AP® PHYSICS C: ELECTRICITY AND MAGNETISM
2016 SCORING GUIDELINES

Question 1

15 points total **Distribution of points**

(a) 3 points

For indicating that the total potential is the sum of the potential from individual point charges — 1 point

Example using point B: $V_B = 0 = V_1 + V_2$

For correctly substituting into the above equation (signs are ignored at this step) — 1 point

$-V_1 = V_2$

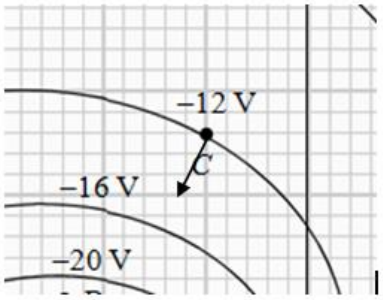
$-\frac{kq_1}{r_1} = \frac{kq_2}{r_2}$

$-\frac{q_1}{(5 \times 0.5m)} = \frac{(2.0\ \text{nC})}{(2 \times 0.5\ \text{m})}$

For a correct answer with correct sign and units — 1 point

$q_1 = -5.0\ \text{nC}$

(b) 2 points



For drawing a vector perpendicular to the equipotential line for *C* — 1 point

For drawing a vector in the direction of the -16 V line — 1 point

(c) 2 points

For using the equation relating the electric field to potential difference — 1 point

$E = -\frac{dV}{dx}$

$|E| \simeq \frac{\Delta V}{\Delta x}$

For substituting values from the figure — 1 point

$E = \frac{(-20\ \text{V} - (-24\ \text{V}))}{(2 \times 0.1\ \text{m})}$

$E = 20\ \text{N/C}$

Question 1 (continued)

Distribution of points

(d) 2 points

For using a correct equation for the electric flux 1 point

$$\Phi_E = \frac{q_{enc}}{\varepsilon_0}$$

$$\Phi_E = \frac{(2.0\ \text{nC})}{\left(8.85 \times 10^{-12}\ \text{C}^2/(\text{N}\cdot\text{m}^2)\right)}$$

For a correct answer with units 1 point

$$\Phi_E = 226\ (\text{N}\cdot\text{m}^2)/\text{C}$$

(e)

i. 2 points

For using an equation that relates the work done to the change in potential energy 1 point

$$W = -q\Delta V = -(1.6 \times 10^{-19}\ \text{C})(-4\ \text{V} - (4\ \text{V}))$$

For a correct answer including sign and units 1 point

$$W = 1.28 \times 10^{-18}\ \text{J} = 8.0\ \text{eV}$$

ii. 2 points

For indicating that the kinetic energy of the proton at E will be equal to the work done 1 point

$$W = \Delta K = \frac{1}{2}mv^2$$

For correctly substituting the answer from part (e) i. into the above equation 1 point

$$(1.28 \times 10^{-18}\ \text{J}) = \left(\frac{1}{2}\right)(1.67 \times 10^{-27}\ \text{kg})v^2$$

$$v = 3.92 \times 10^4\ \text{m/s}$$

(f) 2 points

For correctly selecting Left 1 point

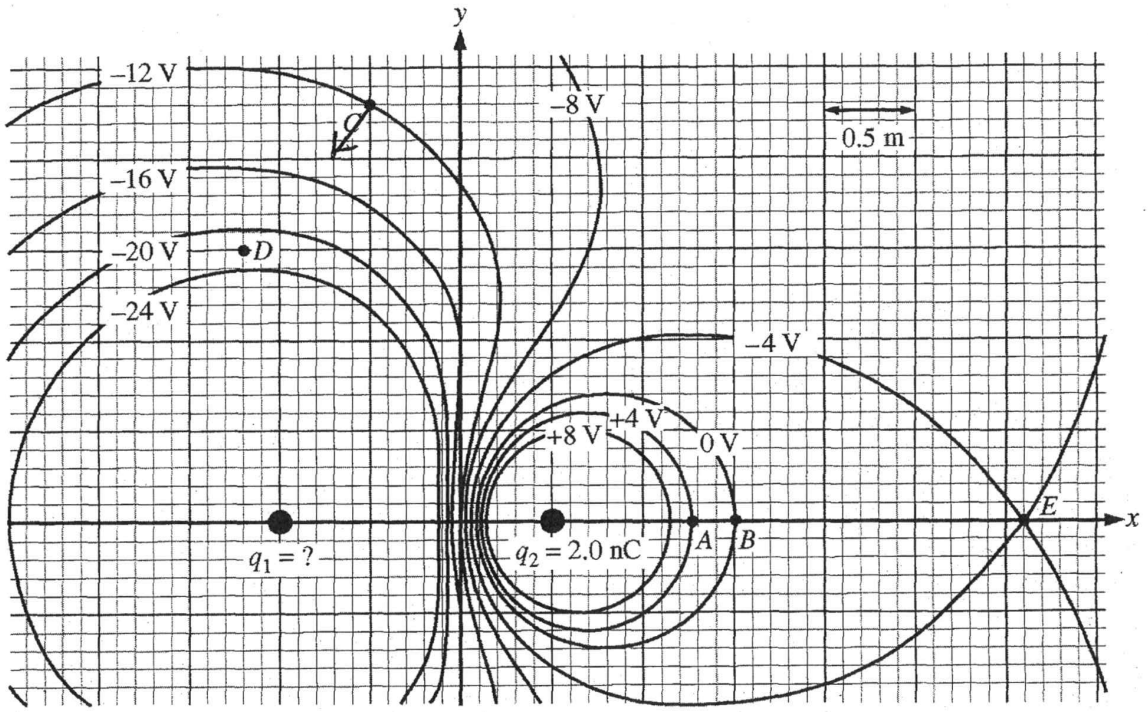
For a correct justification 1 point

Example: Electrons accelerate in the direction perpendicular to equipotential surfaces and toward higher potential. Therefore, at point B, an electron would accelerate toward the left.

No points are earned if the wrong answer is selected.

PHYSICS C: ELECTRICITY AND MAGNETISM
SECTION II
Time—45 minutes
3 Questions

Directions: Answer all three questions. The suggested time is about 15 minutes for answering each of the questions, which are worth 15 points each. The parts within a question may not have equal weight. Show all your work in this booklet in the spaces provided after each part.



E&M.1.

Two point charges, q_1 and q_2, are fixed in place on the x-axis at positions $x_1 = -1.00$ m and $x_2 = +0.50$ m, respectively. Charge q_2 has a value of +2.0 nC. Values of electric potential are illustrated by the given equipotentials in the diagram shown above, which is drawn to scale.

(a) Calculate the value of q_1.

$\frac{kq_2}{(1m)} - \frac{kq_1}{(2.5m)} = 0$ $\quad \frac{k(2E-9)}{1} = \frac{kq_1}{2.5}$

$q_1 = -5nC$

(b) At point C on the diagram, draw a vector representing the direction of the electric field at that point.

(c) Calculate the approximate magnitude of the electric field strength at point D on the diagram.

$E = \frac{dV}{dx} = \frac{24-20}{1.4-1.6} = 20\ \frac{V}{m}$

GO ON TO THE NEXT PAGE.

(d) The equipotential labeled 0 V is the cross section of a nearly spherical surface. Calculate the electric flux for this surface.

$\Phi_E = \oint E \cdot dA = \frac{Q}{\epsilon_0}$

$Q = 2nC$

$\Phi_E = \frac{(2E\text{-}9\ C)}{(8.85E\text{-}12)} = 225.99\ \frac{N \cdot m^2}{C}$

(e) A proton is placed at point *A* and then released from rest.

i. Calculate the work done by the electric field on the proton as it moves from point *A* to point *E*.

$W = q\Delta V = (1.6E\text{-}19)(-4-4) = +1.28E\text{-}18\ J$

ii. Calculate the speed of the proton when it reaches point *E*.

$\frac{1}{2} m_p v^2 = q\Delta V = 1.28E\text{-}18$

$v = \sqrt{\frac{2(1.28E\text{-}18)}{(1.67E\text{-}27)}}$

$v = 39152\ m/s$

(f) An electron is released from rest at point *B*. Which of the following indicates the direction of the initial acceleration, if any, of the electron?

____ Up ____ Down

__X__ Left ____ Right

____ Into the page ____ Out of the page

____ The direction is undefined since the acceleration is zero.

Justify your answer.

Electric field lines are always perpendicular to voltage lines and go from high voltage to low voltage. That means E-field is to the right at point B. Electrons get a force opposite the direction of electric field so the electron would accelerate to the left

GO ON TO THE NEXT PAGE.

E Q1 B1

PHYSICS C: ELECTRICITY AND MAGNETISM

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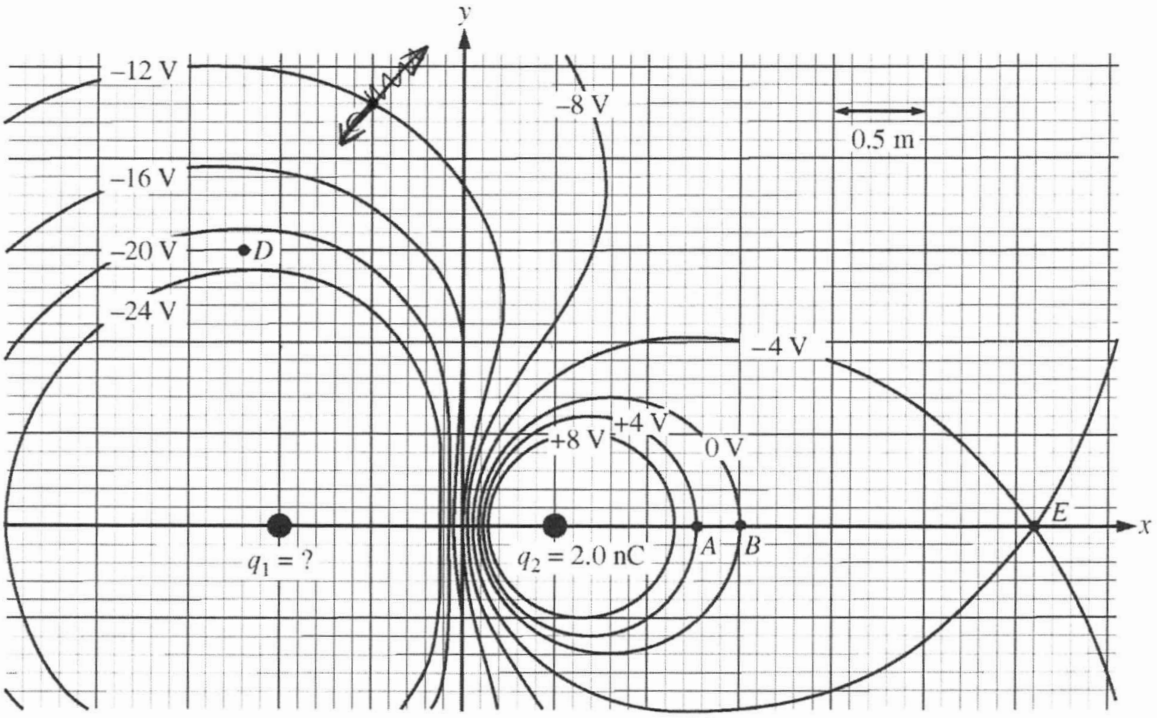

E&M.1.

Two point charges, q_1 and q_2, are fixed in place on the x-axis at positions $x_1 = -1.00$ m and $x_2 = +0.50$ m, respectively. Charge q_2 has a value of +2.0 nC. Values of electric potential are illustrated by the given equipotentials in the diagram shown above, which is drawn to scale.

(a) Calculate the value of q_1.

$V = \frac{kq_1}{r}$ $r = 1.5$ $V = -24V$ $-24 = \frac{k \cdot q_1}{1.5}$

$q_1 = -4$ nC

(b) At point C on the diagram, draw a vector representing the direction of the electric field at that point.

(c) Calculate the approximate magnitude of the electric field strength at point D on the diagram.

$E = \frac{\Delta V}{d}$ $\Delta V = +4$ $d \approx .2$

$E \approx \frac{4}{.2} \approx 20$ V/m

GO ON TO THE NEXT PAGE.

(d) The equipotential labeled 0 V is the cross section of a nearly spherical surface. Calculate the electric flux for this surface.

$\oint E\,d\vec{a} = \frac{Q}{\varepsilon}$ $\Phi_E = \frac{Q}{\varepsilon_0} = \frac{2\times10^{-9}}{8.85\times10^{-12}} = 225.98$ [redacted]^2

(e) A proton is placed at point *A* and then released from rest.

i. Calculate the work done by the electric field on the proton as it moves from point *A* to point *E*.

$W = \Delta E$ $E = q \cdot V$

$W = E_E - E_A$ $q = 1.6\times10^{-19}$

$W = q\cdot 4 - q\cdot -4$

$W = 1.28\times10^{-18}\ J$

ii. Calculate the speed of the proton when it reaches point *E*.

$W = \Delta K = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$ $v_i = 0$

$1.28\times10^{-18} = \frac{1}{2}m\cdot v_f^2$

$v = 39152.7\ m/s$

(f) An electron is released from rest at point *B*. Which of the following indicates the direction of the initial acceleration, if any, of the electron?

____ Up ____ Down

✓ Left ____ Right

____ Into the page ____ Out of the page

____ The direction is undefined since the acceleration is zero.

Justify your answer.

The electron will begin to accelerate towards q_2 because it is positive, and electrons move against electric field lines, + at point B, the field line points to the right.

E Q1 C1

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SECTION II

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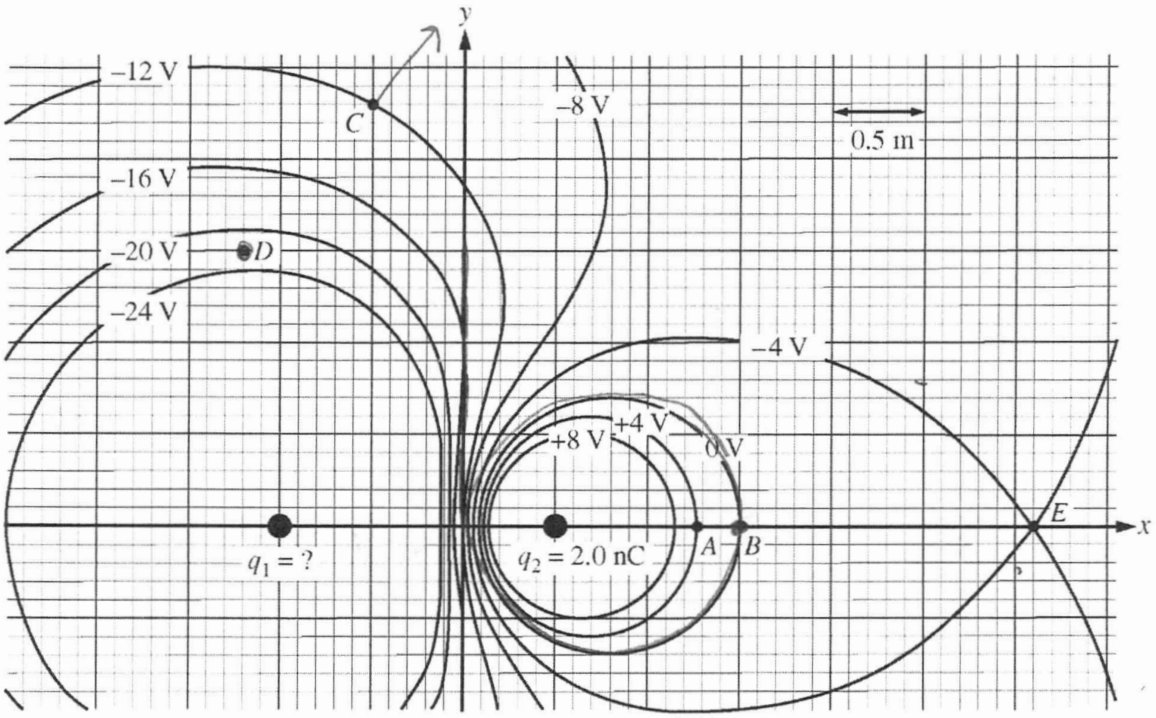

E&M.1.

Two point charges, q_1 and q_2, are fixed in place on the x-axis at positions $x_1 = -1.00$ m and $x_2 = +0.50$ m, respectively. Charge q_2 has a value of +2.0 nC. Values of electric potential are illustrated by the given equipotentials in the diagram shown above, which is drawn to scale.

(a) Calculate the value of q_1.

$-24 = \frac{K(q_1)}{-1m}$ $V = \frac{KQ}{r}$ $24 = Kq_1$ $q_1 = 2.67 \times 10^{-9}$ C

(b) At point C on the diagram, draw a vector representing the direction of the electric field at that point.

(c) Calculate the approximate magnitude of the electric field strength at point D on the diagram.

$V = EO$ $V = -22$ V $E = \frac{-22}{1.5m} = 14.67$ N

GO ON TO THE NEXT PAGE.

(d) The equipotential labeled 0 V is the cross section of a nearly spherical surface. Calculate the electric flux for this surface.

$V = \frac{d\Phi}{dt}$

flux = $A = \pi r^2 = (1.5)^2 \pi$

flux = 7.06 $\frac{N}{C}$

(e) A proton is placed at point *A* and then released from rest.

i. Calculate the work done by the electric field on the proton as it moves from point *A* to point *E*.

$W = Fq$

$W = Fqx$

$W = VQ$

$W = 8(1.6 \times 10^{-19})$

$W = 1.28 \times 10^{-18}$ J

$F = Eq$

$W = Eqx$

ii. Calculate the speed of the proton when it reaches point *E*.

$1.28 \times 10^{-18} = \frac{1}{2}(1.67 \times 10^{-27})(V^2)$

V = 39152.7 m/s

(f) An electron is released from rest at point *B*. Which of the following indicates the direction of the initial acceleration, if any, of the electron?

____ Up ____ Down

____ Left ____ Right

____ Into the page ____ Out of the page

__✓__ The direction is undefined since the acceleration is zero.

Justify your answer.

The acceleration is zero has a charge does not move along an equipotential line or across it unless work is done on the charge.

AP® PHYSICS C: ELECTRICITY AND MAGNETISM
2016 SCORING COMMENTARY

Question 1

Overview

The intent was to assess understanding of electrical potential maps, the principal of superposition, the relation between potential and the electric field vector, the work done on charges, the direction of acceleration of a charge in an electric field, and Gauss's law.

Sample: E Q1 A
Score: 15

Part (a) earned 3 points for correctly summing the electric potentials from the individual point charges, substituting, and calculating a correct answer with units. Part (b) earned 2 points for drawing an arrow perpendicular to point C and pointing toward the –16 V line. Part (c) earned 2 points for using a correct equation and substituting from the figure to calculate the electric field. Part (d) earned 2 points for using a correct equation to determine the electric flux and calculating a correct answer with units. Part (e)(i) earned 2 points for using a correct equation to determine the work done by the electric field and calculating a correct answer with units and sign. Part (e)(ii) earned 2 points for using the work-energy theorem and substituting for work from part (e)(i). Part (f) earned 2 points for selecting "Left" and a justification that correctly states that the electric field points perpendicularly toward lower potential and the electrons experience a force toward higher potentials.

Sample: E Q1 B
Score: 11

Part (a) earned no credit because there is no indication that a correct equation was used. Parts (b) and (c) earned full credit. Part (d) earned 1 point for using a correct equation to determine the electric flux; however, the answer had no units. Part (e) earned full credit. Part (f) earned 2 points for selecting "Left" and a correct justification that stated electrons move in a direction opposite to the electric field.

Sample: E Q1 C
Score: 5

Part (a) earned no credit because there is no indication that a correct equation was used. Part (b) earned 1 point for an arrow drawn perpendicular to point C, but the arrow pointed away from the –16 V line. Parts (c) and (d) earned no credit because there is no indication that correct equations were used. Part (e) earned full credit. Part (f) earned no credit for an incorrect selection.