were consistent):

$$E = -\frac{(9\times10^9)(30)}{(3\times10^3)^2} + \frac{(9\times10^9)(30)}{(2\times10^3)^2} + \frac{(9\times10^9)(30)}{(2\times10^3)^2} - \frac{(9\times10^9)(30)}{(3\times10^3)^2}$$

For correct substitutions shown in the above equation — **1 point**

$E = -30{,}000\ \text{N/C} + 67{,}500\ \text{N/C} + 67{,}500\ \text{N/C} - 30{,}000\ \text{N/C}$

$E = 75{,}000\ \text{N/C}$, directed upward

For correct magnitude ($E = \dfrac{8\times10^{-6}}{4\pi\epsilon_0}$ or $k\left(8\times10^{-6}\right)$ also accepted) — **1 point**

For correct direction, either stated or shown by an upward directed arrow — **1 point**

Notes: If wrong signs were used in the substitution, the point for correct magnitude was not awarded. If calculation was done using only the two real charges, a maximum of **3 points** was awarded as follows: **1 point** for the formula, **1 point** for the calculation, **1 point** for direction.

1. (b) i. **1 point**

For correctly indicating direction, such as by an upward directed arrow at point P_2, — **1 point**

1. (b) ii. **2 points**

For correctly checking the space in front of "Less" — **1 point**

For correct justification, such as "P_2 is farther from all the charges than P_1, so the net field is less." If student chose to work out the actual magnitude of the field at P_2 (which is about 45,000 N/C), the justification point was awarded for any calculated numerical value less than 75,000 N/C. — **1 point**

Note: **No points** were awarded for (b) ii. if the wrong space was checked.

Question 1 (cont.)

1. (c) i. **2 points** — **Distribution of Points**

The potential at P_1 is 0, which can be determined without calculation from symmetry considerations.

For stating $V = 0$ or for just 0 — **2 points**

Alternate Solution — *Alternate points*

For a correct formula for determining the potential — *1 point*

$$V = \sum \frac{kQ}{r}$$

$$V = k\left(\frac{30}{3000} - \frac{30}{2000} + \frac{30}{2000} - \frac{30}{3000}\right) = 0$$

For the correct answer — *1 point*

1. (c) ii. **2 points**

The potential at P_2 is 0, which can also be determined without calculation from symmetry considerations.

For stating $V = 0$ or for just 0 — **2 points**

Alternate Solution — *Alternate points*

For a correct formula for determining the potential — *1 point*

$$V = \sum \frac{kQ}{r}$$

$$V = k\left(\frac{30}{\sqrt{10}\times 10^3} - \frac{30}{\sqrt{5}\times 10^3} + \frac{30}{\sqrt{5}\times 10^3} - \frac{30}{\sqrt{10}\times 10^3}\right) = 0$$

For the correct answer — *1 point*

1. (d) **2 points**

For a correct formula for determining the potential — **1 point**

$$V = \sum \frac{kQ}{r}$$

For correct substitution of values (no credit lost for failing to convert kilometers to meters) — **1 point**

$$V_P = k\left(\frac{30}{(3-1)\times 10^3} - \frac{30}{(2-1)\times 10^3} + \frac{30}{(2+1)\times 10^3} - \frac{30}{(3+1)\times 10^3}\right)$$

$$V_P = -1.12\times 10^8\ \text{V} \approx -10^8\ \text{V}$$

Question 1 (cont.)

1. (e) **2 points** — **Distribution of Points**

For a correct formula for the potential energy (must include a summation sign) — **1 point**

$$U = k\sum_{i,j}\frac{q_i q_j}{r_{ij}} \quad \underline{\text{or}} \quad U = \sum qV$$

For correct substitution without regard to sign error (no credit lost for failing to convert kilometers to meters) — **1 point**

$$U = \left(9\times10^9\right)\left[\frac{30(-30)}{10^3} + \frac{30(30)}{5\times10^3} + \frac{30(-30)}{6\times10^3} + \frac{-30(30)}{4\times10^3} + \frac{-30(-30)}{5\times10^3} + \frac{30(-30)}{10^3}\right] \text{J}$$

$$U = -1.6\times10^{10}\ \text{J}$$

Question 2

15 points total

2. (a) **4 points** — **Distribution of Points**

There were three methods generally used to solve this problem.

Method 1.

For a correct method based on determining the time constant using values from the graph — **2 points**

$\tau = RC \approx 60 \text{ min} = 3600 \text{ s}$

For correct substitution of values with proper units — **1 point**

$$R = \frac{\tau}{C} = \frac{3600 \text{ s}}{8.0\times10^{-6} \text{ F}}$$

For answer consistent with values used — **1 point**

$R = 4.5\times10^{8}\ \Omega$

Method 2.

$V = V_0 e^{-t/RC}$

For using the above equation with given value of C and values for V, V_0, and t from the graph with t correlating with V — **2 points**

Example: $V_0 = 10$ V, and $V = 2$ V at $t = 100$ min

For correct substitution of values — **1 point**

$2 = 10e^{(-6000 \text{ s})/R(8\times10^{-6} \text{ F})}$

$\ln(2/10) = (6000)R(8\times10^{-6})$

For answer consistent with values used — **1 point**

$R = 4.7\times10^{8}\ \Omega$

Method 3.

Find a correct relationship that depends on the slope of the graph:

Example: $R = \dfrac{V}{i} = \dfrac{V}{dQ/dt}$

But $dQ = CdV$

So $R = \dfrac{V}{C(dV/dt)}$

For estimating dV/dt by computing $\Delta V/\Delta t$ for a particular value of V — **2 points**

For substituting values in equation above — **1 point**

For answer consistent with values used — **1 point**

Note: The value used for V must be that at the point where the slope is taken and clearly indicated.

Question 2 (cont.)

2. (b) **3 points** — **Distribution of Points**

For a correct equation for the capacitance — **1 point**

$$C = \frac{\kappa \epsilon_0 A}{d}$$

For correct algebraic solution for area A and substitution of variables — **1 point**

$$A = \frac{Cd}{\kappa \epsilon_0} = \frac{\left(8.0\times10^{-6}\ \text{F}\right)\left(1.0\times10^{-4}\ \text{m}\right)}{5.6\left(8.85\times10^{-12}\ \text{C}^2/\text{N}\bullet\text{m}\right)}$$

For the correct answer — **1 point**

$$A = 16\ \text{m}^2$$

2. (c) **3 points**

For a correct equation for the resistance — **1 point**

$$R = \frac{\rho L}{A}$$

For correct algebraic solution for resistivity ρ and substitution of variables — **1 point**

$$\rho = \frac{RA}{L} = \frac{\left(4.5\times10^{8}\ \Omega\right)\left(16\ \text{m}^2\right)}{1.0\times10^{-4}\ \text{m}}$$

For answer consistent with values used — **1 point**

$$\rho = 7.2\times10^{13}\ \Omega\bullet\text{m}$$

Question 2 (cont.)

2. (d) **4 points**	**Distribution of Points**
There were four general methods for solving this problem. Solutions were scored as follows:	
For using a correct method	**2 points**
For substituting appropriate values	**1 point**
For answer consistent with values obtained in earlier parts	**1 point**

Method 1:

$\Delta Q = C\Delta V$, and substitute values obtained from graph

Example: $Q_i = (8.0\times10^{-6}\text{ F})(10\text{ V})$ and $Q_f = (8.0\times10^{-6}\text{ F})(2\text{ V})$

So $\Delta Q = 6.4\times10^{-5}\text{ C}$ or $64\ \mu\text{C}$

Method 2:

$$Q = \int_0^{6000\,t} I\,dt = \frac{V_0}{R}\int_0^{6000\,t} e^{-t/RC}\,dt = \frac{10\text{ V}}{4.5\times10^8\,\Omega}\int_0^{6000\,t} e^{-t/3600}dt$$

$$Q = (2.22\times10^{-8})(-3600)e^{-t/3600}\Big|_0^{6000\text{ s}}$$

$$Q = 6.5\times10^{-5}\text{ C or } 65\ \mu\text{C}$$

Method 3:

$$Q = CV_0\left(1-e^{-t/RC}\right)$$

$$Q = (8.0\times10^{-6}\text{ F})(10\text{ V})\left(1-e^{-6000\text{ s}/(4.5\times10^8\ \Omega)(8.0\times10^{-6}\text{ F})}\right)$$

$$Q = 6.5\times10^{-5}\text{ C or } 65\ \mu\text{C}$$

Method 4:

Determine the area under the curve of *I vs.t*, which is the *V vs.t* graph shown with $I = V_0/R$.

Each block has area equal to $Vt/R = 1.3\times10^{-6}$ C.

Estimating 47 blocks under the curve gives

$Q = 6.3\times10^{-5}\text{ C}$ or $63\ \mu\text{C}$

Unit point: For correct units given on answers for **three** of the **four** parts — **1 point**

Question 3

15 points total

3. (a) **2 points** — **Distribution of Points**

Using Ohm's law:
$V = IR$

For correct equation for I — **1 point**

$$I = \frac{\mathcal{E}}{R}$$

For correctly indicating the current direction on the diagram or in the answer space, such as by stating that it is clockwise, or to the left, or by showing an arrow pointing left — **1 point**

3. (b) **4 points**

For indicating on the diagram or in the answer space a direction opposite to the answer in part (a). If part (a) does not contain a direction, then for an indication that the direction is to the right or by showing an arrow pointing right. — **1 point**

For a complete justification — **3 points**

Full credit awarded for an answer that indicated the right-hand rule to obtain the magnetic field directed out of the page at the rod, and then used the cross product to obtain that the force on the rod is up

2 points partial credit awarded for an answer that just stated the rule that antiparallel currents repel or that just stated $I\,\boldsymbol{\ell} \times \mathbf{B}$ and the right-hand rule

1 point partial credit awarded for an answer that just stated the right-hand rule <u>or</u> $I\,\boldsymbol{\ell} \times \mathbf{B}$ <u>or</u> some fragment with some correct element

3. (c) **4 points**

For indicating that the gravitational force will be equal to $I\,\boldsymbol{\ell} \times \mathbf{B}$ — **1 point**

$F = I\,\boldsymbol{\ell} \times \mathbf{B} = mg$

For giving the correct equation for the magnetic field — **1 point**

$$B = \frac{\mu_0 i}{2\pi r}$$

For correctly substituting in the first equation above the values for B and for I from part (a) — **1 point**

$$\frac{\mu_0 I_c \ell \mathcal{E}}{2\pi rR} = mg$$

For the correct answer — **1 point**

$$I_c = \frac{2\pi mgrR}{\mu_0 \ell \mathcal{E}}$$

Question 3 (cont.)

3. (d) **5 points** **Distribution of Points**

For the correct expression for ϕ **1 point**

$\phi = \int \mathbf{B} \cdot d\mathbf{A}$, where $B = \dfrac{\mu_0 I_c}{2\pi x}$, and x is the vertical distance from the cable

Letting $dA = \ell\, dx$ and substituting the values for B above and for I_c from part (c):

$$\phi = \int_r^{r+d} \frac{\mu_0 2\pi\, mgrR\ell}{2\pi\mu_0 \ell \mathcal{E}} \frac{dx}{x}$$

For correct limits of integration **1 point**
For correct substitution of the values consistent with previous answers **1 point**
For correct integration **1 point**

$$\phi = \frac{mgrR}{\mathcal{E}} \ln x \Big|_r^{r+d}$$

For the correct answer **1 point**

$$\phi = \frac{mgrR}{\mathcal{E}} \ln\left(\frac{r+d}{r}\right)$$