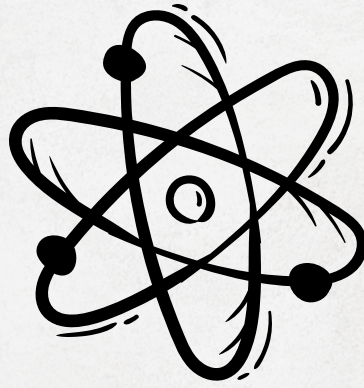


Physics Revision

مراجعة الفيزياء
12 متقدم - الفصل الأول



12 Advanced: Physics C 102

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Electric Charge

Law of Electric Charges

Like charges repel and opposite charges attract.

الشحنات المتشابهة تتنافر، والمختلفة تتجاذب.

Law of Electric Charges

The total electric charge of an isolated system is conserved.

الشحنة الكهربائية الكلية لنظام معزول محفوظة.

Elementary Charge (e)

The smallest unit of charge is known as the elementary charge which has a magnitude of 1.602×10^{-19} .

الشحنة الأساسية هي أقل وحدة للشحنة الكهربائية.

Quarks

Quarks are smaller parts of protons and neutrons with fractional charges.

الكوارك هي جزيئات صغيرة مُكوّنة للبروتونات والنيوترونات.

Charges are Quantized

The quantization of electric charge means that electric charge exists only in discrete values. Charges in nature are integer multiples of the elementary charge.

الشحنات مُكمّاة، وهذا يعني أن الشحنات لا تأتي بكميات عشوائية أو متصلة، بل تأتي بكميات محددة من مضاعفات الشحنة الأساسية.

Millikan oil drop experiment verified the quantization of the electric charge. تجربة قطرة الزيت تثبت أن الشحنات مُكمّاة.

<https://www.youtube.com/watch?v=UFiPWv03f6g>

What did the subatomic duck say?

"Quark, quark!"



Electric Charge

$$q = e(N_p - N_e)$$

- q : the **net charge** of the object in coulombs (C).
- e : the **elementary charge**, which is the magnitude of the charge carried by a single electron or proton. (1.602×10^{-19} coulombs)
- N_p : the number of protons in the object.
- N_e : the number of electrons in the object.

EXAMPLE 1.1

Net Charge

PROBLEM

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?

Molar mass of iron (M): 56

Avogadro's number (N_A) = 6.022×10^{23} atoms/mol

atomic number of iron = 26

حاول أن تحل السؤال، ثم انظر للإجابة في الصفحة التالية

Electric Charge

EXAMPLE 1.1

Net Charge

PROBLEM

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?

حل المسألة:

$$N_{\text{atoms}} = \frac{m \times N_A}{M}$$

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

Molar mass of iron (M): 56 g/mol
Converted g to kg
56/1000



$$N_e = N_{\text{atoms}} \times 26$$



Each iron atom has 26 electrons (since atomic number of iron = 26)

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

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

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

We found the number of electrons removed, but the problem asks for the fraction



Problem:

The Oxygen ion has 10 electrons, 8 protons, and 8 newtons. Find net electric charge of Oxygen ion.

$$q = e(N_p - N_e)$$

$$q = 1.6 \times 10^{-19} (8 - 10)$$

$$q = -3.2 \times 10^{-19} \text{ C}$$

Insulators, Conductors, Semiconductors, and Superconductors

Property	Conductors	Insulators (Nonconductors)	Semiconductors	Superconductors
Definition	Materials that allow easy flow of electric charge	Materials that prevent or severely limit the flow of electric charge	Materials that can switch between conducting and insulating states	Materials with zero electrical resistance
Electron Behavior	Loosely bound electrons that move freely	Electrons are tightly bound to atoms; no free movement	Can have both free electrons and holes depending on conditions	Electrons form Cooper pairs and flow without resistance
Common Examples	- Copper - Aluminum - Gold - Silver - Salt water	- Glass - Plastic - Rubber - Wood - Pure distilled water	- Silicon - Germanium - Gallium arsenide	- Niobium-titanium alloy - High-Tc ceramic materials
Charge Carriers	Only negative charges (electrons) move in solid conductors	No charge carriers available for conduction	- n-type: negative charges - p-type: positive holes	Electron pairs
Temperature Effect	Conductivity decreases as temperature increases	Generally unaffected by temperature	Conductivity increases with temperature	Only works below critical temperature
Operating Temperature	Any temperature	Any temperature	Room temperature	- Traditional: 4.2 K (liquid helium) - High-Tc: 77.3 K (liquid nitrogen)
Primary Applications	- Electrical wiring - Power transmission - Electronic components	- Electrical safety equipment - Circuit board substrate - Cable insulation	- Computer chips - Transistors - Electronic devices - Solar cells	- MRI machines - Particle accelerators - High-power electromagnets
Special Characteristics	- Different materials have different conductivity levels - Some are more suitable for specific applications	- Can hold static charge - Used as protective materials	- Can be doped to modify properties - Properties can be controlled	- Requires cooling systems - Perfect diamagnetism (Meissner effect)

Insulators, Conductors, Semiconductors, and Superconductors

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

سؤال وزاري

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

Which of the following are materials that have ($R=0 \Omega$)?

سؤال وزاري

- Insulators
- Semiconductors
- Conductors
- **Superconductors**

Electrostatic Charging

How to charge an object

- Electrostatic charging can be achieved through several methods using a power supply
- Power supplies (like car batteries) use chemical reactions to create charge separation
- Objects can be connected to Earth (grounding) to neutralize their charge
- The Earth serves as an infinite charge reservoir

Methods of charging

1. Charging by Conduction (By contact)

A negatively charged rod touches the electroscope, so the negative charges will move from the rod to the electroscope

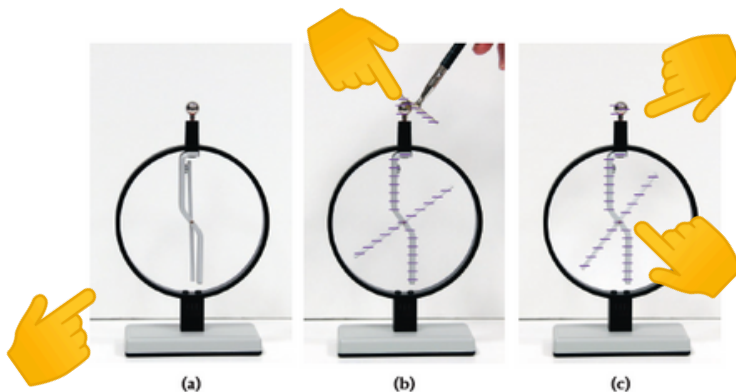


FIGURE 1.10 Charging by contact: (a) An uncharged electroscope. (b) A negatively charged paddle touches the electroscope. (c) The negatively charged paddle is removed.

the electroscope is now negatively charged (since the electrons moved to the electroscope by conduction)

Neutral electroscope

- Direct physical contact between charged and uncharged objects.
- Electrons transfer between objects.
- Charge remains after separation.
- Works with both positive and negative charges.



For example:

- When the paddle touches the electroscope, electrons move from paddle to electroscope
- When you take the paddle away (separation), those transferred electrons STAY on the electroscope

Electrostatic Charging

1. Charging by Induction

Positive charges attract near the negatively charged rod (unlike charges)

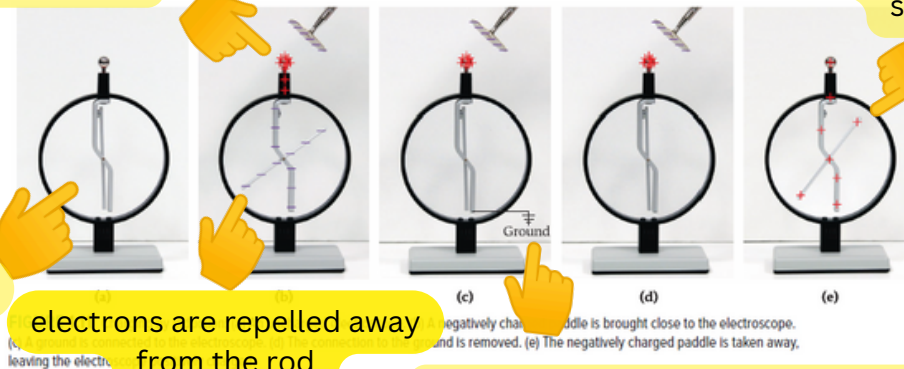
A negatively charged rod brought close to the electroscope. (Not touching)

Now the electroscope is positively charged since it lost some electrons.

Neutral electroscope

electrons are repelled away from the rod

When ground is connected, some electrons flow into the ground (out of the electroscope)



Induction WITHOUT Grounding

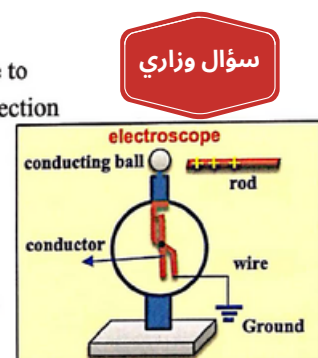
- No physical contact occurs
- No actual charge transfer
- Effect is temporary
- Charge effect disappears when source is removed
- Electroscope returns to neutral state

Induction WITH Grounding

- Actual charge transfer occurs through ground
- Creates permanent charge **opposite to the source**
- Charge remains after source is removed
- Electroscope gets opposite charge of the source
- Effect is permanent until neutralized

2- In the figure, a rod carrying a positive charge is brought close to an uncharged electroscope without touching it. When the connection to the ground is removed, **which of the following is true?**

- ☐ a ball and conductor are both negatively charged.
- ☐ a ball and conductor are both positively charged.
- ☐ a ball is positively charged and conductor is negatively charged.
- ☐ a ball is positively charged and the conductor is uncharged.



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Induction with grounding results in opposite charge to the source.

- If **positive rod** used → Electroscope becomes **negatively charged**
- If **negative rod** used → Electroscope becomes **positively charged**

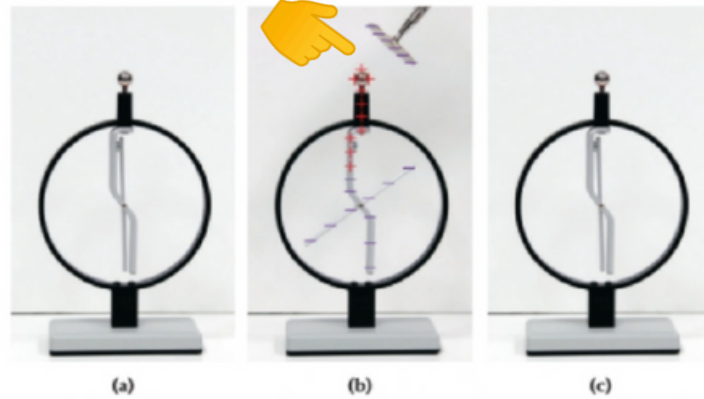
The correct answer is the **third** option.

Electrostatic Charging

The figure below shows charging by _____

سؤال وزاري

Not touching



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

Electrostatic Force

Coulomb's Law:

$$F = k \frac{|q_1 q_2|}{r^2},$$

Where:

- F is the electrostatic force between the charges (N).
- k is Coulomb's constant, which is approximately equal to $k = 8.99 \times 10^9 \frac{\text{N m}^2}{\text{C}^2}$
- q1 and q2 are the magnitudes of the charges on the two objects, measured in coulombs (C).
- r is the distance between the centers of the two charges, measured in meters (m).

Coulomb's constant

$$k = \frac{1}{4\pi\epsilon_0} \cdot$$

Coulomb's constant and electric permittivity of free space ϵ_0

$$\epsilon_0 = 8.85 \times 10^{-12} \frac{\text{C}^2}{\text{N m}^2} \cdot$$

Value of the electric permittivity of free space ϵ_0 (constant value)

EXAMPLE 1.2

Electrostatic Force inside the Atom

PROBLEM 1

What is the magnitude of the electrostatic force that the two protons inside the nucleus of a helium atom exert on each other?

Given:

$$q = 1.6 \times 10^{-19}$$

$$r = 2 \cdot 10^{-15} \text{ m}$$

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

The distance between the two protons

يجب معرفة كيفية جمع المتجهات لحل المسائل المتعلقة بهذا الدرس.

You need to know vectors addition to be able to solve problems in this topic.

Electrostatic Force

PROBLEM 2

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

Given:

$$r = 4.88 \times 10^{-12} \text{ m}$$

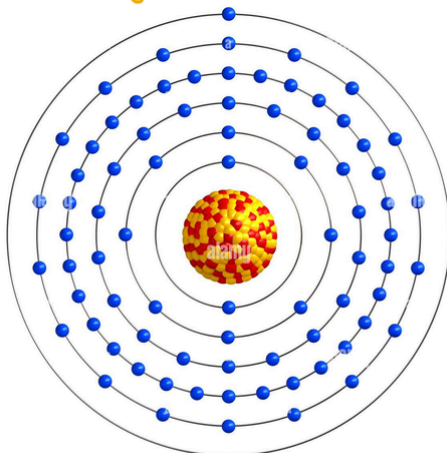
$$q_1 (\text{electron charge}) = -1.6 \times 10^{-19} \text{ C}$$

Gold atomic number = 79



This means that each gold atom has **79 protons** in its nucleus

This image is not given in the problem, it is just for clarification



79 Protons 118 Neutrons 79 Electrons

Solution:

one electron charge

79 protons x the charge of one proton

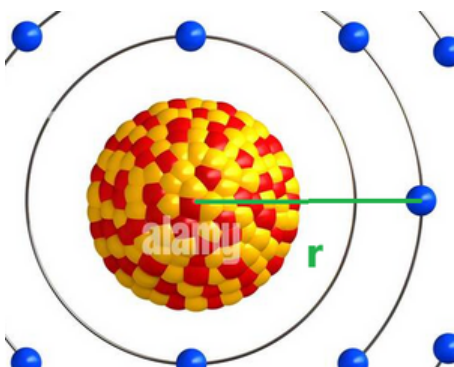


$$F = k \frac{|q_e q_N|}{r^2} = \left(8.99 \times 10^9 \frac{\text{N m}^2}{\text{C}^2} \right) \frac{(1.60 \times 10^{-19} \text{ C}) [(79)(1.60 \times 10^{-19} \text{ C})]}{(4.88 \times 10^{-12} \text{ m})^2} = 7.63 \times 10^{-4} \text{ N.}$$



The distance between the electron and the gold nucleus

The nucleus of the gold atom is the yellow and red sphere in the center. Electrons orbit around the atom. The problem gives the distance between one of the electron and the atom and asks us to calculate the force between the atom and the electron.



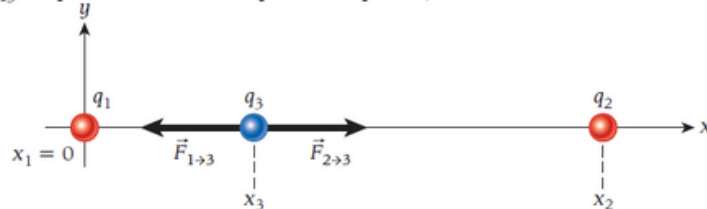
Electrostatic Force

EXAMPLE 1.3

Equilibrium Position

PROBLEM

Two charged particles are placed as shown in Figure 1.16: $q_1 = 0.15 \mu\text{C}$ 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)?



Solution:

The problem stated that we need q_3 to be at equilibrium point

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

This is the distance between q_3 and q_2 . Note that the distance between q_1 (the origin) and q_2 is x_2 and it is 0.40 m

Equilibrium means that the net force acting on the charge is zero.

$$F_1 - F_2 = 0$$

$$F_1 = F_2$$

$$k \frac{|q_1 q_3|}{(x_3 - x_1)^2} = k \frac{|q_3 q_2|}{(x_2 - x_3)^2}.$$

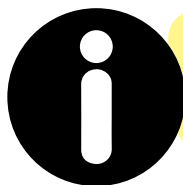
Distance between q_1 and q_3

$$k \frac{|q_1 \cancel{q_3}|}{(x_3 - x_1)^2} = k \frac{|q_3 \cancel{q_2}|}{(x_2 - x_3)^2}.$$

Math stuff

$$q_1(x_2 - x_3)^2 = q_2(x_3 - x_1)^2.$$

$$x_3 = \frac{\sqrt{q_1} x_2 + \sqrt{q_2} x_1}{\sqrt{q_1} + \sqrt{q_2}} = \frac{\sqrt{0.15 \mu\text{C}} (0.40 \text{ m})}{\sqrt{0.15 \mu\text{C}} + \sqrt{0.35 \mu\text{C}}} = 0.16 \text{ m}.$$



All values in the equation are provided except for x_3 . Use the variable ' x ' to represent this missing value and calculate the final answer using your calculator and don't worry about this math stuff, buddy.

Electrostatic Force

PROBLEM

Two identical charged balls hang from the ceiling by insulated ropes of equal length, $\ell = 1.50 \text{ m}$ (Figure 1.17). A charge $q = 25.0 \mu\text{C}$ 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 (Figure 1.17a). What is the mass of each ball?

Solution: (We need to find the mass of each ball)

Key data given:

Length of each rope, $L = 1.50 \text{ m}$

Charge on each ball, $q = 25.0 \mu\text{C} = 25.0 \times 10^{-6} \text{ C}$

Angle with the vertical, $\theta = 25.0^\circ$

The two balls hang at rest

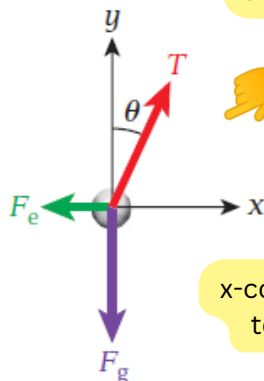
when an object is at rest, it is at static equilibrium, net force is 0

Net Force on x-axis = 0

Net force on y-axis = 0

Because the balls are at rest

As the tension force is inclined to both axes, it needs to be resolved into its x and y components for force addition.



There are 3 forces that act on the ball, tension force T , electrostatic force F_e , force due to gravity F_g

x-component of the tension force T

sin is used for x component because the angle given is with respect to the vertical.

You can use cos but the angle will be $90 - 25 = 65$ degrees (with respect to the horizontal)

$$T \sin \theta - F_e = 0,$$

Forces on x-axis are equal to 0. (ball at rest)

$$T \cos \theta - F_g = 0.$$

Forces on y-axis are equal to 0. (ball at rest)

y-component of the tension force T

$$F = mg$$

Force of gravity formula

Electrostatic force

$$F_e = k \frac{q^2}{d^2},$$

q^2 because the two balls have the same charge $q \cdot q = q^2$

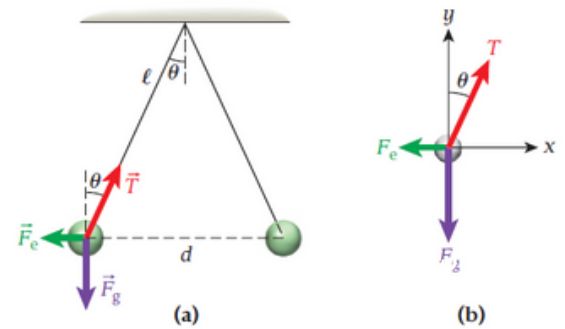
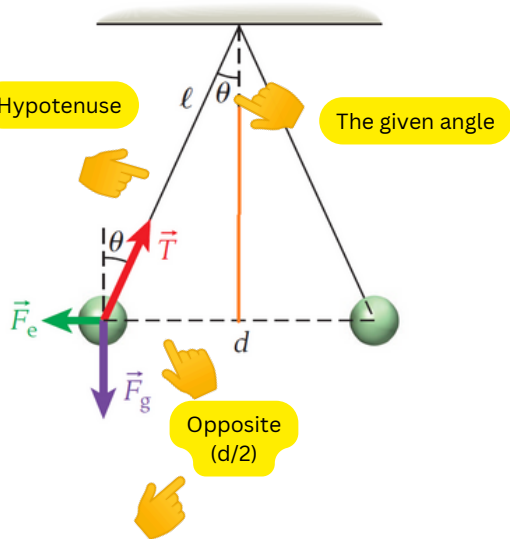


FIGURE 1.17 (a) Two charged balls hanging from the ceiling in their equilibrium position. (b) Free-body diagram for the left-hand charged ball.

As I mentioned before, you need to know how to add vectors in order to be able to solve such problems. If you need a file that explains vector addition, contact me on Telegram: @YaserOdat

Electrostatic Force



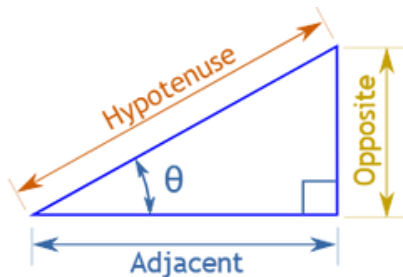
$$\sin \theta = \frac{d/2}{\ell}$$

Sine function in trigonometry to find the distance between the two charges:
 $\sin(\text{angle}) = \text{opposite/hypotenuse}$

$$F_e = k \frac{q^2}{(2\ell \sin \theta)^2}$$

The distance between the two balls = d
 $d = 2\ell \sin(\theta)$

$$\begin{aligned} \sin \theta &= \frac{\text{Opposite}}{\text{Hypotenuse}} \\ \cos \theta &= \frac{\text{Adjacent}}{\text{Hypotenuse}} \\ \tan \theta &= \frac{\text{Opposite}}{\text{Adjacent}} \end{aligned}$$



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

Since the ball is at rest, the net force on x-axis is 0, the net force on y-axis is 0

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

$$\tan \theta = \frac{F_e}{F_g}$$

$$\sin(\theta)/\cos(\theta) = \tan(\theta)$$

Value of F_e

$$\tan \theta = \frac{k \frac{q^2}{4\ell^2 \sin^2 \theta}}{mg} = \frac{kq^2}{4mg\ell^2 \sin^2 \theta}$$

Value of F_g

Solving the equation for m

$$m = \frac{kq^2}{4g\ell^2 \sin^2 \theta \tan \theta}$$

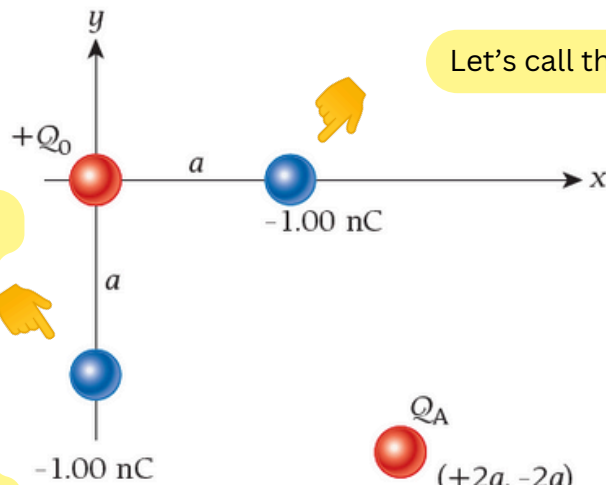
The ball's mass required

Putting in the numerical values

$$m = \frac{(8.99 \times 10^9 \text{ N m}^2/\text{C}^2)(25.0 \mu\text{C})^2}{4(9.81 \text{ m/s}^2)(1.50 \text{ m})^2(\sin^2 25.0^\circ)(\tan 25.0^\circ)} = 0.764116 \text{ kg.}$$

Electrostatic Force

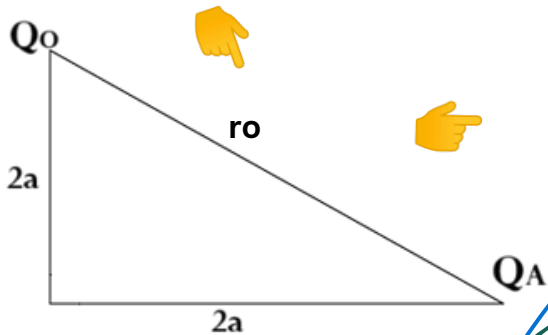
•1.82 In the figure, the net electrostatic force on charge Q_A is zero. If $Q_A = +1.00 \text{ nC}$, determine the magnitude of Q_0 .



Let's call this q

and this is also q
(same value)

r_0 is the hypotenuse which is the distance between Q_0 and Q_A . Use the Pythagorean theorem



$$r_0 = \sqrt{(2a)^2 + (2a)^2} = \sqrt{8a^2} = \sqrt{8}a$$

$$r_1 = r_2 = \sqrt{a^2 + (2a)^2} = a\sqrt{5}$$

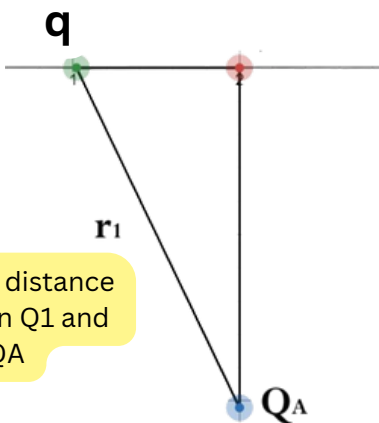
Since the net force on Q_A is 0, the net force on y-axis is 0

$$\theta = \tan^{-1}\left(\frac{a}{2a}\right) = \tan^{-1}\left(\frac{1}{2}\right) = 26.57^\circ$$

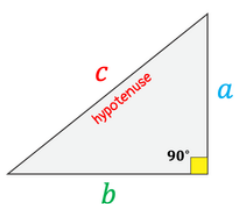
$$F_{1y} + F_{2y} = F_{0y}$$

Since the net force on Q_A is 0, the net force in the y-direction is 0

r_1 is the distance between Q_1 and Q_A



PYTHAGOREAN THEOREM



$$c^2 = a^2 + b^2$$

$$\star c = \sqrt{a^2 + b^2}$$

$$\star a = \sqrt{c^2 - b^2}$$

$$\star b = \sqrt{c^2 - a^2}$$

$$F_0 = \frac{kQ_0Q_A}{r_0^2}, \quad F_1 = \frac{kqQ_A}{r_1^2}, \quad F_2 = \frac{kqQ_A}{r_1^2}$$

$$F_{1y} = F_1 \sin \theta = \frac{kqQ_A \sin \theta}{r_1^2} = \frac{kqQ_A \sin 26.57^\circ}{(\sqrt{5}a)^2}$$

$$F_{2y} = F_2 \cos \theta = \frac{kqQ_A \cos \theta}{r_1^2} = \frac{kqQ_A \cos 26.57^\circ}{(\sqrt{5}a)^2}$$

$$F_{0y} = F_0 \sin 45^\circ = \frac{kQ_0Q_A \sin 45^\circ}{(\sqrt{8}a)^2}$$

To find the y-components of each force

Electrostatic Force

$$\frac{kqQ_A \sin 26.57^\circ}{(\sqrt{5}a)^2} + \frac{kqQ_A \cos 26.57^\circ}{(\sqrt{5}a)^2} = \frac{kQ_0Q_A \sin 45^\circ}{(\sqrt{8}a)^2}$$

$$\frac{\cancel{k}q\cancel{Q}_A \sin 26.57^\circ}{(\sqrt{5}\cancel{a})^2} + \frac{\cancel{k}q\cancel{Q}_A \cos 26.57^\circ}{(\sqrt{5}\cancel{a})^2} = \frac{\cancel{k}Q_0\cancel{Q}_A \sin 45^\circ}{(\sqrt{8}\cancel{a})^2}$$

$$\frac{q(\sin 26.57^\circ + \cos 26.57^\circ)}{5} = \frac{Q_0 \sin 45^\circ}{8} \quad \text{👉}$$

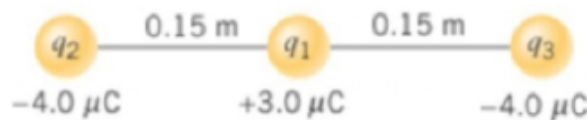
At this point you can use the calculator to solve the equation.

$$Q_0 = \frac{(1 \times 10^{-9}) \times 10.728}{3.535} \approx 3.036 \times 10^{-9} \text{ C} \quad \text{👉}$$

Final answer:
Q₀ = 3 nC

According to the figure below, what is the magnitude of the net force on q₁?

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- a. 4.8 nN
- b. 9.6 nN
- c. 6.4 nN
- d. 0

Electrostatic Force

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 . (Use $k = 9 \times 10^9 \frac{\text{N.m}^2}{\text{C}^2}$, $1.0 \mu = 1.0 \times 10^{-6}$).

سؤال وزاري

في الشكل المجاور، $q_1 = 10.0 \mu\text{C}$ و $q_2 = -20.0 \mu\text{C}$ و $q_3 = 30.0 \mu\text{C}$. تقاس المسافات على المحور الأفقي بالمتر. أوجد مقدار القوة الكهربائية المؤثرة على الشحنة q_3 والناجمة عن الشحنتين q_1 و q_2 . (استخدم $k = 9 \times 10^9 \frac{\text{N.m}^2}{\text{C}^2}$ ، $1.0 \mu = 1.0 \times 10^{-6}$).



Attraction force due to q_2
(negative with positive)

- because the two force vectors are in opposite directions



Repulsive force due to q_1

$$F_{\text{net},3} = F_{1,3} - F_{2,3}$$

$$F_{1,3} = k \frac{|q_1 q_3|}{r_{1,3}^2}$$

$$F_{1,3} = 9 \times 10^9 \frac{(10 \times 10^{-6})(30 \times 10^{-6})}{3^2}$$

$$F_{1,3} = \frac{9 \times 10^9 \times 300 \times 10^{-12}}{9} = 0.3 \text{ N}$$

$$F_{2,3} = k \frac{|q_2 q_3|}{r_{2,3}^2}$$

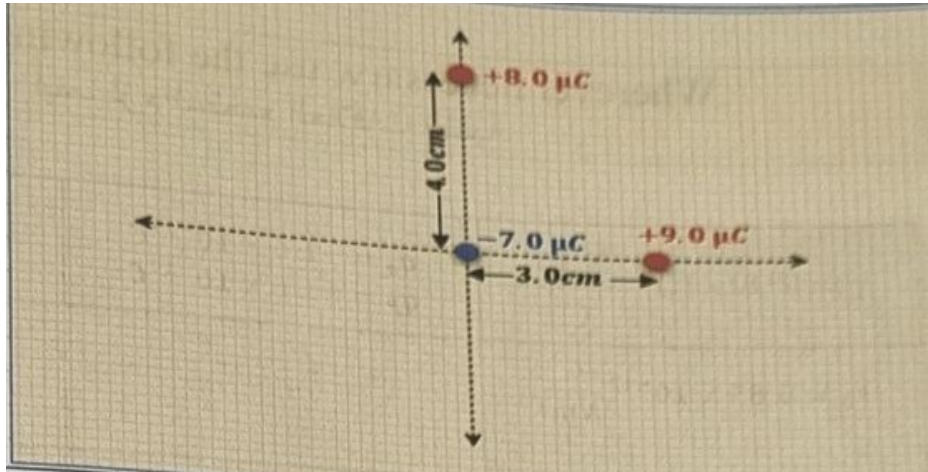
$$F_{2,3} = 9 \times 10^9 \frac{(20 \times 10^{-6})(30 \times 10^{-6})}{2^2}$$

$$F_{2,3} = \frac{9 \times 10^9 \times 600 \times 10^{-12}}{4} = 1.35 \text{ N}$$

$$F_{\text{net},3} = F_{1,3} - F_{2,3}$$

$$F_{\text{net},3} = 0.3 \text{ N} - 1.35 \text{ N} = -1.05 \text{ N}$$

Electrostatic Force



سؤال وزاري

- A. Calculate the magnitude of the resultant electrostatic force acting on the charge $-7.0 \mu\text{C}$
- B. Find the direction of the resultant electrostatic force acting on the charge $-7.0 \mu\text{C}$ (By finding the angle).

Solution:

$$F = k \frac{|q_1 q_2|}{r^2}$$
$$F_1 = 8.99 \times 10^9 \frac{|9.0 \times 10^{-6} \times -7.0 \times 10^{-6}|}{(3.0 \times 10^{-2})^2}$$
$$F_1 = 6.29 \times 10^2 \text{ N}$$
$$F_2 = 8.99 \times 10^9 \frac{|8.0 \times 10^{-6} \times -7.0 \times 10^{-6}|}{(4.0 \times 10^{-2})^2}$$
$$F_2 = 3.15 \times 10^2 \text{ N}$$
$$F_{\text{net}} = \sqrt{F_1^2 + F_2^2}$$
$$F_{\text{net}} = \sqrt{(6.29 \times 10^2)^2 + (3.15 \times 10^2)^2}$$
$$F_{\text{net}} = 7.04 \times 10^2 \text{ N}$$
$$\tan^{-1} \theta = \frac{3.15 \times 10^2}{6.29 \times 10^2}$$
$$\theta = 26.57^\circ$$

Electric Field

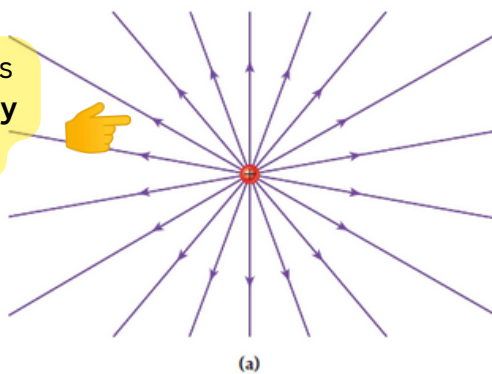
$$\vec{E}(\vec{r}) = \frac{\vec{F}(\vec{r})}{q}$$

- **E(r):** The **electric field vector** at a point in space located at position vector $\vec{r}$.
- **F(r):** The **force vector** acting on a charge q placed at the same position $\vec{r}$.
- **q:** The magnitude of the **charge** placed at position $\vec{r}$.

Concepts

- **Test charge** is a tiny positive charge used to measure an electric field.
- A positive charge moves with the field, while a negative charge moves against it.
- **Electric field lines** are invisible lines that show the direction and strength of an electric field.
- Field lines start from positive charges and end at negative charges.
- Although electric fields are 3D, they are often shown in 2D for simplicity.
- Field lines don't cross each other.
- The closer the field lines are together, the stronger the electric field (density of the field lines)

Electric field lines always **point away** from positive charges



Electric field lines always **point towards** negative charges.

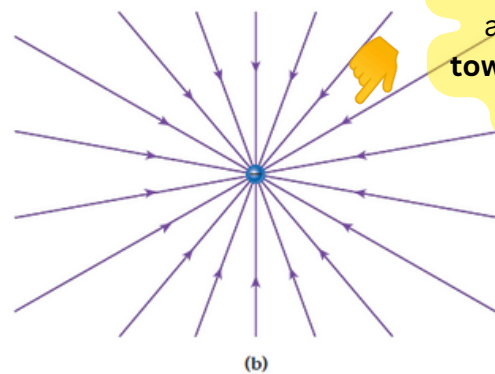


FIGURE 2.6 Electric field lines (a) from a single positive point charge and (b) to a single negative point charge.

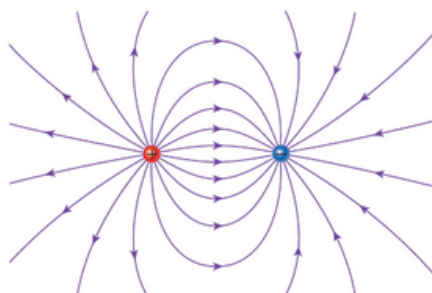


FIGURE 2.7 Electric field lines from two oppositely charged point charges. Each charge has the same magnitude.

The lines avoid connecting, showing the repulsive force between like charges.

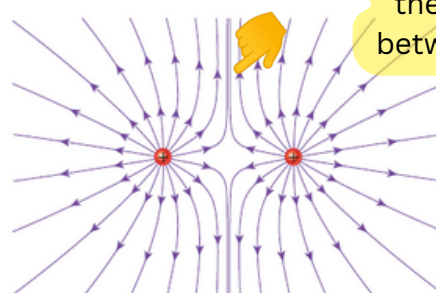
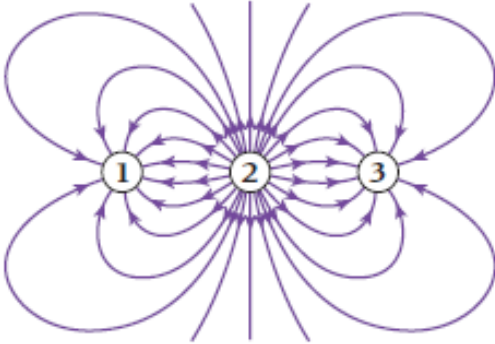


FIGURE 2.8 Electric field lines from two positive point charges with the same magnitude.

Electric Field

Concept Check 2.1

Which of the charges in the figure is (are) positive?

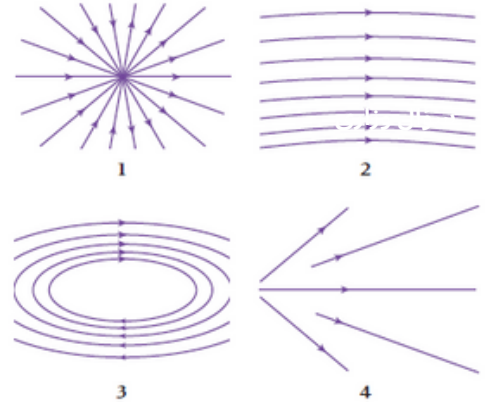


- a) 1
- b) 2
- c) 3
- d) 1 and 3
- e) All three charges are positive.

Concept Check 2.2

Assuming that there are no charges in the four regions shown in the figure, which of the patterns could represent an electric field?

- a) only 1
- b) only 2
- c) 2 and 3
- d) 1 and 4
- e) None of the patterns represent an electric field.

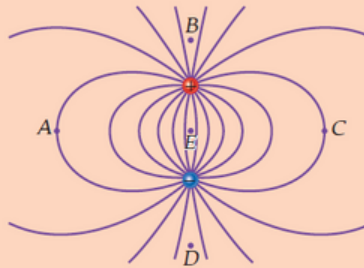


Correct Answer: b

Electric field lines never form closed loops and always point from higher potential to lower potential.

Self-Test Opportunity 2.1

The figure shows a two-dimensional view of electric field lines due to two opposite charges. What is the direction of the electric field at the five points A, B, C, D, and E? At which of the five points is the magnitude of the electric field the largest?



The strength of the electric field is indicated by the density of the field lines: where they are closer together, the field is stronger. In this image, the field lines are closest around point E, directly between the charges, so E has the largest electric field magnitude.

$$E = \left| \frac{F}{q_0} \right| = \frac{1}{4\pi\epsilon_0} \frac{|q|}{r^2}$$

- q_0 : A small test charge
- F: Electrostatic force
- r: The distance between the point we are measuring the electric field and the source charge

test charge is like a tiny explorer we send into this electric field to understand the field strength and direction

point charge, the charge that creates the electric field

$$E = \frac{k \cdot |q|}{r^2}$$

It is just the same formula

Electric Field

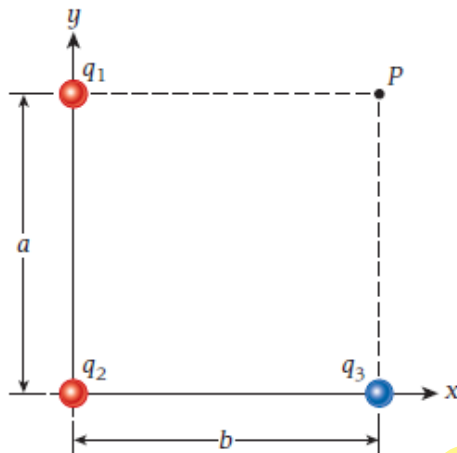


FIGURE 2.9 Locations of three point charges.

EXAMPLE 2.1

Three Charges

Figure 2.9 shows three fixed point charges: $q_1 = +1.50 \mu\text{C}$, $q_2 = +2.50 \mu\text{C}$, and $q_3 = -3.50 \mu\text{C}$. Charge q_1 is located at $(0, a)$, q_2 is located at $(0, 0)$, and q_3 is located at $(b, 0)$, where $a = 8.00 \text{ m}$ and $b = 6.00 \text{ m}$.

PROBLEM

What electric field, $\vec{E}$ do these three charges produce at the point $P = (b, a)$?

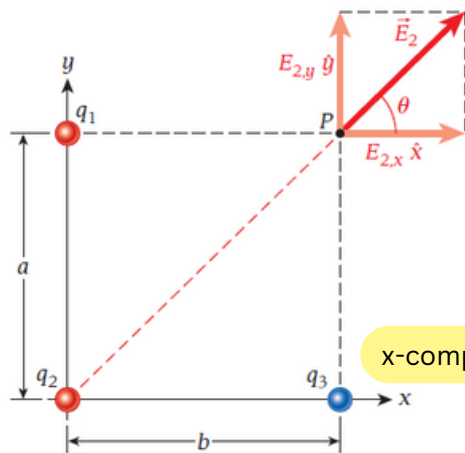


FIGURE 2.10 Electric field due to q_2 and its x- and y-components at point P .

$$\vec{E}_1 = E_{1,x}\hat{x} + E_{1,y}\hat{y}$$

E1 y-component is 0

$$E_{1,x} = \frac{kq_1}{b^2}$$

Finding the electric field due to charge q_1 .
b is the distance between the point P and q_1

$$E_{3,y} = \frac{kq_3}{a^2}$$

E3 x-component is 0

$$\vec{E}_2 = E_{2,x}\hat{x} + E_{2,y}\hat{y}$$

$$E_2 = \frac{k|q_2|}{a^2 + b^2}$$

Finding the magnitude of E_2

We need x and y components of E_2

y-component of E_2

$$\vec{E} = (E_{1,x} + E_{2,x})\hat{x} + (E_{2,y} + E_{3,y})\hat{y}$$

x-component of E_2

$$= \left(\frac{kq_1}{b^2} + \frac{kq_2 \cos \theta}{a^2 + b^2} \right) \hat{x} + \left(\frac{kq_2 \sin \theta}{a^2 + b^2} + \frac{kq_3}{a^2} \right) \hat{y}$$

$\tan^{-1}(\text{opposite/adjacent})$

$$E_x = \left(8.99 \times 10^9 \text{ N m}^2/\text{C}^2 \right) \left(\frac{1.50 \times 10^{-6} \text{ C}}{(6.00 \text{ m})^2} + \frac{(2.50 \times 10^{-6} \text{ C})(\cos 53.1^\circ)}{100 \text{ m}^2} \right) = 509 \text{ N/C}$$

$$E_y = \left(8.99 \times 10^9 \text{ N m}^2/\text{C}^2 \right) \left(\frac{(2.50 \times 10^{-6} \text{ C})(\sin 53.1^\circ)}{100 \text{ m}^2} + \frac{-3.50 \times 10^{-6} \text{ C}}{(8.00 \text{ m})^2} \right) = -312 \text{ N/C}$$

$$E = \sqrt{E_x^2 + E_y^2} = \sqrt{(509 \text{ N/C})^2 + (-312 \text{ N/C})^2} = 597 \text{ N/C}$$

$$\varphi = \tan^{-1} \left(\frac{E_y}{E_x} \right) = \tan^{-1} \left(\frac{-312 \text{ N/C}}{509 \text{ N/C}} \right) = -31.5^\circ$$

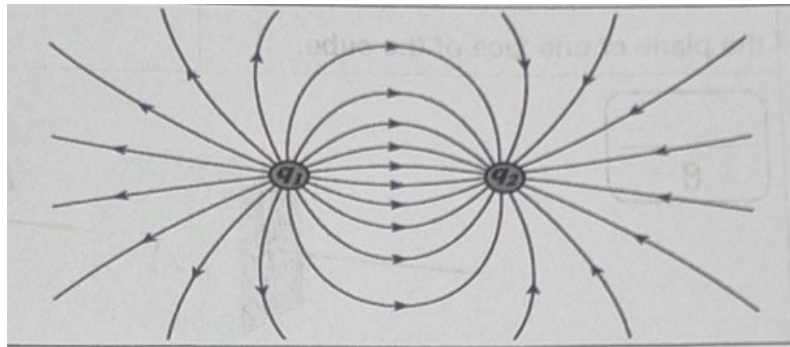
WARNING

If you don't understand how we found the net electric field or x and y-components of the electric field vectors, then you need to revise vectors and study it!

Electric Field

The figure shows the electric field lines of two point charges.

سؤال وزاري



- What is the type of charge q_1 and charge q_2 ?
- If the magnitude of charge q_2 is equal to $6.0 \mu\text{C}$, what is the magnitude of charge q_1 ?
- Draw two lines on the above figure representing equipotential surfaces, one surrounding the charge q_1 and the other surrounding the charge q_2 .

Answers:

A. q_1 is positive, q_2 is negative



The electric field lines point away from the positive charge and towards the negative charge.

B. $6.0 \mu\text{C}$

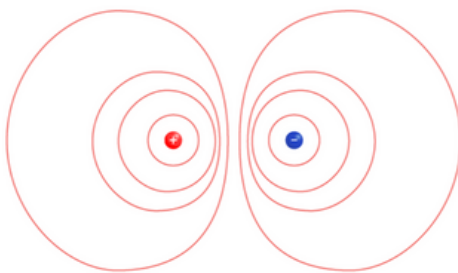


$$\frac{q_1}{q_2} = \frac{\text{Number of field lines for } q_1}{\text{Number of field lines for } q_2}$$



The electric field lines density is same around both charges, that means the magnitudes of the charges are equal

C.

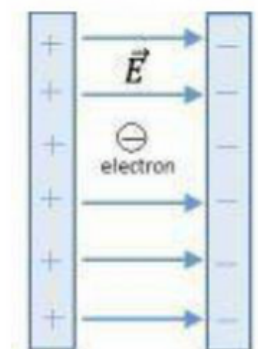


This is from chapter 03

An electron is placed in a uniform electric field E as shown in the figure. Then it is released to start its motion from rest. Which of the following statements describes the motion of the electron?

سؤال وزاري

- The electron will move to the left.
- The electron will move to the right.
- The electron will not move from its place.
- The given information is not sufficient to determine the motion of the electron.



Correct Answer: A

General Charge Distributions

Adding electric fields from multiple charges quickly becomes difficult or even impossible especially for a vast number of charges like in real world applications.

To simplify, we use **integration**, especially when charges are arranged in regular distributions (For example: along a surface or a wire).

Types of Charge Distributions:

- 1. **One-dimensional (line):** Charge spread along a wire.
- 2. **Two-dimensional (surface):** Charge on a metallic surface.
- 3. **Three-dimensional (volume):** Charge in a solid object.

Linear Charge Density

$$\lambda = \frac{Q}{L}$$

$$dq = \lambda dx$$

Surface Charge Density

$$\sigma = \frac{Q}{A}$$

$$dq = \sigma dA$$

Volume Charge Density

$$\rho = \frac{Q}{V}$$

$$dq = \rho dV$$

Symbol Interpretation:

- linear charge density λ
- surface charge density σ
- volume charge density ρ
- Q is the total charge distributed
- L is the total length of the line.
- A is the total area of the surface.
- V is the total volume of the region.
- dx is an infinitesimal length along the line.
- dA is an infinitesimal area on the surface.
- dV is an infinitesimal volume element.

Distribution Type	Charge Density	Units of Charge Density	Total Charge Formula	Differential Charge Formula
Line (1D)	λ	C/m	$Q=\lambda \cdot L$	$dq=\lambda dx$
Surface (2D)	σ	C/m^2	$Q=\sigma \cdot A$	$dq=\sigma dA$
Volume (3D)	ρ	C/m^3	$Q=\rho \cdot V$	$dq=\rho dV$

Note that a conducting sphere is 2D in terms of the charge distribution (surface) when it is in electrostatic equilibrium.

Because the charge resides only on the surface of the sphere



General Charge Distributions

What is the unit of measuring the linear charge density on a thin long rod?

تمرین

Answer: A

- A) C/m
- B) C/m²
- C) C/m³
- D) C/N

Which of the following best represents the unit for volume charge density?

تمرین

Answer: C

- A) Coulombs per square meter (C/m²)
- B) Coulombs per meter (C/m)
- C) Coulombs per cubic meter (C/m³)
- D) Coulombs per second (C/s)

For a thin cylindrical rod with a uniform linear charge density λ , how is the total charge Q distributed along the length L of the rod calculated?

تمرین

Answer: A

- A) $Q = \lambda \times L$
- B) $Q = \lambda/L$
- C) $Q = \lambda \times L^2$
- D) $Q = \lambda + L$

A conducting spherical shell has a radius of $R=10\text{cm}$ and carries a total charge of $Q=8\mu\text{C}$. The charge is uniformly distributed over the surface of the shell. Calculate the surface charge density on the conducting sphere.

تمرین

$$R = 10 \text{ cm} = 0.1 \text{ m}$$

$$Q = 8 \mu\text{C} = 8 \times 10^{-6} \text{ C}$$

$$A = 4\pi R^2$$

$$A = 4\pi(0.1)^2 = 4\pi \times 0.01 \text{ m}^2 = 0.1256 \text{ m}^2$$

$$\sigma = \frac{Q}{A}$$

$$\sigma = \frac{8 \times 10^{-6} \text{ C}}{0.1256 \text{ m}^2} = 6.37 \times 10^{-5} \text{ C/m}^2$$

General Charge Distributions

A thin, flat sheet of charge has a surface charge density of $\sigma = 30.0 \mu\text{C}/\text{m}^2$. If a smaller section of this sheet has an area of 0.015 cm^2 , what is the total charge on this smaller section?

تمرین

$$0.015 \text{ cm}^2 = 0.015 \times 10^{-4} \text{ m}^2 = 1.5 \times 10^{-6} \text{ m}^2$$

Total charge formula for a surface charge distribution



$$Q = \sigma \times A$$

Converting from cm^2 to m^2

$$Q = 30.0 \times 10^{-6} \text{ C}/\text{m}^2 \times 1.5 \times 10^{-6} \text{ m}^2 = 45 \times 10^{-12} \text{ C} = 45 \text{ pC}$$

p = pico

A thin wire with a uniform charge distribution has a total charge of $8.0 \mu\text{C}$ and a length of 4 m . What is the linear charge density λ of the wire?

تمرین

$$\lambda = \frac{Q}{L} = \frac{8.0 \mu\text{C}}{4 \text{ m}} = 2.0 \mu\text{C}/\text{m}$$

Electric Field Due to Charge Distributions

- Point Charge:

$$E = k_e \frac{q}{r^2}$$

- Line Charge:

$$E = \frac{\lambda}{2\pi\epsilon_0 r}$$

- Surface Charge:

$$E = \frac{\sigma}{\epsilon_0}$$

$$E = \frac{\sigma}{2\epsilon_0}$$

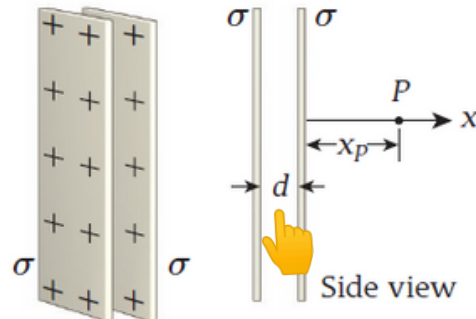
For a **conducting plane**, charges spread across the surface

For a **non-conducting plane** where the charge only exists on one side

General Charge Distributions

2.5 Two infinite nonconducting plates are parallel to each other, with a distance $d = 10.0$ cm between them, as shown in the figure. Each plate carries a uniform charge distribution of $\sigma = 4.5 \mu\text{C}/\text{m}^2$. What is the electric field, $\vec{E}$ at point P (with $x_P = 20.0$ cm)?

- a) 0 N/C
- b) 2.54×10^5 N/C
- c) $(-5.08 \times 10^5) \hat{x}$ N/C
- d) $(5.08 \times 10^5) \hat{x}$ N/C
- e) $(-1.02 \times 10^6) \hat{x}$ N/C
- f) $(1.02 \times 10^6) \hat{x}$ N/C



the electric field due to one
nonconducting plate

distances don't matter because for infinite plates with uniform charge, the electric field generated is uniform. (Constant in magnitude and direction at any point near the plate)

$$E = \frac{\sigma}{2\epsilon_0} = \frac{4.5 \times 10^{-6} \text{ C/m}^2}{2 \times 8.85 \times 10^{-12} \text{ C}^2/\text{N} \cdot \text{m}^2}$$

$$E = 2.54 \times 10^5 \text{ N/C}$$

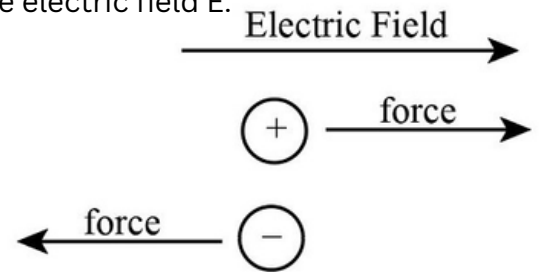
$$E_{\text{total}} = 2 \times 2.54 \times 10^5 \text{ N/C} = 5.08 \times 10^5 \text{ N/C}$$

Because there are
two plates

Force due to an Electric Field

$$\vec{F} = q \cdot \vec{E}$$

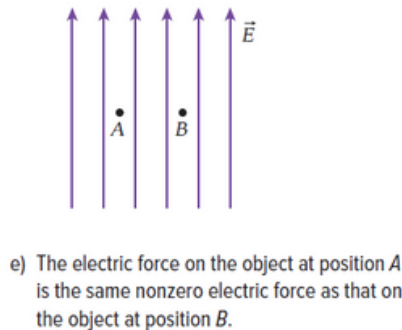
- For a **positive charge** the force F acts **in the same direction** as the electric field E .
- For a **negative charge** F acts **opposite** to the electric field E .



Concept Check 2.6

A small positively charged object could be placed in a uniform electric field at position A or position B in the figure. How do the electric forces on the object at the two positions compare?

- The magnitude of the electric force on the object is greater at position A .
- The magnitude of the electric force on the object is greater at position B .
- There is no electric force on the object at either position A or position B .
- The electric force on the object at position A has the same magnitude as the force on the object at position B but is in the opposite direction.



The correct answer is **e** because In a uniform electric field, the electric field E has the same magnitude and direction at every point. Since the electric field E is uniform, the force on the charge will also be uniform (same magnitude and direction) regardless of its position in the field.

$$\vec{F} = q \cdot \vec{E}$$

This is going to also be uniform because E is the only vector in the other side of the equation

If this is uniform

Concept Check 2.5

A small positively charged object is placed at rest in a uniform electric field as shown in the figure. When the object is released, it will

-
- not move.
 - begin to move with a constant speed.
 - begin to move with a constant acceleration.
 - begin to move with an increasing acceleration.
 - move back and forth in simple harmonic motion.

Since the electric field is uniform, the force F on the object will also be constant in magnitude and direction. his constant force results in a constant acceleration (from Newton's second law:

$$\vec{F} = m \cdot \vec{a}$$

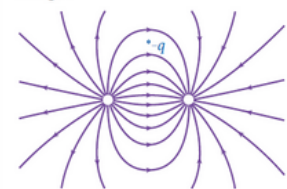
If this is constant

this is going to also be constant

(c) begin to move with a constant acceleration.

Concept Check 2.7

A negative charge $-q$ is placed in a nonuniform electric field as shown in the figure. What is the direction of the electric force on this negative charge?



- - ↑
 - ←
 - ↓
 - The force is zero.
- Correct answer: C

For a negative charge F acts opposite to the electric field E .

E is to the right (as shown in the figure) so F is to the left

Force due to an Electric Field

An electron (with charge $q = -1.6 \times 10^{-19} \text{ C}$) is placed in a uniform electric field of magnitude $E = 2000 \text{ N/C}$. What is the direction and magnitude of the force acting on the electron?

تمرین

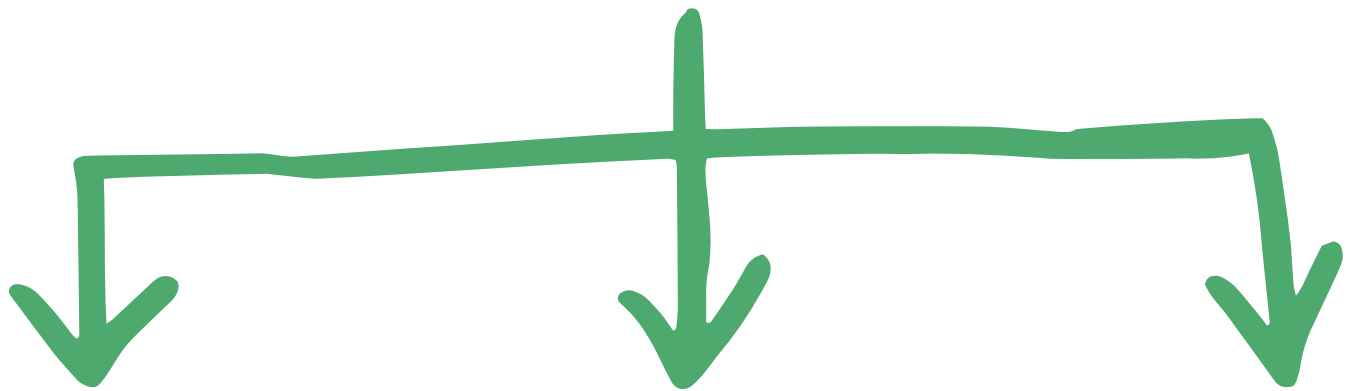
Using $F = qE$:

$$F = (-1.6 \times 10^{-19} \text{ C})(2000 \text{ N/C})$$

$$F = -3.2 \times 10^{-16} \text{ N}$$

The negative sign indicates that the force is in the direction opposite to the electric field (since the electron has a negative charge).

Essential Formulas



Vertical Displacement due to Constant Acceleration

$$y_f - y_0 = -\frac{1}{2}at^2$$

Kinetic Energy

$$K = \frac{1}{2}mv_0^2$$

- K is the kinetic energy of the electron
- m is the mass of the object (like a charge or an electron)
- v_0 : is the initial horizontal speed

Acceleration of a Charge

$$a = \frac{F}{m} = \frac{qE}{m}$$

Force due to an Electric Field

SOLVED PROBLEM 2.2

Electron Moving over a Charged Plate

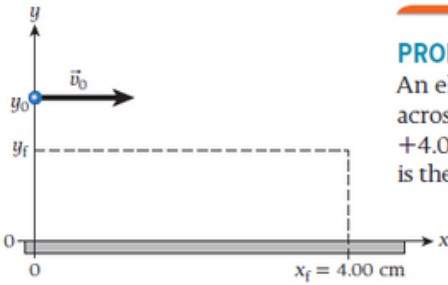


FIGURE 2.18 An electron moving to the right with initial velocity $\vec{v}_0$ over a charged conducting plate.

PROBLEM

An electron with a kinetic energy of 2.00 keV ($1 \text{ eV} = 1.602 \times 10^{-19} \text{ J}$) is fired horizontally across a horizontally oriented charged conducting plate with a surface charge density of $+4.00 \times 10^{-6} \text{ C/m}^2$. Taking the positive direction to be upward (away from the plate), what is the vertical deflection of the electron after it has traveled a horizontal distance of 4.00 cm?

Find the vertical deflection

Vertical deflection is calculated as the difference between the final vertical position (y_f) and the initial vertical position (y_0):

$$y_f - y_0$$

$$y_f = y_0 - \frac{1}{2}at^2 \Rightarrow y_f - y_0 = -\frac{1}{2}at^2$$

This is the equation of vertical displacement with constant acceleration. You have studied this in the 11th Grade

- y_f : Final vertical position of the object
- y_0 : Initial vertical position of the object
- a : Acceleration of the object
- t : Time elapsed

$$F = qE = e \frac{\sigma}{\epsilon_0}$$

e is an electron charge

$$E = \frac{\sigma}{\epsilon_0}$$

Electric field due to a conducting plane

Newton's Second Law: $F = ma$

$$a = \frac{F}{m} = \frac{e\sigma}{m\epsilon_0}$$

$$t = \frac{x_f}{v_0}$$

time = distance/speed

$$K = \frac{1}{2}mv_0^2$$

Kinetic energy of the electron

$$v_0 = \sqrt{\frac{2K}{m}}$$

$$y_f - y_0 = -\frac{1}{2}at^2$$

Substitute

$$y_f - y_0 = -\frac{1}{2} \left(\frac{e\sigma}{m\epsilon_0} \right) \left(\frac{x_f}{v_0} \right)^2$$

$$y_f - y_0 = -\frac{e\sigma x_f^2}{4\epsilon_0 K}$$

Substitute v_0

Plugging values

$$y_f - y_0 = -\frac{(1.602 \times 10^{-19})(4.00 \times 10^{-6})(0.04)^2}{4(8.85 \times 10^{-12})(3.204 \times 10^{-16})}$$

$$y_f - y_0 = -0.0904 \text{ m} = -9.04 \text{ cm}$$

Electric Flux

Electric flux measures how much of an electric field "passes through" a given surface, similar to how we can measure the amount of water flowing through a ring in a stream.

$$\Phi = EA \cos \theta$$

- θ : is the angle between E and A .
- E : Electric field strength
- A : Area of the surface (always perpendicular to the surface)

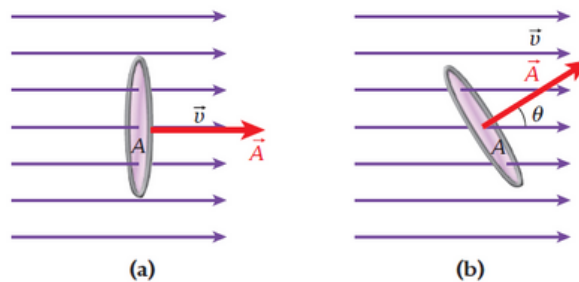
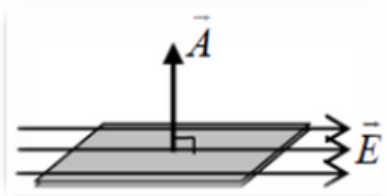


FIGURE 2.22 Water flowing with velocity of magnitude v through a ring of area A . (a) The area vector is parallel to the flow velocity. (b) The area vector is at an angle θ to the flow velocity.

$$\cos(90)=0$$



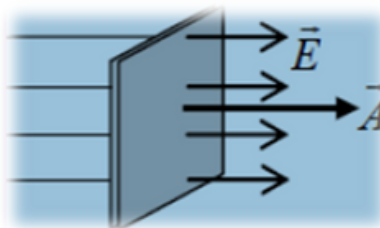
If the Electric field is perpendicular to the surface ($\theta = 90^\circ$), Electric flux is 0.



$$\cos(0)=1 \text{ (maximum flux)}$$

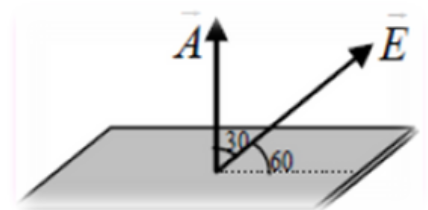


If the field is parallel to the surface ($\theta = 0^\circ$)



If the field is antiparallel to the surface ($\theta = 180^\circ$), this means that the electric field exists (leaves) the surface in the opposite direction

A given angle between the field the surface for example ($\theta = 60^\circ$)



Electric Flux

EXAMPLE 2.5 Electric Flux through a Cube

Figure 2.25 shows a cube that has faces of area A in a uniform electric field, $\vec{E}$ that is perpendicular to the plane of one face of the cube.

PROBLEM

What is the net electric flux passing through the cube?

FIGURE 2.24 A nonuniform electric field, $\vec{E}$, passing through a differential area, $d\vec{A}$

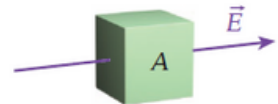
$$\Phi = EA \cos \theta$$

In this face of the cube, E is antiparallel to A (180 degrees)
 $\cos(180) = -1$

$$\Phi_1 = EA \cos(180) = -EA$$

In this face of the cube, E is parallel to A (0 degrees)
 $\cos(0) = +1$

$$\Phi_2 = EA \cos(0) = +EA$$

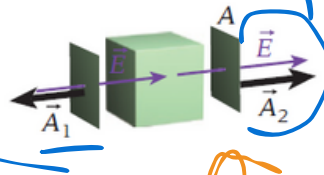


For these faces, the angle is 90 (E is perpendicular to A) $\cos(90) = 0$

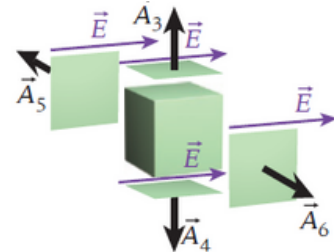
$$\Phi_{3456} = EA \cos(90) = 0$$

$$\Phi_{\text{net}} = \Phi_1 + \Phi_2 + \Phi_{3456}$$

$$\Phi_{\text{net}} = -EA + EA + 0 = 0$$



(a)



(b)

Question	2	السؤال
Figure shows a cube with volume 0.001 m^3 in a uniform electric field $E = 3.0 \times 10^{-2} \text{ N/C}$ that is perpendicular to the plane of one face of the cube.		يوضح الشكل مكعباً حجمه 0.001 m^3 في مجال كهربائي منتظم $E = 3.0 \times 10^{-2} \text{ N/C}$ عمودي على مستوى أحد أوجه المكعب.
8		
A- Calculate the electric flux passing through the left (dark) face of the cube.		
- احسب التدفق الكهربائي الذي يعبر الوجه الأيسر (الداكن) للمكعب؟		
To find the area of a cube	$A = s^2 = (0.1)^2 = 0.01 \text{ m}^2$	
The electric flux Φ through a surface	$\Phi = E \cdot A \cdot \cos(\theta)$	$\Phi = (3.0 \times 10^{-2}) \times 0.01 \times \cos(180) = -3.0 \times 10^{-4} \text{ N} \cdot \text{m}^2/\text{C}$
B- If a charge $+3.2 \text{ } \mu\text{C}$ is placed inside the cube, find the net electric flux passing through the cube.		
- إذا تم وضع شحنة $+3.2 \text{ } \mu\text{C}$ داخل المكعب، جد التدفق الكهربائي الكلي المار عبر المكعب.		
the net electric flux Φ_{net} through a closed surface	$\Phi_{\text{net}} = \frac{q}{\epsilon_0}$	$\Phi_{\text{net}} = \frac{3.2 \times 10^{-6}}{8.854 \times 10^{-12}} \approx 3.61 \times 10^5 \text{ N} \cdot \text{m}^2/\text{C}$

You may ask yourself: "Why didn't we take into account the external electric field passing through the cube when calculating the net electric flux?"

An external electric field produces equal but opposite flux through opposite faces of the cube, resulting in zero net flux as in Example 2.5

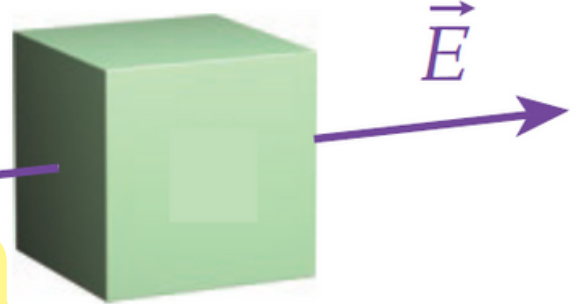
Electric Flux

According to the figure, a uniform electric field ($E = 360 \text{ N/C}$) is perpendicular to the plane of one face of the cube. If the electric flux passing through the left shaded face is equal to $(-1.2 \text{ Nm}^2/\text{C})$, what is the cube side length?

سؤال وزاري



We need to find the cube's side length



$$A = \text{side length}^2$$



The cube's area formula.
*You should know this, it won't be given in the exam, dude

We can find the area and then find the side length

$$\Phi = E \cdot A \cdot \cos(\theta)$$

$$\Phi = E \cdot A \cdot \cos(180^\circ)$$



This is the angle between the area vector and the electric field vector

$$-1.2 = 360 \cdot A \cdot (-1)$$



You can use the calculator at this point

$$A = \frac{1.2}{360} = 0.00333 \text{ m}^2$$

$$\text{side length}^2 = \frac{-1.2}{360}$$

$$\text{side length}^2 = -0.00333$$

$$\text{side length} = \sqrt{0.00333} \approx 0.0577 \text{ m}$$

Gauss's Law

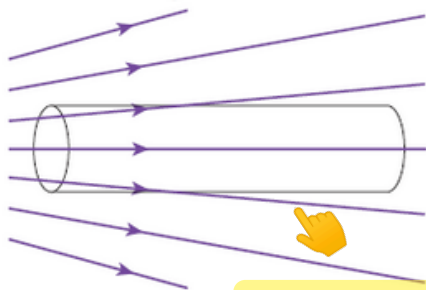
Gauss's Law states that the net electric flux through a closed surface is proportional to the total charge within that surface:

$$\Phi = \frac{q}{\epsilon_0}$$

- Gaussian Surface: Any closed shape used to apply Gauss's Law.
- Gauss's Law helps calculate electric fields, especially when shapes are symmetrical.
- Electric flux is independent of the shape and size of the object. (For closed surfaces)

Concept Check 2.8

A cylinder made of an insulating material is placed in an electric field as shown in the figure. The net electric flux passing through the surface of the cylinder is



- a) positive.
- b) negative.
- c) zero.

The net charge inside the cylinder is zero, so the flux is zero

According to Gauss Law:

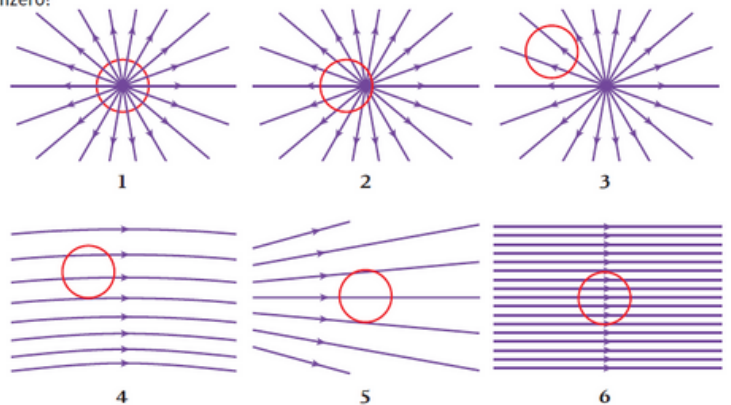
$$\Phi = \frac{q}{\epsilon_0}$$

q is the charge enclosed by the surface. If it is 0, the flux is 0

Concept Check 2.9

The lines in the figure are electric field lines, and the circle is a Gaussian surface. For which case(s) is (are) the total electric flux nonzero?

- a) 1 only
- b) 2 only
- c) 4, 5, and 6
- d) 6 only
- e) 1 and 2



Only 1 and 2 since there is a charge enclosed by the circle

We did not use this, it is irrelevant As we mentioned, Electric flux is independent of the shape and size of the object

A point charge $q = +3.0 \mu C$ is placed at the center of a spherical surface with a radius of $0.2 m$. Using Gauss's Law, calculate the electric flux through the spherical surface.

$$\Phi = \frac{q}{\epsilon_0}$$

$$\Phi_E = \frac{3.0 \times 10^{-6} C}{8.85 \times 10^{-12} C^2/N \cdot m^2}$$

$$\Phi_E = 3.39 \times 10^5 N \cdot m^2/C$$

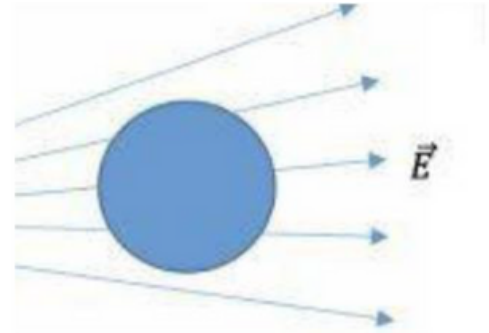
تمرین

Gauss's Law

A neutral ball made of an insulating material is placed in an external electric field as shown in the figure. The total electric flux through the surface of the ball is:

سؤال وزاري

- A. Zero
- B. Negative
- C. Positive
- D. Cannot be determined



Correct Answer: A



According to Gauss's Law, the total electric flux through a closed surface is proportional to the net charge enclosed within the surface. In this case, the ball is neutral, meaning it has no net charge. Therefore, the total electric flux through its surface is zero.

Proving Gauss's Law

Let's derive Gauss's Law using Coulomb's Law for a point charge and a spherical Gaussian surface.

Electric Field Due to a Point Charge



$$E = \frac{q}{4\pi\epsilon_0 r^2}$$

Since the electric field is radial and constant in magnitude, we can take it outside the integral

Electric Flux



$$\Phi_E = \oint_S \mathbf{E} \cdot d\mathbf{A} = E \oint_S dA$$

$$\Phi_E = E \cdot 4\pi r^2 = \left(\frac{q}{4\pi\epsilon_0 r^2} \right) \cdot 4\pi r^2$$

Area of a sphere



$$\Phi_E = E \cdot 4\pi r^2 = \left(\frac{q}{\cancel{4\pi\epsilon_0 r^2}} \right) \cdot \cancel{4\pi r^2}$$

$$\Phi_E = \frac{q}{\epsilon_0}$$

Gauss's Law

7- A point charge sits at the center of a cube. The electric flux through one side of the cube is $(6.0 \times 10^{10} \text{ Nm}^2/\text{C})$. What is the **charge** at the center of the cube?

سؤال وزاري

- ☐ 0.53 C
- ☐ 3.2 C
- ☐ 1.6 C
- ☐ 2.1 C

$$\Phi = \frac{q_{\text{enc}}}{\epsilon_0}$$



Gauss's Law

By symmetry, the electric flux from a point charge at the center of a cube is equally distributed among the six faces of the cube. Thus, the flux through one side is one-sixth of the total flux.

$$\Phi_{\text{total}} = 6 \times (6.0 \times 10^{10} \text{ Nm}^2/\text{C}) = 3.6 \times 10^{11} \text{ Nm}^2/\text{C}$$

the total flux through all six sides of the cube

$$q_{\text{enc}} = \Phi_{\text{total}} \times \epsilon_0$$

$$q_{\text{enc}} = (3.6 \times 10^{11} \text{ Nm}^2/\text{C}) \times (8.85 \times 10^{-12} \text{ C}^2/\text{N} \cdot \text{m}^2)$$

$$q_{\text{enc}} = 3.186 \text{ C} \approx 3.2 \text{ C}$$

A point charge $q = +5.0 \mu\text{C}$ is placed at the center of a cube with a side length of 0.4 m .

Part (a): Calculate the total electric flux through the entire surface of the cube.

تمرين

Part (b): Now, calculate the electric flux through one face of the cube if there is an additional external electric field of $E = 1000 \text{ N/C}$ directed parallel to one of the faces. The cube still has the charge $q = +5.0 \mu\text{C}$ at its center.

A) $\Phi_E = \frac{q_{\text{enc}}}{\epsilon_0}$



the total electric flux through a closed surface

the flux is symmetrically distributed across all the 6 faces of the cube

B) $\Phi_{\text{total}} = \Phi_{\text{one face}} + \Phi_{\text{ext}}$



$$\Phi_{\text{one face}} = \frac{\Phi_E}{6}$$

$$\Phi_{\text{one face}} = \frac{5.65 \times 10^5 \text{ N} \cdot \text{m}^2/\text{C}}{6}$$

The flux from the central charge + the flux from the external electric field

$$\Phi_{\text{one face}} = 9.42 \times 10^4 \text{ N} \cdot \text{m}^2/\text{C}$$

$$\Phi_{\text{ext}} = E \cdot A \quad \Phi_{\text{ext}} = 1000 \text{ N/C} \times 0.16 \text{ m}^2$$

$$\Phi_{\text{ext}} = 160 \text{ N} \cdot \text{m}^2/\text{C}$$

$$\Phi_{\text{total}} = 9.42 \times 10^4 \text{ N} \cdot \text{m}^2/\text{C} + 160 \text{ N} \cdot \text{m}^2/\text{C}$$

$$\Phi_{\text{total}} = 9.42 \times 10^4 \text{ N} \cdot \text{m}^2/\text{C} + 1.60 \times 10^2 \text{ N} \cdot \text{m}^2/\text{C}$$

$$\Phi_E = \frac{5.0 \times 10^{-6} \text{ C}}{8.85 \times 10^{-12} \text{ C}^2/\text{N} \cdot \text{m}^2}$$

$$\Phi_E = 5.65 \times 10^5 \text{ N} \cdot \text{m}^2/\text{C}$$

Gauss's Law

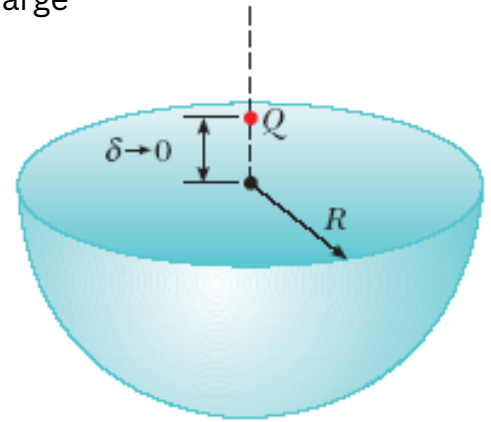
The diagram shows a surface shaped like a hemisphere with a radius of 0.20 m. A point charge $Q=+8.0$ is located at its center. Calculate the electric flux passing through the surface due to the influence of the point charge

تمرین

$$\Phi_E = \frac{Q_{\text{enc}}}{\epsilon_0}$$

Total Flux for a Full Sphere

$$\Phi_{\text{total}} = \frac{8.0 \times 10^{-9}}{8.85 \times 10^{-12}} = 9.04 \times 10^2 \text{ N}$$



$$\Phi_{\text{hemisphere}} = \frac{1}{2} \times \Phi_{\text{total}} = \frac{1}{2} \times 9.04 \times 10^2 = 4.52 \times 10^2$$

hemisphere = half of a sphere

A point charge is located at the center of a cube. If the electric flux passing through one face of the cube is $5.0 \times 10^4 \text{ Nm}^2/\text{C}$, what is the magnitude of the charge at the center of the cube?

سؤال وزاري

- $44 \mu\text{C}$
- $3.2 \mu\text{C}$
- $1.6 \mu\text{C}$
- $2.7 \mu\text{C}$

$$q = \Phi_{\text{total}} \times \epsilon_0$$

$$q = (3.0 \times 10^5) \times (8.85 \times 10^{-12})$$

$$q \approx 2.655 \times 10^{-6} \text{ C}$$

Gauss's Law

Suppose there exists a thin spherical surface (a hollow sphere) made of conductive material with a radius of a , surrounded by another thin spherical surface made of conductive material with a radius of b (where $b > a$). Both surfaces are concentric, as shown in the diagram. Each surface is uniformly charged, resulting in a surface charge density σ on each of them.

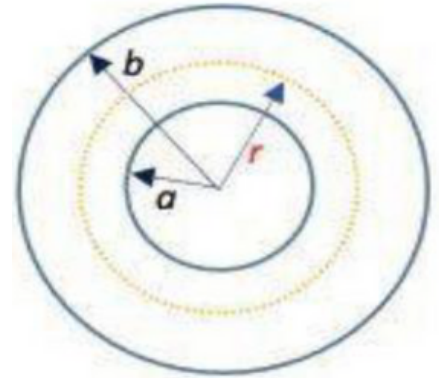
سؤال وزاري

Determine the intensity of the electric field between the two spherical surfaces at a distance r from the center.

Given that the surface area of a sphere is $4\pi r^2$, use the following mathematical relations:

$$E_s = -\frac{\partial V}{\partial s}$$

$$\oint \vec{E} \cdot d\vec{A} = \frac{q}{\epsilon_0}$$



Solution:

$$\oint \vec{E} \cdot d\vec{A} = \frac{q}{\epsilon_0}$$

$$E(r) \cdot 4\pi r^2 = \frac{q}{\epsilon_0}$$

$$q = \sigma \cdot 4\pi a^2$$

Surface charge distribution

$$E(r) \cdot 4\pi r^2 = \frac{\sigma \cdot 4\pi a^2}{\epsilon_0}$$

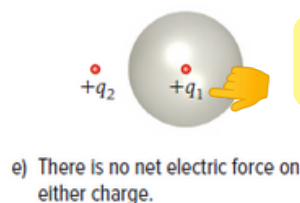
$$E(r) = \frac{\sigma \cdot a^2}{\epsilon_0 \cdot r^2}$$

We need to calculate the electric field $E(r)$ between the two spheres

Concept Check 2.11

A hollow, conducting sphere is initially uncharged. A positive charge, $+q_1$, is placed inside the sphere, as shown in the figure. Then, a second positive charge, $+q_2$, is placed near the sphere but outside it. Which of the following statements describes the net electric force on each charge?

- There is a net electric force on $+q_2$ but not on $+q_1$.
- There is a net electric force on $+q_1$ but not on $+q_2$.
- Both charges are acted on by a net electric force with the same magnitude and in the same direction.
- Both charges are acted on by a net electric force with the same magnitude but in opposite directions.



The net electric force on q_1 is 0 because the conducting sphere shields the inside from external electric fields (Faraday cage effect).

- There is no net electric force on either charge.

Correct Answer: A

For a conducting sphere:

- It shields its interior from external electric fields.
- The sphere's outer surface acquires an equal charge of the same sign as the internal charge.
- A charge **inside** the sphere ($+q_1$) experiences **no net force**.
- A charge **outside** the sphere ($+q_2$) interacts with the induced charge on the outer surface, experiencing a net force.

Special Symmetries

Cylindrical Symmetry

$$E = \frac{\lambda}{2\pi\epsilon_0 r}$$

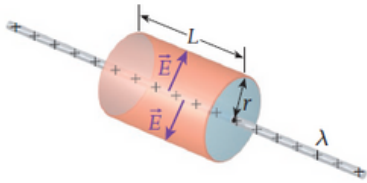


FIGURE 2.33 Long wire with charge per unit length λ surrounded by a Gaussian surface in the form of a right cylinder with radius r and length L . Representative electric field vectors are shown inside the cylinder.

Planar Symmetry

Conducting Surface

$$E = \frac{\sigma}{\epsilon_0}$$

Nonconducting Surface

$$E = \frac{\sigma}{2\epsilon_0}$$

Inside the Sphere

$$E=0$$

The charge resides entirely on the surface, and the electric field inside a conductor is always zero.

Conducting Sphere

Nonconducting Sphere

Outside the Sphere

$$E = \frac{kq}{r^2}$$

Inside the Sphere

$$E = \frac{\rho r}{3\epsilon_0}$$

Outside the Sphere

$$E = \frac{1}{4\pi\epsilon_0} \frac{Q}{r^2}, \quad r \geq R$$

$$Q = \rho \cdot \frac{4}{3}\pi R^3$$

$$E = \frac{\rho R^3}{3\epsilon_0 r^2}$$

Inside the Sphere ($r < R$)

Outside the Sphere ($r \geq R$)

r بحرف صغير: بعد مركز الكرة عن النقطة المراد حساب المجال الكهربائي عندها

R بحرف كبير: نصف قطر الكرة

- r : The radial distance from the center of the sphere to the point of interest.
- R : The radius of the sphere.

Special Symmetries

The electric field produced by an infinite, thin, non-conductive flat plate, uniformly charged with an electric charge, is:

$$3.00 \times 10^3 \text{ N/C}$$

Assuming the charge is uniformly distributed, what is the surface charge density?

سؤال وزاري

Solution:

$$E = \frac{\sigma}{2\epsilon_0}$$

The electric field produced by an infinite, uniformly charged non-conductive plate

Solving for the surface charge density σ (sigma)

$$\sigma = 2\epsilon_0 E$$

$$\sigma = 2 \times (8.85 \times 10^{-12} \text{ C}^2/\text{N} \cdot \text{m}^2) \times (3.00 \times 10^3 \text{ N/C})$$

$$\sigma = 5.31 \times 10^{-8} \text{ C/m}^2$$

Concept Check 2.12

A total of 1.45×10^6 excess electrons are placed on an initially electrically neutral wire of length 1.13 m. What is the magnitude of the electric field at a point at a perpendicular distance of 0.401 m away from the center of wire? (Hint: Assume that 1.13 m is close enough to "infinitely long.")

- a) $9.21 \times 10^{-3} \text{ N/C}$
- b) $2.92 \times 10^{-1} \text{ N/C}$
- c) $6.77 \times 10^1 \text{ N/C}$
- d) $8.12 \times 10^2 \text{ N/C}$
- e) $3.31 \times 10^3 \text{ N/C}$

Solution:

We need λ to find E

$$E = \frac{\lambda}{2\pi\epsilon_0 r}$$

Ops.. We need Q to find λ

$$\lambda = \frac{Q}{L}$$

$$Q = ne$$

$$Q = (1.45 \times 10^6) \cdot (1.60 \times 10^{-19}) = 2.32 \times 10^{-13} \text{ C}$$

$$\lambda = \frac{2.32 \times 10^{-13}}{1.13} \approx 2.05 \times 10^{-13} \text{ C/m}$$

$$E = \frac{\lambda}{2\pi\epsilon_0 r}$$

$$E = \frac{2.05 \times 10^{-13}}{2\pi(8.85 \times 10^{-12})(0.401)}$$

$$E \approx \frac{2.05 \times 10^{-13}}{2.23 \times 10^{-11}} \approx 9.21 \times 10^{-3} \text{ N/C}$$

Electric Potential Energy

Electric Potential Energy (ΔU):

Defined as the negative of the work (W) done by the electric force:

$$\Delta U = U_f - U_i = -W$$

Final potential energy

Initial potential energy.

Electric Potential (V):

The electric potential at a point is the potential energy per unit charge:

$$V = \frac{U}{q}$$

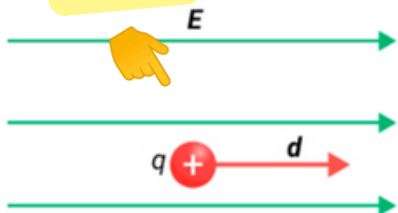
electric potential (V) as the electric potential energy (U) per unit charge (q).

- Scalar quantity.
- The **SI units for electric potential** are joules/coulomb (J/C). This combination has been named the **volt (V)**

$$W = qEd \cos \theta$$

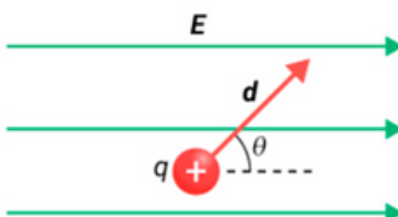
- E : Electric field strength.
- d : Displacement.
- θ : Angle between field and displacement.

The angle between E and d is 0, $\cos(0)=+1$



$$\Delta U = -W$$

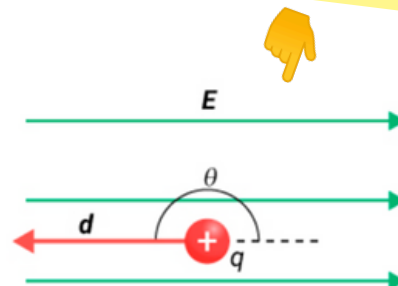
$$\Delta U = -qEd$$



$$\Delta U = -W$$

$$\Delta U = -qEd \cos \theta$$

The angle between E and d is 180, $\cos(180)=-1$



$$\Delta U = -W$$

$$\Delta U = +qEd$$

Equipotential Surfaces and Lines

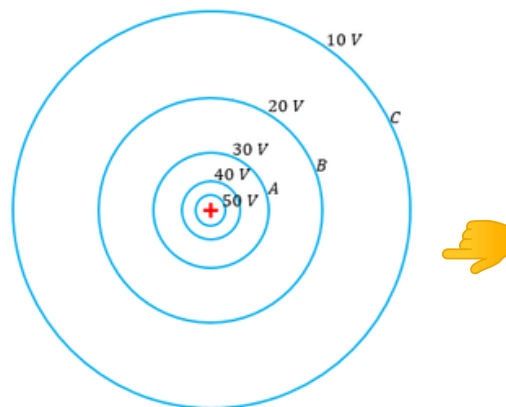
Key Concepts:

- Equipotential surfaces are imaginary surfaces where the electric potential is the same everywhere along the surface.
- Inside a conductor, the potential is uniform, making the conductor an equipotential body.
- Equipotential surfaces are always perpendicular to electric field lines.
- Work is zero when moving a charged particle along an equipotential surface because there's no change in electric potential energy.

Case 1: Single Point Charge

Concept:

- The surface of any conductor is an equipotential.
- Equipotential surfaces are closer near the charge, indicating a stronger electric field.



The space between the equipotential surfaces is larger when far from the charge. (Denser surfaces near the charge)

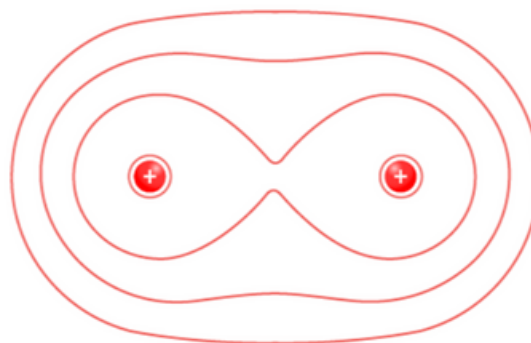
An example of equipotential surfaces around a point charge.

Case 2: Two Identical Point Charges

Concept:

Equipotential surfaces are distorted due to the repulsion between like charges. Central symmetry results in high potential regions between charges.

You only need to know how the surfaces look like for identical and opposite charges.



Equipotential surfaces around a two identical charges.

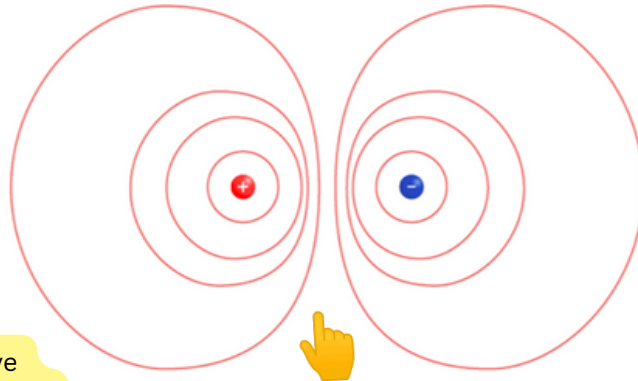
Equipotential Surfaces and Lines

Case 3: Two Oppositely Charged Point Charges

Concept:

- Equipotential surfaces are distorted by the attraction between opposite charges.
- Equipotential surfaces are closer near the charge, indicating a stronger electric field.

Equipotential surfaces are positive and concentrated closer to the charge.



Equipotential surfaces are negative and concentrated closer to the charge.



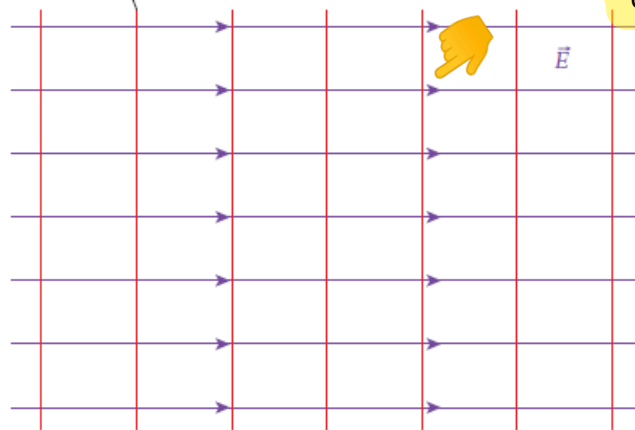
This occurs where the positive potential due to the positive charge exactly cancels the negative potential due to the negative charge.



zero-potential point

An example of equipotential surfaces around two oppositely charged point charges

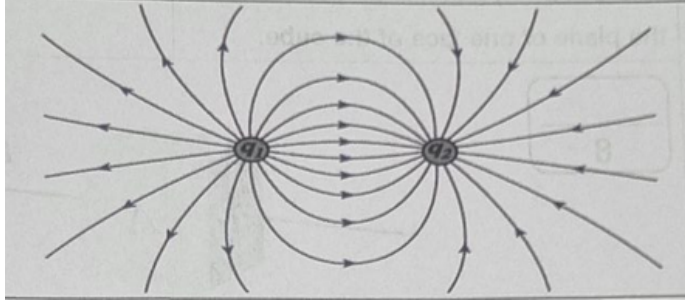
Equipotential surface



Equipotential surfaces are always perpendicular (90 degrees)

FIGURE 3.16 Equipotential surfaces (red lines) from a constant electric field. The purple lines with the arrowheads represent the electric field.

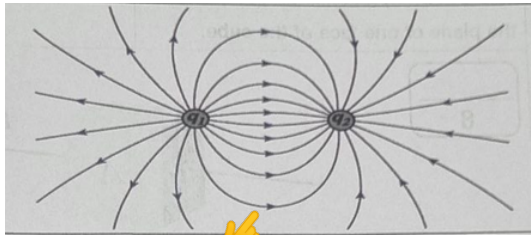
Equipotential Surfaces and Lines



سؤال وزاري

Draw two lines on the above figure representing equipotential surfaces, one surrounding the charge q_1 and the other surrounding the charge q_2 .

Solution:

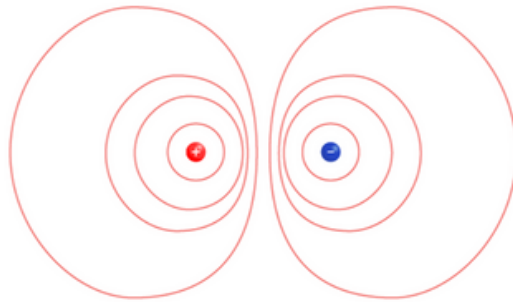


The electric field lines radiate outward the positive charge and inward the negative one.

So:

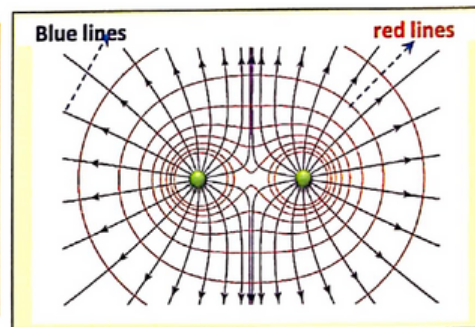
q_1 is positive
 q_2 is negative
(opposite charges)

خطوط المجال تكون خارجة من الشحنة الموجبة وتوجه إلى الشحنة السالبة. مما يعني أن الشحنتين مختلفتين، وعليه يمكن رسم خطوط تساوي الجهد Equipotential Surfaces على النحو الآتي:



10- The figure shows the electric field lines and equipotential surfaces of two point charges. Which of the following is **correct**?

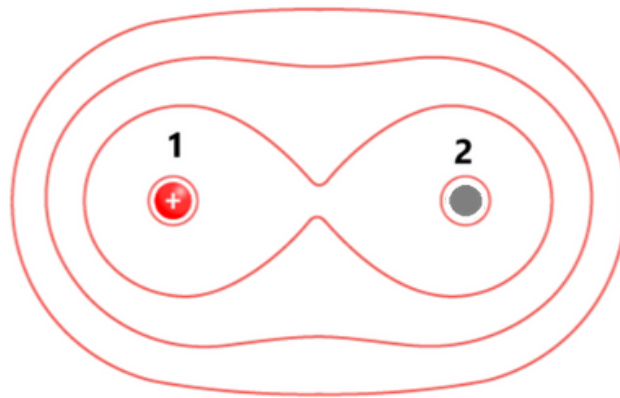
	point charges	red lines
☐	identical and positive	electric field lines
☐	identical and positive	equipotential surfaces
☐	identical and negative	electric field lines
☐	identical and negative	equipotential surfaces



سؤال وزاري

Correct Answer: 2nd Option الخيار الثاني

Equipotential Surfaces and Lines



تمرین

If charge 1 is positive, what is the sign of charge 2?

Correct Answer: Positive

Electric Potential of Various Charge Distributions

- Electric potential is the work required to bring a unit charge to a point in space from infinity.
- Work involves a force acting over a distance, and in this context, the force comes from the electric field.

Electric potential due to a point charge

The electric potential V at a distance r from a point charge q is derived from Coulomb's law and the work-energy relationship:

$$V = \frac{kq}{r}$$

Electric potential due to multiple point charges

$$V = \sum_{i=1}^n V_i = \sum_{i=1}^n \frac{kq_i}{r_i}$$

It is just the same as the potential due to a point charge but find the sum of the potentials.

$$V_{\text{total}} = V_1 + V_2$$

Electric Potential of Various Charge Distributions

A point charge $q = -3.0 \text{ nC}$ creates an electric field of magnitude E . What is the electric potential 10 cm away from the center of the charge?

تمرین

$$V = \frac{1}{4\pi\epsilon_0} \frac{q}{r}$$

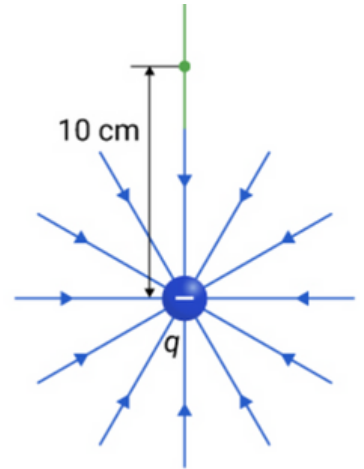
The same formula as: $V = \frac{kq}{r}$

$$\frac{1}{4\pi\epsilon_0} = 9.0 \times 10^9 \text{ N m}^2/\text{C}^2$$

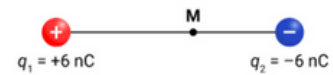
It is k

$$V = 9.0 \times 10^9 \text{ N m}^2/\text{C}^2 \times \frac{(-3.0 \times 10^{-9} \text{ C})}{0.10 \text{ m}}$$

$$V = -270 \text{ V}$$



An electric dipole consists of two point charges $q_1 = +6 \text{ nC}$ and $q_2 = -6 \text{ nC}$, placed 10 cm apart.



تمرین

Calculate the electric potential at the point M between the two point charges. Given M is 6 cm from q_1 and 4 cm from q_2 .

Two point charges, two electric potentials (System of charges)

$$V_{\text{total}} = V_1 + V_2$$

$$V_{\text{total}} = (9.0 \times 10^9 \text{ N m}^2/\text{C}^2) \frac{6 \times 10^{-9} \text{ C}}{0.06 \text{ m}} + (9.0 \times 10^9 \text{ N m}^2/\text{C}^2) \frac{-6 \times 10^{-9} \text{ C}}{0.04 \text{ m}}$$

$$V_{\text{total}} = 900 \text{ V} + (-1350 \text{ V})$$

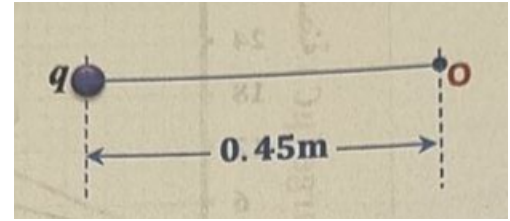
$$V_{\text{total}} = -500 \text{ V}$$

Electric Potential of Various Charge Distributions

According to the figure, the magnitude of the electric potential V produced by a point charge q at point O is equal to $+9.0 \times 10^2 \text{ V}$. The distance between the charge q and point O is 0.45 m .

سؤال وزاري

1. A) Calculate the magnitude of the charge q .
2. B) Find the magnitude of the electric field E at point O .
3. C) If another point charge is placed at point O , does the magnitude of the electric field at point O change? Explain your answer.



A	$V = k \frac{q}{r}$
	$+9.0 \times 10^2 \text{ V} = 8.99 \times 10^9 \times \frac{q}{0.45}$
	$q = 4.5 \times 10^{-12} \text{ C}$
B	$E = \frac{V}{r}$
	$E = \frac{9.0 \times 10^2}{0.45}$
	$E = 0.2 \text{ N/C}$
C	No لا
	Because the point charge does not exert a force on itself لأن الشحنة النقطية لا تؤثر بقوة في نفسها

A negative electric charge of $q = -4 \mu\text{C}$ is placed on the y-axis at $y = 2.0 \text{ m}$. Find the electric potential at the point $y = 5.0 \text{ m}$ due to this charge.

سؤال وزاري

$$r = |5.0 - 2.0| = 3.0 \text{ m}$$

$$V = \frac{kq}{r} = \frac{(9 \times 10^9)(-4 \times 10^{-6})}{3.0}$$

$$V = \frac{-36 \times 10^3}{3} = -12 \times 10^3 \text{ V} = -1.2 \times 10^4 \text{ V}$$

$$V = -1.2 \times 10^4 \text{ V}$$

Finding the Electric Field from the Electric Potential

The electric field (E) can be calculated using the electric potential (V) by finding the rate of change of potential with respect to distance.

The symbol "d" represents differentiation

$$\vec{E} = - \left(\frac{dV}{dx}, \frac{dV}{dy}, \frac{dV}{dz} \right)$$

E is the first derivative of V with respect to the position

Just another way to represent differentiation. ∇ is the gradient operator

$$\mathbf{E} = -\nabla V$$

You should know the basics differentiation to be able to solve the problems related to this lesson.

Rules of Differentiation

1. Constant Rule

If $f(x) = c$, where c is a constant, then the derivative is:

$$f'(x) = 0$$

Example:

If $f(x) = 5$, then $f'(x) = 0$.

This indicates that y is a function of x

represents the rate of change of y with respect to x .

$$\frac{dy}{dx}$$

Is the same as:

$$f'(x)$$

2. Power Rule

If $f(x) = x^n$, where n is a number, then the derivative is:

$$f'(x) = n \cdot x^{n-1}$$

Example:

If $f(x) = x^3$, then

$$f'(x) = 3 \cdot x^{3-1} = 3x^2.$$

Rules of Differentiation

3. Sum/Difference Rule

If $f(x) = g(x) + h(x)$ or $f(x) = g(x) - h(x)$, then the derivative is:

$$f'(x) = g'(x) + h'(x) \quad \text{or} \quad f'(x) = g'(x) - h'(x)$$

Example:

If $f(x) = x^3 + x^2$, then

$$f'(x) = 3x^2 + 2x.$$

That's all you need to know about differentiation. Now let's get back to our topic.

Finding the Electric Field from the Electric Potential

So to find the electric field from the electric potential just find the first derivative of the electric field.

$$E_x = -V'_x, E_y = -V'_y, E_z = -V'_z$$

Don't forget the minus

It is very easy if you know how to find the first derivative.

Let's consider a simple case where the electric potential changes uniformly along the x -axis:

$$V(x) = -5x \text{ V/m}$$

تمرین

This means that for every meter you move along the x -axis, the potential decreases by 5 volts. To find the electric field, we take the derivative of $V(x)$ with respect to x :

$$E_x = -\frac{dV}{dx} = -(-5) = 5 \text{ V/m}$$

the electric field is the negative first derivative of the electric potential.

Finding the Electric Field from the Electric Potential

Concept Check 3.7

Suppose an electric potential is described by $V(x, y, z) = -(5x^2 + y + z)$ in volts. Which of the following expressions describes the associated electric field, in units of volts per meter?

- a) $\vec{E} = 5\hat{x} + 2\hat{y} + 2\hat{z}$
- b) $\vec{E} = 10x\hat{x}$
- c) $\vec{E} = 5x\hat{x} + 2\hat{y}$
- d) $\vec{E} = 10x\hat{x} + \hat{y} + \hat{z}$
- e) $\vec{E} = 0$

Solution:

when deriving with respect to x, consider z and y constant.

$$\vec{E} = -\nabla V = -(V'_x \hat{x} + V'_y \hat{y} + V'_z \hat{z})$$

$$V'_x = \frac{\partial V}{\partial x} = -(5x^2 + y + z)'_x = -10x$$

These are constant with respect to x. The first derivative of a constant is 0

$$V'_y = \frac{\partial V}{\partial y} = -(5x^2 + y + z)'_y = -1$$

These are constant with respect to y. The first derivative of a constant is 0

$$V'_z = \frac{\partial V}{\partial z} = -(5x^2 + y + z)'_z = -1$$

$$\vec{E} = -\nabla V = -(V'_x \hat{x} + V'_y \hat{y} + V'_z \hat{z})$$

$$\vec{E} = -(-10x\hat{x} - 1\hat{y} - 1\hat{z})$$

$$\vec{E} = 10x\hat{x} + \hat{y} + \hat{z}$$

12- An electric potential is described in volts by $V(x, y, z) = 3x^2 + 2y - 5z$.

What is the magnitude of an electric field at the point $(+4.0 \text{ m}, -2.0 \text{ m}, -1.0 \text{ m})$?

سؤال وزاري

- ☐ 27.0 V/m
- ☐ 31.0 V/m
- ☐ 24.6 V/m
- ☐ 8.16 V/m

hint

$$E_s = -\frac{\partial V}{\partial s}$$

Solution:

$$V'_x = \frac{\partial}{\partial x}(3x^2 + 2y - 5z) = 6x$$

$$V'_y = \frac{\partial}{\partial y}(3x^2 + 2y - 5z) = 2$$

$$V'_z = \frac{\partial}{\partial z}(3x^2 + 2y - 5z) = -5$$

Finding the first derivative

Evaluate the point (4, -2, -1)

$$V'_x = 6x = 6(4.0) = 24 \text{ V/m}$$

$$V'_y = 2 \text{ V/m (independent of } y)$$

$$V'_z = -5 \text{ V/m (independent of } z)$$

$$\vec{E} = -\nabla V = -(V'_x \hat{x} + V'_y \hat{y} + V'_z \hat{z})$$

$$\vec{E} = -(24\hat{x} + 2\hat{y} - 5\hat{z})$$

$$\vec{E} = -24\hat{x} - 2\hat{y} + 5\hat{z} \text{ V/m}$$

This is to find the magnitude of E. (Vector magnitude)

$$|\vec{E}| = \sqrt{(-24)^2 + (-2)^2 + (5)^2}$$

$$|\vec{E}| = \sqrt{576 + 4 + 25} = \sqrt{605} \approx 24.6 \text{ V/m}$$

Finding the Electric Field from the Electric Potential

An electric potential is described in volts by:

$$V(x, y, z) = 2x^2y + z$$

تمرین

What is the magnitude of the electric field at the point (1.0 m, 3.0 m, -2.0 m)?

Solution:

With respect to x
(y and z are constant)

$$\text{👉 } V'_x = \frac{\partial}{\partial x}(2x^2y + z) = \frac{\partial}{\partial x}(2x^2y) = 4xy$$

With respect to y
(x and z are constant)

$$\text{👉 } V'_y = \frac{\partial}{\partial y}(2x^2y + z) = \frac{\partial}{\partial y}(2x^2y) = 2x^2$$

With respect to z
(x and y are constant)

$$\text{👉 } V'_z = \frac{\partial}{\partial z}(2x^2y + z) = \frac{\partial}{\partial z}(z) = 1$$

$$V'_x = 4xy = 4(1.0)(3.0) = 12 \text{ V/m}$$

$$V'_y = 2x^2 = 2(1.0)^2 = 2 \text{ V/m}$$

$$V'_z = 1 \text{ V/m}$$

$$\mathbf{E} = -\nabla V = -(V'_x \hat{x} + V'_y \hat{y} + V'_z \hat{z})$$

$$|\mathbf{E}| = \sqrt{(-12)^2 + (-2)^2 + (-1)^2}$$

$$\mathbf{E} = -(12 \hat{x} + 2 \hat{y} + 1 \hat{z})$$

$$|\mathbf{E}| = \sqrt{144 + 4 + 1} = \sqrt{149} \approx 12.2 \text{ V/m}$$

$$\mathbf{E} = -12 \hat{x} - 2 \hat{y} - 1 \hat{z} \text{ V/m}$$

Electric Potential Energy of a System of Point Charges

The potential energy of two point charges:

$$U = k \frac{q_1 q_2}{r}$$

Consider two **identical** charges of $q = 50\mu\text{C}$ each, placed **5.0 m** apart. Find the **electrostatic potential energy** stored in the configuration.

(Use $k = 9 \times 10^9 \frac{\text{N.m}^2}{\text{C}^2}$, $1.0 \mu = 1.0 \times 10^{-6}$).

سؤال وزاري

افترض وجود شحنتين متماثلتين مقدار كل منهما $q = 50\mu\text{C}$ ، وتفصل بينهما مسافة 5.0 m . أوجد طاقة الوضع الكهربائية المخزنة في هذا النظام. (استخدم $k = 9 \times 10^9 \frac{\text{N.m}^2}{\text{C}^2}$ ، $1.0 \mu = 1.0 \times 10^{-6}$).

$$U = k \frac{q_1 q_2}{r}$$

$$U = (9.0 \times 10^9) \frac{(50 \times 10^{-6})(50 \times 10^{-6})}{5.0}$$

$$U = (9.0 \times 10^9)(0.5 \times 10^{-9}) = 4.5 \text{ J}$$

What happens to the magnitude of the electric potential energy of a system of two point charges when the distance between them decreases?

سؤال وزاري

- a) It becomes zero.
- b) It remains the same.
- c) It increases.
- d) It decreases.

(c) It increases.

EXAMPLE 3.7 Four Point Charges

Let's calculate the electric potential energy of a system of four point charges, shown in Figure 3.31. The four point charges have the values $q_1 = +1.0 \mu\text{C}$, $q_2 = +2.0 \mu\text{C}$, $q_3 = -3.0 \mu\text{C}$, and $q_4 = +4.0 \mu\text{C}$. The charges are placed with $a = 6.0 \text{ m}$ and $b = 4.0 \text{ m}$.

PROBLEM

What is the electric potential energy of this system of four point charges?

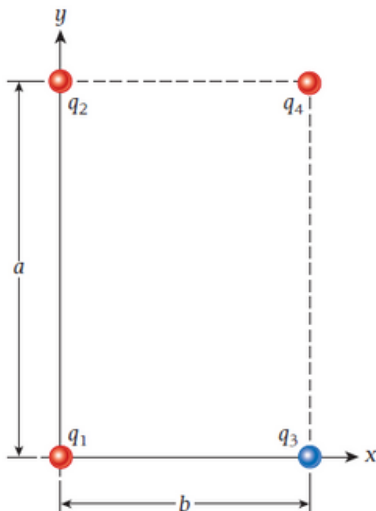


FIGURE 3.31 Calculating the potential energy of a system of four point charges.

Bringing q_3 in from an infinite distance and placing it at $(b,0)$ changes the potential energy of the system through the interaction of q_3 with q_1 and the interaction of q_3 with q_2 . The new potential energy is

$$U = \frac{kq_1q_2}{a} + \frac{kq_1q_3}{b} + \frac{kq_2q_3}{\sqrt{a^2 + b^2}}$$

Finally, bringing in q_4 and placing it at (b,a) changes the potential energy of the system through interactions with q_1 , q_2 , and q_3 , bringing the total electric potential energy of the system to

$$U = \frac{kq_1q_2}{a} + \frac{kq_1q_3}{b} + \frac{kq_2q_3}{\sqrt{a^2 + b^2}} + \frac{kq_1q_4}{\sqrt{a^2 + b^2}} + \frac{kq_2q_4}{b} + \frac{kq_3q_4}{a}$$

Note that the order in which the charges are brought from infinity will not change this result. (You can try a different order to verify this statement.) Putting in the numerical values, we obtain

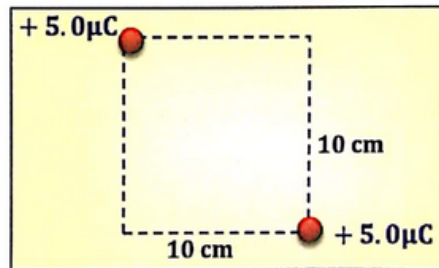
$$U = (3.0 \times 10^{-3} \text{ J}) + (-6.7 \times 10^{-3} \text{ J}) + (-7.5 \times 10^{-3} \text{ J}) + (5.0 \times 10^{-3} \text{ J}) + (1.8 \times 10^{-2} \text{ J}) + (-1.8 \times 10^{-2} \text{ J}) = -6.2 \times 10^{-3} \text{ J}$$

Electric Potential Energy of a System of Point Charges

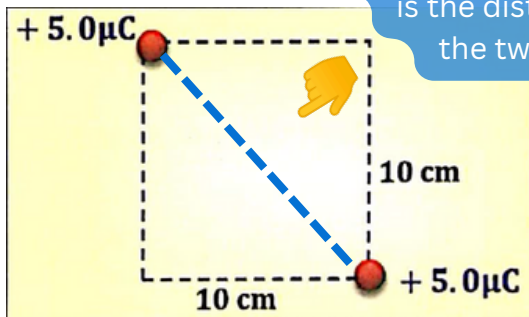
11– Two ($+ 5.0 \mu\text{C}$) point charges arranged at the corners of a square with side length (10 cm) as shown in the figure. What is the **potential energy** of a system of two charges ?

سؤال وزاري

- ☐ 0.0 J
- ☐ 0.80 J
- ☐ 1.6 J
- ☐ 2.3 J



The diagonal of the square is the distance between the two charges r .



$$r = \sqrt{s^2 + s^2} = \sqrt{2s^2} = s\sqrt{2}$$

$$r = 0.10\sqrt{2} \text{ m} \approx 0.1414 \text{ m}.$$

10 cm is 0.10 m

$$U = k \frac{q_1 q_2}{r}$$

$$U = (9 \times 10^9) \frac{(5.0 \times 10^{-6}) (5.0 \times 10^{-6})}{0.1414}$$

$$U \approx 1.59 \text{ J}$$

Capacitance

Capacitance is the ability of a device to store electric charge.

What is a Capacitor?

- A capacitor is made of two separated conductors, usually called plates.
- The plates are separated by an insulating layer.
- Capacitors can take various physical forms depending on their construction and use.

$$C = \left| \frac{q}{\Delta V} \right|$$

- **C is the capacitance** (in farads, F),
- **q is the charge** (in coulombs, C),
- **ΔV is the potential difference** between the plates.

$$1 \text{ F} = \frac{1 \text{ C}}{1 \text{ V}}.$$

The capacitance of a parallel plate capacitor



$$C = \frac{\epsilon_0 A}{d}$$

- **$\epsilon_0 = 8.85 \times 10^{-12}$ F/m** is the permittivity of free space,
- **A is the area** of one plate (in m^2),
- **d is the separation between the plates** (in meters).

The electric potential difference V across the plates of a parallel plate capacitor is related to the electric field E



$$V = E \cdot d$$

Capacitance

تمرین

Given:

- Capacitance $C = 100 \mu F$,
- Potential difference $\Delta V = 12 V$.

Find: The charge q on the capacitor.

Solution: Using $C = \frac{q}{\Delta V}$,

$$q = C \cdot \Delta V.$$

$$q = (100 \times 10^{-6}) \cdot 12.$$

$$q = 1.2 \times 10^{-3} C = 1.2 mC.$$

EXAMPLE 4.1

Area of a Parallel Plate Capacitor

A parallel plate capacitor has plates that are separated by 1.00 mm (Figure 4.11).

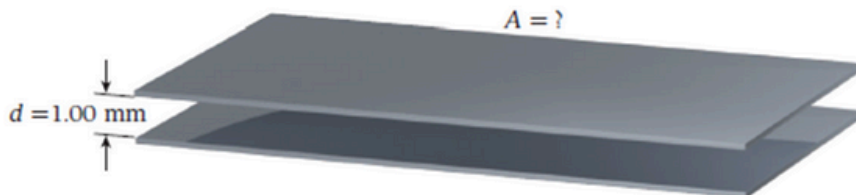


FIGURE 4.11 A parallel plate capacitor with plates separated by 1.00 mm.

PROBLEM

What is the area required to give this capacitor a capacitance of 1.00 F?

$$A = \frac{dC}{\epsilon_0} = \frac{(1.00 \times 10^{-3} \text{ m})(1.00 \text{ F})}{(8.85 \times 10^{-12} \text{ F/m})} = 1.13 \times 10^8 \text{ m}^2.$$

Capacitance

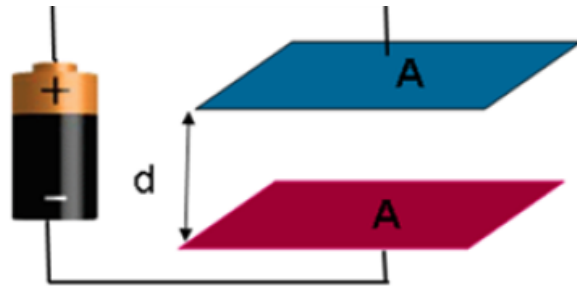
According to the figure of a parallel plate capacitor, if $A = 0.01 \text{ m}^2$ and $d = 0.10 \text{ m}$, what is the capacitance C ?

$$C = \frac{\epsilon_0 A}{d}$$

$$C = \frac{8.85 \times 10^{-12} \times 0.01}{0.10}$$

$$C = \frac{8.85 \times 10^{-14}}{0.10}$$

$$C = 8.85 \times 10^{-13} \text{ F}$$



سؤال وزاري

Given that the capacitance $C = 1.77 \times 10^{-12} \text{ F}$ and the area $A = 0.02 \text{ m}^2$, find the separation d between the plates of a parallel plate capacitor.

$$d = \frac{\epsilon_0 A}{C}$$

$$d = \frac{8.85 \times 10^{-12} \times 0.02}{1.77 \times 10^{-12}}$$

$$d = \frac{1.77 \times 10^{-13}}{1.77 \times 10^{-12}}$$

$$d = 0.10 \text{ m}$$

سؤال وزاري

Capacitance

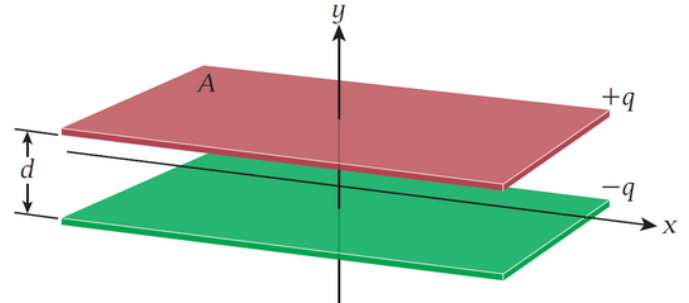
According to the figure, a parallel plate capacitor in vacuum consists of two conducting plates, each having area A and opposite charges, separated by a distance d . If the electric potential difference between the two plates of the capacitor is 20.0 V , what is the electric potential difference between the two plates when the distance between them is equal to $0.5d$?

E is constant
(doesn't change)

$$V_1 = E \cdot d_1$$

$$V_2 = E \cdot d_2$$

$$\frac{V_1}{d_1} = \frac{V_2}{d_2}$$

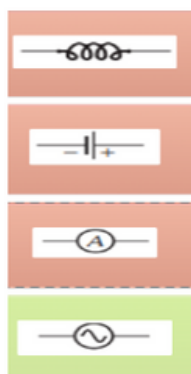


$$\frac{V_1}{d_1} = \frac{V_2}{0.5 \cdot d_1} \quad V_2 = 0.5 \cdot V_1 \quad V_2 = 0.5 \cdot 20.0\text{ V} = 10.0\text{ V}$$

Circuit Element Symbols

	Wire		Galvanometer
	Capacitor		Voltmeter
	Resistor		Ammeter
	Inductor		Battery
	Switch		AC source

FIGURE 4.8 Commonly used symbols for circuit elements.



Which of the following symbols represents (alternating current) power source AC?

أي من الرموز التالية يمثل
مصدر تيار متناوب AC؟

سؤال وزاري

خاتمة

في حال وجود أية استفسارات يمكنكم التواصل معي عبر تلغرام:



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مع تمنياتي لكم بالتوفيق والنجاح.

والحمد لله رب العالمين.