Chapter 1: Electric Charges and Fields

Exercises — Exercises

Q1 What is the force between two small charged spheres having charges of 2 × 10^{-7} C and 3 × 10^{-7} C placed 30 cm apart in air?

SOLUTION

Given: $q_1 = 2 \times 10^{-7}$ C, $q_2 = 3 \times 10^{-7}$ C, r = 30 cm = 0.30 m
$k = 9 \times 10^9$ N m^2 C^{-2}

Using Coulomb's law:
$F = k\, q_1\, q_2 / r^2$
$F = (9 \times 10^9 \times 2 \times 10^{-7} \times 3 \times 10^{-7}) / (0.30)^2$
$F = (9 \times 10^9 \times 6 \times 10^{-14}) / 0.09$
$F = (5.4 \times 10^{-4}) / 0.09$
$F = 6.0 \times 10^{-3}$ N

Since both charges are positive, the force is repulsive.

Answer: $F = 6.0 \times 10^{-3}$ N (repulsive)

Q2 The electrostatic force on a small sphere of charge 0.4 μC due to another small sphere of charge -0.8 μC in air is 0.2 N. (a) What is the distance between the two spheres? (b) What is the force on the second sphere due to the first?

SOLUTION

Given: $q_1 = 0.4$ μC = 0.4×10^{-6} C, $q_2 = -0.8$ μC = -0.8×10^{-6} C, F = 0.2 N
$k = 9 \times 10^9$ N m^2 C^{-2}

(a) From Coulomb's law: F = k	q_1		q_2	/ r^2
r^2 = k	q_1		q_2	/ F

$r^2 = (9 \times 10^9 \times 0.4 \times 10^{-6} \times 0.8 \times 10^{-6}) / 0.2$
$r^2 = (9 \times 10^9 \times 3.2 \times 10^{-13}) / 0.2$
$r^2 = 2.88 \times 10^{-3} / 0.2 = 1.44 \times 10^{-2}$ m^2
r = 0.12 m = 12 cm

(b) By Newton's third law, the force on sphere 2 due to sphere 1 is equal in magnitude and opposite in direction:
F_{21} = 0.2 N (attractive, directed toward sphere 1)

Answer: (a) r = 12 cm; (b) F = 0.2 N (attractive)

Q3 Check that the ratio $ke^2 / G m_e m_p$ is dimensionless. Look up a Table of Physical Constants and determine the value of this ratio. What does the ratio signify?

SOLUTION

Dimensional check:

$[k] = N m^2 C^{-2} = kg\ m^3 s^{-2} C^{-2}$

$[e^2] = C^2$

$[G] = m^3 kg^{-1} s^{-2}$

$[m_e m_p] = kg^2$

$[k e^2] = kg\ m^3 s^{-2} C^{-2} \times C^2 = kg\ m^3 s^{-2}$

$[G m_e m_p] = m^3 kg^{-1} s^{-2} \times kg^2 = kg\ m^3 s^{-2}$

=> ratio $ke^2 / (G m_e m_p)$ is dimensionless. Confirmed.

Using standard values:

$k = 9 \times 10^9\ N m^2 C^{-2}$

$e = 1.6 \times 10^{-19}\ C$

$G = 6.67 \times 10^{-11}\ m^3 kg^{-1} s^{-2}$

$m_e = 9.11 \times 10^{-31}\ kg$, $m_p = 1.67 \times 10^{-27}\ kg$

$ke^2 / (G m_e m_p) = (9 \times 10^9 \times (1.6 \times 10^{-19})^2) / (6.67 \times 10^{-11} \times 9.11 \times 10^{-31} \times 1.67 \times 10^{-27})$

$= (9 \times 10^9 \times 2.56 \times 10^{-38}) / (1.015 \times 10^{-67})$

$\approx 2.3 \times 10^{39}$

Physical significance: The electrostatic force between an electron and a proton is about 2.3×10^{39} times stronger than the gravitational force between them. This shows that on the atomic scale, electric forces dominate completely over gravitational forces.

Answer: $ke^2 / (G m_e m_p) \approx 2.3 \times 10^{39}$ (dimensionless); electric force between electron and proton is ~2.3×10^{39} times the gravitational force between them

Q4 (a) Explain the meaning of the statement 'electric charge of a body is quantised'. (b) Why can one ignore quantisation of electric charge when dealing with macroscopic i.e., large scale charges?

SOLUTION

(a) Quantisation of electric charge means that the charge on any body is always an integral multiple of the elementary charge $e = 1.6 \times 10^{-19}$ C:
$q = ne$, where $n = 0, \pm1, \pm2, \pm3, ...$
Charge cannot take arbitrary values; it can only change in discrete steps of e. A body cannot carry a charge of, say, 1.5e or 0.7e.

(b) At macroscopic scales, the charges involved are enormously large compared to e. For example, 1 μC contains about 6×10^{12} elementary charges. At this scale, adding or removing one electron changes the total charge by only 1 part in 6×10^{12} — an imperceptibly tiny step. The granularity of charge is completely invisible, and charge behaves as if it were a continuous variable. Quantisation can therefore be safely ignored in macroscopic problems.

Answer: (a) $q = ne$ (n integer); charge changes only in discrete units of $e = 1.6 \times 10^{-19}$ C. (b) Macroscopic charges are so large (~10^{12} e) that the discrete step size is negligible.

Q5 When a glass rod is rubbed with a silk cloth, charges appear on both. A similar phenomenon is observed with many other pairs of bodies. Explain how this observation is consistent with the law of conservation of charge.

SOLUTION

When a glass rod is rubbed with silk, electrons are transferred from the glass rod to the silk cloth. The glass rod loses electrons and becomes positively charged; the silk gains the same number of electrons and becomes equally negatively charged.

No new charge is created in this process. The positive charge gained by the glass equals in magnitude the negative charge gained by the silk. The algebraic sum of the total charge of the system (glass rod + silk) remains zero throughout — the same as before rubbing.

This is fully consistent with conservation of charge: the total charge of an isolated system remains constant. Rubbing merely redistributes existing charges between the two bodies; it neither creates nor destroys net charge.

Answer: Rubbing transfers electrons from glass to silk (or vice versa). Equal and opposite charges appear on each, keeping the total charge of the system unchanged (zero). This is consistent with conservation of charge.

Q6 Four point charges $q_A = 2\ \mu C$, $q_B = -5\ \mu C$, $q_C = 2\ \mu C$, and $q_D = -5\ \mu C$ are located at the corners of a square ABCD of side 10 cm. What is the force on a charge of 1 μC placed at the centre of the square?

SOLUTION

Given: $q_A = q_C = 2\ \mu C = 2 \times 10^{-6}$ C, $q_B = q_D = -5\ \mu C = -5 \times 10^{-6}$ C
Side of square a = 10 cm = 0.10 m
Test charge $q_0 = 1\ \mu C = 1 \times 10^{-6}$ C at center O

Distance from each corner to center: $d = a\sqrt{2}/2 = 0.10 \times \sqrt{2}/2 = 0.0707$ m

Arrangement: In a square ABCD, A and C are diagonally opposite (both carry +2 μC), B and D are diagonally opposite (both carry -5 μC).

Force on q_0 due to q_A (at A) and q_C (at C):
Both charges are equal (+2 μC) and lie at equal distances on opposite sides of O.
=> Forces F_A and F_C are equal in magnitude, opposite in direction => they cancel.

Force on q_0 due to q_B (at B) and q_D (at D):
Both charges are equal (-5 μC) and lie at equal distances on opposite sides of O.
=> Forces F_B and F_D are equal in magnitude, opposite in direction => they cancel.

Total force on the charge at center = $F_A + F_C + F_B + F_D = 0$

Answer: Force on the 1 μC charge at the centre = 0 (by symmetry, forces from diagonally opposite equal charges cancel pairwise)

Q7 (a) An electrostatic field line is a continuous curve. That is, a field line cannot have sudden breaks. Why not? (b) Explain why two field lines never cross each other at any point?

SOLUTION

(a) A field line represents the path a unit positive test charge would continuously follow under the influence of the electric field. If a field line had a sudden break, it would imply that the electric force on the test charge abruptly vanishes at that

point and reappears at another — which is physically impossible since the electric field exists continuously at every point in space (except at the location of a point charge). Therefore field lines must be continuous curves.

(b) If two field lines crossed at a point, the electric field at that point would have two different directions simultaneously (one tangent along each line). This is physically impossible because the electric field at any point in space is a unique vector — it has a single, well-defined direction. Therefore two field lines can never cross.

Answer: (a) Electric field is continuous everywhere, so the path it traces (field line) must be a continuous curve with no breaks. (b) At the crossing point the field would have two directions simultaneously, contradicting the uniqueness of E at any point.

Q8 Two point charges $q_A = 3\ \mu C$ and $q_B = -3\ \mu C$ are located 20 cm apart in vacuum. (a) What is the electric field at the midpoint O of the line AB joining the two charges? (b) If a negative test charge of magnitude 1.5×10^{-9} C is placed at this point, what is the force experienced by the test charge?

SOLUTION

Given: $q_A = +3\ \mu C = 3 \times 10^{-6}$ C, $q_B = -3\ \mu C = -3 \times 10^{-6}$ C, AB = 20 cm
Distance from each charge to midpoint O: r = 10 cm = 0.10 m
$k = 9 \times 10^9$ N m² C⁻²

(a) Electric field at O due to q_A (positive charge):
$E_A = k\, q_A / r^2 = (9 \times 10^9 \times 3 \times 10^{-6}) / (0.10)^2$
$E_A = 2.7 \times 10^7 / 0.01 = 2.7 \times 10^6$ N/C, directed from A toward B (away from +charge)

Electric field at O due to q_B (negative charge):
$E_B = k\, |q_B| / r^2 = 2.7 \times 10^6$ N/C, directed from O toward B (toward -charge)

Both E_A and E_B point in the same direction (from A toward B).
$E_{total} = E_A + E_B = 2.7 \times 10^6 + 2.7 \times 10^6 = 5.4 \times 10^6$ N/C
Direction: along AB from A to B

(b) Test charge $q_t = -1.5 \times 10^{-9}$ C
Force on test charge: $F = q_t \times E_{total}$
Magnitude: $|F| = 1.5 \times 10^{-9} \times 5.4 \times 10^6 = 8.1 \times 10^{-3}$ N
Since q_t is negative, F is opposite to E, i.e., directed from B toward A.

Answer: (a) $E = 5.4 \times 10^{6}$ N/C directed from A to B; (b) $F = 8.1 \times 10^{-3}$ N directed from B to A

Q9 A system has two charges $q_A = 2.5 \times 10^{-7}$ C and $q_B = -2.5 \times 10^{-7}$ C located at points A: (0, 0, -15 cm) and B: (0, 0, +15 cm), respectively. What are the total charge and electric dipole moment of the system?

SOLUTION

Given: $q_A = +2.5 \times 10^{-7}$ C at A(0, 0, -0.15 m), $q_B = -2.5 \times 10^{-7}$ C at B(0, 0, +0.15 m)

Total charge:
$Q = q_A + q_B = +2.5 \times 10^{-7} + (-2.5 \times 10^{-7}) = 0$

Electric dipole moment:
The system forms an electric dipole with +q at A and -q at B.
Magnitude: $|p| = |q| \times 2a = 2.5 \times 10^{-7}$ C $\times$ 0.30 m $= 7.5 \times 10^{-8}$ C m

Direction: by convention, the dipole moment vector points from -q to +q, i.e., from B (0, 0, +0.15 m) to A (0, 0, -0.15 m) => in the -z direction.

Therefore, $p = 7.5 \times 10^{-8}$ C m along the -z direction (from B to A).

Answer: Total charge = 0; electric dipole moment $p = 7.5 \times 10^{-8}$ C m directed along -z axis (from B to A)

Q10 An electric dipole with dipole moment 4×10^{-9} C m is aligned at 30° with the direction of a uniform electric field of magnitude 5×10^{4} N C^{-1}. Calculate the magnitude of the torque acting on the dipole.

SOLUTION

Given: $p = 4 \times 10^{-9}$ C m, $E = 5 \times 10^{4}$ N C^{-1}, $\theta = 30°$

The torque on a dipole in a uniform electric field is:
$\tau = p \times E \Rightarrow |\tau| = pE \sin\theta$

	τ	$= 4 \times 10^{-9} \times 5 \times 10^{4} \times \sin 30°$
	τ	$= 4 \times 10^{-9} \times 5 \times 10^{4} \times 0.5$
	τ	$= 20 \times 10^{-5} \times 0.5$
	τ	$= 1.0 \times 10^{-4}$ N m

Answer: Torque $\tau = 1.0 \times 10^{-4}$ N m

Q11 A polythene piece rubbed with wool is found to have a negative charge of 3×10^{-7} C. (a) Estimate the number of electrons transferred (from which to which?). (b) Is there a transfer of mass from wool to polythene?

SOLUTION

Given: charge on polythene = -3×10^{-7} C
$e = 1.6 \times 10^{-19}$ C, $m_e = 9.11 \times 10^{-31}$ kg

(a) Polythene gains a negative charge, so electrons are transferred from wool to polythene.
Number of electrons transferred:
$n = |q| / e = (3 \times 10^{-7}) / (1.6 \times 10^{-19})$
$n = 1.875 \times 10^{12} \approx 1.9 \times 10^{12}$ electrons
Transfer direction: from wool to polythene.

(b) Yes, each transferred electron carries a tiny mass. The mass transferred is:
$\Delta m = n \times m_e = 1.875 \times 10^{12} \times 9.11 \times 10^{-31}$ kg
$\Delta m \approx 1.71 \times 10^{-18}$ kg
This is an extremely small mass, negligible in practice, but it is a real transfer of mass from wool to polythene.

Answer: (a) ~1.9×10^{12} electrons transferred from wool to polythene; (b) Yes, mass $\approx 1.7 \times 10^{-18}$ kg is transferred from wool to polythene (mass of electrons transferred)

Q12 (a) Two insulated charged copper spheres A and B have their centres separated by a distance of 50 cm. What is the mutual force of electrostatic repulsion if the charge on each is 6.5×10^{-7} C? The radii of A and B are negligible compared to the distance of separation. (b) What is the force of repulsion if each sphere is charged double the above amount, and the distance between them is halved?

SOLUTION

Given: $q = 6.5 \times 10^{-7}$ C on each sphere, $r = 50$ cm $= 0.50$ m
$k = 9 \times 10^{9}$ N m^2 C^{-2}

(a) $F = k q^2 / r^2$
$F = (9 \times 10^{9} \times (6.5 \times 10^{-7})^2) / (0.50)^2$
$F = (9 \times 10^{9} \times 4.225 \times 10^{-13}) / 0.25$

$F = (3.8025 \times 10^{-3}) / 0.25$
$F = 1.52 \times 10^{-2}$ N

(b) New charge: $q' = 2q = 1.3 \times 10^{-6}$ C; new distance: $r' = r/2 = 0.25$ m
$F' = k\, q'^2 / r'^2$
$F' = k\,(2q)^2 / (r/2)^2 = k \times 4q^2 / (r^2/4) = 16 \times (k\, q^2 / r^2) = 16F$
$F' = 16 \times 1.52 \times 10^{-2} = 0.243$ N

Answer: (a) $F = 1.52 \times 10^{-2}$ N ≈ 0.015 N; (b) $F' = 0.243$ N (16 times the original force)

Q13 Figure 1.30 shows tracks of three charged particles in a uniform electrostatic field. Give the signs of the three charges. Which particle has the highest charge to mass ratio?

SOLUTION

In Figure 1.30, the uniform electric field is directed downward (positive plate at top, negative at bottom). Three particle tracks enter from the left.

Sign of charges:
Particle 1 (top track, curves upward toward positive plate): A positive charge would accelerate downward (in the direction of E). This particle curves upward, i.e., opposite to E => it is a negative charge.
Particle 2 (middle track, slight upward curve): also curves upward (opposite to E) => negative charge.
Particle 3 (bottom track, curves sharply downward in the direction of E): positive charge.

Highest charge-to-mass ratio:
For a particle in a uniform electric field, the transverse acceleration is $a = qE/m$. Greater deflection for the same path length indicates higher q/m ratio.
Particle 3 shows the greatest curvature (deflects most), so it has the highest charge-to-mass ratio.

Answer: Particle 1: negative; Particle 2: negative; Particle 3: positive. Particle 3 has the highest charge-to-mass ratio (greatest curvature in the field).

Q14 Consider a uniform electric field $E = 3 \times 10^3 \hat{i}$ N/C. (a) What is the flux of this field through a square of 10 cm on a side whose plane is parallel to the yz plane? (b) What is the flux through the same square if the normal to its plane makes a 60° angle with the x-axis?

SOLUTION

Given: $E = 3 \times 10^3 \hat{i}$ N/C, side of square = 10 cm = 0.10 m
Area of square: $A = (0.10)^2 = 0.01$ m²

(a) If the plane is parallel to the yz plane, the outward normal to the square is along the x-axis ($\hat{i}$ direction).
Angle between E and normal: $\theta = 0°$
Flux $\varphi = E \times A \times \cos\theta = 3 \times 10^3 \times 0.01 \times \cos 0°$
$\varphi = 3 \times 10^3 \times 0.01 \times 1 = 30$ N m² C⁻¹

(b) If the normal makes 60° with the x-axis:
Flux $\varphi = E \times A \times \cos 60°$
$\varphi = 3 \times 10^3 \times 0.01 \times 0.5$
$\varphi = 15$ N m² C⁻¹

Answer: (a) $\varphi = 30$ N m² C⁻¹; (b) $\varphi = 15$ N m² C⁻¹

Q15 What is the net flux of the uniform electric field of Exercise 1.14 through a cube of side 20 cm oriented so that its faces are parallel to the coordinate planes?

SOLUTION

The electric field $E = 3 \times 10^3 \hat{i}$ N/C is uniform (constant in magnitude and direction throughout space).

For faces perpendicular to x-axis (left and right faces):
The field enters through the left face and exits through the right face with the same magnitude (uniform field).
Flux in = -E × A (inward, negative), Flux out = +E × A (outward, positive)
Net contribution from these two faces = E × A - E × A = 0

For the four faces parallel to the x-axis (top, bottom, front, back):
The field E is parallel to these faces, so $E \cdot \hat{n} = 0$ for each.
Flux through each of these faces = 0.

Total net flux through cube = 0.

Alternatively, by Gauss's law: the cube encloses no charges (the field is external

and uniform), so net flux = q_enclosed / ε_0 = 0.

Answer: Net flux = 0 (uniform field has equal flux entering and leaving any closed surface; no charge enclosed)

Q16 Careful measurement of the electric field at the surface of a black box indicates that the net outward flux through the surface of the box is 8.0×10^3 N m^2/C. (a) What is the net charge inside the box? (b) If the net outward flux through the surface of the box were zero, could you conclude that there were no charges inside the box? Why or Why not?

SOLUTION

Given: net outward flux $\varphi = 8.0 \times 10^3$ N m^2 C^{-1}
$\varepsilon_0 = 8.854 \times 10^{-12}$ C^2 N^{-1} m^{-2}

(a) By Gauss's law: $\varphi = q_{enclosed} / \varepsilon_0$
$q_{enclosed} = \varepsilon_0 \times \varphi$
$q_{enclosed} = 8.854 \times 10^{-12} \times 8.0 \times 10^3$
$q_{enclosed} = 7.08 \times 10^{-8}$ C ≈ 70.8 nC

(b) No, you cannot conclude there are no charges inside the box.
Zero net flux means the total (net) enclosed charge is zero: $\Sigma q = 0$.
But the box could contain equal amounts of positive and negative charges that cancel each other — for example, +5 μC and -5 μC simultaneously inside. There would be charges inside, but their algebraic sum would be zero, giving zero net flux.

Answer: (a) q = 7.08×10^{-8} C ≈ 70.8 nC; (b) No — zero flux implies zero NET charge, but equal and opposite charges inside could produce zero net flux while individually present.

Q17 A point charge +10 μC is a distance 5 cm directly above the centre of a square of side 10 cm, as shown in Fig. 1.31. What is the magnitude of the electric flux through the square? (Hint: Think of the square as one face of a cube with edge 10 cm.)

SOLUTION

Given: q = +10 μC = $+10 \times 10^{-6}$ C, charge is 5 cm above centre of a 10 cm × 10 cm square.

Key insight (from the hint): Imagine a cube of edge 10 cm centred on the charge. The given square is exactly one face of this cube. The charge is at the centre of the cube (5 cm from each face).

Total flux through the cube (by Gauss's law):
$\varphi_{cube} = q / \varepsilon_0 = (10 \times 10^{-6}) / (8.854 \times 10^{-12})$
$\varphi_{cube} = 1.13 \times 10^{6}\ N\ m^2\ C^{-1}$

By symmetry, the flux is distributed equally through all 6 faces.
Flux through one face (the given square):
$\varphi_{square} = \varphi_{cube} / 6$
$\varphi_{square} = 1.13 \times 10^{6} / 6$
$\varphi_{square} \approx 1.88 \times 10^{5}\ N\ m^2\ C^{-1}$

Answer: $\varphi = 1.88 \times 10^{5}\ N\ m^2\ C^{-1}$

Q18 A point charge of 2.0 μC is at the centre of a cubic Gaussian surface 9.0 cm on edge. What is the net electric flux through the surface?

SOLUTION

Given: $q = 2.0\ \mu C = 2.0 \times 10^{-6}\ C$
$\varepsilon_0 = 8.854 \times 10^{-12}\ C^2\ N^{-1}\ m^{-2}$
Note: The size of the Gaussian surface does not affect the flux (Gauss's law).

By Gauss's law:
$\varphi = q / \varepsilon_0$
$\varphi = (2.0 \times 10^{-6}) / (8.854 \times 10^{-12})$
$\varphi = 2.26 \times 10^{5}\ N\ m^2\ C^{-1}$

Answer: $\varphi = 2.26 \times 10^{5}\ N\ m^2\ C^{-1}$

Q19 A point charge causes an electric flux of $-1.0 \times 10^{3}\ N\ m^2/C$ to pass through a spherical Gaussian surface of 10.0 cm radius centred on the charge. (a) If the radius of the Gaussian surface were doubled, how much flux would pass through the surface? (b) What is the value of the point charge?

SOLUTION

Given: $\varphi = -1.0 \times 10^{3}\ N\ m^2\ C^{-1}$, $r = 10.0$ cm
$\varepsilon_0 = 8.854 \times 10^{-12}\ C^2\ N^{-1}\ m^{-2}$

(a) By Gauss's law, the total flux through any closed surface enclosing a charge

depends only on the enclosed charge, not on the size or shape of the surface.
=> If radius is doubled to 20 cm, the same charge is enclosed.
Flux remains: $\varphi = -1.0 \times 10^3$ N m² C^{-1}

(b) From Gauss's law: $q = \varepsilon_0 \times \varphi$
$q = 8.854 \times 10^{-12} \times (-1.0 \times 10^3)$
$q = -8.85 \times 10^{-9}$ C ≈ -8.85 nC
The negative flux indicates the charge is negative.

Answer: (a) $\varphi = -1.0 \times 10^3$ N m² C^{-1} (unchanged); (b) $q = -8.85 \times 10^{-9}$ C ≈ -8.85 nC

Q20 A conducting sphere of radius 10 cm has an unknown charge. If the electric field 20 cm from the centre of the sphere is 1.5×10^3 N/C and points radially inward, what is the net charge on the sphere?

SOLUTION

Given: r = 20 cm = 0.20 m from centre, $E = 1.5 \times 10^3$ N/C (radially inward)
$k = 9 \times 10^9$ N m² C^{-2}

For a conducting sphere, all charge resides on the surface. Outside the sphere, the field is equivalent to that of a point charge at the centre.

E = k	q	/ r²
	q	= E × r² / k
	q	= (1.5 × 10³ × (0.20)²) / (9 × 10⁹)
	q	= (1.5 × 10³ × 0.04) / (9 × 10⁹)
	q	= 60 / (9 × 10⁹)
	q	= 6.67 × 10⁻⁹ C

Since the field points radially inward, the charge is negative:
$q = -6.67 \times 10^{-9}$ C ≈ -6.67 nC

Answer: $q = -6.67 \times 10^{-9}$ C ≈ -6.67 nC (negative, since field points inward)

Q21 A uniformly charged conducting sphere of 2.4 m diameter has a surface charge density of 80.0 μC/m². (a) Find the charge on the sphere. (b) What is the total electric flux leaving the surface of the sphere?

SOLUTION

Given: diameter = 2.4 m => radius R = 1.2 m, $\sigma = 80.0\ \mu C/m^2 = 80.0 \times 10^{-6}\ C/m^2$
$\varepsilon_0 = 8.854 \times 10^{-12}\ C^2\ N^{-1}\ m^{-2}$

(a) Surface area of sphere: $A = 4\pi R^2 = 4\pi \times (1.2)^2 = 4\pi \times 1.44 = 18.09\ m^2$
Total charge: $q = \sigma \times A = 80.0 \times 10^{-6} \times 18.09$
$q = 1.448 \times 10^{-3}\ C \approx 1.45 \times 10^{-3}\ C = 1.45\ mC$

(b) By Gauss's law, total electric flux:
$\varphi = q / \varepsilon_0 = (1.448 \times 10^{-3}) / (8.854 \times 10^{-12})$
$\varphi = 1.63 \times 10^{8}\ N\ m^2\ C^{-1}$

Answer: (a) $q = 1.45 \times 10^{-3}\ C \approx 1.45\ mC$; (b) $\varphi = 1.63 \times 10^{8}\ N\ m^2\ C^{-1}$

Q22 An infinite line charge produces a field of 9×10^4 N/C at a distance of 2 cm. Calculate the linear charge density.

SOLUTION

Given: $E = 9 \times 10^4$ N/C, r = 2 cm = 0.02 m
$\varepsilon_0 = 8.854 \times 10^{-12}\ C^2\ N^{-1}\ m^{-2}$

For an infinite line charge, the electric field at distance r is:
$E = \lambda / (2\pi\varepsilon_0 r)$

Solving for λ:
$\lambda = E \times 2\pi\varepsilon_0 \times r$
$\lambda = 9 \times 10^4 \times 2\pi \times 8.854 \times 10^{-12} \times 0.02$
$\lambda = 9 \times 10^4 \times 1.113 \times 10^{-12} \times 0.02 \times 2\pi$

Computing step by step:
$2\pi\varepsilon_0 = 2 \times 3.1416 \times 8.854 \times 10^{-12} = 5.563 \times 10^{-11}\ C\ N^{-1}\ m^{-1}$
$\lambda = 9 \times 10^4 \times 5.563 \times 10^{-11} \times 0.02$
$\lambda = 9 \times 10^4 \times 1.113 \times 10^{-12}$
$\lambda = 1.0 \times 10^{-7}\ C/m = 0.1\ \mu C/m$

Answer: $\lambda = 1.0 \times 10^{-7}\ C/m = 0.1\ \mu C/m$

Q23 Two large, thin metal plates are parallel and close to each other. On their inner faces, the plates have surface charge densities of opposite signs and of magnitude 17.0×10^{-22} C/m². What is E: (a) in the outer region of the first plate, (b) in the outer region of the second plate, and (c) between the plates?

SOLUTION

Given: surface charge densities on inner faces: +σ (plate 1) and -σ (plate 2), $\sigma = 17.0 \times 10^{-22}$ C/m²

$\varepsilon_0 = 8.854 \times 10^{-12}$ C² N⁻¹ m⁻²

Each infinite plate with surface charge density σ produces a field $E = \sigma/(2\varepsilon_0)$ on each side.

Let plate 1 have +σ on its inner face and plate 2 have -σ on its inner face.

(a) Outer region of first plate (to the left of plate 1):
Field due to plate 1 (+σ): $\sigma/(2\varepsilon_0)$ pointing away from plate 1 (to the left)
Field due to plate 2 (-σ): $\sigma/(2\varepsilon_0)$ pointing toward plate 2 (to the right)
These two contributions are equal and opposite, so they cancel: $E_{outer_1} = 0$

(b) Outer region of second plate (to the right of plate 2):
By the same symmetry argument, fields from the two plates cancel.
$E_{outer_2} = 0$

(c) Between the plates:
Field from plate 1 (+σ) points rightward (away from +plate) = $\sigma/(2\varepsilon_0)$ to the right
Field from plate 2 (-σ) points rightward (toward -plate) = $\sigma/(2\varepsilon_0)$ to the right
Both fields add:
$E_{between} = \sigma/\varepsilon_0 = (17.0 \times 10^{-22}) / (8.854 \times 10^{-12})$
$E_{between} = 1.92 \times 10^{-10}$ N/C

Answer: (a) E = 0 in the outer region of the first plate; (b) E = 0 in the outer region of the second plate; (c) $E = \sigma/\varepsilon_0 = 1.92 \times 10^{-10}$ N/C between the plates