B8 · Extra practice, worked solutions

Energy conservation and 2-D motion of charges | Diploma-style set of 8

Easy · B8-X01. A charged pith ball of mass 2.00×10^{-4} kg is released from rest. It loses 8.00×10^{-7} J of electric potential energy as it moves, and no other energy changes. Find its final speed in m/s.

1. Givens: starts from rest; $m = 2.00 \times 10^{-4}$ kg; $\Delta E_p = -8.00 \times 10^{-7}$ J. Question: v.

2. Energy is conserved, so the lost potential energy becomes kinetic energy: $\frac{1}{2}mv^2 = 8.0 \times 10^{-7}$ J.

3. $v = \sqrt{(2E_k \div m)} = \sqrt{(2 \times 8.00 \times 10^{-7} \div (2.00 \times 10^{-4}))} = 0.0894$ m/s.

4. Answer: 0.0894 m/s

Easy · B8-X02. An electron enters the space between two plates moving parallel to them at 4.00×10^{6} m/s. The plates are 0.0800 m long. Find the time it takes to travel the length of the plates, in seconds.

1. Givens: horizontal speed 4.00×10^{6} m/s (no force in this direction, so it is constant); length 0.0800 m. Question: t.

2. Constant speed: $\Delta x = vt$.

3. $t = \Delta x \div v = 0.0800 \div (4.00 \times 10^{6}) = 2.00 \times 10^{-8}$ s.

4. Answer: 2.00×10^{-8} s

Easy · B8-X03. A charge enters the space between horizontal plates moving sideways. While it is between the plates, what is true about its horizontal velocity?

A. It increases, because the electric force pushes it forward.

B. It decreases, because the plates slow it down.

C. It becomes zero halfway through.

D. It stays constant, because the electric force has no horizontal part.

1. Givens: the plates make a vertical field and so a vertical force. Question: the horizontal velocity.

2. No force acts horizontally, so there is no horizontal acceleration. The horizontal velocity stays constant.

3. Answer: D. It stays constant, because the electric force has no horizontal part.

Medium · B8-X04. A charged particle at A has 3.00×10^{-7} J of kinetic energy and 9.00×10^{-7} J of electric potential energy. At B its potential energy is 2.00×10^{-7} J. Only the electric force acts. Find its kinetic energy at B, in joules.

1. Givens: $E_k(A) = 3.00 \times 10^{-7}$ J; $E_p(A) = 9.00 \times 10^{-7}$ J; $E_p(B) = 2.00 \times 10^{-7}$ J. Question: $E_k(B)$.

2. Total energy is conserved: $E_k(A) + E_p(A) = E_k(B) + E_p(B)$.

3. Total $= 3.00 \times 10^{-7} + 9.00 \times 10^{-7} = 1.20 \times 10^{-6}$ J.

4. $E_k(B) = 1.20 \times 10^{-6} - 2.00 \times 10^{-7} = 1.00 \times 10^{-6}$ J.

5. Answer: 1.00×10^{-6} J

Medium · B8-X05. An electron enters between plates at 5.00×10^{6} m/s, parallel to them. The plates are 0.100 m long, and the electron has a constant acceleration of 2.20×10^{14} m/s² across the plates. Find its sideways shift across the plates, in metres.

1. Givens: horizontal speed 5.00×10^{6} m/s; length 0.100 m; vertical acceleration 2.20×10^{14} m/s²; no vertical speed at the start (so $v_{yi} = 0$ m/s). Question: Δy.

2. Time from the horizontal motion: $t = \Delta x \div v = 0.100 \div (5.00 \times 10^{6}) = 2.00 \times 10^{-8}$ s.

3. Vertical shift: $\Delta y = \frac{1}{2}at^2 = \frac{1}{2}(2.20 \times 10^{14})(2.00 \times 10^{-8})^2 = 0.0440$ m.

4. Answer: 0.0440 m

Medium · B8-X06. A charge enters sideways between two plates. Which pair of equations describes its horizontal and vertical motion while it is between them?

A. Horizontal: $\Delta x = vt$; vertical: $\Delta y = \frac{1}{2}at^2$
B. Horizontal: $\Delta x = \frac{1}{2}at^2$; vertical: $\Delta y = vt$
C. Horizontal: $\Delta x = \frac{1}{2}at^2$; vertical: $\Delta y = \frac{1}{2}at^2$
D. Horizontal: $\Delta x = vt$; vertical: $\Delta y = vt$

1. Givens: a sideways entry, so no vertical speed to start. Question: the two equations.

2. Horizontally there is no force, so the speed is constant: $\Delta x = vt$.

3. Vertically the force is constant and the starting vertical speed is zero, so $\Delta y = \frac{1}{2}at^2$.

4. Answer: A. Horizontal: $\Delta x = vt$; vertical: $\Delta y = \frac{1}{2}at^2$

Challenging · B8-X07. An electron enters midway between two plates that are 0.0400 m apart, moving parallel to them at 3.00×10^{6} m/s. The plates are 0.0900 m long. The electron must just miss the plate, so it can shift sideways by at most half the gap. Use $e = 1.60 \times 10^{-19}$ C and electron mass $m_e = 9.11 \times 10^{-31}$ kg. Find the largest potential difference that lets it leave, in volts.

1. Givens: $\Delta d = 0.0400$ m; most shift = 0.0200 m; $v = 3.00 \times 10^{6}$ m/s; $L = 0.0900$ m; $v_{yi} = 0$ m/s. Question: ΔV.

2. Time: $t = L \div v = 0.0900 \div (3.00 \times 10^{6}) = 3.00 \times 10^{-8}$ s.

3. Acceleration from $\Delta y = \frac{1}{2}at^2$: $a = 2\Delta y \div t^2 = 2(0.0200) \div (3.00 \times 10^{-8})^2 = 4.44 \times 10^{13}$ m/s².

4. $F = ma$, $E = F/q$: $E = ma/q = (9.11 \times 10^{-31})(4.44 \times 10^{13}) \div (1.60 \times 10^{-19}) = 253$ V/m.

5. $\Delta V = E\Delta d = (253)(0.0400) = 10.1$ V.

6. Answer: 10.1 V

Challenging · B8-X08. An electron is accelerated from rest through a potential difference, then enters the gap between two other plates sideways. Say which physics principle you use to find its speed entering the gap, and which two ideas you use to find how far it is shifted across the gap. Give the order.

1. Givens: acceleration from rest through ΔV, then a sideways entry between plates. Question: which principle gives the speed, which ideas give the shift, and in what order.

2. Step 1: conservation of energy. $q\Delta V = \frac{1}{2}mv^2$ gives the speed v at the entrance.

3. Step 2: uniform motion, horizontally: $\Delta x = vt$ gives the time in the gap.

4. Step 3: uniform acceleration, vertically: $a = qE/m$ and $\Delta y = \frac{1}{2}at^2$, using that time. The speed comes first because the time needs it.