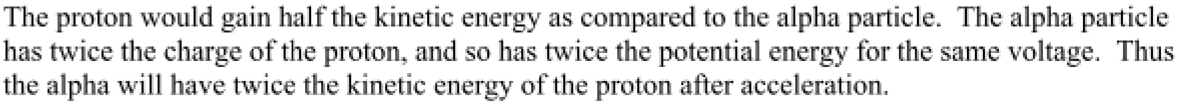
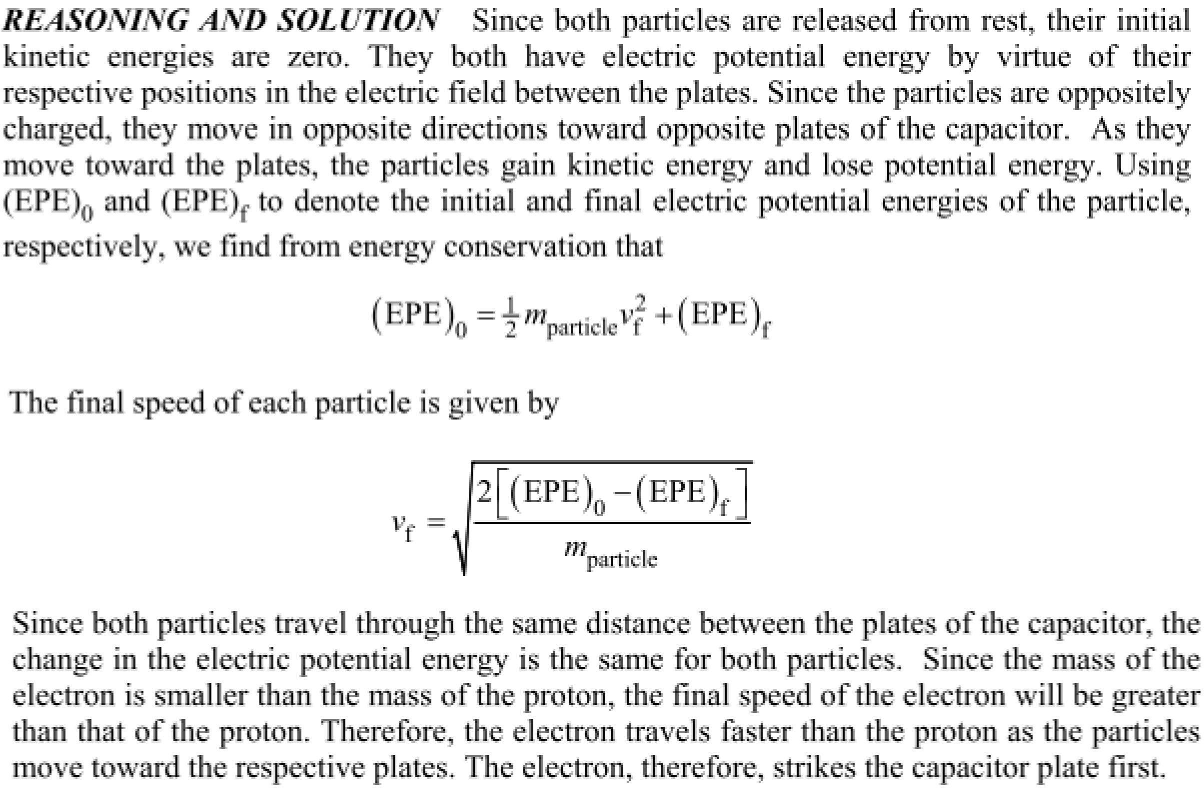
Conceptual Questions

1. Compare the kinetic energy gained by a proton ($q = +e$) to the energy gained by an alpha particle ($q = +2e$) accelerated by the same voltage ΔV. [1]



The proton would gain half the kinetic energy as compared to the alpha particle. The alpha particle has twice the charge of the proton, and so has twice the potential energy for the same voltage. Thus the alpha will have twice the kinetic energy of the proton after acceleration.

2. A proton and an electron are released from rest at the midpoint between the plates of a charged parallel plate capacitor. Except for these particles, nothing else is between the plates. Ignore the attraction between the proton and the electron, and decide which particle strikes a capacitor plate first. Why?[2]



REASONING AND SOLUTION Since both particles are released from rest, their initial kinetic energies are zero. They both have electric potential energy by virtue of their respective positions in the electric field between the plates. Since the particles are oppositely charged, they move in opposite directions toward opposite plates of the capacitor. As they move toward the plates, the particles gain kinetic energy and lose potential energy. Using $(\mathrm{EPE})_0$ and $(\mathrm{EPE})_f$ to denote the initial and final electric potential energies of the particle, respectively, we find from energy conservation that

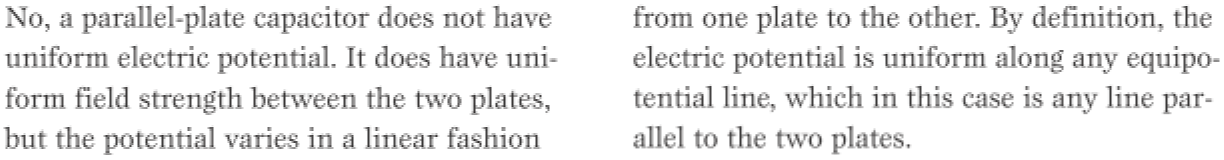
$$(\mathrm{EPE})_0 = \tfrac{1}{2} m_{\text{particle}} v_f^2 + (\mathrm{EPE})_f$$

The final speed of each particle is given by

$$v_f = \sqrt{\frac{2\left[(\mathrm{EPE})_0 - (\mathrm{EPE})_f\right]}{m_{\text{particle}}}}$$

Since both particles travel through the same distance between the plates of the capacitor, the change in the electric potential energy is the same for both particles. Since the mass of the electron is smaller than the mass of the proton, the final speed of the electron will be greater than that of the proton. Therefore, the electron travels faster than the proton as the particles move toward the respective plates. The electron, therefore, strikes the capacitor plate first.

3. Does a parallel-plate capacitor (apparatus) have uniform potential as well as field strength? If not, is there any path that a charge can take where the potential is uniform (does not change)? If so, what is the path called?[3]



No, a parallel-plate capacitor does not have uniform electric potential. It does have uniform field strength between the two plates, but the potential varies in a linear fashion from one plate to the other. By definition, the electric potential is uniform along any equipotential line, which in this case is any line parallel to the two plates.

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[1] Physics 6th Edition, Giancoli, Chapter 17 Questions, #7
[2] Physics, 7th Edition, Cutnell & Johnson, Chapter 19 Conceptual Questions, #16
[3] Physics Book Two, Irwin Publishing, Chapter 8 Conceptual Questions, #29

4. Two parallel plates are placed a distance ***D*** away from each other and a potential difference of ***ΔV*** is applied across them. Point ***A*** is located ***⅔D*** from the positive plate and point ***B*** located on the positive plate. [4]

   a) Which point will have the higher electric field strength? Explain.

   The electric field strength is constant at all locations in a parallel-plate apparatus (sufficiently far from the edges), so the electric field strength at both locations ***A*** and ***B*** will be equal.

   b) Which point will have the higher electric potential? Explain.

   The electric potential of a charged particle in a parallel plate apparatus has a linear dependence (***V α d***) on its distance from the oppositely charged plate. Assuming a positive test charge, point ***B*** is further from the negative plate than point ***A***, so the electric potential at point ***B*** will be higher.

Problems

5. How much kinetic energy is gained by an electron that is allowed to move freely through a potential difference of 2.5×10^4 V?[5]

$V = 2.5 \times 10^4\ \text{V}$
$\Delta E_K = ?$

$$\begin{aligned} \Delta E_K &= q\Delta V \\ &= (1.6\times10^{-19}\ \text{C})(2.5\times10^4\ \text{V}) \\ \Delta E_K &= 4.0\times10^{-15}\ \text{J} \end{aligned}$$

The amount of kinetic energy gained is 4.0×10^{-15} J.

6. A 1.0×10^{-6} C test charge is 40.0 cm from a 3.2×10^{-3} C charged sphere. How much work was required to move it there from a point 1.0×10^2 cm away from the sphere?[6]

$q_1 = 1.0 \times 10–6\ \text{C}$
$q_2 = 3.2 \times 10^{-3}\ \text{C}$
$r_1 = 1.0 \times 10^2\ \text{cm}$
$r_2 = 40.0\ \text{cm} = 0.400\ \text{m}$
$W = ?$

First we must calculate the electric potential before the charge moved:

$$\begin{aligned} V_2 &= \frac{kq}{r_2} \\ &= \frac{(9.0\times10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)(3.2\times10^{-3}\ \text{C})}{0.40\ \text{m}} \\ V_2 &= 7.2\times10^7\ \text{V} \end{aligned}$$

Now we must calculate the electric potential after the charge moved

$$\begin{aligned} V_1 &= \frac{kq}{r_1} \\ &= \frac{(9.0\times10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)(3.2\times10^{-3}\ \text{C})}{1.0\ \text{m}} \\ V_1 &= 2.9\times10^7\ \text{V} \end{aligned}$$

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[4] Almeida, F., Physics Department, Victoria Park C.I.

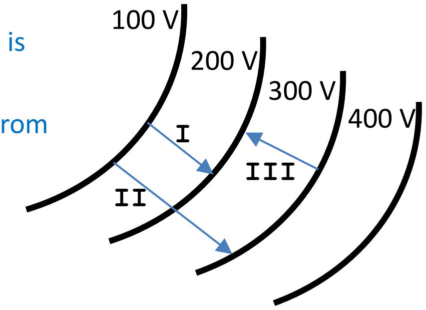
[5] Physics 12, Nelson Education, Section 7.4 Questions, #8

[6] Physics 12, Nelson Education, Chapter 7 Review, #20

To calculate the work:

$$\begin{aligned} W &= q\Delta V \\ &= q(V_2 - V_1) \\ &= (1.0\times10^{-6}\,\mathrm{C})(7.2\times10^{7}\,\mathrm{V} - 2.9\times10^{7}\,\mathrm{V}) \\ W &= 43\ \mathrm{J} \end{aligned}$$

The amount of work required was 43 J.



7. The provided diagram shows lines along which the electric potential is constant and has the value given.

a) Find the work that is required if a charge of 5.0 C is to be moved from the 100.0 V line to the 200.0 V line along path ***I***.

$$W_{NC} = \Delta E_K + \Delta E_P$$
$$W_{NC} = E_{K2} - E_{K1} + E_{E2} - E_{E1}$$
$$W_{NC} = 0 - 0 + qV_2 - qV_1$$
$$W_{NC} = (5.0\ C)(200\ V - 100\ V)$$
$$W_{NC} = 500\ J$$

b) How much work would be required if the same charge were moved along path ***II***?

$$W_{NC} = \Delta E_K + \Delta E_P$$
$$W_{NC} = E_{K2} - E_{K1} + E_{E2} - E_{E1}$$
$$W_{NC} = 0 - 0 + qV_2 - qV_1$$
$$W_{NC} = (5.0\ C)(300\ V - 100\ V)$$
$$W_{NC} = 1000\ J$$

c) If the 5.0 C charge were first to move to the 300.0 V line along path ***II*** and then to the 200.0 V line along path ***III***, how much work would be required then? Compare your answer to that in a).[7]

$$W_{NC} = \Delta E_K + \Delta E_P$$
$$W_{NC} = E_{K2} - E_{K1} + E_{E2} - E_{E1}$$
$$W_{NC} = 0 - 0 + qV_2 - qV_1$$
$$W_{NC} = (5.0\ C)(200\ V - 100\ V)$$
$$W_{NC} = 500\ J$$

This answer is identical to the answer in a). The work required does not depend on the path tha charge takes.

8. An electron is released from rest from the negative plate of a parallel-plate apparatus.[8]

a) At what speed will the electron hit the positive plate if a 450-V potential difference is applied?

$V = 450$ V, $m_e = 9.11 \times 10^{-31}$ kg,
$e = 1.602 \times 10^{-19}$ C

a) $\Delta E_e = qV$
$$\Delta E_e = (1.602 \times 10^{-19}\ \mathrm{C})(450\ \mathrm{V})$$
$$\Delta E_e = 7.21 \times 10^{-17}\ \mathrm{J}$$

Therefore,
$$E_k = \Delta E_e$$
$$\frac{1}{2}mv^2 = \Delta E_e$$
$$v = \sqrt{\frac{2\Delta E_e}{m}}$$
$$v = \sqrt{\frac{2(7.21 \times 10^{-17}\ \mathrm{J})}{9.11 \times 10^{-31}\ \mathrm{kg}}}$$
$$v = 1.26 \times 10^{7}\ \mathrm{m/s}$$

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[7] Physics for the IB Diploma, 4th Edition, Cambridge University Press, Chapter 5.2 Questions, #9

[8] Physics Book Two, Irwin Publishing, Chapter 8 Problems, #91

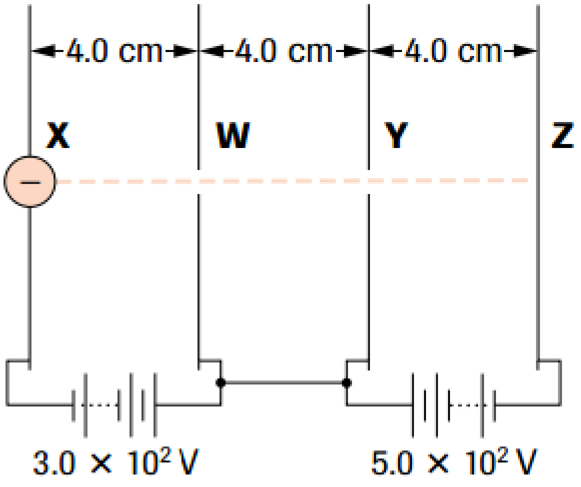
b) What is the electron's speed one-third of the way between the plates?

$$\frac{1}{2}mv^2 = \frac{1}{3}\Delta E_e$$
$$v = \sqrt{\frac{2\Delta E_e}{3m}}$$
$$v = \sqrt{\frac{2(7.21 \times 10^{-17}\ \text{J})}{3(9.11 \times 10^{-31}\ \text{kg})}}$$
$$v = 7.26 \times 10^6\ \text{m/s}$$

9. An electron with a speed of 5.0×10^6 m/s is injected into a parallel plate apparatus through a hole in the positive plate. It moves across the vacuum between the plates, colliding with the negative plate at 1.0×10^6 m/s. What is the potential difference between the plates?[9]

$$W_{NC} = \Delta E_K + \Delta E_P$$
$$W_{NC} = E_{K2} - E_{K1} + E_{E2} - E_{E1}$$
$$0 = \tfrac{1}{2}mv_2^2 - \tfrac{1}{2}mv_1^2 + 0 - qd_1\frac{\Delta V}{D}$$
$$\Delta V = 0.5m\frac{D}{qD}(v_1^2 - v_2^2)$$
$$\Delta V = \frac{0.5m}{q}(v_1^2 - v_2^2)$$
$$\Delta V = \frac{0.5(9.11\times10^{-31}kg)}{1.602\times10^{-19}C}[(5.0\times10^6 m/s)^2 - (1.0\times10^6 m/s)^2]$$
$$\Delta V = 68\ V$$

10. Four parallel plates are connected in a vacuum as shown. An electron, essentially at rest, drifts into the hole in plate ***X*** and is accelerated to the right. The vertical motion of the electron continues to be negligible. The electron passes through holes ***W*** and ***Y***, then continues moving toward plate ***Z***. Using the information given in the diagram, calculate[10]



a) the speed of the electron at hole ***W***.

$r_{XW} = r_{WY} = r_{YZ} = 4.0$ cm
$V_1 = 3.0 \times 10^2$ V
$V_2 = 5.0 \times 10^2$ V
(a) $v = ?$

$$\frac{1}{2}mv^2 = qV$$
$$v = \sqrt{\frac{2qV}{m}}$$
$$= \sqrt{\frac{2(1.6\times10^{-19}\text{C})(3.0\times10^2\text{V})}{9.11\times10^{-31}\text{kg}}}$$
$$v = 1.0\times10^7\ \text{m/s}$$

The speed of the electron at hole W is 1.0×10^7 m/s.

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[9] Fundamentals of Physics: A Senior Course, Martindale, 15.9 Review Problems #38
[10] Physics 12, Nelson Education, Chapter 7 Review, #33

b) the distance from plate ***Z*** to the point at which the electron changes direction.

(b) Since plates W and Y are connected together, there is no field between them, so the charge drifts with a constant speed through hole Y. Since 3.0 × 10^2 V was used to accelerate the electron then the same amount is required to stop it. The distance from the plate Y is:

$$\frac{d}{4.0\text{ cm}} = \frac{3.0\times10^2\text{ V}}{5.0\times10^2\text{ V}}$$

$$d = 2.4\text{ cm}$$

Therefore the electron is 4.0 cm – 2.4 cm = 1.6 cm from plate Z when it stops.

c) the speed of the electron when it arrives back at plate ***X***.

The path is reversible, so that the electron arrives back at X with $v = 0$ m/s. Since this 3.0 × 10^2 V was initially used to accelerate the electron then it will also stop it.