# AP® PHYSICS 2
# 2016 SCORING GUIDELINES

## Question 3

**12 points total** | **Distribution of points**

(a) 1 point

For correctly labeling the magnitude of lines ( $A = 60$ V and $B = 80$ V, units not required) and for having the correct signs on each line (either explicit positive signs or no negative signs) — 1 point

(b)

i. 2 points

For indicating that *Y* has more charge than *X* with a correct explanation, such as the nearest potential of the same value is farther from *Y* — 1 point

For indicating *X* and *Y* must be the same sign with a correct explanation — 1 point

Examples:

- Field vectors are perpendicular to equipotentials, and the pattern of field vectors indicates that both must have the same sign.
- There is no zero potential line between the spheres, so the potentials from the two charges do not cancel anywhere.

ii. 1 point

For a correct explanation that addresses the charge to mass ratio and distance relationship — 1 point

Example: Both spheres would gravitationally attract a third sphere just like two charges of the same sign would attract a third charge of the opposite sign because both forces are dependent on the distance and also dependent on the product of the charges or masses.

(c) 2 points

For a similarity that does not generally apply to all forces — 1 point

Example: The forces have the same dependence on the distance and are both functions of $1/r^2$.

For a difference that does not generally apply to all forces — 1 point

Examples:

The proton is the same sign as the spheres, so it is electrostatically repelled, but gravity is always attractive. Therefore, the directions of the forces are different.

The forces are different in magnitude.

**Question 3 (continued)**

**Distribution of points**

(d)

i. 2 points

The proton is repelled by both spheres, so it will move toward point $A$.
For some attempt to apply $\Delta U_E = q\Delta V$ using the given variables — 1 point
For using the correct variables and getting $\Delta U = q(V_A - V_B)$ (no credit for using numeric values of electric potential) — 1 point

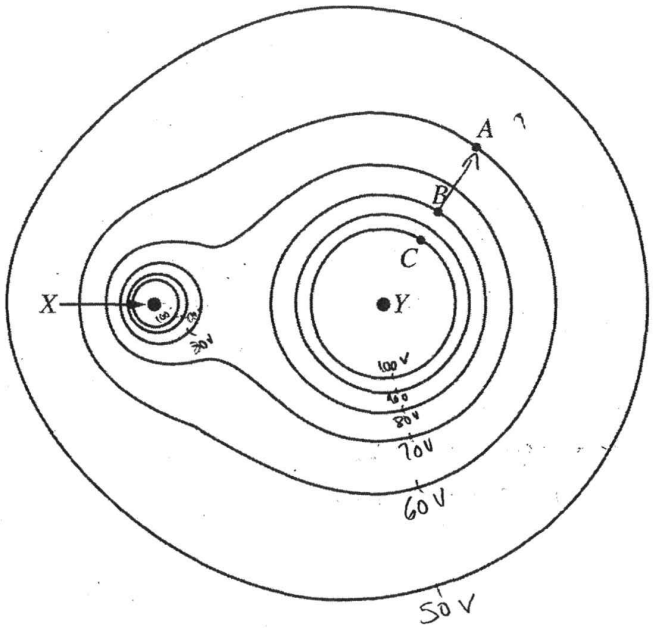
ii. 2 points

For using a correct expression for work — 1 point
$W = Fd$ or $-\Delta U_E = q\Delta V$
For a correct expression for $F$ or $\Delta V$ in terms of $E_{avg}$ — 1 point
$F_{avg} = qE_{avg}$ or $\Delta V = E_{avg}d$
$W = qE_{avg}d$ (full credit is awarded for just writing the correct expression)

iii. 2 points

For indicating that student 1 is correct and a correct discussion of why — 1 point
Example: Student 1 is correct. Because the system contains all the objects, the energy is transferred from one form to another within the system due to the law of conservation of energy.
For indicating that student 2 is correct and a correct discussion of why — 1 point
Example: Student 2 is correct. Because the system is just the proton, there must be a force external to the system due to the electric field of the two spheres. That force does work on the proton which changes the kinetic energy of the proton.

P2 Q3 A1




3. (12 points, suggested time 25 minutes)

The dots in the figure above represent two identical spheres, $X$ and $Y$, that are fixed in place with their centers in the plane of the page. Both spheres are charged, and the charge on sphere $Y$ is positive. The lines are isolines of electric potential, also in the plane of the page, with a potential difference of 10 V between each set of adjacent lines. The absolute value of the electric potential of the outermost line is 50 V.

(a) Indicate the values of the potentials, including the signs, at the labeled points $A$ and $B$.

Potential at point $A$ 60 V  Potential at point $B$ 80 V

(b)

i. How do the magnitudes and the signs of the charges of the spheres compare? Explain your answer in terms of the isolines of electric potential shown.

As the isolines of equivalent potentials are further from Y than X, Y must have a greater charge. As the lines envelope both spheres, and aren't uniformly parallel directly between the two spheres, they must hve the same sign.

ii. The spheres at points $X$ and $Y$ have masses in the same ratio as the magnitudes of their charges. The isolines of gravitational potential for the spheres have shapes similar to those of the isolines shown. Explain why the two sets of isolines have similar shapes.

Gravitational and electric potential both vary inversly will distance from the source, and, as both charges are the same sign and gravity can only go one direction, the potentials from both spheres will combine similarly.

Let the potentials at the three labeled points be $V_A$, $V_B$, and $V_C$. A proton with charge $+q$ and mass $m$ is released from rest at point $B$.

(c) Based on your answer to part (b)(ii), briefly describe one similarity and one difference between the electric and gravitational forces exerted on the proton by the system of the two spheres. The similarity and difference you describe must not be ones that generally apply to all forces.

One difference is that gravity would cause the proton to move toward spheres, but as the proton and spheres have the same sign, the electric force would repel the proton away from spheres.

The similarity between both forces is that both magnitudes would vary proportionally to the inverse square of the proton's distance from spheres.

(d) At some time after being released from rest at point $B$, the proton has moved through a potential difference of magnitude 20 V.

i. Determine the change in electric potential energy of the proton-spheres system when the proton has moved through the 20 V potential difference. Express your answer symbolically in terms of $q$, $V_A$, $V_B$, $V_C$, and physical constants, as appropriate.

$\Delta U_E = q\,\Delta V$

$V_A - V_B = -20\text{V}$ Proton moves away from Point Y, (B to A)

$\boxed{\Delta U_E = q\,(V_A - V_B)}$

ii. As it moved through the 20 V potential difference, the proton was displaced a distance $d$ by the electric force. Determine a symbolic expression for the total work done on the proton by the electric field in terms of the average magnitude $E_{avg}$ of the electric field over that distance.

$W = F_{avg} \cdot d \quad \because \quad F_{avg} = E_{avg} \cdot q$

$= \boxed{E_{avg} \cdot q \cdot d}$

Question 3 continues on next page.

iii. Two students are discussing how and why the kinetic energy of the proton would change after it is released.

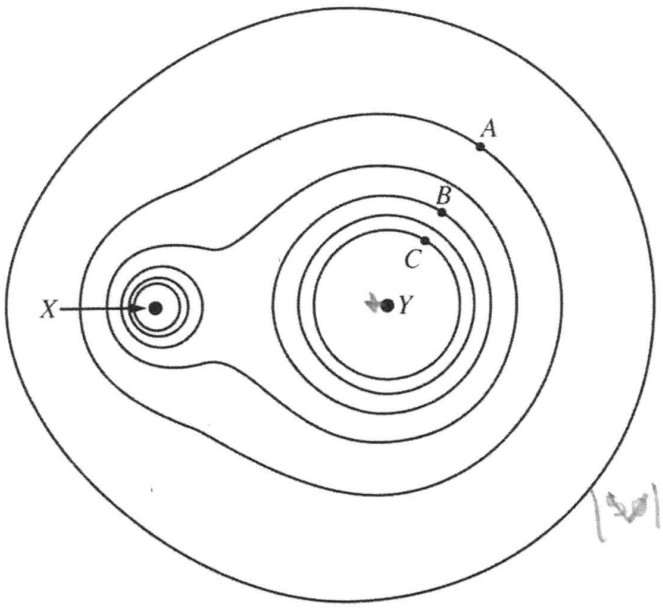
- Student 1 says that if the system is defined as the proton and the spheres, the increase in the proton's kinetic energy is due to a change in the system's potential energy as the proton moves through the 20 V potential difference.
- Student 2 says that if the system is defined as only the proton, the kinetic energy of the proton increases because positive work is done on the proton by the electric field as the proton moves through the 20 V potential difference.

Discuss each student's claims, explaining why each is correct or incorrect.

Student 1 is correct, as some of the electrical potential energy of the proton in the proton-sphere system is lost as it moves through the 20 V potential difference, and converted into kinetic energy via the electric field doing work on the proton.

Student 2 is also correct, because alone the proton gaings kinetic energy from moving through the 20 V potential difference due to the electric force acting on the proton over a given distance.

P2 Q3 B1

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(a) Indicate the values of the potentials, including the signs, at the labeled points $A$ and $B$.

Potential at point $A$ -40V Potential at point $B$ -20V

(b)

i. How do the magnitudes and the signs of the charges of the spheres compare? Explain your answer in terms of the isolines of electric potential shown.

The magnitude of ~~the charges~~ charge on X is much greater than Y, because the electric field is greater, due to the isolines changing more over a smaller distance. Y is ~~negatively~~ positively charged, because the isolines don't continue to increase between them.

ii. The spheres at points $X$ and $Y$ have masses in the same ratio as the magnitudes of their charges. The isolines of gravitational potential for the spheres have shapes similar to those of the isolines shown. Explain why the two sets of isolines have similar shapes.

They have similar shapes because the charge is the same in the shown diagram, and in a gravitational potential the mass would be the same. Having the same amount of interacting quantity will create the same isolines of potential in either graph.



GO ON TO THE NEXT PAGE.

Let the potentials at the three labeled points be $V_A$, $V_B$, and $V_C$. A proton with charge $+q$ and mass $m$ is released from rest at point $B$.

(c) Based on your answer to part (b)(ii), briefly describe one similarity and one difference between the electric and gravitational forces exerted on the proton by the system of the two spheres. The similarity and difference you describe must not be ones that generally apply to all forces.

The proton will experience a much greater electric force than gravitational force because the electric force is much stronger, especially concerning particles. Also, the gravity force would be attractive, the electric force is repulsive. They are similar in that both will be effected by distance from the two points X+Y.

(d) At some time after being released from rest at point $B$, the proton has moved through a potential difference of magnitude 20 V.

i. Determine the change in electric potential energy of the proton-spheres system when the proton has moved through the 20 V potential difference. Express your answer symbolically in terms of $q$, $V_A$, $V_B$, $V_C$, and physical constants, as appropriate.

20V difference is point B to point A.

$$\Delta EPE = q\Delta V = q(V_A - V_C)$$

ii. As it moved through the 20 V potential difference, the proton was displaced a distance $d$ by the electric force. Determine a symbolic expression for the total work done on the proton by the electric field in terms of the average magnitude $E_{avg}$ of the electric field over that distance.

Total Work $= F_e \cdot d$ $\qquad E_{avg} \cdot d = 20V$

Total Work $= q \cdot \vec{E}_{avg} \cdot d$

Total work $= 20q$

Question 3 continues on next page.

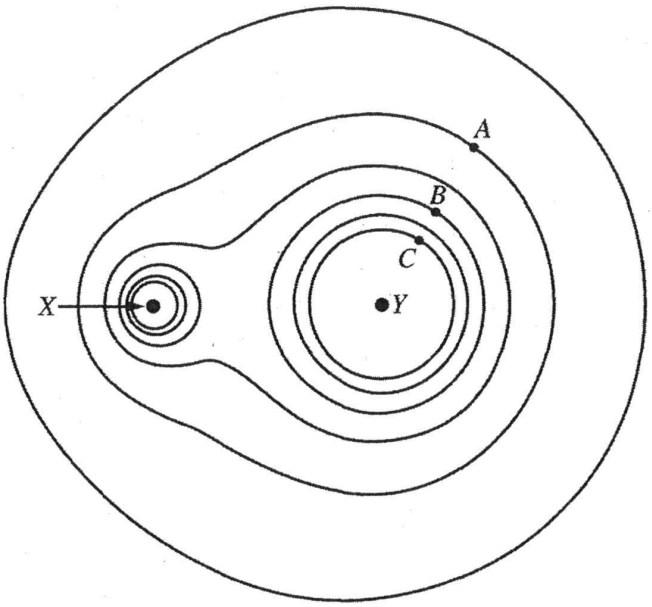
iii. Two students are discussing how and why the kinetic energy of the proton would change after it is released.

- Student 1 says that if the system is defined as the proton and the spheres, the increase in the proton's kinetic energy is due to a change in the system's potential energy as the proton moves through the 20 V potential difference.
- Student 2 says that if the system is defined as only the proton, the kinetic energy of the proton increases because positive work is done on the proton by the electric field as the proton moves through the 20 V potential difference.

Discuss each student's claims, explaining why each is correct or incorrect.

Student 1 claims that if the potential energy is defined as the proton AND spheres, than moving the 20V potential difference changed the potential energy between the proton and spheres, turning it into kinetic energy. This is correct, as the potential is determined by location in the field. The proton changed location, so the potential changed for it, and some of the energy went into kinetic energy.

Student 2 claims that the field does positive work on the proton as it moves 20V. This is also correct because the electric force is the same direction as the distance traveled, which makes it positive work caused by the electric force.

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(a) Indicate the values of the potentials, including the signs, at the labeled points $A$ and $B$.

Potential at point $A$ __+__ Potential at point $B$ __+__

(b)

i. How do the magnitudes and the signs of the charges of the spheres compare? Explain your answer in terms of the isolines of electric potential shown.

Sphere X has a larger magnitude. The closer proximity of the isolines represents a stronger electric potential.

ii. The spheres at points $X$ and $Y$ have masses in the same ratio as the magnitudes of their charges. The isolines of gravitational potential for the spheres have shapes similar to those of the isolines shown. Explain why the two sets of isolines have similar shapes.

The strength of a gravitational field is determined on how massive and object is, it has the same correlation of charge magnitude and electric potential.

Let the potentials at the three labeled points be $V_A$, $V_B$, and $V_C$. A proton with charge $+q$ and mass $m$ is released from rest at point $B$.

(c) Based on your answer to part (b)(ii), briefly describe one similarity and one difference between the electric and gravitational forces exerted on the proton by the system of the two spheres. The similarity and difference you describe must not be ones that generally apply to all forces.

The charge would be repelled by the electric force because of the sign of its charge magnitude, however it would be attracted by the gravitational force as it is less massive.

(d) At some time after being released from rest at point $B$, the proton has moved through a potential difference of magnitude 20 V.

i. Determine the change in electric potential energy of the proton-spheres system when the proton has moved through the 20 V potential difference. Express your answer symbolically in terms of $q$, $V_A$, $V_B$, $V_C$, and physical constants, as appropriate.

$\Delta U_E = q(\Delta V)$

~~$\Delta U_c = q(V_c - V_B)$~~

$\Delta U_c = q(V_c - V_B)$

ii. As it moved through the 20 V potential difference, the proton was displaced a distance $d$ by the electric force. Determine a symbolic expression for the total work done on the proton by the electric field in terms of the average magnitude $E_{avg}$ of the electric field over that distance.

$E = \frac{F_c}{q}$

$F_c = E(q)$

$W = F(d)$

$W = (E)(q)(d)$

Question 3 continues on next page.

iii. Two students are discussing how and why the kinetic energy of the proton would change after it is released.

- Student 1 says that if the system is defined as the proton and the spheres, the increase in the proton's kinetic energy is due to a change in the system's potential energy as the proton moves through the 20 V potential difference.
- Student 2 says that if the system is defined as only the proton, the kinetic energy of the proton increases because positive work is done on the proton by the electric field as the proton moves through the 20 V potential difference.

Discuss each student's claims, explaining why each is correct or incorrect.

Student 1 is correct, $\Delta U_{ES} = q\Delta V$

# AP® PHYSICS 2
# 2016 SCORING COMMENTARY

## Question 3

### Overview

This question assessed learning objectives 2.E.2.1, 2.E.2.2, 2.E.3.2, 3.A.3.4, 3.C.2.2, 5.B.4.1, 5.B.4.2, and 5.B.5.4. The question assessed student understanding of an electric potential map, and how the resulting electric forces do work and change the energy of charged masses. The question also assessed understanding of the similarities and differences between the electric and gravitational field.

**Sample: P2 Q3 A**
**Score: 12**

Part (a) earned 1 point for correctly indicating magnitudes and signs of the potentials. Part (b)(i) correctly states that sphere *Y* has a greater magnitude charge because equivalent equipotentials are further from *Y* than *X*. The response also correctly indicates that the signs must be the same because there are no equipotential lines "uniformly parallel directly between the two spheres," i.e., there is no zero potential line or no set of lines that definitively indicate electric field vectors pointing from one sphere to another. Part (b)(i) earned 2 points. Part (b)(ii) earned 1 point. The response correctly refers to the inverse dependence on distance of both the gravitational and the electric potential. While not directly referring to the charge and mass ratios, the second part of the response shows that this was considered since "the potentials from both spheres will combine similarly." Part (c) earned 2 points for describing the difference in the directions of the forces and the similarity of their inverse square dependence on distance. Parts (d)(i) and (d)(ii) both have appropriate work and determine correct expressions, and earned 2 points each. Part (d)(iii) earned 2 points for indicating that both students are correct and giving a correct explanation of the energy or work in terms of each system defined.

**Sample: P2 Q3 B**
**Score: 8**

Part (a) earned no credit. The values in the response would be correct if the given 50 V line was negative, but the negative values are inconsistent with the convention in the exam's table of information that indicates zero potential infinitely far from charged objects. Part (b)(i) earned 1 point for correctly describing how the isolines indicate that *X* is positively charged. But the response incorrectly applies the spacing of the isolines when discussing the relative charge magnitudes. Part (b)(ii) earned no credit because there is no direct discussion of any distance relationship. Part (c) earned 2 points. There are two correct differences mentioned, strength and direction, and a correct similarity in the dependence on distance. The response in part (d)(i) applies the correct potential energy expression, but the wrong potential difference is used, so only 1 point was earned. Part (d)(ii) determines the correct expression for work and earned 2 points. Part(d)(iii) earned 2 points for correctly explaining why each student is correct.

**Sample: P2 Q3 C**
**Score: 3**

Part (a) earned no credit for just indicating signs. Part (b) also earned no credit. In (b)(i) there is no explanation of relative signs, and the reasoning for the magnitudes is incorrect. In (b)(ii) there is some discussion of mass and charge, but it is not a sufficiently clear response, and nothing is mentioned about the distance dependency. Part (c) earned 1 point for correctly indicating a difference — that the proton would be repelled by the charges on the spheres but attracted to them gravitationally. Part (d)(i) earned 1 point for applying the correct equation for the change in potential energy. Part (d)(ii) earned 1 point for using a correct expression for work but does not substitute $E_{avg}$. Part (d)(iii) is incomplete and earned no credit.