

Charges, coulomb's law and electric potential

Physics grades 11-12 (A Level · IB · Class 11-12) · Worksheet answers

Each answer gives the formula, the substitution and a result with its unit. Remember that charges must be in coulombs and distances in metres, and that small differences in the last digit are acceptable when you round at a different step.

Level: Physics grades 11-12 (A Level · IB · Class 11-12) · **Curriculum:** IB D.2

Problem 1 Field from a measured force

- $E = F / q = 6.0 \times 10^{-5} / 2.0 \times 10^{-9} = \mathbf{3.0 \times 10^4 \text{ N/C}}$.
- $F = qE = 5.0 \times 10^{-9} \times 3.0 \times 10^4 = \mathbf{1.5 \times 10^{-4} \text{ N}}$.

Problem 2 Distance and force

- $F = kQ_1Q_2 / r^2 = (8.99 \times 10^9 \times 1.0 \times 10^{-6} \times 2.0 \times 10^{-6}) / (0.30)^2 = 0.200 \text{ N}$, so **F ≈ 0.20 N, repulsive** (like charges).
- Doubling r divides the force by $2^2 = 4$, so **F ≈ 0.050 N**.

Problem 3 Capacitor-style plates

$d = 3.0 \text{ mm} = 3.0 \times 10^{-3} \text{ m}$. $E = V / d = 12 / 3.0 \times 10^{-3} = \mathbf{4.0 \times 10^3 \text{ V/m}}$.

Problem 4 Electronvolts

- The gain is **200 eV**.
- $E = 200 \times 1.60 \times 10^{-19} = \mathbf{3.2 \times 10^{-17} \text{ J}}$.

Problem 5 Direction of field and force

- Field lines point **away from** a positive charge and **towards** a negative charge.
- The force on a negative charge is opposite to the field, so it points **west**.
- Closer field lines mean a **stronger field**, so a larger force per unit charge.

Problem 6 Field of a point charge

$E = kQ / r^2 = (8.99 \times 10^9 \times 4.0 \times 10^{-9}) / (0.30)^2 = 399.6 \text{ N/C}$, so **E ≈ 4.0 × 10² N/C**, directed away from the sphere.

Problem 7 Proton in a field

- $F = eE = 1.60 \times 10^{-19} \times 2.5 \times 10^4 = \mathbf{4.0 \times 10^{-15} \text{ N}}$.

- $a = F / m = 4.0 \times 10^{-15} / 1.67 \times 10^{-27} = \mathbf{2.4 \times 10^{12} \text{ m/s}^2}$.
- Weight = $mg = 1.67 \times 10^{-27} \times 9.81 = 1.6 \times 10^{-26} \text{ N}$. The ratio $F / W = 2.4 \times 10^{11}$, so the weight is **negligible**.

Problem 8 Work against a charge

- $V = kQ / r$: at 0.15 m, $V = 360 \text{ V}$; at 0.060 m, $V = 899 \text{ V}$.
- $W = q\Delta V = 2.0 \times 10^{-9} \times (899 - 360) = 1.1 \times 10^{-6} \text{ J}$, so $\mathbf{W \approx 1.1 \times 10^{-6} \text{ J}}$, done by the person pushing the charges together.

Problem 9 Suspended droplet

- $E = V / d = 600 / 0.010 = \mathbf{6.0 \times 10^4 \text{ V/m}}$.
- The electric force balances the weight: $qE = mg$, so $q = mg / E = (2.0 \times 10^{-15} \times 9.81) / 6.0 \times 10^4 = \mathbf{3.3 \times 10^{-19} \text{ C}}$.
- $n = q / e = 2.04 \approx \mathbf{2 \text{ electrons}}$. The force on a negative droplet must point up, so the field points down and the **top plate is positive**.

Problem 10 Midpoint of two charges

Each charge is 0.10 m from the midpoint. Each field = $kQ / r^2 = (8.99 \times 10^9 \times 4.0 \times 10^{-9}) / (0.10)^2 = 3596 \text{ N/C}$. Away from + and towards – point in the same direction, so the fields add: $E = \mathbf{7192 \text{ N/C} \approx 7.2 \times 10^3 \text{ N/C}}$, directed towards the negative charge.

Problem 11 Reading a potential graph

- $V = kQ / r = (kQ) \times (1 / r)$, which has the form $y = mx$, so V is proportional to $1/r$.
- Gradient = $270 / 10 = \mathbf{27 \text{ V m}}$ ($1/r = 10 \text{ m}^{-1}$ at 0.10 m).
- Gradient = kQ , so $Q = 27 / 8.99 \times 10^9 = \mathbf{3.0 \times 10^{-9} \text{ C}}$ (3.0 nC).

Problem 12 Accelerating through a gun

- $KE = eV = 1.60 \times 10^{-19} \times 1500 = \mathbf{2.4 \times 10^{-16} \text{ J}}$.
- $v = \sqrt{(2KE / m)} = \sqrt{(2 \times 2.4 \times 10^{-16} / 9.11 \times 10^{-31})} = \mathbf{2.3 \times 10^7 \text{ m/s}}$.
- $v = \sqrt{(2 \times 2.4 \times 10^{-16} / 1.67 \times 10^{-27})} = \mathbf{5.4 \times 10^5 \text{ m/s}}$, smaller by a factor of about 43 because the proton is far heavier.

Problem 13 Electric against gravity

- $F_e = ke^2 / r^2 = (8.99 \times 10^9 \times (1.60 \times 10^{-19})^2) / (1.0 \times 10^{-9})^2 = \mathbf{2.3 \times 10^{-10} \text{ N}}$.
- $F_g = Gm^2 / r^2 = (6.67 \times 10^{-11} \times (1.67 \times 10^{-27})^2) / (1.0 \times 10^{-9})^2 = \mathbf{1.9 \times 10^{-46} \text{ N}}$.
- $F_e / F_g = \mathbf{1.2 \times 10^{36}}$. Both forces follow $1/r^2$, so the ratio **does not change** with distance.

Problem 14 Spot the error

1. The distance was not converted to metres and not squared, and the force actually falls to one quarter, not one half, when r doubles.
2. $F = (8.99 \times 10^9 \times 25 \times 10^{-18}) / (0.050)^2 = 2.2475 \times 10^{-7} / 2.5 \times 10^{-3} = \mathbf{9.0 \times 10^{-5} \text{ N}}$.
3. Force at 10 cm = $9.0 \times 10^{-5} / 4 = \mathbf{2.2 \times 10^{-5} \text{ N}}$.

Problem 15 Reading a field pattern

1. Lines leave A and end on B, so **A is positive and B is negative**.
2. More lines leave A than arrive at B, with extra lines escaping to the left, so **A has the larger magnitude of charge**.
3. The field at P points from A to B (to the right). An electron is negative, so the force is opposite: **towards A (to the left)**.

Problem 16 Ball on a thread

1. Weight mg (down), electric force qE (horizontal, towards the negative plate) and tension T (along the thread).
2. In equilibrium $\tan \theta = qE / mg$, so $E = mg \tan \theta / q = (1.0 \times 10^{-3} \times 9.81 \times \tan 20^\circ) / 2.0 \times 10^{-6} = \mathbf{1785 \text{ N/C} \approx 1.8 \times 10^3 \text{ N/C}}$.
3. $T \cos \theta = mg$, so $T = mg / \cos 20^\circ = 9.81 \times 10^{-3} / 0.9397 = \mathbf{10.4 \times 10^{-3} \text{ N} \approx 1.04 \times 10^{-2} \text{ N}}$.

Problem 17 Beam between plates

1. $E = V / d = 400 / 0.020 = \mathbf{2.0 \times 10^4 \text{ V/m}}$.
2. The horizontal speed is constant: $t = L / v = 0.040 / 3.0 \times 10^7 = \mathbf{1.3 \times 10^{-9} \text{ s}}$.
3. $a = eE / m = 3.5 \times 10^{15} \text{ m/s}^2$. $y = \frac{1}{2}at^2 = 0.5 \times 3.5 \times 10^{15} \times (1.3 \times 10^{-9})^2 = \mathbf{3.1 \text{ mm}}$. $v_y = at = 4.7 \times 10^6 \text{ m/s}$, so $\tan \theta = v_y / v = 0.156$ and $\theta \approx \mathbf{8.9^\circ}$, towards the positive plate.

Problem 18 Alpha particle and gold nucleus

1. $KE = 5.0 \times 1.60 \times 10^{-13} = \mathbf{8.0 \times 10^{-13} \text{ J}}$.
2. $U = kQ_1Q_2 / r = k(2e)(79e) / r$.
3. At closest approach all the kinetic energy has become potential energy: $r = k(2e)(79e) / KE = (8.99 \times 10^9 \times 158 \times (1.60 \times 10^{-19})^2) / 8.0 \times 10^{-13} = \mathbf{4.5 \times 10^{-14} \text{ m}}$, about 45 fm.

Problem 19 Zero potential but not zero field

Let x be the distance from the $+6.0 \text{ nC}$ charge. $V = 0$ requires $k(6.0 \times 10^{-9})/x = k(2.0 \times 10^{-9})/(0.40 - x)$, so $6(0.40 - x) = 2x$, $2.4 = 8x$ and $\mathbf{x = 0.30 \text{ m}}$.

Field from the positive charge: $kQ/r^2 = 599 \text{ N/C}$, towards the negative charge. Field from the negative charge (0.10 m away): 1798 N/C , also towards the negative charge. Total $E = \mathbf{2397 \text{ N/C} \approx 2.4 \times 10^3 \text{ N/C}}$ towards the -2.0 nC charge.

Problem 20 Spark from a metal sphere

1. $V = Ed = 3.0 \times 10^6 \times 2.0 \times 10^{-3} = \mathbf{6.0 \times 10^3 \text{ V}}$.

2. Outside a sphere the field is $E = kQ / R^2$, so $Q = ER^2 / k = (3.0 \times 10^6 \times (0.050)^2) / 8.99 \times 10^9 = \mathbf{8.3 \times 10^{-7} \text{ C}}$ (0.83 μC).

3. $V = kQ / R = ER = 3.0 \times 10^6 \times 0.050 = \mathbf{1.5 \times 10^5 \text{ V}}$.