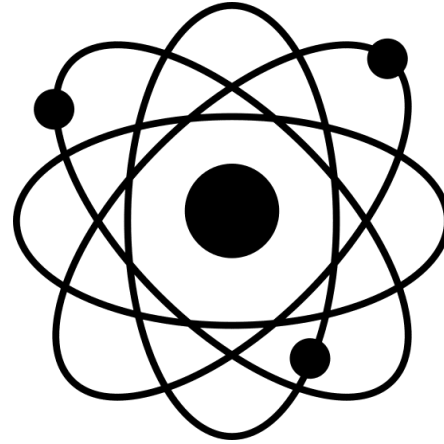


Chapter 1

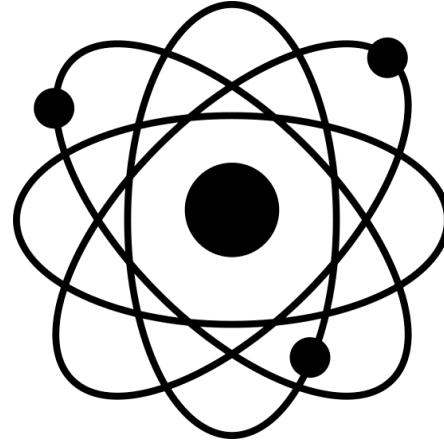
Electrostatics



Revision Paper

Lesson 2

Electric Charge



Revision Paper

Concept Check 1.1

01

How many electrons does it take to make **1.00 C** of charge?

- a) 1.60×10^{19}
- b) 6.60×10^{19}
- c) 3.20×10^{16}
- d) 6.24×10^{18}
- e) 6.66×10^{17}

Concept Check 1.1

02

How many electrons does it take to make **1.00 C** of charge?

- a) 1.60×10^{19}
- b) 6.60×10^{19}
- c) 3.20×10^{16}
- d) **6.24×10^{18}**
- e) 6.66×10^{17}

$$q = ne$$

$$n = \frac{q}{e}$$

$$= \frac{1}{1.602 \times 10^{-19}} = 6.24 \times 10^{18}$$

Multiple Choice Question 1.1

03

When a metal plate is given a **positive** charge, which of the following is taking place?

- a) Protons (positive charges) are transferred to the plate from another object.
- b) Electrons (negative charges) are transferred from the plate to another object.
- c) Electrons (negative charges) are transferred from the plate to another object, and protons (positive charges) are also transferred to the plate from another object.
- d) It depends on whether the object conveying the charge is a conductor or an insulator.

Multiple Choice Question 1.1 – EOT1 20-21 Exam Question

04

When a metal plate is given a **positive** charge, which of the following is taking place?

- a) Protons (positive charges) are transferred to the plate from another object.
- b) Electrons (negative charges) are transferred from the plate to another object.**
- c) Electrons (negative charges) are transferred from the plate to another object, and protons (positive charges) are also transferred to the plate from another object.
- d) It depends on whether the object conveying the charge is a conductor or an insulator.

Multiple Choice Question 1.4

05

Which one of these systems has the most negative charge?

- a) 2 electrons
- b) 3 electrons and 1 proton
- c) 5 electrons and 5 protons
- d) N electrons and $N - 3$ protons
- e) 1 electron

Multiple Choice Question 1.4

o6

Which one of these systems has the most negative charge?

- a) 2 electrons
- b) 3 electrons and 1 proton
- c) 5 electrons and 5 protons
- d) N electrons and $N - 3$ protons**
- e) 1 electron

Multiple Choice Question 1.7

07

Two protons placed near one another with no other objects close by would

- a) accelerate away from each other.
- b) remain motionless.
- c) accelerate toward each other.
- d) be pulled together at constant speed.
- e) move away from each other at constant speed.

Multiple Choice Question 1.7

o8

Two protons placed near one another with no other objects close by would

- a) accelerate away from each other.
- b) remain motionless.
- c) accelerate toward each other.
- d) be pulled together at constant speed.
- e) move away from each other at constant speed.

Self Test Opportunity 1.1

09

Give the charge of the following elementary particles or atoms in terms of the elementary charge $e = 1.602 \times 10^{-19} \text{ C}$.

- a) Proton _____
- b) Neutron _____
- c) Helium atom (*two protons, two neutron, and two electrons*) _____
- d) Hydrogen atom (*one proton and one electron*) _____
- e) Electron _____
- f) Alpha particle (*two protons and two neutrons*) _____

Multiple Choice Question 1.1 – Page 21

1.2 Electric Charge

Self Test Opportunity 1.1

10

Give the charge of the following elementary particles or atoms in terms of the elementary charge $e = 1.602 \times 10^{-19} \text{ C}$.

- | | |
|---|------------|
| a) Proton | <u>+e</u> |
| b) Neutron | <u>0</u> |
| c) Helium atom (<i>two protons, two neutron, and two electrons</i>) | <u>0</u> |
| d) Hydrogen atom (<i>one proton and one electron</i>) | <u>0</u> |
| e) Electron | <u>-e</u> |
| f) Alpha particle (<i>two protons and two neutrons</i>) | <u>+2e</u> |

Self Test Opportunity 1.1 – Page 6

1.2 Electric Charge

Example 1.1

11

If we wanted a block of iron of mass **3.25 kg** to acquire a positive charge of **0.100 C**, what **fraction** of the electrons would we have to remove?

Example 1.1

12

If we wanted a block of iron of mass **3.25 kg** to acquire a positive charge of **0.100 C**, what **fraction** of the electrons would we have to remove?

$$N_{\text{atom}} = \frac{(3.25 \text{ kg})(6.022 \times 10^{23} \text{ atoms/mole})}{0.0560 \text{ kg/mole}} = 3.495 \times 10^{25} = 3.50 \times 10^{25} \text{ atoms}$$

$$N_e = 26N_{\text{atom}} = (26)(3.495 \times 10^{25}) = 9.09 \times 10^{26} \text{ electrons}$$

$$q = e \cdot N_{\Delta e} \Rightarrow N_{\Delta e} = \frac{q}{e} = \frac{0.100 \text{ C}}{1.602 \times 10^{-19} \text{ C}} = 6.24 \times 10^{17}.$$

$$\frac{N_{\Delta e}}{N_e} = \frac{6.24 \times 10^{17}}{9.09 \times 10^{26}} = 6.87 \times 10^{-10}.$$

Example 1.1 – Page 6

1.2 Electric Charge

Exercise 1.31

13

Faraday is a unit of charge that consists of exactly **1 mole** of elementary charges. Calculate the number of coulombs in **1.000** faraday.

Exercise 1.31

14

Faraday is a unit of charge that consists of exactly **1 mole** of elementary charges. Calculate the number of coulombs in **1.000** faraday.

$$1.000 \text{ F} = N_A e = (6.022 \cdot 10^{23} \text{ atoms/mol})(1.602 \cdot 10^{-19} \text{ C}) = 96470 \text{ C}.$$

Exercise 1.33

15

A current of **5.00 mA** is enough to make your muscles twitch. Calculate how many electrons flow through your skin if you are exposed to such a current for **10.0 s**.

Exercise 1.33

16

A current of **5.00 mA** is enough to make your muscles twitch. Calculate how many electrons flow through your skin if you are exposed to such a current for **10.0 s**.

$$I \cdot t = (5.00 \cdot 10^{-3} \text{ A})(10.0 \text{ s}) = 0.0500 \text{ A s} = 0.0500 \text{ C};$$

$$\frac{0.0500 \text{ C}}{1.602 \cdot 10^{-19} \text{ C} / e} = 3.12 \cdot 10^{17} \text{ electrons.}$$

Exercise 1.34

17

How many electrons does **1.00 kg** of water contain?

Exercise 1.33 – Page 22

1.2 Electric Charge

Exercise 1.34

18

How many electrons does **1.00 kg** of water contain?

$$\eta = \frac{m}{m_{\text{W}}} \cdot N_{\text{A}} \cdot \frac{10 \text{ electrons}}{\text{H}_2\text{O atom}}$$

$$\eta = \left(\frac{1.00 \cdot 10^3 \text{ g}}{18.015 \text{ g/mol}} \right) (6.022 \cdot 10^{23} \text{ mol}^{-1}) (10 \text{ electrons}) = 3.34277 \cdot 10^{26} \text{ electrons}$$

EOT1 20-21 Exam Question

19

One way to change a neutral metallic object with a negative charge is to do one of the following;

- a) Add some electrons
- b) Cut out a part of the object
- c) Remove some electrons
- d) Add some neutral atoms

EOT1 20-21 Exam Question

1.2 Electric Charge

EOT1 20-21 Exam Question

20

One way to change a neutral metallic object with a negative charge is to do one of the following;

- a) **Add some electrons**
- b) Cut out a part of the object
- c) Remove some electrons
- d) Add some neutral atoms

EOT1 20-21 Exam Question

1.2 Electric Charge

EOT1 21-22 Exam Question

21

How many electrons does it take to make (-2.00 C) of charge?

- a) 1.60×10^{19}
- b) 1.60×10^{-19}
- c) 2.00
- d) 1.25×10^{19}

EOT1 21-22 Exam Question

1.2 Electric Charge

EOT1 21-22 Exam Question

22

How many electrons does it take to make (-2.00 C) of charge?

a) 1.60×10^{19}

b) 1.60×10^{-19}

c) 2.00

d) 1.25×10^{19}

$$q = ne$$

$$n = \frac{q}{e}$$

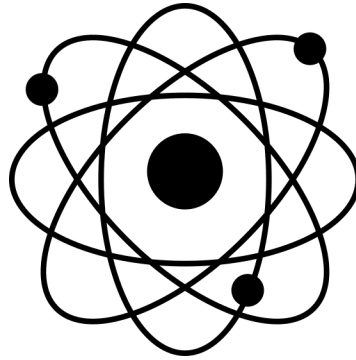
$$= \frac{-2}{-1.602 \times 10^{-19}} = 1.25 \times 10^{19}$$

EOT1 21-22 Exam Question

1.2 Electric Charge

Lesson 3

Insulators, Conductors, Semiconductors, and Superconductors



Revision Paper

Multiple Choice Question

23

Which of the following statements is true about superconductors?

- a) superconductors have zero resistance.
- b) Most materials have critical temperature between zero Kelvin and 10 Kelvin.
- c) A material can become superconductor when its temperature drops below the material's critical temperature.
- d) All of the above.

Multiple Choice Question

1.3 Insulators, Conductors, Semiconductors, and Superconductors

Multiple Choice Question

24

Which of the following statements is true about superconductors?

- a) superconductors have zero resistance.
- b) Most materials have critical temperature between zero Kelvin and 10 Kelvin.
- c) A material can become superconductor when its temperature drops below the material's critical temperature.
- d) All of the above.**

Multiple Choice Question

1.3 Insulators, Conductors, Semiconductors, and Superconductors

Multiple Choice Question

25

A student performed an experiment to find the conductivity of some material. Which piece of data tells him that this material is a superconductor?

- a) $R = 10^6 \Omega$
- b) $R = 1600 \Omega$
- c) $R = 0 \Omega$
- d) $R = 10^{-2} \Omega$

Multiple Choice Question

1.3 Insulators, Conductors, Semiconductors, and Superconductors

Multiple Choice Question

26

A student performed an experiment to find the conductivity of some material. Which piece of data tells him that this material is a superconductor?

a) $R = 10^6 \Omega$

b) $R = 1600 \Omega$

c) $R = 0 \Omega$

d) $R = 10^{-2} \Omega$

Multiple Choice Question

1.3 Insulators, Conductors, Semiconductors, and Superconductors

Multiple Choice Question

27

Why is the copper wire protected using insulating rubber?

- a) Insulating rubber allows the charges to be conducted away from the copper wire.
- b) Insulating rubber conducts electricity, allowing the cable to carry more charges.
- c) Insulating rubber stops other conducting materials from touching the wire, keeping the charges in the copper wire.
- d) Insulating rubber has more free electrons than the copper wire.

Multiple Choice Question

1.3 Insulators, Conductors, Semiconductors, and Superconductors

Multiple Choice Question

28

Why is the copper wire protected using insulating rubber?

- a) Insulating rubber allows the charges to be conducted away from the copper wire.
- b) Insulating rubber conducts electricity, allowing the cable to carry more charges.
- c) Insulating rubber stops other conducting materials from touching the wire, keeping the charges in the copper wire.**
- d) Insulating rubber has more free electrons than the copper wire.

Multiple Choice Question

1.3 Insulators, Conductors, Semiconductors, and Superconductors

Multiple Choice Question

29

What happens to the conductivity of a distilled water when you dissolve table salt in it?

- a) Increases
- b) Stays the same
- c) Decreases
- d) None of the above

Multiple Choice Question

1.3 Insulators, Conductors, Semiconductors, and Superconductors

Multiple Choice Question

30

What happens to the conductivity of a distilled water when you dissolve table salt in it?

- a) **Increases**
- b) Stays the same
- c) Decreases
- d) None of the above

Multiple Choice Question

1.3 Insulators, Conductors, Semiconductors, and Superconductors

EOT1 21-22 Exam Question

31

Which of the following are materials that have zero resistance to the conduction of electricity?

- a) Insulators
- b) Semiconductors
- c) Conductors
- d) Superconductors

EOT1 21-22 Exam Question

1.3 Insulators, Conductors, Semiconductors, and Superconductors

EOT1 21-22 Exam Question

32

Which of the following are materials that have zero resistance to the conduction of electricity?

- a) Insulators
- b) Semiconductors
- c) Conductors
- d) Superconductors**

EOT1 21-22 Exam Question

1.3 Insulators, Conductors, Semiconductors, and Superconductors

EOT1 20-21 Exam Question

33

Which of the following statements is correct about electrical conductivity?

- a) Electrical resistance of superconductors is zero at very low temperatures.
- b) Insulators have low electrical resistance.
- c) Metals are bad conductors of electricity.
- d) Silicon and germanium are examples of superconductors.

EOT1 20-21 Exam Question

1.3 Insulators, Conductors, Semiconductors, and Superconductors

EOT1 20-21 Exam Question

34

Which of the following statements is correct about electrical conductivity?

- a) **Electrical resistance of superconductors is zero at very low temperatures.**
- b) Insulators have low electrical resistance.
- c) Metals are bad conductors of electricity.
- d) Silicon and germanium are examples of superconductors.

EOT1 20-21 Exam Question

1.3 Insulators, Conductors, Semiconductors, and Superconductors

EOT1 20-21 Exam Question

35

Which of the following statements is correct about electrical conductivity?

- a) Electrical resistance of superconductors is zero at room temperatures.
- b) Insulators have low electrical resistance.
- c) Metals are good conductors of electricity.
- d) Silicon and germanium are examples of superconductors.

EOT1 20-21 Exam Question

1.3 Insulators, Conductors, Semiconductors, and Superconductors

EOT1 20-21 Exam Question

36

Which of the following statements is correct about electrical conductivity?

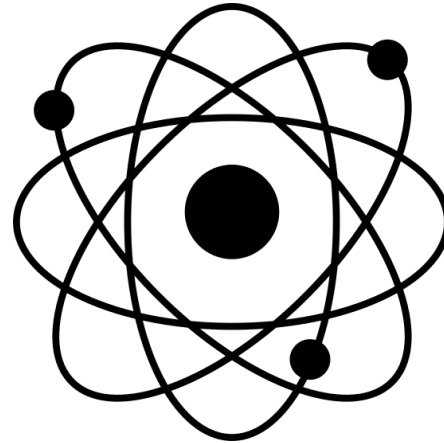
- a) Electrical resistance of superconductors is zero at room temperatures.
- b) Insulators have low electrical resistance.
- c) **Metals are good conductors of electricity.**
- d) Silicon and germanium are examples of superconductors.

EOT1 20-21 Exam Question

1.3 Insulators, Conductors, Semiconductors, and Superconductors

Lesson 4

Electrostatic Charging



Revision Paper

Concept Check 1.2

37

The hinged conductor moves away from the fixed conductor if a charge is applied to the electroscope, because

- a) like charges repel each other.
- b) like charges attract each other.
- c) unlike charges attract each other.
- d) unlike charges repel each other.

Concept Check 1.2

38

The hinged conductor moves away from the fixed conductor if a charge is applied to the electroscope, because

- a) **like charges repel each other.**
- b) like charges attract each other.
- c) unlike charges attract each other.
- d) unlike charges repel each other.

Multiple Choice Question 1.8

39

Two lightweight metal spheres are suspended near each other from insulating threads. One sphere has a net charge; the other sphere has no net charge. The spheres will;

- a) attract each other.
- b) exert no net electrostatic force on each other.
- c) repel each other.
- d) do any of these things depending on the sign of the net charge on the one sphere.

Multiple Choice Question 1.8

40

Two lightweight metal spheres are suspended near each other from insulating threads. One sphere has a net charge; the other sphere has no net charge. The spheres will;

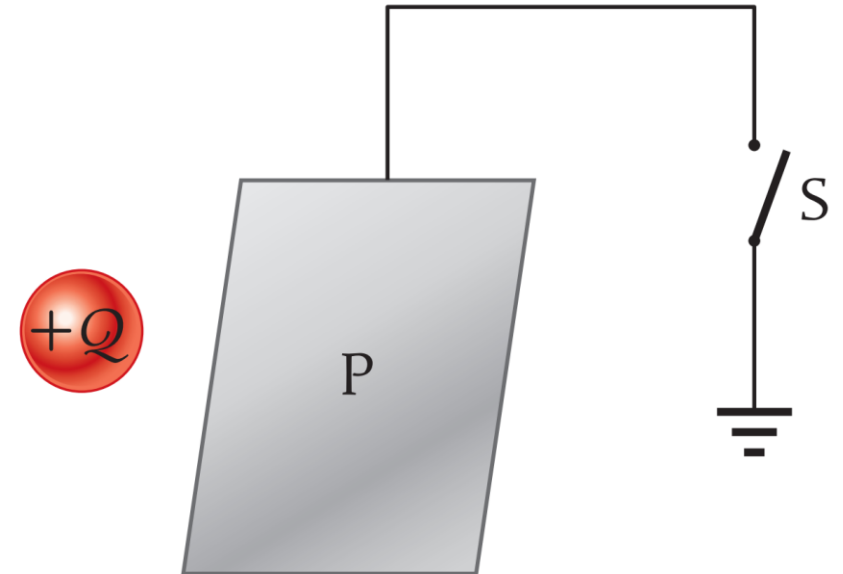
- a) **attract each other.**
- b) exert no net electrostatic force on each other.
- c) repel each other.
- d) do any of these things depending on the sign of the net charge on the one sphere.

Multiple Choice Question 1.9

41

A metal plate is connected by a conductor to a ground through a switch. The switch is initially closed. A charge $+Q$ is brought close to the plate without touching it, and then the switch is opened. After the switch is opened, the charge $+Q$ is removed. What is the charge on the plate then?

- a) The plate is uncharged.
- b) The plate is positively charged.
- c) The plate is negatively charged.
- d) The plate could be either positively or negatively charged, depending on the charge it had before $+Q$ was brought near.



Multiple Choice Question 1.9 – Page 21

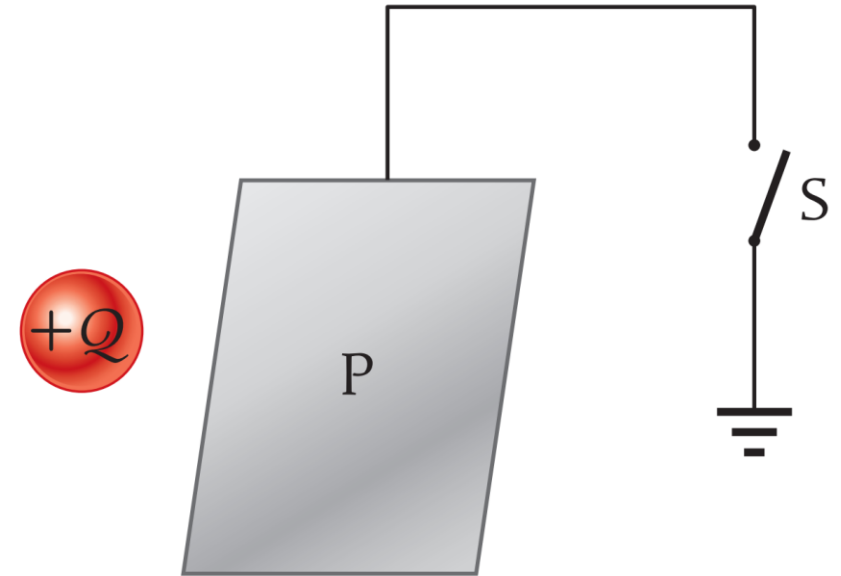
1.4 Electrostatic Charging

Multiple Choice Question 1.9

42

A metal plate is connected by a conductor to a ground through a switch. The switch is initially closed. A charge $+Q$ is brought close to the plate without touching it, and then the switch is opened. After the switch is opened, the charge $+Q$ is removed. What is the charge on the plate then?

- a) The plate is uncharged.
- b) The plate is positively charged.
- c) **The plate is negatively charged.**
- d) The plate could be either positively or negatively charged, depending on the charge it had before $+Q$ was brought near.



Multiple Choice Question 1.9 – Page 21

1.4 Electrostatic Charging

Multiple Choice Question 1.10

43

You bring a negatively charged rubber rod close to a grounded conductor without touching it. Then you disconnect the ground. What is the sign of the charge on the conductor after you remove the charged rod?

- a) negative
- b) positive
- c) no charge
- d) cannot be determined from the information given

Multiple Choice Question 1.10

44

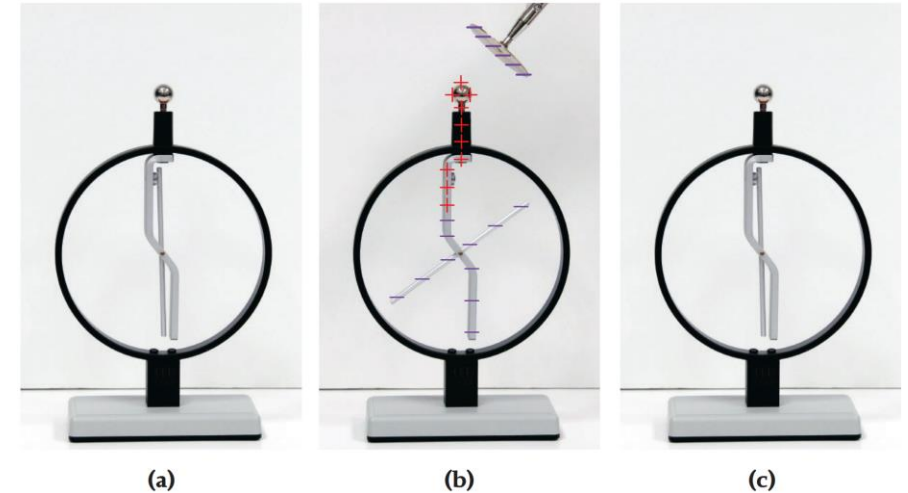
You bring a negatively charged rubber rod close to a grounded conductor without touching it. Then you disconnect the ground. What is the sign of the charge on the conductor after you remove the charged rod?

- a) negative
- b) positive**
- c) no charge
- d) cannot be determined from the information given

EOT1 21-22 Exam Question

The figure shows charging by;

- a) Triboelectric
- b) Grounding
- c) Induction
- d) Contact



45

EOT1 21-22 Exam Question

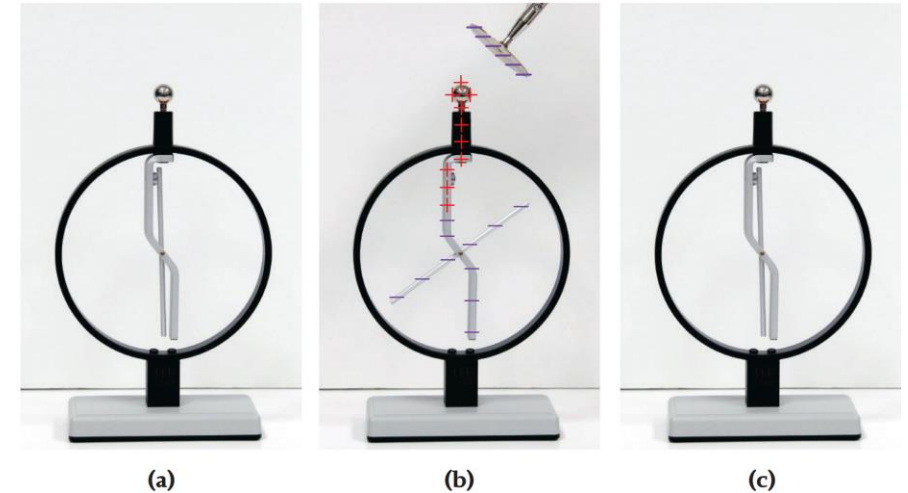
1.4 Electrostatic Charging



EOT1 21-22 Exam Question

The figure shows charging by;

- a) Triboelectric
- b) Grounding
- c) Induction**
- d) Contact



46

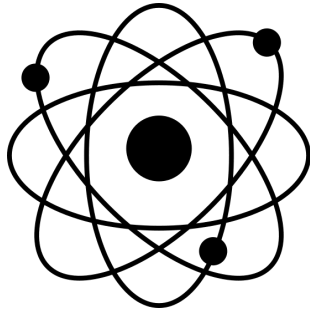
EOT1 21-22 Exam Question

1.4 Electrostatic Charging



Lesson 5

Electrostatic Force – Coulomb's Law



Revision Paper



Concept Check 1.3

47

You place two charges a distance r apart. Then you double each charge and double the distance between the charges. How does the force between the two charges change?

- a) The new force is twice as large.
- b) The new force is half as large.
- c) The new force is four times larger.
- d) The new force is four times smaller.
- e) The new force is the same.

Concept Check 1.3 – Page 10

1.5 Electrostatic Force – Coulomb's Law

Concept Check 1.3

48

You place two charges a distance r apart. Then you double each charge and double the distance between the charges. How does the force between the two charges change?

- a) The new force is twice as large.
- b) The new force is half as large.
- c) The new force is four times larger.
- d) The new force is four times smaller.
- e) The new force is the same.**

$$\frac{k \times a \times a}{r^2} \quad \frac{k \times 2a \times 2a}{(2r)^2}$$

$$\frac{k \times a^2}{r^2} \quad \frac{k \times 4a^2}{4r^2}$$

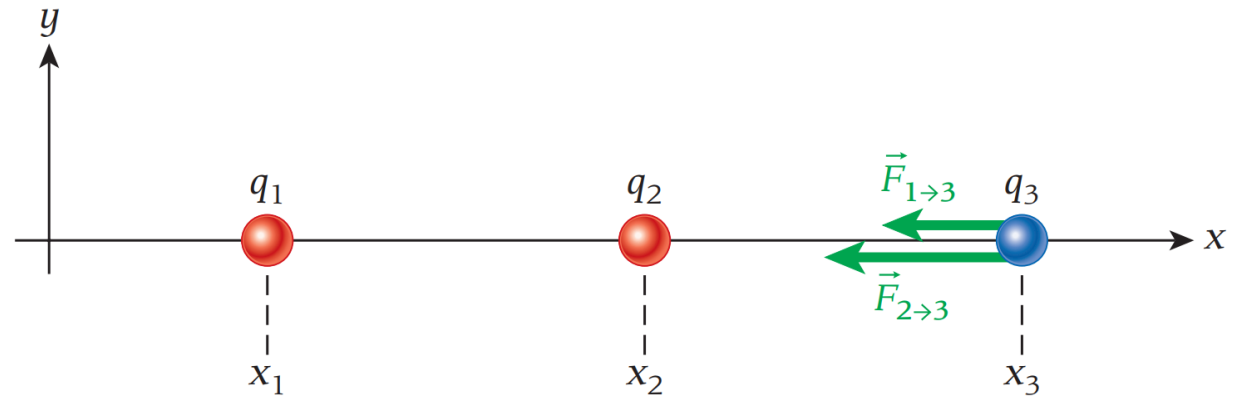
$$\frac{k \times a^2}{r^2} = \frac{k \times a^2}{r^2}$$

Concept Check 1.4

49

What do the forces acting on the charge q_3 in the figure indicate about the signs of the three charges?

- a) All three charges must be positive.
- b) All three charges must be negative.
- c) Charge q_3 must be zero.
- d) Charges q_1 and q_2 must have opposite signs.
- e) Charges q_1 and q_2 must have the same sign, and q_3 must have the opposite sign.



Concept Check 1.4 – Page 11

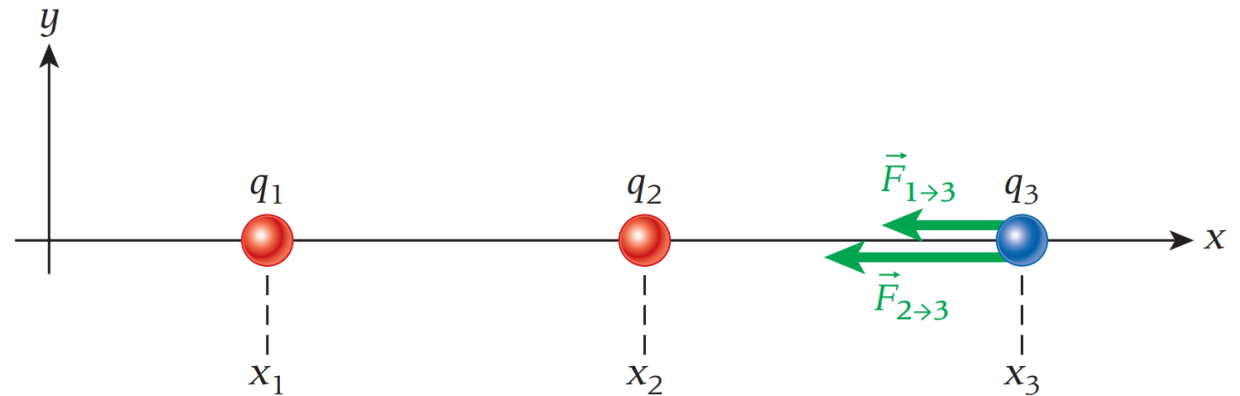
1.5 Electrostatic Force – Coulomb's Law

Concept Check 1.4

50

What do the forces acting on the charge q_3 in the figure indicate about the signs of the three charges?

- a) All three charges must be positive.
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- c) Charge q_3 must be zero.
- d) Charges q_1 and q_2 must have opposite signs.
- e) Charges q_1 and q_2 must have the same sign, and q_3 must have the opposite sign.



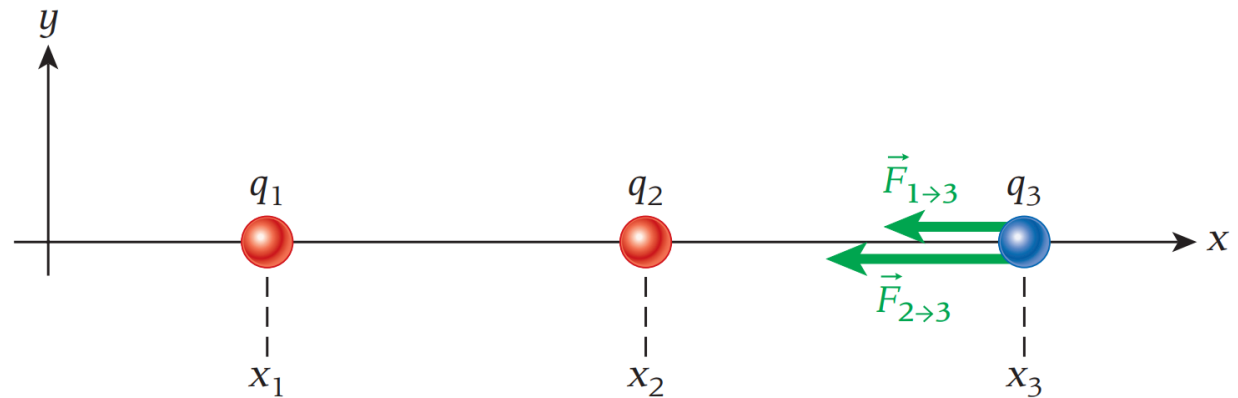
Concept Check 1.5

51

Assuming that the lengths of the vectors in the figure are proportional to the magnitudes of the forces they represent, what do they indicate about the magnitudes of the charges q_1 and q_2 ?

(Hint: The distance between x_1 and x_2 is the same as the distance between x_2 and x_3 .)

- a) $|q_1| < |q_2|$
- b) $|q_1| = |q_2|$
- c) $|q_1| > |q_2|$
- d) The answer cannot be determined



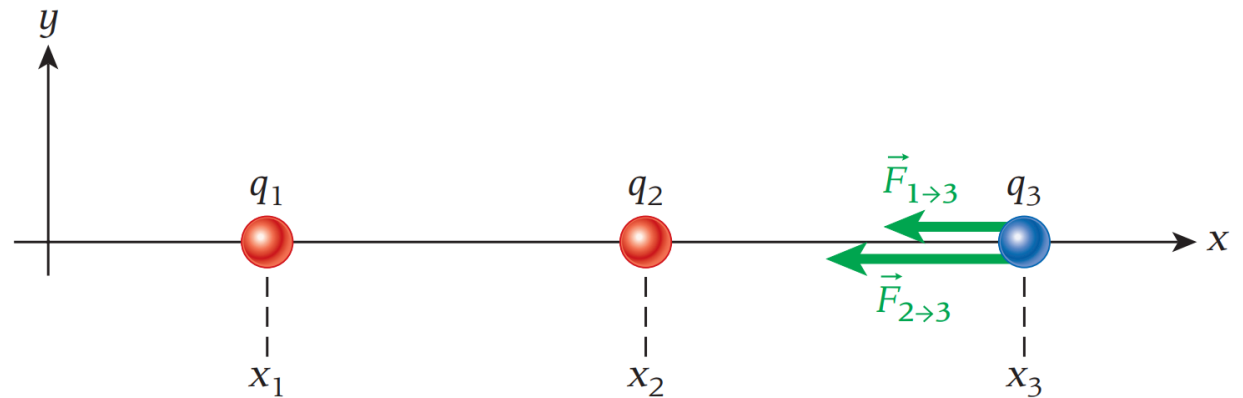
Concept Check 1.5

52

Assuming that the lengths of the vectors in the figure are proportional to the magnitudes of the forces they represent, what do they indicate about the magnitudes of the charges q_1 and q_2 ?

(Hint: The distance between x_1 and x_2 is the same as the distance between x_2 and x_3 .)

- a) $|q_1| < |q_2|$
- b) $|q_1| = |q_2|$
- c) $|q_1| > |q_2|$
- d) The answer cannot be determined



Example 1.2

53

What is the magnitude of the electrostatic force that the **two protons** inside the nucleus of a helium atom exert on each other? ($r = 2 \cdot 10^{-15}$)

Example 1.2 – Problem 1 – Page 12

1.5 Electrostatic Force – Coulomb's Law

Example 1.2

54

What is the magnitude of the electrostatic force that the **two protons** inside the nucleus of a helium atom exert on each other? ($r = 2 \cdot 10^{-15}$)

$$F = k \frac{|q_p q_p|}{r^2}$$
$$= \left(8.99 \times 10^9 \frac{\text{N m}^2}{\text{C}^2} \right) \frac{(+1.6 \times 10^{-19} \text{ C})(+1.6 \times 10^{-19} \text{ C})}{(2 \times 10^{-15} \text{ m})^2} = 58 \text{ N.}$$

Example 1.2 – Problem 1 – Page 12

1.5 Electrostatic Force – Coulomb's Law

Example 1.2

55

What is the magnitude of the electrostatic force between a gold nucleus and an electron of the gold atom in an orbit with radius $4.88 \times 10^{-12} \text{ m}$? (*Atomic number of gold is 79*)

Example 1.2 – Problem 2 – Page 12

1.5 Electrostatic Force – Coulomb's Law

Example 1.2

56

What is the magnitude of the electrostatic force between a gold nucleus and an electron of the gold atom in an orbit with radius $4.88 \times 10^{-12} \text{ m}$? (*Atomic number of gold is 79*)

$$\begin{aligned} F &= k \frac{|q_e q_N|}{r^2} \\ &= \left(8.99 \times 10^9 \frac{\text{N m}^2}{\text{C}^2} \right) \frac{(1.60 \times 10^{-19} \text{ C}) [(79)(1.60 \times 10^{-19} \text{ C})]}{(4.88 \times 10^{-12} \text{ m})^2} \\ &= 7.63 \times 10^{-4} \text{ N.} \end{aligned}$$

Example 1.2 – Problem 2 – Page 12

1.5 Electrostatic Force – Coulomb's Law

Concept Check 1.6

57

Three charges are arranged on a straight line as shown in the figure. What is the direction of the electrostatic force on the middle charge?



- a) $\rightarrow$
- b) $\leftarrow$
- c) $\uparrow$
- d) $\downarrow$
- e) There is no force on that charge.

Concept Check 1.6

58

Three charges are arranged on a straight line as shown in the figure. What is the direction of the electrostatic force on the middle charge?

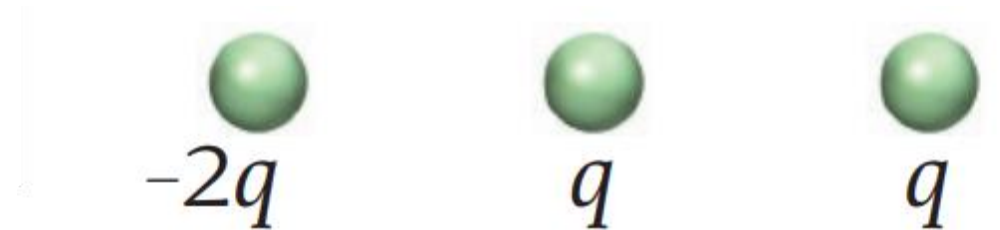


- a) $\rightarrow$
- b) $\leftarrow$
- c) $\uparrow$
- d) $\downarrow$
- e) There is no force on that charge.

Concept Check 1.7

59

Three charges are arranged on a straight line as shown in the figure. What is the direction of the electrostatic force on the right charge?

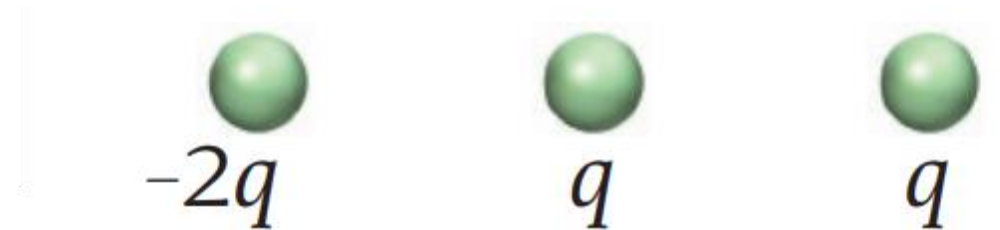


- a) $\rightarrow$
- b) $\leftarrow$
- c) $\uparrow$
- d) $\downarrow$
- e) There is no force on that charge.

Concept Check 1.7

60

Three charges are arranged on a straight line as shown in the figure. What is the direction of the electrostatic force on the right charge?

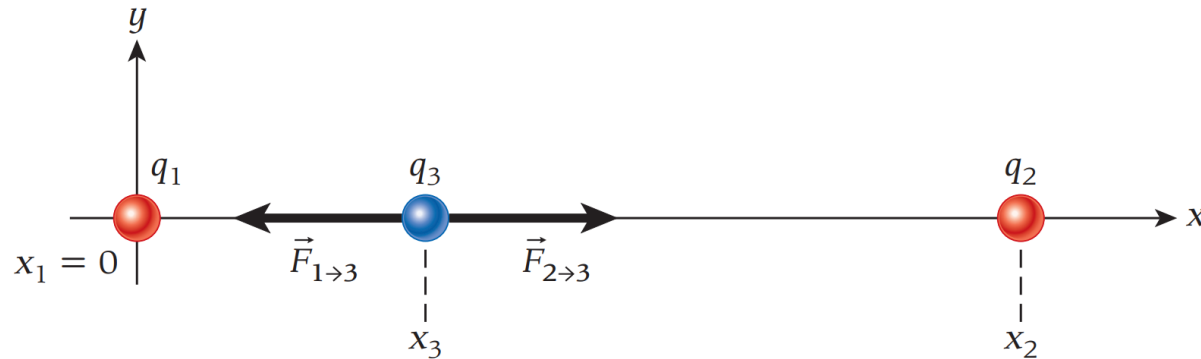


- a) $\rightarrow$
- b) $\leftarrow$
- c) $\uparrow$
- d) $\downarrow$
- e) There is no force on that charge.

Example 1.3

61

Two charged particles are placed as shown in the figure: $q_1 = 0.15 \mu\text{C}$ is located at the origin, and $q_2 = 0.35 \mu\text{C}$ is located on the positive x-axis at $x_2 = 0.40 \text{ m}$. Where should a third charged particle, q_3 , be placed to be at an equilibrium point (*such that the forces on it sum to zero*)?



Example 1.3 – Page 13

1.5 Electrostatic Force – Coulomb's Law

Example 1.3

62

Two charged particles are placed as shown in the figure: $q_1 = 0.15 \mu\text{C}$ is located at the origin, and $q_2 = 0.35 \mu\text{C}$ is located on the positive x-axis at $x_2 = 0.40 \text{ m}$. Where should a third charged particle, q_3 , be placed to be at an equilibrium point (*such that the forces on it sum to zero*)?

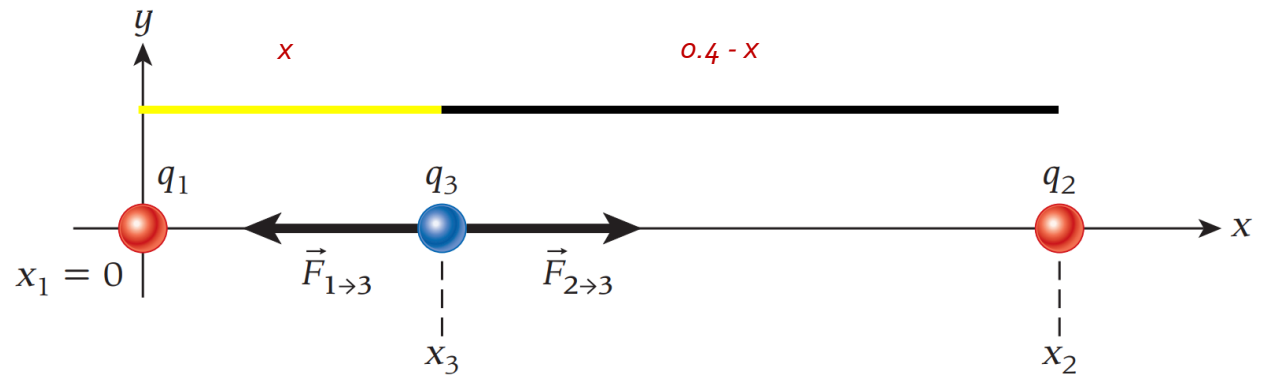
$$|\vec{F}_{1 \rightarrow 3}| = |\vec{F}_{2 \rightarrow 3}|$$

$$\frac{k \times q_1 \times q_3}{r_1^2} = \frac{k \times q_2 \times q_3}{r_2^2}$$

$$\frac{q_1}{r_1^2} = \frac{q_2}{r_2^2} \rightarrow \frac{q_1}{x^2} = \frac{q_2}{(0.4 - x)^2}$$

$$x = 0.16 \text{ m}$$

A third charged particle (q_3) should be placed at $x = 0.16 \text{ m}$ to be at an equilibrium point.



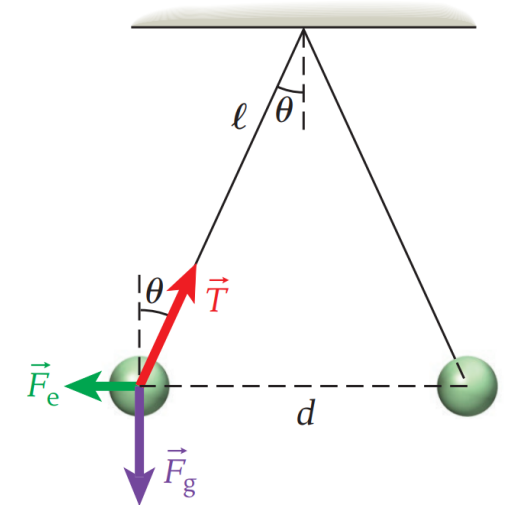
Example 1.3 – Page 13

1.5 Electrostatic Force – Coulomb's Law

Solved Problem 1.1

63

Two identical charged balls hang from the ceiling by insulated ropes of equal length, $\ell = 1.50 \text{ m}$. A charge $q = 25.0 \text{ } \mu\text{C}$ is applied to each ball. Then the two balls hang at rest, and each supporting rope has an angle of 25.0° with respect to the vertical. What is the mass of each ball?



Solved Problem 1.1 – Page 14

1.5 Electrostatic Force – Coulomb's Law

Solved Problem 1.1

64

Two identical charged balls hang from the ceiling by insulated ropes of equal length, $\ell = 1.50 \text{ m}$. A charge $q = 25.0 \text{ } \mu\text{C}$ is applied to each ball. Then the two balls hang at rest, and each supporting rope has an angle of 25.0° with respect to the vertical. What is the mass of each ball?

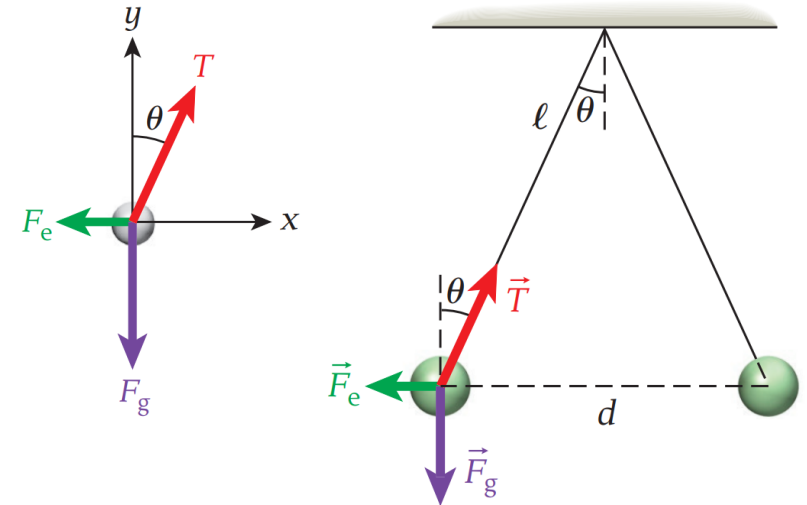
$$T \sin \theta = F_e$$

$$T \cos \theta = F_g$$

$$\frac{T \sin \theta}{T \cos \theta} = \frac{F_e}{F_g}$$

$$\tan \theta = \frac{F_e}{F_g} \qquad \tan \theta = \frac{\frac{kq_1q_2}{r^2}}{mg}$$

$$\tan \theta = \frac{kq_1q_2}{r^2mg}$$



Solved Problem 1.1 – Page 14

1.5 Electrostatic Force – Coulomb's Law

Solved Problem 1.1

65

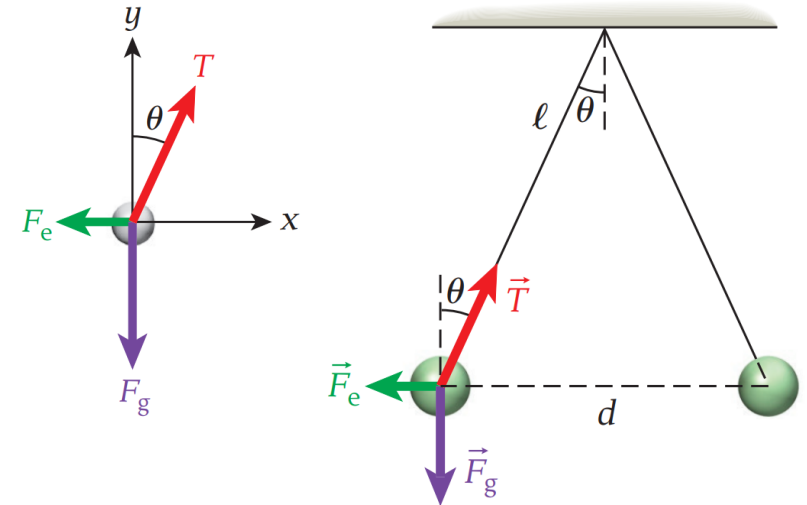
Two identical charged balls hang from the ceiling by insulated ropes of equal length, $\ell = 1.50 \text{ m}$. A charge $q = 25.0 \text{ } \mu\text{C}$ is applied to each ball. Then the two balls hang at rest, and each supporting rope has an angle of 25.0° with respect to the vertical. What is the mass of each ball?

$$m = \frac{kq_1q_2}{r^2 g \tan \theta}$$

$$m = \frac{8.99 \times 10^9 \times 25^2 \times 10^{-12}}{(3 \sin 25^\circ)^2 \times 9.81 \times \tan 25^\circ}$$

$$m = 0.76 \text{ kg}$$

$$\sin \theta = \frac{d/2}{1.5} \quad d = 3 \sin \theta$$



Concept Check 1.8

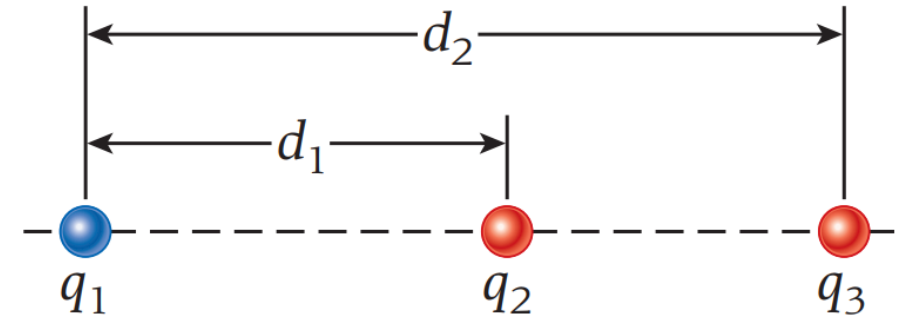
Consider three charges placed along the x-axis, as shown in the figure. The values of the charges are

$q_1 = -8.10 \mu\text{C}$, $q_2 = 2.16 \mu\text{C}$, and $q_3 = 2.16 \text{ pC}$.

The distance between q_1 and q_2 is $d_1 = 1.71 \text{ m}$.

The distance between q_1 and q_3 is $d_2 = 2.62 \text{ m}$.

What is the magnitude of the total electrostatic force exerted on q_3 by q_1 and q_2 ?



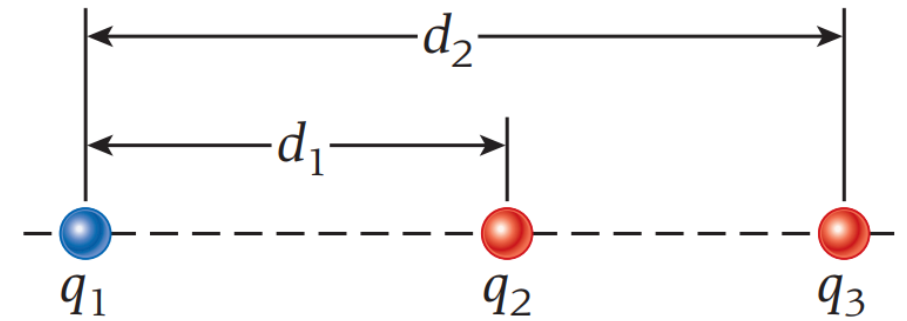
66

Concept Check 1.8

Consider three charges placed along the x-axis, as shown in the figure. The values of the charges are

$q_1 = -8.10 \mu\text{C}$, $q_2 = 2.16 \mu\text{C}$, and $q_3 = 2.16 \text{ pC}$.

The distance between q_1 and q_2 is $d_1 = 1.71 \text{ m}$. The distance between q_1 and q_3 is $d_2 = 2.62 \text{ m}$. What is the magnitude of the total electrostatic force exerted on q_3 by q_1 and q_2 ?



$$F_{1 \rightarrow 3} = \frac{kq_1q_3}{r^2} = \frac{8.99 \times 10^9 \times 8.10 \times 2.16 \times 10^{-18}}{2.62^2} = 2.29 \times 10^{-8} \text{ N } x^-$$

$$F_{2 \rightarrow 3} = \frac{kq_2q_3}{r^2} = \frac{8.99 \times 10^9 \times 2.16 \times 2.16 \times 10^{-18}}{(2.62 - 1.71)^2} = 5.07 \times 10^{-8} \text{ N } x^+$$

$$F_{\text{net} \rightarrow 3} = F_{1 \rightarrow 3} + F_{2 \rightarrow 3} = (-2.29 \times 10^{-8}) + 5.07 \times 10^{-8} = 2.77 \times 10^{-8} \text{ N } x^+$$

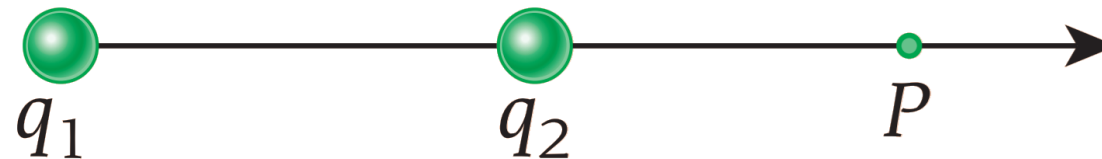
Concept Check 1.8 – Page 15

1.5 Electrostatic Force – Coulomb's Law

Self-Test Opportunity 1.2

68

A positive point charge $+q$ is placed at point P , to the right of two charges q_1 and q_2 , as shown in the figure. The net electrostatic force on the positive charge $+q$ is found to be zero. Identify each of the following statements as true or false.



- a) Charge q_2 must have the opposite sign from q_1 and be smaller in magnitude.
- b) The magnitude of charge q_1 must be smaller than the magnitude of charge q_2 .
- c) Charges q_1 and q_2 must have the same sign.
- d) If q_1 is negative, then q_2 must be positive.
- e) Either q_1 or q_2 must be positive.

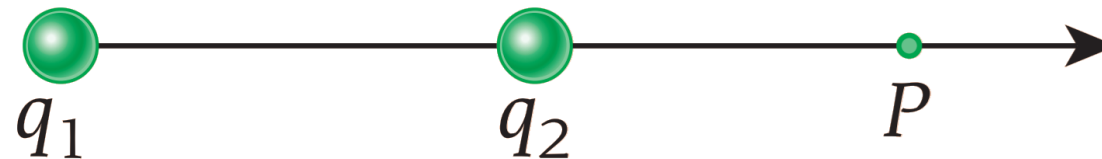
Self-Test Opportunity 1.2 – Page 15

1.5 Electrostatic Force – Coulomb's Law

Self-Test Opportunity 1.2

69

A positive point charge $+q$ is placed at point P , to the right of two charges q_1 and q_2 , as shown in the figure. The net electrostatic force on the positive charge $+q$ is found to be zero. Identify each of the following statements as true or false.



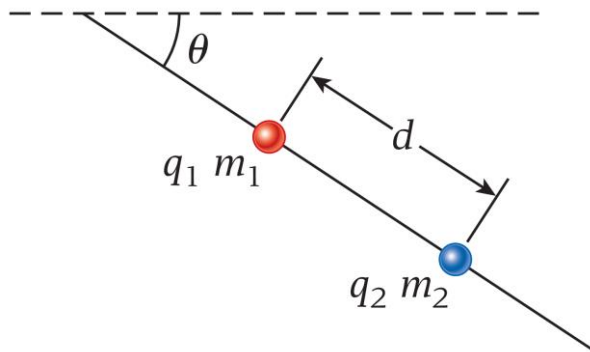
- a) Charge q_2 must have the opposite sign from q_1 and be smaller in magnitude.
- b) The magnitude of charge q_1 must be smaller than the magnitude of charge q_2 .
- c) Charges q_1 and q_2 must have the same sign.
- d) If q_1 is negative, then q_2 must be positive.
- e) Either q_1 or q_2 must be positive.

True
False
False
True
True

Solved Problem 1.2

70

A bead with charge $q_1 = +1.28 \mu\text{C}$ is fixed in place on an insulating wire that makes an angle of $\theta = 42.3^\circ$ with respect to the horizontal. A second bead with charge $q_2 = -5.06 \mu\text{C}$ slides without friction on the wire. At a distance $d = 0.380 \text{ m}$ between the beads, the net force on the second bead is zero. What is the mass, m_2 , of the second bead?



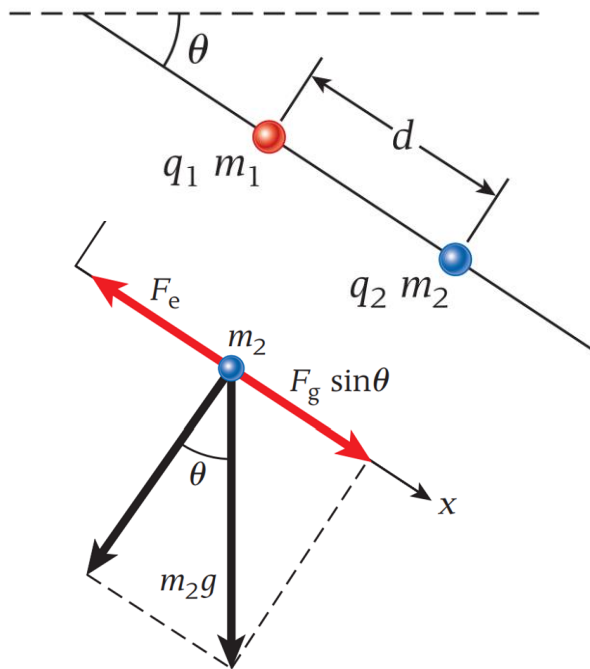
Solved Problem 1.2 – Page 16

1.5 Electrostatic Force – Coulomb's Law

Solved Problem 1.2

71

A bead with charge $q_1 = +1.28 \mu\text{C}$ is fixed in place on an insulating wire that makes an angle of $\theta = 42.3^\circ$ with respect to the horizontal. A second bead with charge $q_2 = -5.06 \mu\text{C}$ slides without friction on the wire. At a distance $d = 0.380 \text{ m}$ between the beads, the net force on the second bead is zero. What is the mass, m_2 , of the second bead?



$$F_{e,1 \rightarrow 2} = F_g$$

$$\frac{kq_1q_2}{r^2} = m_2g \sin \theta \quad m_2 = \frac{kq_1q_2}{r^2g \sin \theta}$$

$$= \frac{8.99 \times 10^9 \times 1.28 \times 5.06 \times 10^{-12}}{0.380^2 \times 9.81 \times \sin 42.3^\circ}$$

$$= 0.0611 \text{ kg} = 61.1 \text{ g}$$

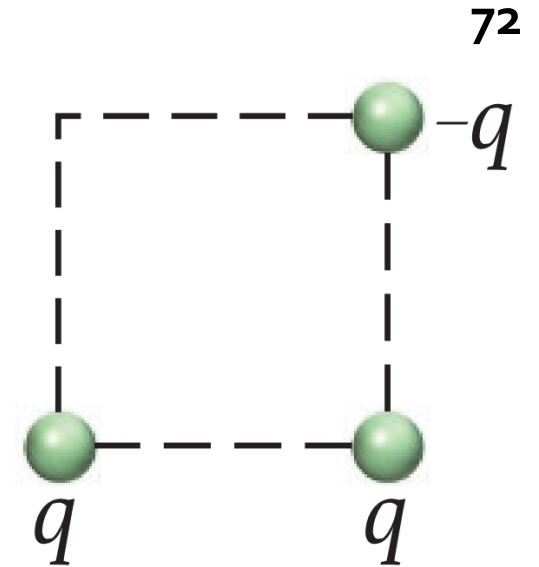
Solved Problem 1.2 – Page 16

1.5 Electrostatic Force – Coulomb's Law

Concept Check 1.9

Three charges are arranged at the corners of a square as shown in the figure. What is the direction of the electrostatic force on the lower-right charge?

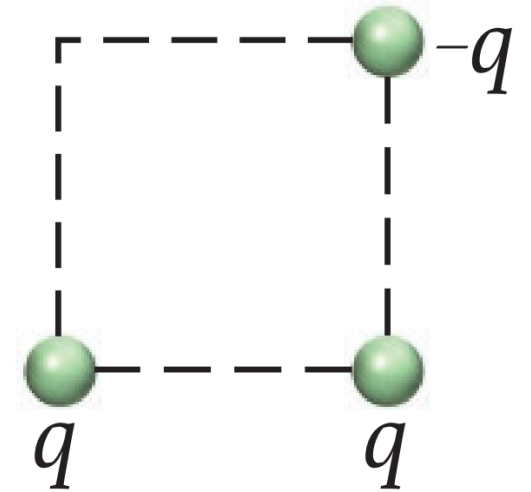
- a) 
- b) 
- c) 
- d) 
- e) There is no force on that charge.



Concept Check 1.9

Three charges are arranged at the corners of a square as shown in the figure. What is the direction of the electrostatic force on the lower-right charge?

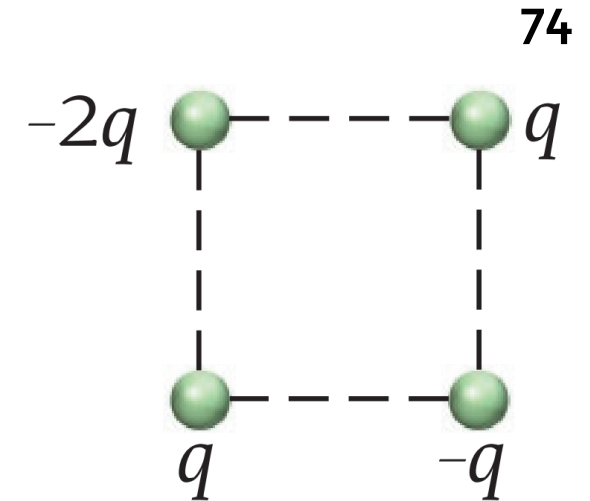
- a) 
- b) 
- c) 
- d) 
- e) There is no force on that charge.



Concept Check 1.10

Four charges are arranged at the corners of a square as shown in the figure. What is the direction of the electrostatic force on the lower-right charge?

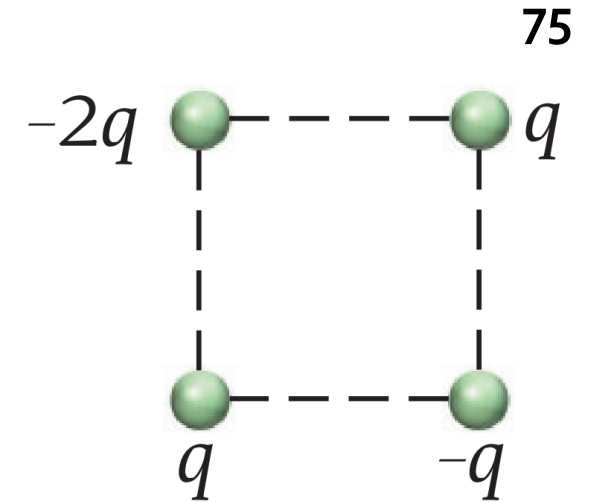
- a) 
- b) 
- c) 
- d) 
- e) There is no force on that charge.



Concept Check 1.10

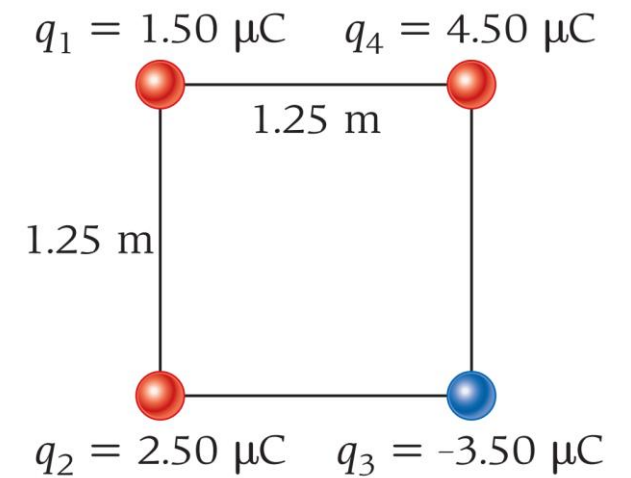
Four charges are arranged at the corners of a square as shown in the figure. What is the direction of the electrostatic force on the lower-right charge?

- a) 
- b) 
- c) 
- d) 
- e) There is no force on that charge.



Solved Problem 1.3

What are the magnitude and the direction of the electrostatic force on q_4 resulting from the other three charges?



76

Solved Problem 1.3 – Page 17

1.5 Electrostatic Force – Coulomb's Law

Solved Problem 1.3

77

What are the magnitude and the direction of the electrostatic force on q_4 resulting from the other three charges?

$$F_{1 \rightarrow 4} = k \frac{|q_1 q_4|}{r_{14}^2} = \frac{(8.99 \times 10^9 \text{ N m}^2/\text{C}^2)(1.50 \mu\text{C})(4.50 \mu\text{C})}{(1.25 \text{ m})^2} = 0.0388 \text{ N}.$$

For $\vec{F}_{2 \rightarrow 4}$, we get

$$F_{2 \rightarrow 4} = k \frac{|q_2 q_4|}{r_{24}^2} = \frac{(8.99 \times 10^9 \text{ N m}^2/\text{C}^2)(2.50 \mu\text{C})(4.50 \mu\text{C})}{[\sqrt{2}(1.25 \text{ m})]^2} = 0.0324 \text{ N}.$$

For $F_{3 \rightarrow 4}$ we get

$$F_{3 \rightarrow 4} = k \frac{|q_3 q_4|}{r_{34}^2} = \frac{(8.99 \times 10^9 \text{ N m}^2/\text{C}^2)(3.50 \mu\text{C})(4.50 \mu\text{C})}{(1.25 \text{ m})^2} = 0.0906 \text{ N}$$

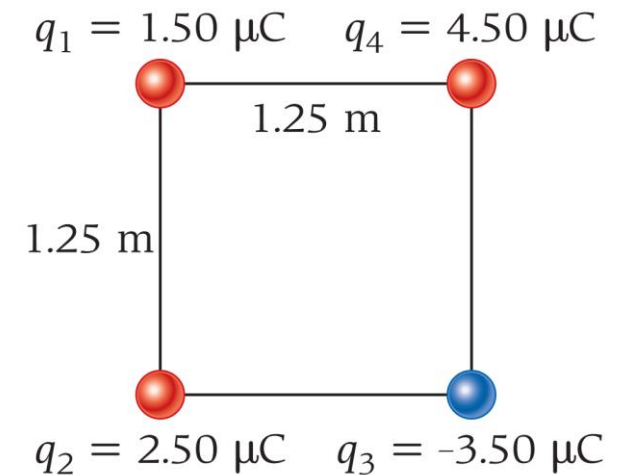
$$\theta = \tan^{-1} \frac{F_{\text{net} \rightarrow 4, y}}{F_{\text{net} \rightarrow 4, x}}$$

$$\theta = -47.7^\circ$$

$$F_{\text{net} \rightarrow 4, x} = F_{1 \rightarrow 4, x} + F_{2 \rightarrow 4, x} + F_{3 \rightarrow 4, x} = 0.0388 + 0.0324 \times \cos 45^\circ + 0 = 0.0617 \text{ N}$$

$$F_{\text{net} \rightarrow 4, y} = F_{1 \rightarrow 4, y} + F_{2 \rightarrow 4, y} + F_{3 \rightarrow 4, y} = 0 + 0.0324 \times \sin 45^\circ + (-0.0906) = -0.0677 \text{ N}$$

$$F_{\text{net} \rightarrow 4} = \sqrt{(F_{\text{net} \rightarrow 4, x})^2 + (F_{\text{net} \rightarrow 4, y})^2} = \sqrt{(0.0617)^2 + (-0.0677)^2} = 0.0916 \text{ N}$$



Solved Problem 1.3 – Page 17

1.5 Electrostatic Force – Coulomb's Law

Multiple Choice Question 1.2

78

The force between a charge of $25 \mu\text{C}$ and a charge of $-10 \mu\text{C}$ is 8.0 N . What is the separation between the two charges?

- a) 0.28 m
- b) 0.53 m
- c) 0.45 m
- d) 0.15 m

Multiple Choice Question 1.2

79

The force between a charge of $25 \mu\text{C}$ and a charge of $-10 \mu\text{C}$ is 8.0 N . What is the separation between the two charges?

- a) 0.28 m
- b) 0.53 m**
- c) 0.45 m
- d) 0.15 m

Multiple Choice Question 1.3

80

A charge Q_1 is positioned on the x-axis at $x = a$. Where should a charge $Q_2 = -4Q_1$ be placed to produce a net electrostatic force of zero on a third charge, $Q_3 = Q_1$, located at the origin?

- a) at the origin
- b) at $x = 2a$
- c) at $x = -2a$
- d) at $x = -a$

Multiple Choice Question 1.3

81

A charge Q_1 is positioned on the x-axis at $x = a$. Where should a charge $Q_2 = -4Q_1$ be placed to produce a net electrostatic force of zero on a third charge, $Q_3 = Q_1$, located at the origin?

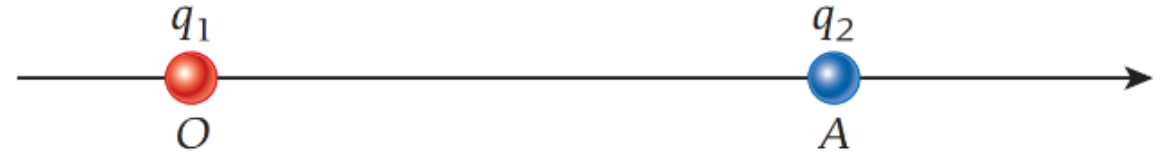
- a) at the origin
- b) at $x = 2a$
- c) at $x = -2a$
- d) at $x = -a$

Multiple Choice Question 1.5

82

Two point charges are fixed on the x-axis: $q_1 = 6.0 \mu\text{C}$ is located at the origin, O , with $x_1 = 0.0 \text{ cm}$, and $q_2 = -3.0 \mu\text{C}$ is located at point A , with $x_2 = 8.0 \text{ cm}$. Where should a third charge, q_3 , be placed on the x-axis so that the total electrostatic force acting on it is zero?

- a) 19 cm
- b) 27 cm
- c) 0.0 cm
- d) 8.0 cm
- e) -19 cm

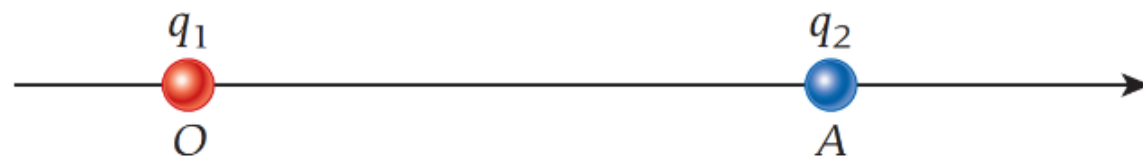


Multiple Choice Question 1.5

83

Two point charges are fixed on the x-axis: $q_1 = 6.0 \mu\text{C}$ is located at the origin, O , with $x_1 = 0.0 \text{ cm}$, and $q_2 = -3.0 \mu\text{C}$ is located at point A , with $x_2 = 8.0 \text{ cm}$. Where should a third charge, q_3 , be placed on the x-axis so that the total electrostatic force acting on it is zero?

- a) 19 cm
- b) 27 cm
- c) 0.0 cm
- d) 8.0 cm
- e) -19 cm



Conceptual Question 1.15

84

If two charged particles (*the charge on each is Q*) are separated by a distance d , there is a force F between them. What is the force if the magnitude of each charge is **doubled** and the distance between them changes to **$2d$** ?

Conceptual Question 1.15

85

If two charged particles (*the charge on each is Q*) are separated by a distance d , there is a force F between them. What is the force if the magnitude of each charge is **doubled** and the distance between them changes to **$2d$** ?

$$F = k \frac{Q_1 Q_2}{d^2} = k \frac{Q^2}{d^2}$$

$$F' = k \frac{4Q^2}{4d^2} = k \frac{Q^2}{d^2}$$

The force is the same as it was in the initial situation.

Conceptual Question 1.21

86

Two charged spheres are initially a distance d apart. The magnitude of the force on each sphere is F . They are moved closer to each other such that the magnitude of the force on each of them is $9F$. By what factor has the distance between the two spheres changed?

$$\begin{aligned} F_1 &= k \frac{Q_1 Q_2}{x_1^2} \quad F_2 = k \frac{Q_1 Q_2}{x_2^2} & x_2^2 &= \frac{F_1}{9F_1} x_1^2 & \rightarrow & x_2 = \sqrt{\frac{F_1}{9F_1} x_1^2} \\ kQ_1 Q_2 &= F_1 x_1^2 = F_2 x_2^2 & x_2 &= \frac{1}{3} x_1 \\ x_2^2 &= \left(\frac{F_1}{F_2} \right) x_1^2 \end{aligned}$$

EOT1 21-22 Exam Question

87

According to the figure, what is the magnitude of net force on q_1 ?

- a) $4.8 \times 10^{-9} \text{ N}$
- b) $9.6 \times 10^{-9} \text{ N}$
- c) $6.4 \times 10^{-9} \text{ N}$
- d) 0.0 N



EOT1 21-22 Exam Question

1.5 Electrostatic Force – Coulomb's Law

EOT1 21-22 Exam Question

88

According to the figure, what is the magnitude of net force on q_1 ?

- a) $4.8 \times 10^{-9} \text{ N}$
- b) $9.6 \times 10^{-9} \text{ N}$
- c) $6.4 \times 10^{-9} \text{ N}$
- d) **0.0 N**



EOT1 21-22 Exam Question

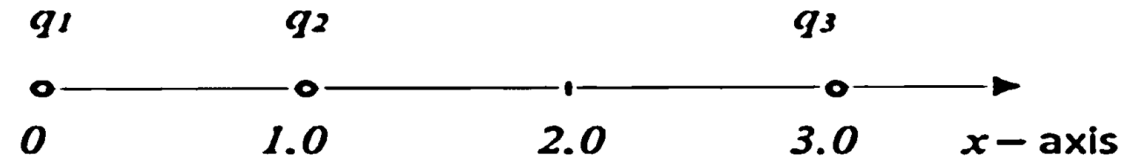
1.5 Electrostatic Force – Coulomb's Law

EOT1 20-21 Exam Question

89

In the figure, $q_1 = -10.0 \mu\text{C}$, $q_2 = 20.0 \mu\text{C}$ and $q_3 = 30.0 \mu\text{C}$. The distances along the x-axis are measured in meters. Find the **electrostatic force** exerted on q_3 due to the other two charges q_1 and q_2 .

- a) 1.05 N , along the positive y-axis
- b) 1.35 N , to the left
- c) 1.05 N , to the right
- d) 1.05 N , to the left



EOT1 20-21 Exam Question

1.5 Electrostatic Force – Coulomb's Law

EOT1 20-21 Exam Question

90

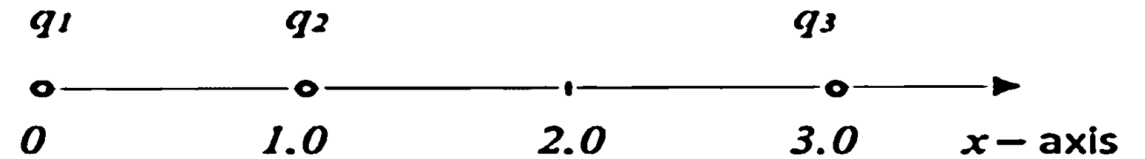
In the figure, $q_1 = -10.0 \mu\text{C}$, $q_2 = 20.0 \mu\text{C}$ and $q_3 = 30.0 \mu\text{C}$. The distances along the x-axis are measured in meters. Find the **electrostatic force** exerted on q_3 due to the other two charges q_1 and q_2 .

a) 1.05 N , along the positive y-axis

b) 1.35 N , to the left

c) 1.05 N , to the right

d) 1.05 N , to the left



EOT1 20-21 Exam Question

1.5 Electrostatic Force – Coulomb's Law

EOT1 20-21 Exam Question

91

Evaluate the magnitude of the **electrostatic force** exchanged between the two charges $q_1 = +30 \mu\text{C}$ and $q_2 = -40 \times 10^{-6} \text{C}$ separated by a distance of **9.0 cm**.

- a) $1.3 \times 10^3 \text{ N}$
- b) $3.0 \times 10^3 \text{ N}$
- c) $3.0 \times 10^4 \text{ N}$
- d) $1.8 \times 10^2 \text{ N}$

EOT1 20-21 Exam Question

1.5 Electrostatic Force – Coulomb's Law

EOT1 20-21 Exam Question

92

Evaluate the magnitude of the **electrostatic force** exchanged between the two charges $q_1 = +30 \mu\text{C}$ and $q_2 = -40 \times 10^{-6} \text{C}$ separated by a distance of **9.0 cm**.

a) $1.3 \times 10^3 \text{ N}$

b) $3.0 \times 10^3 \text{ N}$

c) $3.0 \times 10^4 \text{ N}$

d) $1.8 \times 10^2 \text{ N}$

$$F = \frac{kq_1q_2}{r^2}$$

$$= \frac{9 \times 10^9 \times 30 \times 40 \times 10^{-12}}{0.9^2}$$

$$= 1.3 \times 10^3 \text{ N}$$

EOT1 20-21 Exam Question

1.5 Electrostatic Force – Coulomb's Law

EOT1 19-20 Exam Question

93

Two equal point charges ($+q$) and ($-q$) are separated by a distance of (**9.0 cm**). If the electrostatic force between the charges is (**5.0 N**), what is the magnitude of each charge?

- a) 2.1 nC
- b) 2.1 μC
- c) 7.1 nC
- d) 7.1 μC

EOT1 19-20 Exam Question

1.5 Electrostatic Force – Coulomb's Law

EOT1 19-20 Exam Question

94

Two equal point charges (+ q) and (- q) are separated by a distance of (**9.0 cm**). If the electrostatic force between the charges is (**5.0 N**), what is the magnitude of each charge?

a) 2.1 nC

b) 2.1 μC

c) 7.1 nC

d) 7.1 μC

$$F = \frac{kqq}{r^2} = \frac{kq^2}{r^2}$$

$$q = \sqrt{\frac{F \times r^2}{k}} = \sqrt{\frac{(0.09)^2 \times 5}{9.0 \times 10^9}} \\ = 2.1 \times 10^{-6}$$

EOT1 19-20 Exam Question

1.5 Electrostatic Force – Coulomb's Law

Chapter 1 – Revision Paper

Resources

- Electrostatics, Chapter 21, from University Physics with Modern Physics, 2e by Bauer and Westfall © 2014

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