

Charging objects and the force between charges

AP Physics 2 (algebra-based) · Worksheet answers

Compare each answer with your own working. For full credit on AP-style problems, name the law, substitute with units, give the direction of any force and write the final answer with a sensible number of significant figures.

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

Problem 1 Counting electrons

1. Extra electrons make it **negative**.
2. $Q = Ne = 2.0 \times 10^{13} \times 1.60 \times 10^{-19} = \mathbf{3.2 \times 10^{-6} \text{ C}}$.
3. $N = 1.0 \times 10^{-6} / 1.60 \times 10^{-19} = \mathbf{6.3 \times 10^{12}}$ electrons.

Problem 2 Charging by friction

1. $Q = 5.0 \times 10^{10} \times 1.60 \times 10^{-19} = \mathbf{-8.0 \times 10^{-9} \text{ C}}$.
2. The wool lost the same electrons: $\mathbf{+8.0 \times 10^{-9} \text{ C}}$.
3. The total is **zero**, an example of conservation of charge.

Problem 3 Attract or repel

1. **Repulsive**: like charges repel.
2. **Attractive**: unlike charges attract.
3. **Attractive**: the rod polarises the ball, bringing the opposite charge nearer to the rod than the like charge.

Problem 4 A simple Coulomb force

1. $F = (8.99 \times 10^9)(4.0 \times 10^{-6})(6.0 \times 10^{-6}) / (0.50)^2 = \mathbf{0.86 \text{ N}}$ on each sphere (Newton's third law).
2. **Repulsive**.
3. Directly away from the $+6.0 \mu\text{C}$ sphere, along the line joining them.

Problem 5 Unit conversions

1. $3.5 \times 10^{-6} \text{ C}$: $\mathbf{3.5 \times 10^{-6} \text{ C}}$.
2. $\mathbf{2.5 \times 10^{-7} \text{ C}}$.
3. $\mathbf{0.040 \text{ m}}$.
4. $0.75 \text{ mC} = 0.75 \times 10^{-3} \text{ C} = \mathbf{750 \mu\text{C}}$.

Problem 6 Inverse-square scaling

1. Twice the distance: $12 / 4 = \mathbf{3.0\ N}$.
2. Half the distance: $12 \times 4 = \mathbf{48\ N}$.
3. Three times the distance: $12 / 9 = \mathbf{1.3\ N}$.

Problem 7 Changing charge and distance

1. Factor = $2 / 3^2 = 2/9$, so $F = 0.90 \times 2/9 = \mathbf{0.20\ N}$.
2. Factor = $(2 \times 2) / (\frac{1}{2})^2 = 16$, so $F = \mathbf{14\ N}$ (14.4 N).
3. With one charge zero, $F = \mathbf{0\ N}$.

Problem 8 Charging by induction

1. Free electrons move towards the rod, so the near side is negative and the far side is positive.
2. Electrons flow from the earth, through Bilal, onto the sphere, attracted by the positive rod.
3. The sphere now has extra electrons and, with the earth path gone, keeps them: the final charge is **negative**, opposite to the rod.

Problem 9 Electroscope

1. Electrons are repelled down to the leaves, which become negative and repel each other, while the disc becomes positive.
2. The leaves **fall together** because the electrons return and the electroscope is neutral overall.
3. Some electrons transfer to the electroscope, so it gains a net negative charge and the leaves **stay apart**.

Problem 10 Comb and paper

1. The comb polarises the paper: charge shifts slightly within each atom so the side nearest the comb has the opposite sign.
2. The opposite charge is **closer** to the comb than the like charge, and the force falls with distance, so attraction wins.
3. The pieces gain charge from the comb on contact and then carry the same sign, so they are repelled.

Problem 11 Finding an unknown charge

1. $F = kq^2/r^2$, so $q = r\sqrt{(F/k)}$.
2. $q = 0.10 \times \sqrt{(2.7 / 8.99 \times 10^9)} = 0.10 \times 1.733 \times 10^{-5} = \mathbf{1.7 \times 10^{-6}\ C}$ (1.7 μC).

Problem 12 Net force on a line

1. Attraction towards $-x$: $F = (8.99 \times 10^9)(6.0 \times 10^{-6})(1.0 \times 10^{-6}) / (0.10)^2 = \mathbf{5.4 \text{ N}}$.
2. Attraction towards $+x$, distance 0.30 m: $F = (8.99 \times 10^9)(2.0 \times 10^{-6})(1.0 \times 10^{-6}) / (0.30)^2 = \mathbf{0.20 \text{ N}}$.
3. Net = $5.39 - 0.20 = \mathbf{5.2 \text{ N}}$ towards $-x$.

Problem 13 Sharing charge

1. $F = (8.99 \times 10^9)(8.0 \times 10^{-6})(2.0 \times 10^{-6}) / (0.20)^2 = \mathbf{3.6 \text{ N}}$, attractive.
2. Total $+6.0 \mu\text{C}$ shared equally: $\mathbf{+3.0 \mu\text{C}}$ each.
3. $F = (8.99 \times 10^9)(3.0 \times 10^{-6})^2 / (0.20)^2 = \mathbf{2.0 \text{ N}}$, repulsive.

Problem 14 Electric force in hydrogen

1. $F_e = (8.99 \times 10^9)(1.60 \times 10^{-19})^2 / (5.3 \times 10^{-11})^2 = \mathbf{8.2 \times 10^{-8 \text{ N}}}$.
2. $F_g = Gm_em_p/r^2 = \mathbf{3.6 \times 10^{-47 \text{ N}}}$.
3. $F_e/F_g = \mathbf{2.3 \times 10^{39}}$, so gravity is negligible inside atoms.

Problem 15 Force against $1/r^2$ graph

1. $F = (kq^2)(1/r^2)$, which has the form $y = mx$, so F is proportional to $1/r^2$.
2. Gradient = $0.90 / 100 = \mathbf{9.0 \times 10^{-3} \text{ N} \cdot \text{m}^2}$.
3. $kq^2 = \text{gradient}$, so $q = \sqrt{(9.0 \times 10^{-3} / 8.99 \times 10^9)} = \mathbf{1.0 \times 10^{-6} \text{ C}}$.

Problem 16 Zero-force point

1. Between them, the two forces point in opposite directions, so they can cancel. Outside, both push the same way.
2. $4.0 / x^2 = 1.0 / (0.30 - x)^2$, so $2 / x = 1 / (0.30 - x)$, giving $0.60 - 2x = x$ and $x = \mathbf{0.20 \text{ m}}$.
3. **No**: q cancels in the equation, so the balance point is the same for any third charge.

Problem 17 Hanging charged balls

1. $\sin\theta = 0.050 / 1.00$, so $\theta = \mathbf{2.9^\circ}$.
2. Vertically $T \cos\theta = mg$ and horizontally $T \sin\theta = F$, so $F = mg \tan\theta = 0.0020 \times 9.81 \times 0.0501 = \mathbf{9.8 \times 10^{-4} \text{ N}}$.
3. $q = d\sqrt{(F/k)} = 0.10 \times \sqrt{(9.84 \times 10^{-4} / 8.99 \times 10^9)} = \mathbf{3.3 \times 10^{-8} \text{ C}}$ (33 nC).

Problem 18 Forces in two dimensions

1. $r = \sqrt{(0.20^2 + 0.15^2)} = \mathbf{0.25 \text{ m}}$.
2. $F = (8.99 \times 10^9)(4.0 \times 10^{-6})(2.0 \times 10^{-6}) / (0.25)^2 = \mathbf{1.15 \text{ N}}$ each.
3. The vertical components ($\pm 0.6 \times 1.15 \text{ N}$) cancel and the horizontal parts ($0.8 \times 1.15 \text{ N}$ each) add: net = $1.84 \text{ N} = \mathbf{1.8 \text{ N}}$ in the $+x$ direction.

Problem 19 Hovering sphere

1. The upward electric repulsion equals its downward weight, so the net force is zero.
2. $W = mg = 4.0 \times 10^{-4} \times 9.81 = \mathbf{3.9 \times 10^{-3} \text{ N}}$.
3. $r = \sqrt{(kq^2/F)} = \sqrt{(8.99 \times 10^9 \times (2.5 \times 10^{-8})^2 / 3.92 \times 10^{-3})} = \mathbf{0.038 \text{ m}}$ (3.8 cm).

Problem 20 Unequal charges and motion

1. The forces are **equal in size** and opposite, by Newton's third law, even though the charges differ.
2. $a = F/m$, so the +Q charge has an acceleration **four times larger** than the +4Q charge.
3. The net external force on the system is zero and it started at rest, so the centre of mass **stays at rest**.