

Field maps, voltage and energy per unit charge

AP Physics 2 (algebra-based) · Worksheet answers

Compare your working with each answer. Credit in AP-style marking goes to the correct relation, a substitution with units and a conclusion that states direction or sign where relevant. Small rounding differences are acceptable.

Level: AP Physics 2 (algebra-based) · **Curriculum:** AP P2 Unit 10

Problem 1 Field from a force

1. $E = F/q = 6.0 \times 10^{-6} / 2.0 \times 10^{-9} = \mathbf{3.0 \times 10^3 \text{ N/C}}$.
2. **East**, the direction of the force on a positive charge.
3. Same size, $6.0 \times 10^{-6} \text{ N}$, but **west**, opposite to the field.

Problem 2 Field of a point charge

1. $E = kQ/r^2 = (8.99 \times 10^9)(3.0 \times 10^{-9}) / (0.15)^2 = \mathbf{1.2 \times 10^3 \text{ N/C}}$.
2. Towards the charge, since it is negative.

Problem 3 Reading field lines

1. **Charge A:** the closer the lines, the stronger the field.
2. The direction of the force on a positive test charge.
3. At a crossing point the field would have two directions at once, but the field at a point has only one direction.

Problem 4 Field between plates

1. $E = V/d = 300 / 0.015 = \mathbf{2.0 \times 10^4 \text{ V/m}}$.
2. $F = qE = 4.0 \times 10^{-9} \times 2.0 \times 10^4 = \mathbf{8.0 \times 10^{-5} \text{ N}}$.

Problem 5 Energy from a voltage

1. $\Delta U = q\Delta V = 2.0 \times 10^{-6} \times 12 = \mathbf{2.4 \times 10^{-5} \text{ J}}$.
2. One volt is one joule of energy per coulomb of charge: $1 \text{ V} = 1 \text{ J/C}$.

Problem 6 Electron-volts

1. **250 eV**.
2. $250 \times 1.60 \times 10^{-19} = \mathbf{4.0 \times 10^{-17} \text{ J}}$.
3. $3.2 \times 10^{-17} / 1.60 \times 10^{-19} = \mathbf{200 \text{ eV}}$.

Problem 7 Electron between plates

1. $E = 150 / 0.030 = \mathbf{5.0 \times 10^3 \text{ V/m}}$.
2. $F = eE = 8.0 \times 10^{-16} \text{ N}$, so $a = F/m = \mathbf{8.8 \times 10^{14} \text{ m/s}^2}$.
3. $\frac{1}{2}mv^2 = e\Delta V$, so $v = \sqrt{(2 \times 1.60 \times 10^{-19} \times 150 / 9.11 \times 10^{-31})} = \mathbf{7.3 \times 10^6 \text{ m/s}}$.

Problem 8 Potential of a point charge

1. $V = kQ/r$: at 0.20 m, $\mathbf{3.6 \times 10^2 \text{ V}}$; at 0.40 m, $\mathbf{1.8 \times 10^2 \text{ V}}$.
2. $\Delta V = 360 - 180 = \mathbf{1.8 \times 10^2 \text{ V}}$.
3. $W = q\Delta V = 1.0 \times 10^{-9} \times 180 = \mathbf{1.8 \times 10^{-7} \text{ J}}$, supplied from outside since the charges repel.

Problem 9 Equipotential rings

1. V at the rings: 360 V (0.10 m) and 90 V (0.40 m). $W = q\Delta V = 2.0 \times 10^{-9} \times 270 = \mathbf{5.4 \times 10^{-7} \text{ J}}$.
2. **Zero**: the ring is an equipotential, so $\Delta V = 0$.
3. Radially outward, perpendicular to the ring.

Problem 10 Proton down a potential

1. $\Delta U = q\Delta V = 1.60 \times 10^{-19} \times (-300) = \mathbf{-4.8 \times 10^{-17} \text{ J}}$ (300 eV lost).
2. The kinetic energy gained is $4.8 \times 10^{-17} \text{ J}$, so $v = \sqrt{(2 \times 4.8 \times 10^{-17} / 1.67 \times 10^{-27})} = \mathbf{2.4 \times 10^5 \text{ m/s}}$.

Problem 11 Field from a potential graph

1. Gradient = $(20 - 80) / 6.0 = -10 \text{ V/cm} = \mathbf{-1000 \text{ V/m}}$.
2. $E = -dV/dx = \mathbf{1.0 \times 10^3 \text{ V/m}}$ in the **+x direction** (towards lower potential).
3. $F = eE = 1.60 \times 10^{-19} \times 1000 = \mathbf{1.6 \times 10^{-16} \text{ N}}$ in **+x**.

Problem 12 Midpoint between opposite charges

1. Each: $E = (8.99 \times 10^9)(3.0 \times 10^{-9}) / (0.10)^2 = \mathbf{2.7 \times 10^3 \text{ N/C}}$. Away from the positive charge and towards the negative: both point towards +x.
2. The fields add: $\mathbf{5.4 \times 10^3 \text{ N/C}}$ towards +x.
3. $V = kQ/0.10 - kQ/0.10 = \mathbf{0 \text{ V}}$.

Problem 13 Droplet held at rest

1. $E = 600 / 0.0050 = \mathbf{1.2 \times 10^5 \text{ V/m}}$.
2. $qE = mg$, so $q = 5.9 \times 10^{-15} \times 9.81 / 1.2 \times 10^5 = \mathbf{4.8 \times 10^{-19} \text{ C}}$.
3. $N = 4.8 \times 10^{-19} / 1.60 \times 10^{-19} = \mathbf{3 \text{ electrons}}$. The force is upward, towards the positive plate, so the droplet is negative.

Problem 14 Energy of two charges

- $U = kq_1q_2/r = (8.99 \times 10^9)(2.0 \times 10^{-6})(3.0 \times 10^{-6}) / 0.30 = \mathbf{0.18 \text{ J}}$.
- All the potential energy becomes kinetic: $\frac{1}{2}mv^2 = 0.1798$, so $v = \sqrt{(2 \times 0.1798 / 0.010)} = \mathbf{6.0 \text{ m/s}}$.

Problem 15 Charge inside a conductor

- Zero.**
- Free charges move until their own field cancels the external field inside, which leaves the excess charge on the outer surface.
- The charge flows around the outside of the body and the field inside the cavity is zero, so no current flows through the people.

Problem 16 Electron beam deflection

- $E = 100 / 0.010 = 1.0 \times 10^4 \text{ V/m}$; $a = eE/m = \mathbf{1.76 \times 10^{15} \text{ m/s}^2}$.
- $t = 0.040 / 2.0 \times 10^7 = \mathbf{2.0 \times 10^{-9} \text{ s}}$.
- $y = \frac{1}{2}at^2 = 0.5 \times 1.756 \times 10^{15} \times (2.0 \times 10^{-9})^2 = \mathbf{3.5 \text{ mm}}$, less than the 5.0 mm half-gap, so it escapes.
- $v_y = at = 3.5 \times 10^6 \text{ m/s}$; $\tan\theta = 3.5 \times 10^6 / 2.0 \times 10^7$, so $\theta = \mathbf{10^\circ}$.

Problem 17 Opposite charges on a line

- $V = kQ/0.20 - kQ/0.20 = \mathbf{0 \text{ V}}$. Each field is 449.5 N/C pointing the same way, so $E = \mathbf{9.0 \times 10^2 \text{ N/C}}$ towards the negative charge.
- $V = kQ(1/0.10 - 1/0.30) = 17.98 \times 6.667 = \mathbf{1.2 \times 10^2 \text{ V}}$.
- $W = q\Delta V = 1.0 \times 10^{-9} \times 120 = \mathbf{1.2 \times 10^{-7} \text{ J}}$.

Problem 18 Ball in a horizontal field

- Weight down, tension along the thread, electric force horizontal in the direction of the field (positive charge).
- $T \cos 20^\circ = mg$ and $T \sin 20^\circ = qE$, so $E = mg \tan 20^\circ / q = 0.0020 \times 9.81 \times 0.364 / 5.0 \times 10^{-6} = \mathbf{1.4 \times 10^3 \text{ N/C}}$.
- $\Delta V = Ed = 1428 \times 0.050 = \mathbf{71 \text{ V}}$.

Problem 19 Closest approach

- $K = 5.0 \times 10^6 \times 1.60 \times 10^{-19} = \mathbf{8.0 \times 10^{-13} \text{ J}}$.
- At closest approach all K has become potential energy: $K = k(2e)(79e)/r$.
- $r = (8.99 \times 10^9)(158)(1.60 \times 10^{-19})^2 / 8.0 \times 10^{-13} = \mathbf{4.5 \times 10^{-14} \text{ m}}$.

Problem 20 Reading an equipotential map

1. $20 / 0.020 = \mathbf{1000 \text{ V/m}}$, $20 / 0.020 = \mathbf{1000 \text{ V/m}}$, and $20 / 0.010 = \mathbf{2000 \text{ V/m}}$.
2. Perpendicular to the lines, from high to low potential (from the 60 V side towards the 0 V side).
3. $W = q\Delta V = 2.0 \times 10^{-6} \times 60 = \mathbf{1.2 \times 10^{-4} \text{ J}}$.
4. Between the 40 V and 60 V lines, where the lines are closest: the field and the force are strongest there.