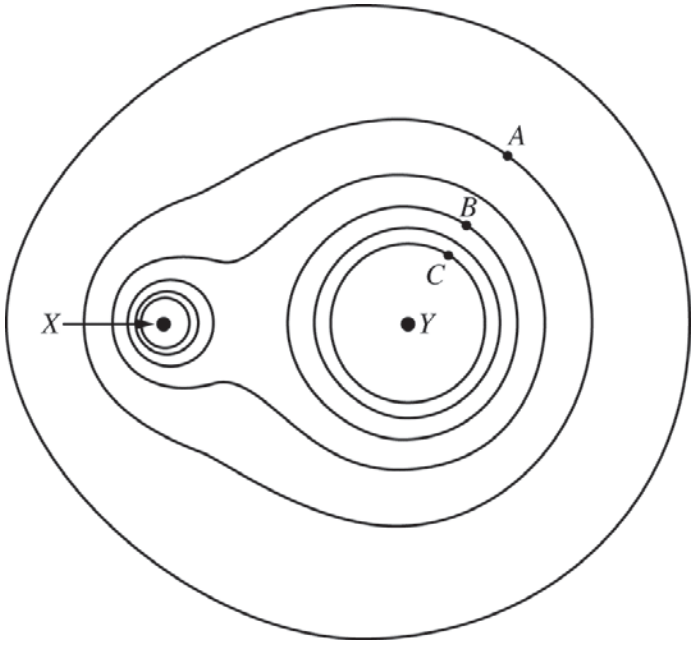

3. (12 points, suggested time 25 minutes)

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* _____ 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.

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.

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.

(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.

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.

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.

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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 ΔV 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.