B8 · Energy conservation and 2-D motion of charges

Student notes - follow the slides, fill the blanks, work the questions

Use energy conservation, then split a sideways-entering charge into constant-speed and accelerated motion.

Name: _____ Date: _____

Slide 1 of 7 · Energy conservation for a charge in a field

Ep means electric potential energy and Ek means kinetic energy, as in B6. “At A” and “at B” name the two points. Only the electric force does work, so total energy _____: Ep(A) + Ek(A) = _____.

If the charge starts _____, Ek(A) = 0, so Ek(B) = _____. The potential energy lost becomes _____.

Then ½mv² = Ek, so v = _____. Use the object’s own _____ (the ball’s, not an electron’s).

The charge q is not needed when the energies are given. To compare speeds at two points, compare the _____: more kinetic energy means more speed for the same mass.

Example. A charged pith ball ($m = 2.00 \times 10^{-4}$ kg, $q = 1.5 \times 10^{-8}$ C) is held at A in a uniform field with 4.0×10^{-7} J of electric potential energy, then released. At B it has 2.5×10^{-8} J of electric potential energy. Find its speed at B.

Work:

Answer: _____

Try it. The same pith ball is released from rest at A, which has 4.0×10^{-7} J of electric potential energy. It reaches a point C where its electric potential energy is 1.0×10^{-7} J. Find its kinetic energy at C and say whether its speed there is greater or less than at B (where Ek = 3.75×10^{-7} J).

Work:

Answer: _____

Slide 2 of 7 · A charge entering a uniform field sideways

A charge entering a field sideways is like a ball rolling off a table: it keeps moving forward while a _____ pulls it down. Here the force is _____, and gravity is too small to matter. The horizontal speed v_x is the speed _____.

The electric force is at _____ to the plates and points toward the plate of the opposite sign (an electron toward the _____ plate). Motion does not need a force in its own direction.

The two directions do not _____ each other. Horizontal: net force _____, acceleration zero, constant velocity v_x, _____ motion. Vertical: constant force, constant acceleration a = _____, speed grows from zero, _____ motion.

Together these make a _____. In explanations say “net force zero” or “constant force” in each direction.

Example. An electron enters the uniform field between parallel plates moving horizontally with speed v_x. Gravity is too small to matter. The top plate is negative and the bottom plate is positive. Complete the table for horizontal and vertical motion (net force, acceleration, velocity, motion type), then name the shape of the path.

Work:

Answer: _____

Try it. A proton enters the same field at the same horizontal speed as the electron, beside the top plate (negative top, positive bottom). Compare the proton’s path with the electron’s path in direction and in how sharply it bends.

Work:

Answer: _____

Sketch (draw and label the diagram):

Slide 3 of 7 · From acceleration back to voltage

To go from motion back to voltage, work the chain backward from what you want, then forward with numbers. The electric force is the only force, so F = _____.

Then E = _____, where q is the charge that feels the force (use the electron's size, 1.60×10^{-19} C; the direction is found separately), and then ΔV = _____ (multiply both sides of E = ΔV/Δd by Δd). Each formula has three quantities, so each step is one _____, with units.

Write the chain of formulas _____, before any numbers: a → F → E → ΔV. Use the electron's mass and charge from the data sheet.

Never use ΔV = ΔEp/q here: the _____ is not given.

Example. An electron ($m = 9.11 \times 10^{-31}$ kg, $q = 1.60 \times 10^{-19}$ C) between parallel plates has an acceleration of 3.00×10^{15} m/s². The plates are 0.0360 m apart. Find the potential difference between the plates.

Work:

Answer: _____

Try it. An electron ($m = 9.11 \times 10^{-31}$ kg, $q = 1.60 \times 10^{-19}$ C) has an acceleration of 2.50×10^{15} m/s² between plates 0.0480 m apart. Find the potential difference between the plates.

Work:

Answer: _____

Slide 4 of 7 · The full two-direction problem

L is the _____ and Δd is the _____. Time is the _____ between the two directions. Horizontal motion is uniform: t = _____.

Vertically $\Delta d = v_i t + \frac{1}{2}at^2$, and the vertical starting speed v_i is _____, so Δd = _____, which gives a = _____. Then run the chain: F = _____, E = _____, ΔV = _____.

“Just reaches the far end of the other plate” means the particle starts beside one plate and covers the full gap Δd (the vertical distance) in the time t. This is the greatest voltage that lets the electron escape: a bigger voltage gives a bigger acceleration, and the electron would hit the plate _____. Set up two columns, horizontal and vertical, and fill in what you know in each.

For the final speed, the vertical speed is v_y = _____ (from $v^2 = v_i^2 + 2ad$ with v_i = 0, and d the vertical distance); combine it with v_x as two sides of a right triangle: v = _____, angle θ = $\tan^{-1}$(_____), measured from the _____. Name the principles in order: uniform motion, then uniform acceleration.

Example. An electron enters horizontally at $v_x = 4.00 \times 10^6$ m/s beside one plate. The plates are L = 0.100 m long and Δd = 0.0400 m apart. It just reaches the far end of the other plate. Find the potential difference between the plates. ($m = 9.11 \times 10^{-31}$ kg, $q = 1.60 \times 10^{-19}$ C)

Work:

Answer: _____

Try it. An electron enters horizontally at 3.00×10^6 m/s beside one plate. The plates are 0.0800 m long and 0.0300 m apart, and it just reaches the far end of the other plate. Find the potential difference between the plates, and name the two physics principles you used, in order.

Work:

Answer: _____

Sketch (draw and label the diagram):

Slide 5 of 7 · Method: how to solve a two-direction problem

Step 1, _____: make an x column (along the plates, _____) and a y column (across the plates, _____).

Step 2, _____: write what you know in each column. A sideways entry means the across speed at the start is _____.

Step 3, _____: time is the _____ between the two columns. Get it from the column with enough numbers: t = _____.

Step 4, _____: across the plates, Δd = _____, F = _____, E = _____ and ΔV = _____. Use the chain forwards or backwards.

Step 5, _____: v_y = _____. Then v = _____ and the angle = _____ from the horizontal.

Check: v_x never changes and v_y grows with time, so the final speed must be _____.

Example. An electron enters horizontally at $v_x = 4.00 \times 10^{6}$ m/s beside one plate. The plates are L = 0.100 m long and Δd = 0.0400 m apart, and it just reaches the far end of the other plate. Use the five steps to find the potential difference between the plates, then the final speed and the angle. ($m = 9.11 \times 10^{-31}$ kg, $q = 1.60 \times 10^{-19}$ C)

Work:

Answer: _____

Try it. NEW, for teacher review. An electron enters horizontally at 2.50×10^{6} m/s beside one plate. The plates are 0.0600 m long and 0.0150 m apart, and it just reaches the far end of the other plate. Use the five steps to find the potential difference between the plates and the final speed.

Work:

Answer: _____

Slide 6 of 7 · Where does the particle land?

A long numerical response is worth doing in order, with each result _____: field, force, acceleration, time, distance.

Field from the voltage and the gap: E = _____. Acceleration with the particle's own charge and mass: a = _____.

Vertical motion starts at zero vertical speed and covers the gap: Δd = _____, so t = _____. Horizontal motion is constant speed, so the horizontal distance is x = _____.

Check the units at the end, then record the answer as _____ with its unit and three digits.

Example. An alpha particle ($q = 3.20 \times 10^{-19}$ C, $m = 6.65 \times 10^{-27}$ kg) enters horizontally at 2.00×10^{5} m/s beside the top plate of a pair of plates 0.0260 m apart with 600 V across them. The top plate is positive and the bottom plate is negative, so the alpha particle is pushed toward the bottom plate and lands on it. Find the horizontal distance it travels. Record the answer as $a.bc \times 10^{n}$ m.

Work:

Answer: _____

Try it. An electron ($q = 1.60 \times 10^{-19}$ C, $m = 9.11 \times 10^{-31}$ kg) enters horizontally at 5.00×10^{6} m/s beside the top plate of a pair of plates 0.0200 m apart with 100 V across them. The top plate is negative and the bottom plate is positive, so the electron is pulled toward the bottom plate and lands on it. Find the horizontal distance it travels.

Work:

Answer: _____

Sketch (draw and label the diagram):

Slide 7 of 7 · Still charges: the oil-drop experiment

A drop that hangs still has _____. The electric force _____ equals the weight _____: qE = _____. So q = _____. Find the field first: E = _____.

Count the extra electrons with n = _____, where e = _____. Electrons are counted, so n is a _____. Use g = _____.

The field points from the positive plate to the negative plate. A drop pushed _____ the field is negative. A negative drop has _____ electrons.

Millikan found that every measured charge was a whole-number multiple of _____: q = _____. A value that gives a _____ when divided by e cannot be right. Charge comes in _____.

Example. An oil drop of mass 1.96×10^{-15} kg hangs still between plates 0.0100 m apart with 400 V across them. The top plate is positive. Find the charge on the drop and the number of extra electrons. ($g = 9.81$ m/s², $e = 1.60 \times 10^{-19}$ C)

Work:

Answer: _____

Try it. NEW, for teacher review. A drop of mass 3.26×10^{-15} kg hangs still between plates 0.0200 m apart with 500 V across them. The top plate is positive. Find the charge on the drop and the number of extra electrons. ($g = 9.81$ m/s², $e = 1.60 \times 10^{-19}$ C)

Work:

Answer: _____

B8 · practice

Energy conservation and 2-D motion of charges | Questions 1-2 of 7

Constants from the Alberta Physics 30 data sheets: $k = 8.99 \times 10^{9}$ N·m²/C², $e = 1.60 \times 10^{-19}$ C, electron mass $m_e = 9.11 \times 10^{-31}$ kg, proton mass $m_p = 1.67 \times 10^{-27}$ kg, $g = 9.81$ m/s².

Easy · B8-N01. A charged ball ($m = 3.00 \times 10^{-4}$ kg) is released from rest where its electric potential energy is 5.0×10^{-6} J. At another point its electric potential energy is 8.0×10^{-7} J. Find its speed there.

Work:

Final answer (with unit and sign): _____

Easy · B8-N02. A proton enters a uniform field between horizontal plates moving parallel to the plates. Which statement describes its motion?

A. Constant velocity parallel to the plates and constant acceleration across them
B. Constant acceleration in both directions
C. Constant velocity in both directions
D. Velocity changes parallel to the plates only

Work:

Final answer (with unit and sign): _____

B8 · practice

Energy conservation and 2-D motion of charges | Questions 3-4 of 7

Easy · B8-N03. Name the shape of the path of a charged particle that enters a uniform electric field at right angles to the field. Explain with one sentence about each direction.

Work:

Final answer (with unit and sign): _____

Medium · B8-N04. An electron has an acceleration of 4.00×10^{15} m/s² between plates 0.0250 m apart. Find the potential difference between the plates.

Work:

Final answer (with unit and sign): _____

B8 · practice

Energy conservation and 2-D motion of charges | Questions 5-6 of 7

Medium · B8-N05. An electron enters horizontally at 5.00×10^6 m/s beside one plate. The plates are 0.120 m long. How long does the electron take to cross the plates?

Work:

Final answer (with unit and sign): _____

Challenging · B8-N06. Use the electron from the previous question. It just reaches the far end of the other plate, so it moves 0.0500 m across the gap during that time. Find the potential difference between the plates.

Work:

Final answer (with unit and sign): _____

B8 · practice

Energy conservation and 2-D motion of charges | Questions 7-7 of 7

Challenging · B8-N07. In the previous two questions, name the principles you used in order. Give one principle that also describes the event but you did not need.

Work:

Final answer (with unit and sign): _____