Electrical and Magnetic

Dr. Mahmoud Al-Saman

First Teams/General Mathematics, Nature and Chemistry

Coulomb's Law

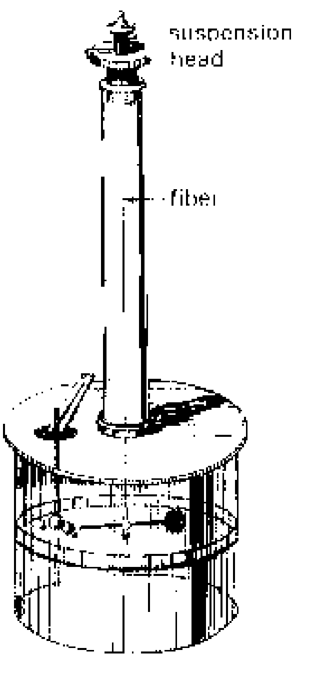
It is well worth reading about the important experiments of Charles Coulomb in 1785. In these experiments he had a small fixed metal sphere which he could charge with electricity, and a second metal sphere attached to a vane suspended from a fine torsion thread. The two spheres were charged and, because of the repulsive force between them, the vane twisted round at the end of the torsion thread. By this means he was able to measure precisely the small forces between the charges, and to determine how the force varied with the amount of charge and the distance between them. Coulomb expressed the basic law of the emerging electrical power between two charged objects.

1- The force is inversely proportional to the square of the distance between the two charged charges.

$$F \propto \frac{1}{r^2}$$

2- The force is directly proportional to the product of the masses of the two charged bodies

$$F \propto q_1 q_2$$



In so doing we can conclude that

$$F \propto \frac{q_1 q_2}{r^2}$$

$$\therefore F = K \frac{q_1 q_2}{r^2}$$

Where k is the Coulomb constant and is equal to 9×10^9 N.m^2 / C^2...

The latter equation is called Coulomb's law and is used to calculate the electrical power generated between two charged objects .In this equation, the electrical force is measured as F

$$K = \frac{1}{4\pi\varepsilon_o}$$

K is the Permittivity constant of free space, equal to 8.85 x 10^{-12} $C^2/N.m^2$

$$K = \frac{1}{4\pi\varepsilon_o} = \frac{1}{4\pi \times 8.85 \times 10^{-12}} = 9 \times 10^9 N.m^2 / C^2$$

Calculate of electrical power

Electrical forces are caused by the effect of a charge on another charge or by the effect of a particular distribution of multiple charges on a particular charge q_1. In order to calculate the electrical force affecting that charge we follow the following steps:

A - Calculation of electrical power between two charged.

To calculated the effect of the electrical forces of one charge on the other as in the case in (fig. 2 left) which represents similar charges either positive or negative where the force is a repulsive force

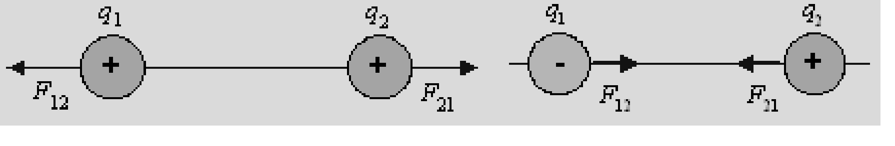


Fig (2)

To calculate the amount of interaction force we call the first charge q1 and the second q2 .The force acting on charge q1 as a result of charge q2 is written F12 and is in the direction of repulsion for q2 .The amount of force is calculated from Coulomb's law as follows:

$$F_{12} = K \frac{q_1 q_2}{r^2} = F_{21}$$

And its direction is:

$$\bar{F}_{12} = -\bar{F}_{21}$$

That is, the two forces are equal in magnitude and opposite in direction.

Similarly, Figure 2-2 (right) represents two different charges, where the reciprocal force is an Attractive force .Here, too, we follow the same steps above and the forces are equal and opposite in direction.

Example (1) Calculate the value of two equal charges if they are repulsed by a force of 0.1 N and the distance between them is 50 cm.

Solution: That's where

$$F = K \frac{q_1 q_2}{r^2}$$

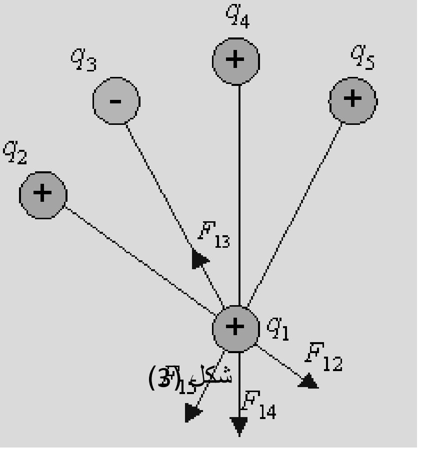
q1 = q2, then

$$0.1 = \frac{9 \times 10^9 \times q^2}{(0.5)^2}$$

q = 1.7x10-6C = 1.7□C

This is the value of the charge that makes the reciprocal force equal 0.1 N

B) Calculation of the power generated between more than one charges



In the case of dealing with more than two charges and to calculate the total electrical forces affecting the charge q1 as in Figure (2.3), this force is F1, which is the directional sum of all the forces exchanged with the charge q1

$$\bar{F}_1 = \bar{F}_{12} + \bar{F}_{13} + \bar{F}_{14} + \bar{F}_{15}$$

To calculate the value and direction of F1, follow these steps:

1- Determine the reciprocal force vectors with charge q1 on the figure according to the charge signal.

2- We take charges q1 & q2, first as both charges are positive .So q1 moves away from charge q2 and along the line between them and the vector F12 is the direction of the force acting on charge q1 as a result of charge q2 and the length of the vector is proportional to the amount of force .Likewise, we take the charges q1 & q3, determine the direction of force F13 , and then define F14 and so on.

3- Here we neglect the reciprocal electric forces between charges q2 & q3 & q4 because we calculate the forces acting on q1.

4-To calculate the amount of force vectors individually, we substitute in Coulomb's law as follows:

$$F_{12} = K \frac{q_1 q_2}{r^2}$$

$$F_{13} = K \frac{q_1 q_3}{r^2}$$

$$F_{14} = K \frac{q_1 q_4}{r^2}$$

5-The result of these forces is F1, but as shown in the figure, the line of action of the forces is different and therefore we use the method of vector analysis into two compounds as follows:

$$\boldsymbol{F}_{1x} = \boldsymbol{F}_{12x} + \boldsymbol{F}_{13x} + \boldsymbol{F}_{14x}$$

$$\boldsymbol{F}_{1y} = \boldsymbol{F}_{12y} + \boldsymbol{F}_{13y} + \boldsymbol{F}_{14y}$$

The sum of the forces

$$F_1 = \sqrt{(F_x)^2 + (F_y)^2}$$

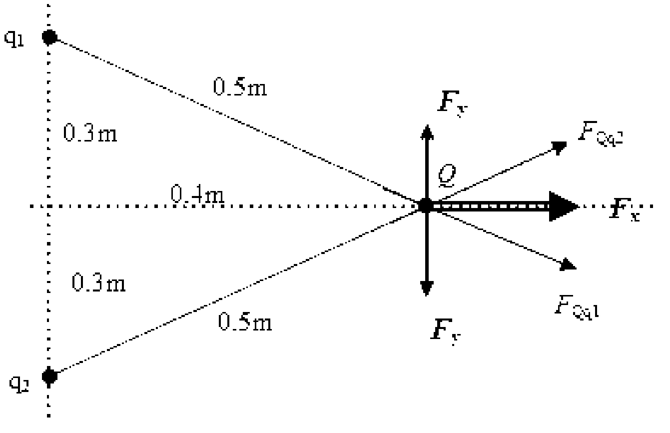
and its direction

$$\theta = \tan^{-1} \frac{F_y}{F_x}$$

Examples of Coulomb's Law

Exampl 1-2

In Fig. 1-4, two charges equal to q = $2x10^{-6}$C interacted with a third charge Q = $4x10^{-6}$C, find the intensity and direction of the resulting force on charge Q



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Solution

To find the sum of the electrical forces affecting charge Q, we apply Coulomb's law to calculate how much force each charge effect on charge Q. Since q1 & q2 are equal and are the same distance from charge Q, the two forces are equal in magnitude and value

$$F_{Qq1} = K\frac{qQ}{r^2} = 9\times10^9\frac{(4\times10^{-6})(2\times10^{-6})}{(0.5)^2} = 0.29\,N = F_{Qq2}$$

Force vector analysis to

$$F_x = F\cos\theta = 0.29\left(\frac{0.4}{0.5}\right) = 0.23\,N$$

$$F_y = -F\sin\theta = -0.29\left(\frac{0.3}{0.5}\right) = -0.17\,N$$

Similarly, the reciprocal force between q_2 and Q charges FQq_2 can be found

$$\sum F_x = 2\times0.23 = 0.46N$$

$$\sum F_y = 0$$

Thus, the amount of force obtained is 0.46N and its direction in the direction of the positive x axis

Example 1-3

In Figure 1-5, what is the force acting on the charge in the bottom left corner of the square ?Assume that $q = 1\times10^{-7}$ C and a= 5cm

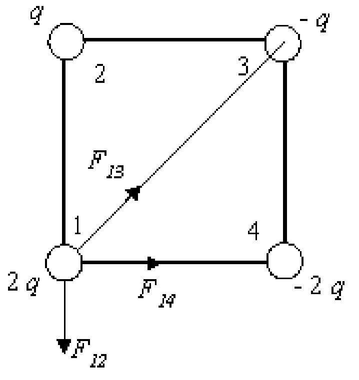


Fig (1-5)

Solution

For simplicity we number the charges as shown in Figure 1-5 and then determine the directions of electrical forces on the required charge

$$\vec{F}_1 = \vec{F}_{12} + \vec{F}_{13} + \vec{F}_{14}$$

$$F_{12} = K\frac{2qq}{a^2}$$

$$F_{13} = K\frac{2qq}{2a^2}$$

$$F_{14} = K\frac{2q2q}{a^2}$$

Note that we neglected to compensate for the charge signal when calculating the amount of force .Compensation in equations results in

F_{12} = 0.072 N,

F_{13} = 0.036 N,

F_{14} = 0.144 N

Notice here that we cannot add the three forces directly because the line of action of the forces is different, so to calculate the result we impose two perpendicular axes x, y and analyze the forces that do not fall on these axes, ie the force vector F $_{13}$ to become

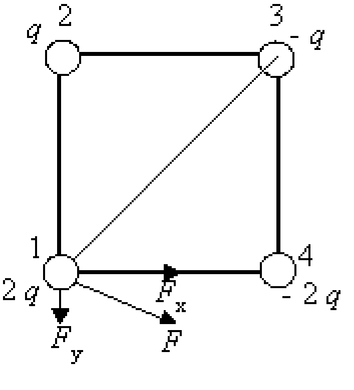
$F_{13x} = F_{13} \sin 45 = 0.025$ N &

$F_{13y} = F_{13} \cos 45 = 0.025$ N

$F_x = F_{13x} + F_{14} = 0.025 + 0.144 = 0.169$ N

$F_y = F_{13y} - F_{12} = 0.025 - 0.072 = -0.047$ N

A negative signal indicates that the direction of the force compound is in the direction of the negative y-axis



The resulting electrical force is equal:

$$F_1 = \sqrt{(F_x)^2 + (F_y)^2} = 0.175 \text{ N}$$

$$\theta = \tan^{-1}\frac{F_y}{F_x} \qquad = -15.5□$$

Example 1-4

Two charges of 1μC -&3μC separated by a distance of 10 cm as shown in Figure 1-6, where a third charge can be placed with the forces acting on it equal to zero.

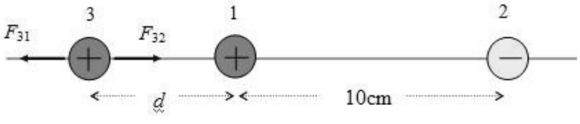


Fig (1-6)

Solution

What is required is where a third charge can be placed so that the sum of the electrical forces acting on it is zero, that is, equilibrium .)Note that the type and amount of charge does not affect the equilibrium point assignment (.For this to happen, the forces acting must be equal in magnitude and opposite in direction .In order for this condition to be met, the third charge must be placed outside the two consignments and near the smaller charge .So we impose a positive charge q3 as in the diagram and determine the direction of the forces acting on it

$$\boldsymbol{F_{31} = F_{32}}$$

$$k\frac{q_3 q_1}{r_{31}^2} = k\frac{q_3 q_2}{r_{32}^2}$$

$$\frac{1\times10^{-6}}{d^2} = \frac{3\times10^{-6}}{(d+10)^2}$$

Solve this equation and find a value of d

Electric field

All charged objects create an electric field that extends outward into the space that surrounds it. The charge alters that space, causing any other charged object that enters the space to be affected by this field. The strength of the electric field is dependent upon how charged the object creating the field is and upon the distance of separation from the charged objects. In this section of Lesson 4, we will investigate electric field from a numerical viewpoint

electric field strength

The electric field strength at a point is known as the electrical force acting on the unit of positive charge q placed at this point and in the same direction of force. Equal to

= Force/charge

E = F/q

= N/C

= NC^{-1}

That is, the electric field strength (E) is a vector of a magnitude and direction.

But what happens if this charge affects the object whose intensity is to be found, in this case we assume that the test charge is small and does not affect the body

Note here that the electric field E is an external field and not the field arising from the charge qo as shown in Fig. 3.1 .Electric field through the electrical forces affecting them.

Fig (4)

Find the direction of the electric field

1- If the electric charge q is positive at point p, the field direction arrow is out of the charge as in Fig. 5.

2- If the charge q is negative at point p, the field direction arrow is opposite to the previous state as in Fig. 5.

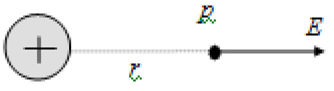


Figure 5 a

Figure 5b

The direction of the field at some point of a positive charge is in the direction of exit from the point as in Fig. 5 (a), and the direction of the field at some point of a negative charge is in the direction of entry from point to shipment as in Fig. 5b.

<u>Calculate the electric field due to a charged particle</u>

From fig. 2-2a, the force acting on qo is given by Coulomb's law as follows:

$$F = \frac{1}{4\pi\varepsilon_o}\frac{Qq_o}{r^2}$$

$$E = \frac{F}{q_o}$$

$$E = \frac{1}{4\pi\varepsilon_o}\frac{Q}{r^2}$$

<u>To find the electric field E for a set of charged points</u>

Suppose the following figure:

1- We number the charges for which the electric field is to be found.

2- Determine the direction of the electric field for each charge individually at the point at which the field result is to be found. In point p, the direction of the field is out of point p if the charge is positive and the direction of the field is entered to the point if the charge is negative as in charge No.

3- The total electric field is the directional sum of the field vectors

$$E_p = E1 + E2 + E3 + E4 \text{ .... } \quad (2.4)$$

4- If the field vectors do not combine a single line of action, we analyze each vector into two vehicles in the x and y axial direction

3- Combine x-axis compounds separately and y-axis compounds.

$$Ex = E1x + E2x + E3x + E4x$$

$$Ey = E1y + E2y + E3y + E4y$$

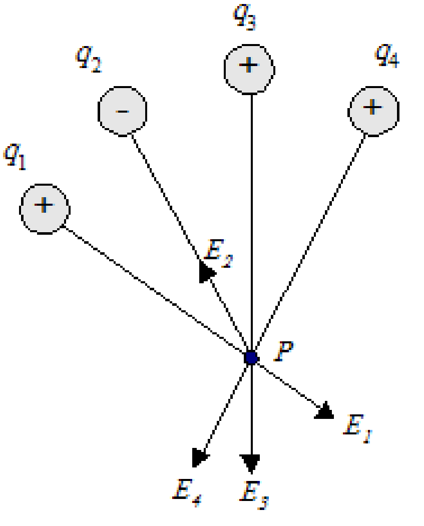


Figure 3.3

6- The value of the electric field at the vacuum point is

$$E = \sqrt{E_x^2 + E_y^2}$$

7- The direction of the field is

$$\theta = \tan^{-1} \frac{E_y}{E_x}$$

<u>Electric field lines</u>

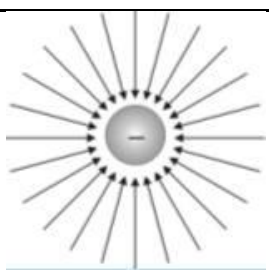
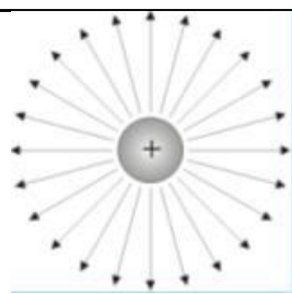
They are imaginary lines that help imagination the field. The line shall be such that its tangent at any point has the same direction as the field at this point.

1- Power lines cannot cross

2- .Power lines converge in areas where the field value is high and diverge when the field strength decreases

Some examples of power lines for the electric field are shown in the following drawing, These drawings illustrate the following:

1- .The lines must start from positive charges and end to negative charges.
2- The number of power lines is proportional to the field strength
3- It does not cross the lines of two electric fields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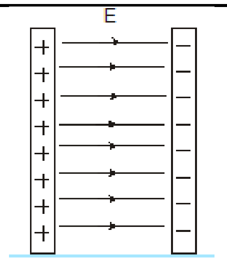
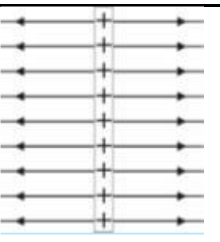
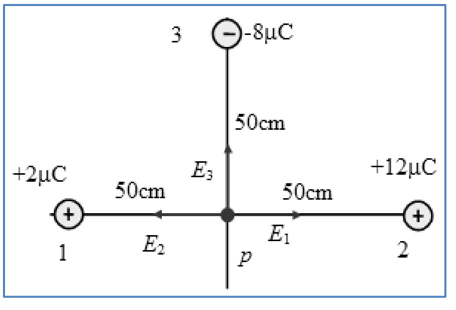
 خطوط المجال الكهربى نتيجةسطحين مشحونين بشحنات مختلفة	 خطوط المجال الكهربى نتيجةخط مشحون بشحنة موجبة

<u>Examples of electric field</u>

<u>Example</u> 2.1

Find the electric field at point P in the following figure due to the charges shown in figure



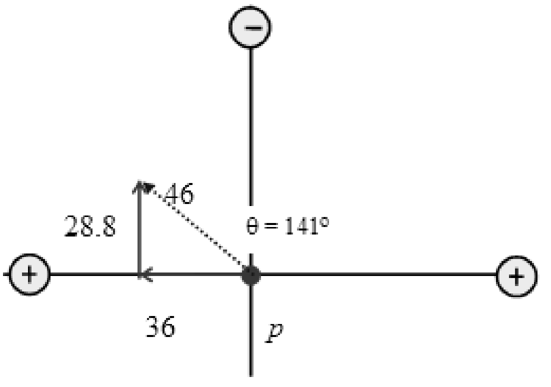
$$\vec{E}_p = \vec{E}_1 + \vec{E}_2 + \vec{E}_3$$

$$\boldsymbol{E_x = E_1 - E_2 = -36\times10^4 N/C}$$

$$\boldsymbol{E_y = E_3 = 28.8\times10^4 N/C}$$

$$\boldsymbol{E_p = \sqrt{(36\times10^4)^2 + (28.8\times10^4)^2} = 46.1 N/C}$$

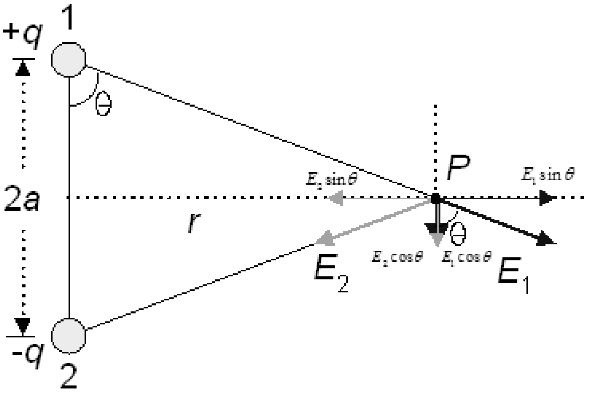
$$\boldsymbol{\theta = 141^o}$$



Electric field affecting point P

Example 2-2

Find the electric field resulting from a bipolar molecule on the x-axis on point p separated by a distance r from the point of origin and then assume that r < a



Solution

The total field at point p is the sum of the fields E_1 from charge q_1 and E_2 from charge q_2

$$\vec{E}_p = \vec{E}_1 + \vec{E}_2$$

Since point p is equal to the two charges, and the charges are equal, then the fields are equal and the field value is given in relation to

$$E_1 = \frac{1}{4\pi\varepsilon_o} \frac{q_1}{a^2 + r^2} = E_2$$

Note here that the separation distance is between the charge and the point at which to find the field.

We analyze the field vector into two compounds as in the figure above

$E_x = E_1 \sin\theta - E_2 \sin\theta$

$E_y = E_1 \cos\theta + E_2 \cos\theta = 2E_1 \cos\theta$

$E_p = 2E_1 \cos\theta$

$$E_p = \frac{1}{4\pi\varepsilon_o} \frac{q}{a^2 + r^2} \cos\theta$$

From the figure

$$\cos\theta = \frac{a}{\sqrt{a^2+r^2}}$$

$$E_p = \frac{1}{4\pi\varepsilon_o} \frac{q}{a^2+r^2} \frac{a}{\sqrt{a^2+r^2}}$$

$$E_p = \frac{2aq}{4\pi\varepsilon_o (r^2+a^2)^{3/2}} \quad \textbf{(3.5)}$$

The direction of the electric field in the direction of the negative x-axis

The quantity 2aq is called the driving force of the bipolar molecule p and has a direction from negative to positive charge When $r < a$

$$\therefore E = \frac{2aq}{4\pi\varepsilon_o r^3}$$

It is clear from the preceding that the electric field generated by electric dipole at a point on the half-column between the two charges is in the opposite direction of the electric dipole momentum. For the point far away from the electric dipole, the field is inversely proportional to the distance cube .In case of only one charge.

Electric Potential

We have learned in the past how to express the electrical forces or electrical effect in the space surrounding one or more charges using the concept of electric field .As we know, the electric field is a vector and we use it for both Coulomb's law and Gauss's law . Gauss's law made it easier for us to find many of the mathematical

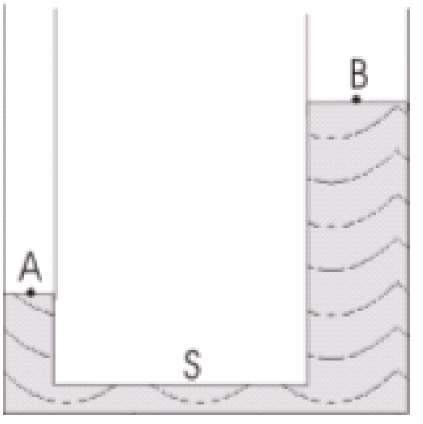
complexities we encountered while finding the electric field of a continuous distribution of charge using Coulomb's law.
In this chapter we will learn how to express the electrical effect in the space surrounding one or more charges by a standard amount called the electric potential .Since electric potential is a standard quantity, it will be easier to deal with it in expressing the electrical effect from the electric field; we will give some illustrative examples.

Example 1

When an object of mass m is raised to the height of h above the ground, we say that an external (positive) work has been done to move the object against the gravitational .The Potential energy increases with distance h because of course the work will increase . If the effect of work done on the object m is removed, it will move from areas with high Potential energy to areas with low Potential energy until the Potential energy difference is equal to zero.

Example 2

We suppose a U-shaped with water as in the following shape .The Potential energy of the water molecule at point B is greater than the position energy at point A, so if tap S is opened, the water will flow in the direction of point A until the difference in Potential energy between points A&B is equal to zero.



Example 3

There is a situation very similar to the two previous cases in electrophysiological, where we assume that the points A&B are in an electric field resulting from a positive charge Q for example as in Figure 3-1. If a q_o test charge (corresponding to the object m in the field of the gravitational as well as the water molecule at point B in the previous example) is located near charge Q, the q_o charge will move from a point close to the charge to a more distant point, ie from B to A and physically We say that the charge q_o moved from areas of high voltage to areas of low voltage. Therefore the voltage difference between two A&B points located in an E field is calculated by calculating the work done by an external force (Fex) against the electrical forces (qE) to move the qo test charge from A to B so that it is always in equilibrium

If there is a 1.5volt voltage difference between the two poles, it means that if it reaches a circuit, the positive charges will move from high voltage to low voltage .As in the case of opening the tap on the U tube, the charge will continue until the voltage difference between the two battery poles is equal to zero.

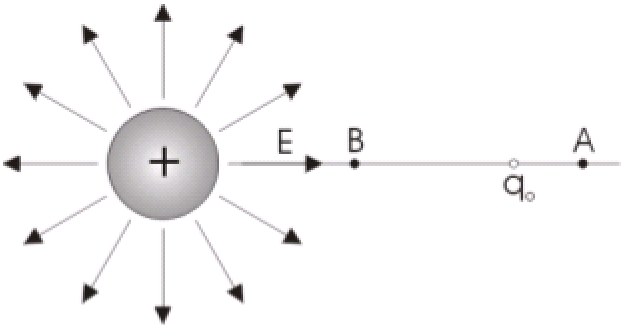


Figure 3-1

Definition of potential difference

The voltage difference between two points A & B is the work done by an external force to move the test charge q0 from point A to point B so that:

$$V_B - V_A = W_{AB} / q_o \qquad (5.1)$$

The voltage difference unit (Joule / Coulomb) is known as Volt (V). Note that:

The work is

Positive if $V_B > V_A$

Negative if $V_B < V_A$

Zero if $V_B = V_A$

You must remember that this work is in the following equation:

$$W = \vec{F}_{ex} \cdot \vec{l} = F_{ex} \cos\theta \, l$$

If 0> θ > 90 cos θ is positive and W is positive

If 90> θ > 180 cos θ is negative and W is negative

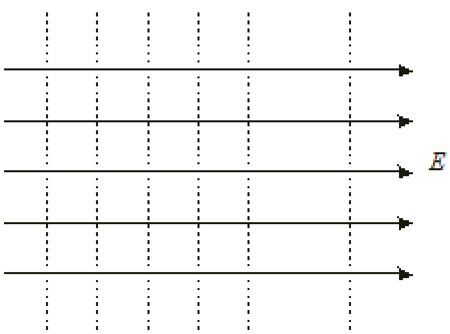
If θ = 90 between F_{ex} & l, w is zero

The difference of the voltage is not dependent on the path between A&B as the work (W_{AB}) moves the test charge q_0 from A to B does not depend on this distance

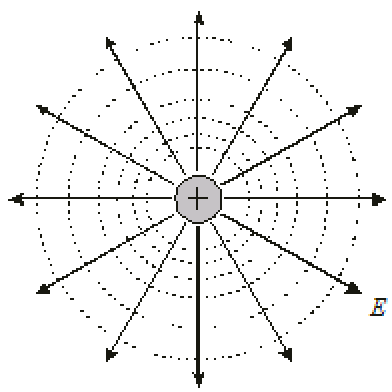
The Equipotent surfaces

As the electric field is drawn by power lines, the potential difference can be drawn as surfaces of equal effect

The Equipotent surfaces is the surface where the voltage at each point is equal, i.e. V_B-V_A = zero between any two points on the surface. In all cases, equal-voltage surfaces operate at right angles to the power lines E.



(a) Figure 3-1



(b) Figure 3-1

Figure 3-1 shows the shape of the equivalent effect surfaces (dotted lines) and electric power lines (non-dotted lines).

Electric circuit

Elements of an Electric circuit:

An Electric circuit consists of following types of elements.

Active elements:

Active elements are the elements of a circuit which possess energy of their own and can impart it to other element of the circuit.

Active elements are of two types

a) Voltage source b) Current source

A Voltage source has a specified voltage across its terminals, independent of current flowing through it.

A current source has a specified current through it independent of the voltage appearing across it

Passive Elements:

The passive elements of an electric circuit do not possess energy of their own. They receive energy from the sources. The passive elements are the resistance, the inductance and the capacitance. When electrical energy is supplied to a circuit element, it will respond in one and more of the following ways

If the energy is consumed, then the circuit element is a pure resistor.

If the energy is stored in a magnetic field, the element is a pure inductor.

And if the energy is stored in an electric field, the element is a pure capacitor

Linear and Non-Linear Elements.

Linear elements show the linear characteristics of voltage & current. That is its voltage-current characteristics are at all-times a straight-line through the origin.

For example, the current passing through a resistor is proportional to the voltage applied through its and the relation is expressed as V I or V = IR. A linear element or network is one which satisfies the principle of superposition, i.e., the principle of homogeneity and additivity.

Resistors, inductors and capacitors are the examples of the linear elements and their properties do not change with a change in the applied voltage and the circuit current.

Non linear element's V-I characteristics do not follow the linear pattern i.e. the current passing through it does not change linearly with the linear change in the voltage across it. Examples are the semiconductor devices such as diode, transistor.

Bilateral and Unilateral Elements

An element is said to be bilateral, when the same relation exists between voltage and current for the current flowing in both directions.

Ex: Voltage source, Current source, resistance, inductance & capacitance.

The circuits containing them are called bilateral circuits.

An element is said to be unilateral, when the same relation does not exist between voltage and current when current flowing in both directions. The circuits containing them are called unilateral circuits.

Ex: Vacuum diodes, Silicon Diodes, Selenium Rectifiers etc

Factors of the electrical circuit

The basic factors in electrical circuits are:

1- Resistors
2- Capacitors
3- Inductors

The behavior of each of these factors depends on the way it is connected with the rest of the circuit and the quality of the current sources in the circuit.

<u>First: Resistors</u>

Ohm's law

The intensity of the current passing through a conductor is directly proportional to the voltage difference between the two ends of the conductor,

$$V \propto I$$

$$V = \text{constant} \times I$$

The current in the circuit is measured by a straight conductor ammeter, and the voltage difference is measured by any resistance in the circuit by a voltmeter connected in parallel with the resistance .These instruments should be such that the measured current or voltage difference does not change

The equation shows that

$$V = R\,.I.$$

Where R is a constant whose value depends on the material and its dimensions. This constant is called conductor resistance .The unit of resistance depends on the units measured by the current and the difference of voltage. The practical unit of the current is the ampere and the practical unit of the voltage is the voltage and the resistance is the ohm .Thus the resistance can be defined as "the resistance of a conductor in which a current of 1 ampere passes and the voltage difference between the two ends is 1 volt".

$R \alpha L$ Positive relationship

$R \alpha l/A$ Inverse relationship

$R = \rho \; L \; /A$

Whereas ρ is the specific resistance, a conductive resistance (measured in ohms) of this material is 5 cm long and a cut area of 1 cm .The resistance of conductor R depends on the type of material (ρ), depending on the type of material (ρ), the specific resistance varies

$$P_t = \rho_0 (1+ \alpha t)$$

Where α is a constant amount called the coefficient of increasing resistance with temperature and the inverse of the specific resistance is called the specific conductivity and the specific conductivity coefficient ie.

$\sigma = 1 / \rho$ = (specific conduction)

$R = \rho \; L / A \Longrightarrow R = L / A \sigma$

$V= R \; .I$

$I = V / R = A \sigma V / L$

Connecting resistors

The resistors can be connected to obtain large or small resistance to obtain a suitable current in the circuit

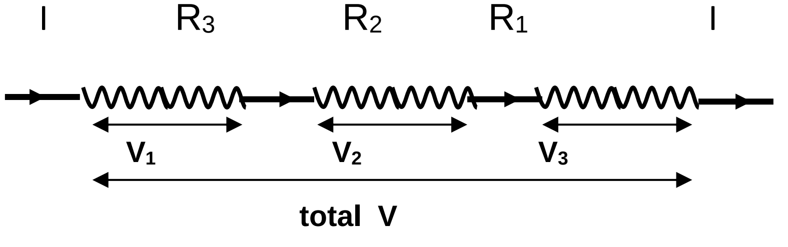
First: Series Resistors   Purpose:

1- Obtaining a large resistance from several small resistors and thus increase the resistance

2- Obtaining a greater resistance than the largest resistance in the circuit $R > R_{eq}$

3- Reducing the electric current passing through the circuit and the value of the current is equal to the resistors

4- Reducing the power drawn in the circuit and the total voltage difference is equal to the algebraic sum of the differentials of those resistors



*Current intensity (I) is one in all resistors

*Voltage difference between resistors

$$IR_{TotaL} = IR_1 + IR_2 + IR_3 + \ldots\ldots$$

$$IR = I(R_1 + R_2 + R_3)$$

$$R_{eq} = (R_1 + R_2 + R_3 + \ldots\ldots)$$

Total resistance values = equivalent resistance

**If the resistors were equal and the number (N) and the value of each r

$$R = N\ r$$

<u>First: parallel Resistors   Purpose:</u>

1- obtaining a small resistance from several large resistors and thus reduce resistance
2- obtaining a resistance smaller than the smallest resistance in the circuit R <Req
3- increase the intensity of electrical current passing the circuit and the value of the difference in the voltage is equal to all resistors
4- increase the power drawn in the circuit and the total voltage difference is equal to the potential difference for each branch of the resistors

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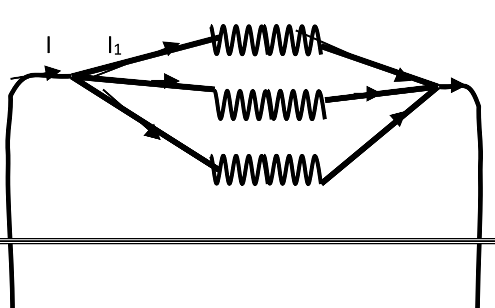


*** One potential difference between the two ends of the resistors**
***The intensity of the current is divided into resistors**

I = I1+I2 +I3 +.... Total current

R_2 I_2

R_3 I_3 I_3

R_1

If the resistors are of equal value and the value of each (r) and its number N:

$$R_{eq} = \frac{r}{N}$$

$$R_{eq} = \frac{R_1 \times R_2}{R_1 + R_2}$$

** Equivalent resistance of two parallel resistors

**Their multiplication is their sum

<u>Ohm's Law for a Closed circuit</u>

We have an electric pole with an electrical impulse (E) and its internal resistance (r) and is related to external resistance (R) in the circuit of its current intensity I:

E=V+Ir

E=IR+Ir

E=I(R+r)

$$\therefore I = \frac{E}{R+r}$$

The relationship between the electromotive force of a column and the voltage difference between the poles

**Ohm's law for a closed circuit and by assuming (VR) the voltage difference between the two ends of the internal resistance is: Vr + E = VR

**But the voltage difference between the poles of the electrical source VR = V The voltage difference between the two ends (R) as well as the voltage difference between the ends of the inner column circuit (source) Ir = Vr

**Any voltage difference between the poles of column V> E by Ir

$$E = V + Ir$$

We conclude that:

1- In case of no electrical current to the column (by opening the - circuit **I = 0 or R =** ∞

Voltage difference between poles **E = V**

2- In case of discharging a charge and passing an electric current

$$\boxed{V = E - Ir}$$

3- If the circuit is closed and an electric current is passed and the battery or column is charged with electricity (reverse discharge)

$$\boxed{V = E + Ir}$$

Exercises

Electricity is delivered to a village through an insulated copper wire with a radius of 1.5 mm and a length of 3 km mounted on six high towers. If the specific resistance of copper is 1.65 X 10-6 ohms, the coefficient of increasing the resistance of copper with high temperature equals 0.0042 and calculated.

A- Total resistance of the wire

B- The change in the wire conductor between two consecutive towers with a temperature rise from zero to 25 o C

Solution

The relationship between the wire's resistance and its specific resistance and the area of its section comes from the following equation

$$R = \rho \frac{L}{A}$$

$$R = 1.65 \times 10^{-6} \frac{300000}{\Pi r^2} \qquad A = \Pi r^2$$

$$R = \frac{1.65 \times 10^{-6} \times 300000 \times 7}{22 \times 0.15 \times 0.15} = 7 \text{ ohm}$$

B - The distance between the two consecutive towers is

$$\frac{3 \times 1000 \times 100}{5} = 60000$$

From the relationship:

$R_{25} = R_0$ (1+ 0.0042 X 25)

Ro = 7/5 = 1.4 اوم

R_{25} = 1.4 (1+ 0.0042 X 25) = 1.547 ohm

Example 2

Wire resistance at 25 º C is 8.1 ohms and resistance at 100 º C is 80.1 ohm I conclude the resistance of the wire at 150 º C as well as the coefficient of increasing the resistance of the wire with Temperature change

Solution

$R_{25} = R_0 (1+\alpha (25-0)$

$R_{100} = R_0 (1+ \alpha(100-0)$

α is the coefficient of increasing resistance by temperature rise, and by dividing the two equations

$$\frac{R_{100}}{R_{25}} = \frac{1+100\,\alpha}{1+25\,\alpha}$$

$$\frac{10.8}{8.1} = \frac{1+100\,\alpha}{1+25\,\alpha}$$

A = 0.005 Ohm / degree

Suppose that the resistance of the wire at 150 degrees is R150

$$\frac{R150}{R_{100}} = \frac{1+150\,\alpha}{1+100\,\alpha}$$

$$\frac{R_{150}}{10.8} = \frac{1+150 \times 0.005}{1+100 \times 0.005}$$

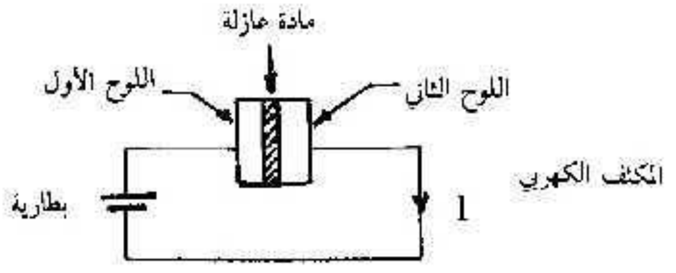
$$\frac{R_{150}}{10.8} = \frac{1+0.75}{1+0.5}$$

$$R_{150} = \frac{10.8 \times 1.75}{1.5}$$

$R_{150} = 12.6$ Ohm

Capacitors

The electric capacitor consists of two plates of conductive material between them as insulating material as shown in the following figure. The type of condenser is determined by the insulation used in its manufacture, If the insulation material between the condenser plates is air, the condenser is called an air condenser. If it is made of plastic, it is called a plastic capacitor. If the mica insulation is called the condenser, the mica condenser is used. If the insulation is ceramic, the condenser is called the ceramic condenser. If a chemical solution is used as a buffer between the condenser plates, the condenser is called the chemical or electrolytic capacitor .They are usually charged with two charges equal in size and different in signal, one settling on one plate and the other on the opposite plate, so the total charge on the capacitor is zero. Each is proportional to the electric field in the area between the plates and the voltage difference between the plates Vab with the numerical value of one of the charges Q



Capacity:

The capacity of a capacitor to store an electric charge is defined as the capacitance or capacitance and its unit of measurement is farad

$$\text{Capacitor capacity (C) in Farad} = \frac{\text{Charge in capacitor}}{\text{The voltage difference between the capacitor tablets}}$$

We conclude from this law that the selection of the value of the capacitor in the electronic circuit is determined by two basic factors are capacitor capacity, the value of the potential difference applied to both ends, and the unit of measurement of Farad capacity can be divided into smaller units are:

$$\text{Microfarad } (\mu f) = \frac{1}{1000000} \text{ farad}$$

$$\text{picofarad } (pf) = \frac{1}{1000000}\ \mu f$$

Factors affecting capacitor capacity:

There are three main factors that directly affect capacitor capacity

:1**- Surface area of condenser plates (a)**

The capacitor capacity is directly proportional to the surface area of the panels.

2**- Distance between panels (d):**

Capacity decreases when the distance between the plates increases and increases as the distance decreases, ie there is an inverse proportion between the capacitor capacity and the space between the plates

4- Insulating media (insulation material (ε)

The capacity of the condenser varies with the change of insulating material between the plates and the air is the main unit for comparing the isolation ability of other materials used in the manufacture of capacitors .Each substance has an insulation called ε

From the above we find that the capacitor capacity in terms of the surface area of the plates (a) and the space between the plates d and the insulation constant of the insulation ε is

$$C = \epsilon \frac{a}{d}$$

The insulation constant ε in the equation is equal to the product of the insulation constant of air ε_o times the relative insulation constant of the insulation material, thus

$$\epsilon = \epsilon_O \cdot \epsilon_r$$

$\epsilon_O = 8{\cdot}85 \times 10^{12}$ F/m تساوى ϵ_O وتكون

Reaction (ohmic capacitor resistance(

The capacitor has an ohmic resistance of Xc (because it is measured in units of ohms) that changes with frequency (F) and is inversely proportional to both amplitude C and frequency F, and can be calculated from the following law:

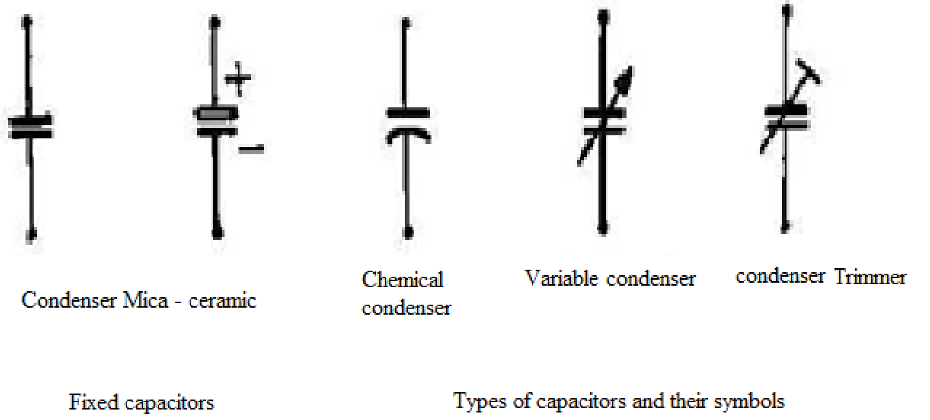
$$X_c = \frac{1}{\omega C} = \frac{1}{2 \pi fc} = \frac{1}{(2x3{\cdot}14\ fc)}$$ من القانون

In the case of constant current, the frequency value is equal to (zero), and therefore the value of the resistance of the ohmic capacitor Xc is very large (infinity) and thus the capacitor prevents the passage of DC in the circuit, while passing the variable current and this characteristic is the most important functions of the capacitor uses in the electronic circuit.

Types and forms of capacitors:

A fixed capacitor (fixed capacitor) is called a capacitor, which can change its capacitance (by changing the area between panels) and is called a variable capacitor .There is also a third type of capacitor that can control the change of its capacity, or leave unaltered for long periods of time and is called (Trimer capacitor), which we may resort to adjust its value when performing maintenance and repair work in the electronic circuit.

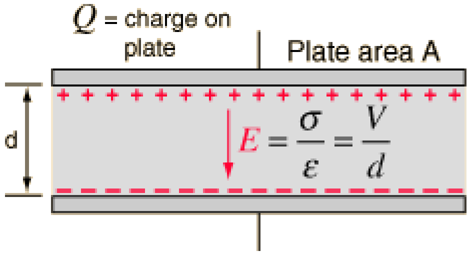
The following figure shows the conventional symbols for these types of capacitors.



Types of capacitors and their symbols

The parallel plate capacitor

The electric field of such capacitors is uniform and concentrated in the area between the plates. The charge distribution on the condenser plates is uniform.



Spherical capacitors

The spherical capacitor consists of two concentric balls according to the following figure, if we assume that the radius of the inner circle r1 and the radius of the outer ball is r2 .If the inner ball is charged with a charge of (-Q), a charge of (+ Q) will be on the surface of the outer ball connected to the earth

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

a- But the voltage of the isolated ball consists of Voltage V1 is the result of the internal ball charge + Q and is equal to

$$V_1 = \frac{Q}{4\pi\varepsilon_0 r_1}$$

B - voltage V2 resulting from the impact charge - Q on the outer and is fixed at all points of the internal surface of this ball and is equal to its voltage at the surface

$$V_2 = \frac{-Q}{4\pi\varepsilon_0 r_2}$$

That is, the total voltage (V) is equal

$$V = V1 + V2$$

$$\frac{Q}{4\pi\varepsilon_0 r_1} + \frac{Q}{4\pi\varepsilon_0 r_2} = \frac{Q}{4\pi\varepsilon_0}\left(\frac{1}{r_1} + \frac{1}{r_2}\right)$$

$$C = \frac{Q}{V} = \frac{Q\, 4\pi\varepsilon_0 (r_1 r_2)}{Q \quad (r_2 - r_1)}$$

$$\mathbf{C = \frac{4\pi\varepsilon_0 (r_1 r_2)}{(r_2 - r_1)}} \qquad *$$

From this equation we see that the capacity of the spherical condenser increases as the distance between the two conductors decreases due to the lack of voltage as a result of the negative charge on the outer ball closer to the positive charge on the internal ball .The capacitance decreases as the distance between the two balls becomes less than possible when the outer ball becomes infinite .This case is equal

$$\mathbf{C = \frac{Q}{V} = \frac{Q}{Q/4\pi\varepsilon_0 r}}$$

The same result can be obtained by substituting in equation * where r1 is neglected in relation to r2 which in this case is infinite and in this case we get

$$C = \frac{4\pi\varepsilon_0 r_1 r_2}{r_2} = 4\pi\varepsilon_0 r_1 \qquad \#$$

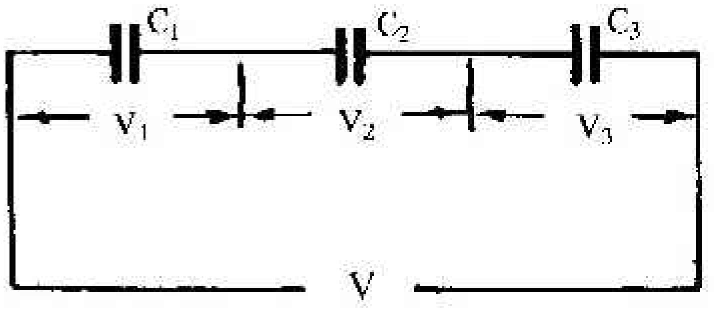
From the comparison of equation * and equation # we note that the capacity of the spherical conductor increases very significantly if surrounded by another connector connected to the ground

Capacitors capacitance variables

It consists of two groups of parallel metal plates, each group is electrically connected together and form one capacitor plate together .One group is fixed and the other is mounted on a movable axis.

<u>Connect the capacitors respectively:</u>

Conduct capacitors respectively to obtain a small total capacity less than the smallest capacitor present in the circuit



$$\because \quad V = V_1 + V_2 + V_3$$

$$\therefore \quad \frac{Q}{C} = \frac{Q_1}{C_1} + \frac{Q_2}{C_2} + \frac{Q_3}{C_3}$$

$$\therefore \quad \frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

Capacitors respectively

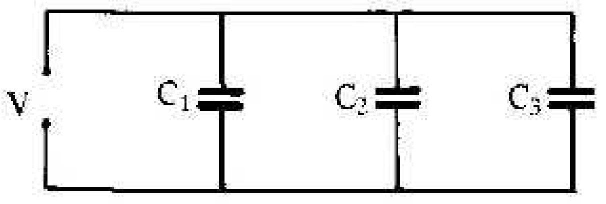
In the case of two capacitors in a row, the total amplitude of C is equal

$$C = \frac{C_1 \times C_2}{C_1 + C_2}$$

We conclude from the above that when calculating the total value of the capacitance of conductive capacitors, respectively, the method of calculation is unlike in the resistors

Connecting capacitors in parallel:

Capacitors are connected in parallel to obtain a large total capacitance equal to the total capacitance of the connected capacitors in parallel in the circuit.



$\because$ الشحنة الكلية $Q = Q_1 + Q_2 + Q_3$

$\therefore V \times C = V \times C1 + V \times C_2 + V \times C3$

$\therefore C = C1 + C2 + C3$

Connecting capacitors in parallel:

<u>Uses of capacitor in electronic circuit:</u>

1- The capacitor is used to pass the variable current and prevent the passage of the DC current in the electronic circuit, where it acts as (coupling capacitor) Coupling or (leakage capacitor) Bypass as shown in the following figures.

2- The chemical capacitor is used for charging and discharging in smoothing circuits that convert the variable current into a constant current.

3- uses a large-capacity chemical capacitor in the camera flash circles where it stores high electrical charges, and when it suddenly emptied gives bright white light necessary for the process of imaging.

4- -A variable capacitor is used in parallel with a coil to select the stations (frequencies) of the radio or television set, as shown in the following figure.

5- The capacitor is connected with the resistance in the electronic circuit to obtain various waveforms. In this case, the circuit is called a differential or integral circuit, as shown in the following figures.

Example1

Calculate the plate area (A) for its capacitor capacitance (C = 1f) and the distance between them is 10-3 m.

Solution

$$C = \varepsilon_0 \frac{A}{d}$$

$$A = \frac{Cd}{\varepsilon_0}$$

$$= \frac{1 \times 10^{-3}}{8.85 \times 10^{-12}} = 1.13 \times 10^{8}\ m^2$$

This is a large area of more than 100 km2.

Example 2

The two parallel capacitor plates (5 x 10-3) are separated from each other and the plate area is 2m2 and the voltage difference is 107 V.

A - capacitor capacity B - charge on each plate
C - electric field strength between the plates

Solution

أ - $C = \varepsilon o \frac{A}{D} = \frac{8.85 \times 10\text{-}12 \times 2}{5 \times 10\text{-}3}$

$C = 3.54 \times 10\text{-}9\ c^2 N^{-1} m^{-1}$

$1\ c^2 N^{-1} m^{-1} = 1\ c^2 j^{-1} = 1\ c\ (J/c)^{-1} = 1\ cv^{-1} = 1\ F$

$C = 3.34 \times 10\text{-}9 \qquad F = 3.5 \times 10^{-3}\ \mu\ F$

b – $Q = CV_{ab} = (3.54 \times 10^{-9})(10^4) = 3.5 \times 10^{-5}\ C$

) ولذلك فأن اللوح ذى الجهد الاعلى عليه شحنة مقدارها +3.54×10^{-5} والاخر (
) عليه شحنة مقدارها -3.54×10^{-5}.(

Therefore, the board with the highest voltage has a charge of (+ 3.54 x 10-5) and the other has a charge of (-3.54 x 10-5).

b- $E = \frac{Q}{\varepsilon_o A} = \frac{3.54 \times 10^{-5}}{(8.85 \times 10^{-12})^2} = 20 \times 10^{5}\ NC^{-1}$, then

field strength = voltage regression

$E = \frac{V_{ab}}{d} = \frac{10^4}{5 \times 10^3} = 20 \times 10^{5}\ Vm^{-1}$

Example 3

Capacitor consists of two plates, each 7.6cm2, separated by a distance of 1.8mm, if the difference between the voltage is 20V calculate

a -The electric field between them

b-The density of the charge formed on the surface of the board Capacity

d-The consignment on each of them

Solution

(a) $E = \frac{V}{d} = \frac{20}{1.8 \times 10^{-3}} = 1.11 \times 10^{4}\ V/m$

(b) $\sigma = \varepsilon_o E = (8.85 \times 10^{-12})(1.11 \times 10^{4}) = 9.83 \times 10^{-8}\ C/m^2$

(c) $C = \frac{\varepsilon_o A}{d} = \frac{(8.85 \times 10^{-12})(7.6 \times 10^{-4})}{1.8 \times 10^{-3}} = 3.74 \times 10^{-12}\ F$

(d) $q = CV = (3.74 \times 10^{-12})(20) = 7.48 \times 10^{-11} C$

Example 4

Two capacitors (2 & 8) microfarad connected respectively .If the voltage difference on the set is 300 v

-Calculate the charge and voltage difference on each capacitor

-If the capacitors arrived in parallel, calculate the charge and voltage difference on each capacitor.

solution

$$C = \frac{C_1 C_2}{C_1 + C_2} = \frac{2 X 8}{2 + 8} = 1.6 \ \mu F$$

$$Q = CV = 1.6 \times 10^{-6} \times 300 = 4.8 \ 10^{-4} \ C$$

The capacitors are straight so the charge is equal but the voltage difference varies

$$Q1 = Q2 = Q = 4.8 \times 10^{-4} \ C$$

$$V_1 = \frac{Q}{C_1} = \frac{4.8 \times 10^{-4}}{2 \times 10^{-6}} = 240 \ v$$

$$V_2 = \frac{Q}{C_2} = \frac{4.8 \times 10^{-4}}{8 \times 10^{-6}} = 60 \ v$$

When connected in parallel the

$C = C_1 + C_2 = 2 + 8 = 10\ \mu F$

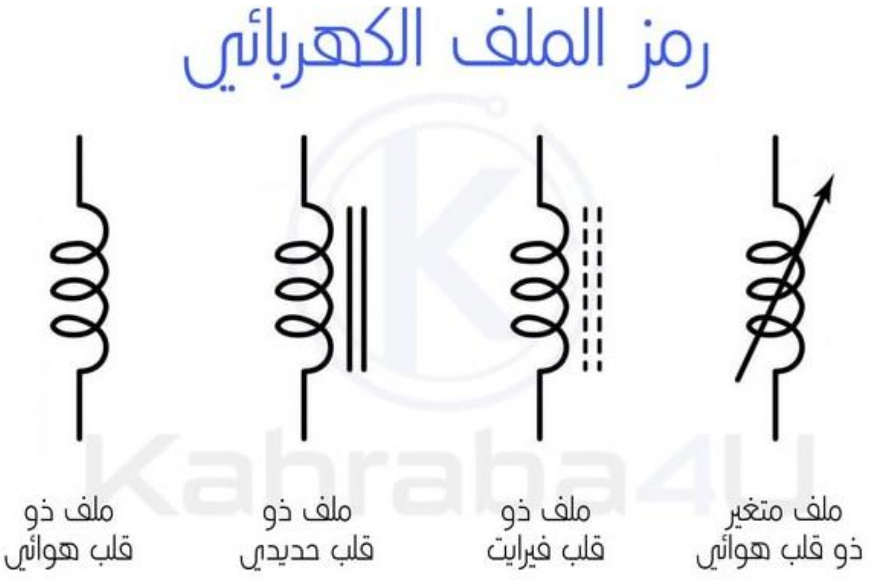
$V_1 = V_2 = V = 300$ volt

$Q_1 = C_1 V = 2 \times 10^{-6} \times 300 = 6 \times 10^{-4}$ C

$Q_2 = C_2 V = 8 \times 10^{-6} \times 300 = 2.4 \times 10^{-3}$ C

Inductors

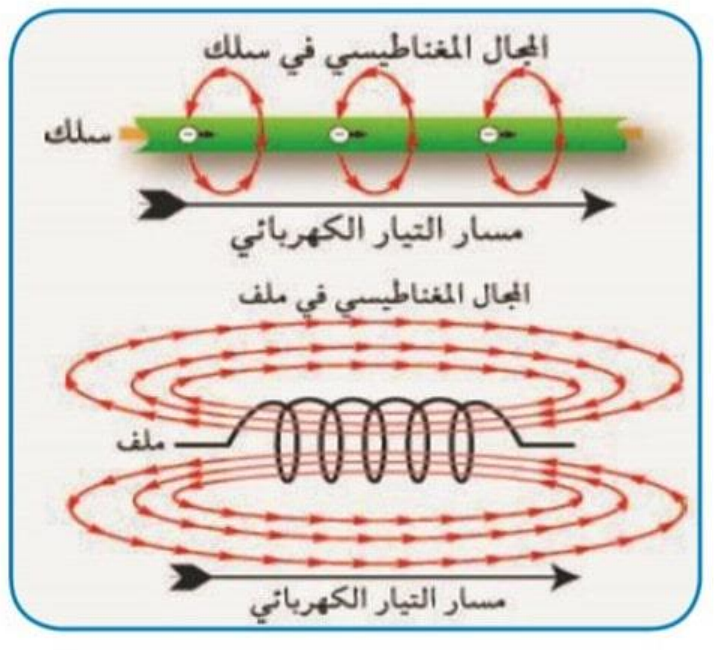
An electrical coil (lnductor) is a wire made of a conductive material such as copper that is insulated and wrapped around an iron core or pneumatic, and when an electric current passes through the coil, a magnetic field is generated around it. The coils differ from each other in terms of the number of coils, the cross-sectional area of the coiled wire, the dimensions of the coil, and the type of frame material around which the wire is wrapped.



One or two parallel lines next to the coil indicate that it is wrapped around a solid core of a material that can be magnetized, while one or two dotted lines indicate that it is wrapped around a core that contains metal particles, such as iron filings. If there is no line or dots, this indicates that it is wrapped around an air core.

How the electrical coil works

When the coil is connected to an electrical current source, the electricity passing through a wire can generate a magnetic field around the wire, and conversely, a magnet moving near the wire can stimulate an electric current in the wire according to the phenomenon of electromagnetic induction.



This principle is used in the electric generator, and also in transformers where the alternating current in the primary coil generates a variable magnetic field in the core, and the magnetic flux in the core converts to alternating current in the secondary winding.

Inductance

Lnductance is defined as the obstruction of the coil to the passage of electric current by it as a result of the generation of a property of the coil called an electromotive force (emf) between the two ends of the coil, resulting from the formation of a magnetic field around it when the electric current passes through it, and because the polarity of this generated electromotive force is opposite to the polarity of the electromotive force of the source, it will push a current opposite to the original current passing through the circuit, which hinders its passage.

The coil stores electrical energy in the form of a magnetic field around the coil, and this energy is discharged into the coil when the current in the electrical circuit is weak or interrupted.

The amount of energy stored in the coil can be found from the following relation

$$W = 0.5 \times L \times I2$$

where (W) is the work and is measured in joules, (L) is the inductance and is measured in henry, and (I) is the current and is measured in amperes. with a symbol for the inductance of the coil with the letter (L), measured by a unit called Henry (H), which is a large unit that uses instead its smaller parts, such as: millihenry mH and microhenry µH

millihenry mH	10^{-3} henry H
microhenry µH	10^{-6} henry H

nanoHenry nH	10^{-9} henry H

Factors affecting the value of inductance

1- **Number of turns of the coil:** As the number of coil bits increases, the magnetic field strength around the coil increases and its inductance increases (L).

2- **File segment area:** The larger the file segment area, the greater its inductance (L)

3**- Coil length**: The longer the coil, the lower the amount of self-induction.

4- **Type of magnetic core material**: The greater the permeability of the core material on which the coil is wrapped, the greater the inductance (L)

Types of electrical coils

Electrical coils can be classified in terms of the type of core, the stability of their value, or the frequencies on which they work to the following:

Types of electrical coils according to heart type:

Antenna core coil

Iron core coil

'File with a Ferrite Heart

Types of files according to their constant value:

Fixed-value files

Variable value files

Types of files in terms of frequencies they work on:

Low Frequency Files

Medium Frequency Coils

High Frequency Files

Self induction:

If the value of the current passing in the inductor changes as well as decreasing as with the alternating current, the value of the magnetic field resulting from the current is also increasing and decreasing. In this case, both ends of the inductor generate an effort to oppose the increase and decrease in the current passing in the inductor .This opposition to change has increased in value and this opposition characteristic is called "self-induction

The transverse voltage of a change is called an induced voltage, a derived voltage or a self-generated voltage .The self-induction of a file is measured in the unit of Henry or Milli Henry.

**Milli Henry is 10^{-3} Henry

Impedance inductor:

Impedance coil = 2 × i × frequency × inductance coil .I = 3.14 Increases self-induction of a file if:

1-Increased area and reduced length.

2-increased the number of his death.

3- .The coil had a core of magnetic material such as iron, iron powder or ferrite.

vice versa , Increases file impedance:

1- -Increase the frequency of the signal passing through the coil.

2- Increase inducted file.

3- -Both.

C**oefficient of electromagnetic correlation between** inductor The coefficient of magnetic correlation between two inductor is defined as the ratio between the actual value of mutual inductance between the inductors to the maximum possible value of this induction, and the maximum value of mutual inductance obtained in the case of ideal inductors when there is no loss of magnetic flux resulting from each of them ie when all the resulting magnetic flux From one file to the other file without loss. If we impose two coils with self-inductance coefficients L_1 & L_2, in practice, the resulting magnetic flux in the first inductor is not entirely related to the second inductor due to magnetic loss. If we assume that part of the magnetic flux in the first coil of K_1 will bind or affect the second coil and similarly K_2 is the part of the magnetic flux that affects the second inductor.

$$M^2 = K_1 K_2 L_1 L_2$$

If we assume that

$$K = K_1 = K_2$$

$$K^2 = K_1 K_2$$

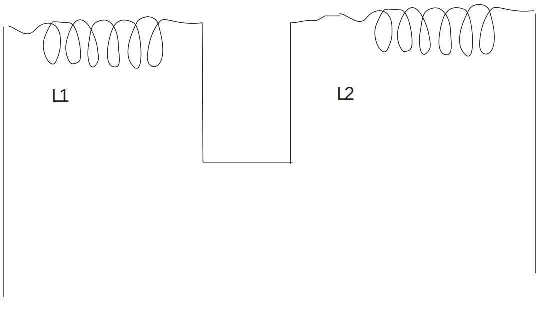
$$M^2 = K^2 L_1 L_2$$

$$K = M /(L_1L_2)^{-1/2} = \underline{M}$$

Since K is the electromagnetic correlation coefficient of the two coils, when K = unit is said to be completely magnetic, and when K = zero the inductors are said to be magnetically isolated.

Calculate the equivalent induction coefficient of a set of inductors

respectively conduction



In this case we will study two methods of connection

The first: When the inductors are connected to each other respectively so that the resulting electromagnetic driving force has the same direction

If we assume that the inductance coefficient between the two inductors M, L1 is the self-inductance coefficient of the first coil, L2 is the self-inductance coefficient of the second inductor.

The electrical impulse generated by the self-impact in the first file is

$$E_1 = -L_1 \frac{di}{dt} \quad \text{volt}$$

The electrical impulse generated by the mutual effect in the first inductor is

$$E_1 = -M \frac{di}{dt} \quad \text{volt}$$

The electrical impulse generated by the self-impact in the second inductor is

$$E_2 = -L_2 \frac{di}{dt} \quad \text{volt}$$

The electric impulse produced by the self-impact in the second inductor is the electrical impulse produced by the mutual effect in the second inductor is

$$E2 = -M \frac{di}{dt} \quad \text{volt}$$

The sum of the driving force is

$$E = -\frac{di}{dt}(L_1 + L_2 + 2M) \quad \text{volt}$$

The result of the group's equivalent induction is

$$L = L_1 + L_2 + 2M \quad \text{hennery}$$

<u>Second: when the inductors are connected in a row so that the resulting electromagnetic driving force is in opposite directions</u>

The electrical impulse generated by the self-impact in the first file is

$$E_1 = -L_1 \frac{di}{dt} \quad \text{volt}$$

The electrical impulse generated by the mutual effect in the first inductor is

$$E_1 = -M \frac{di}{dt} \quad \text{volt}$$

The electrical impulse generated by the self-impact in the second inductor is

$$E_2 = -L_2 \frac{di}{dt} \quad \text{volt}$$

The electric impulse produced by the self-impact in the second inductor is the electrical impulse produced by the mutual effect in the second inductor is

$$E2 = -M \frac{di}{dt} \quad \text{volt}$$

The sum of the driving force is

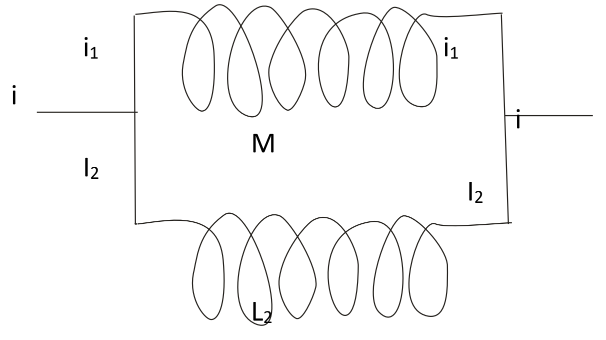
$$E = -\frac{di}{dt}\left(L_1 + L_2 - 2M\right) \quad \text{volt}$$

The result of the group's equivalent induction is

$$L = L_1 + L_2 - 2M \quad \text{hennery}$$

Parallel conduction

The following figure shows two inductors connected in parallel and their inductance coefficient is L_1, L_2 and their mutual inductance coefficient M .So if the total current passing in the group from the source is (i) the current passing in both coils is i_1, i_2



then

$$I = I_1 + I_2$$

The current rate of change of current is

$$\frac{dI}{dt} = \frac{dI_1}{dt} + \frac{dI_2}{dt}$$

As a result of the change in the circuit, each inductor produces an electrical impulse as a result of mutual self-induction. Since the inductors are connected in parallel, the electrical impulse between the two ends of the inductors is equal. This force of both inductors has the same direction.

$$E = L_1 \frac{dI_1}{dt} + M \frac{dI_2}{dt}$$

$$= L_2 \frac{dI_2}{dt} + M \frac{dI_1}{dt}$$

$$\frac{dI_1}{dt}(L_1 - M) = \frac{dI_2}{dt}(L_2 - M)$$

$$\frac{dI_1}{dt} = \frac{(L_2 - M)}{(L_1 - M)} \frac{dI_2}{dt}$$

Compensating in the equation, which represents the rate of time of the current change

$$\frac{dI}{dt} = \left(\frac{L2 - M}{L1 - M} + 1 \right) \frac{dI_2}{dt}$$

From the last two equations we get

$$-L \frac{dI}{dt} = L_1 \frac{dI_1}{dt} + M \frac{dI_2}{dt}$$

$$\frac{dI}{dt} = \frac{1}{L}\left(L_1 \frac{dI_1}{dt} + M \frac{dI_2}{dt} \right)$$

By substituting for the value of dI/ dt we get

$$\frac{dI}{dt} = \frac{1}{L}\left[L_1 \left(\frac{L_2 - M}{L_1 - M} \right) + M \right] \frac{dI_2}{dt}$$

$$\frac{1}{L}\left[L_1 \left(\frac{L_2 - M}{L_1 - M} \right) + M \right] \frac{dI_2}{dt} = \frac{dI_2}{dt}\left[\frac{L_2 - M}{L_1 - M} + 1 \right]$$

$$\left[\frac{L_2 - M}{L_1 - M} + 1 \right] = \frac{1}{L}\left(L_1 \frac{L_2 - M}{L_1 - M} + M \right)$$

$$\frac{L_1 + L_2 - 2M}{L_1 - M} = \frac{1}{L}\left(\frac{L_1 L_2 - M^2}{L_1 - M} \right)$$

Thus, when the overflow is the result of mutual induction in the same direction as the induced overflow

$$L = \left(\frac{L_1 L_2 - M^2}{L_1 + L_2 - 2M} \right)$$

When the overflow is the result of mutual induction, the opposite of the overflow is the result of self-induction

$$L = \left(\frac{L_1 L_2 - M^2}{L_1 + L_2 + 2M} \right)$$

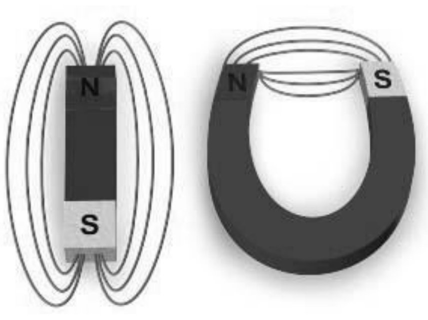
Effects of electric current

Magnetic effect of electric current

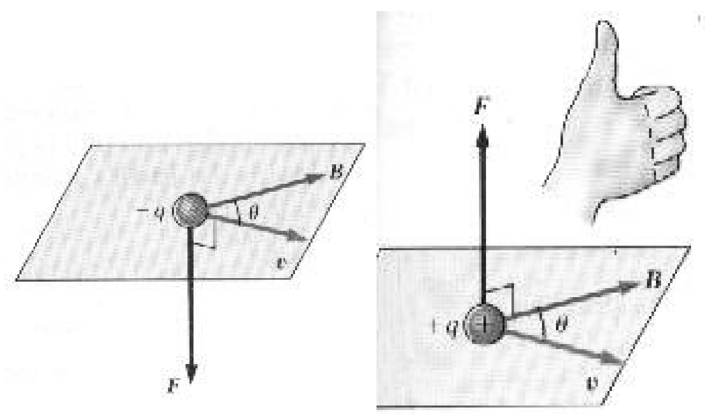
In 1820, the scientist Orested noted that if a current passed through a wire, a magnetic effect would emerge, represented by the deviation of a magnetic needle placed next to the wire and the science of magnetism.

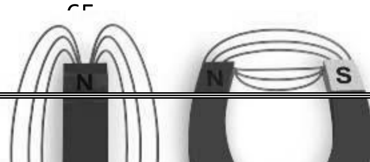
The area around a permanent magnet or conductor through which a current passes is known as a magnetic field. A field is a physical effect that takes different values in a vacuum. The basic vector in magnetic effects is called a magnetic induction vector and is symbolized by B.

The magnetic field can be represented by magnetic force lines so that the density of lines per unit area of a space element perpendicular to the direction of the power lines is the amount of magnetic field. The tangent direction of the power line at any point on it gives the direction of the magnetic field B at that point



The direction of the magnetic field is in the direction of the rotation of the auger rotating from v to B as in the following figure :The wire is the direction of the field and the magnetic force on the negative charge is the opposite of the magnetic force on the negative charge.





The unit of magnetic field B is Tesla and is denoted by T

The Tesla unit is a large unit and the Gaussian unit can be used in the Gaussian system of units where Tesla = 10^4 Gauss

المجال المغناطيسي

Magnetic Fields

Many historians of science believe that the compass, which uses a magnetic needle, was used in China as early as the 13th century BC, its invention being of Arabic or Indian origin. The early Greeks knew about magnetism as early as 800 BC. They discovered that the stone magnetite (Fe_3O_4) attracts pieces of iron. Legend ascribes the name magnetite to the shepherd Magnes, the nails of whose shoes and the tip of whose staff stuck fast to chunks of magnetite while he pastured his flocks.

In 1269, Pierre de Maricourt of France found that the directions of a needle near a spherical natural magnet formed lines that encircled the sphere and passed through two points diametrically opposite each other, which he called the poles of the magnet. Subsequent experiments showed that every magnet, regardless of its shape, has two poles, called north (N) and south (S) poles, that exert forces on other magnetic poles similar to the way electric charges exert forces on one another. That is, like poles (N–N or S–S) repel each other, and opposite poles (N–S) attract each other.

The poles received their names because of the way a magnet, such as that in a compass, behaves in the presence of the Earth's magnetic field. If a bar magnet is suspended from its midpoint and can swing freely in a horizontal plane, it will rotate until its north pole points to the Earth's geographic North Pole and its south pole points to the Earth's geographic South Pole.

In 1600, William Gilbert (1540–1603) extended de Maricourt's experiments to a variety of materials. He knew that a compass needle orients in preferred directions, so he suggested that the Earth itself is a large, permanent magnet. In 1750, experimenters used a torsion balance to show that magnetic poles exert attractive or repulsive forces on each other and that these forces vary as the inverse square of the distance between interacting poles. Although the force between two magnetic poles is otherwise similar to the force between two electric charges, electric charges can be isolated (witness the electron and proton), whereas a single magnetic pole has never been isolated. That is, magnetic poles are always found in pairs. All attempts thus far to detect an isolated magnetic pole have been unsuccessful. No matter how many times a permanent magnet is cut in two, each piece always has a north and a south pole

(هانز كريستيان اورستيد. Hans Christian Oersted فيزيائي وكيميائي دينماركي)
(1777 - 1851)

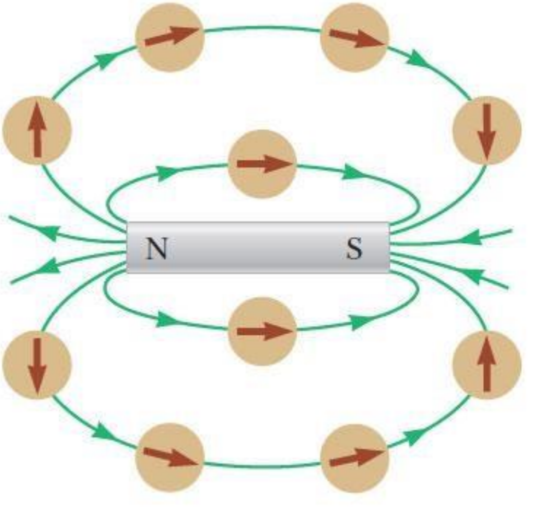
The relationship between magnetism and electricity was discovered in 1819 when, during a lecture demonstration, Hans Christian Oersted found that an electric current in a wire deflected a nearby compass needle.3 In the 1820s, further connections between electricity and magnetism were demonstrated independently by Faraday and Joseph Henry (1797–1878). They showed that an electric current can be produced in a circuit either by moving a magnet near the circuit or by changing the current in a nearby circuit. These observations demonstrate that a changing magnetic field creates an electric field. Years later, theoretical work by Maxwell showed that the reverse is also true: a changing electric field creates a magnetic field

Magnetic Fields and Forces

In our study of electricity, we described the interactions between charged objects in terms of electric fields. Recall that an electric field surrounds any electric charge. In addition to containing an electric field, the region of space surrounding any moving electric charge also contains a magnetic field. A magnetic field also surrounds a magnetic substance making up a permanent magnet.

Historically, the symbol $\vec{B}$ has been used to represent a magnetic field, and we use this notation in this book. The direction of the magnetic field $\vec{B}$ at any location is the direction in which a compass needle points at that location. As with the electric field, we can represent the magnetic field by means of drawings with magnetic field lines

Active Figure 29.1 shows how the magnetic field lines of a bar magnet can be traced with the aid of a compass. Notice that the magnetic field lines outside the magnet point away from the north pole and toward the south pole. One can display magnetic field patterns of a bar magnet using small iron filings as shown in Figure 29.2



Compass needles can be used to trace the magnetic field lines in the region outside a bar magnet.

We can define a magnetic field at some point in space in terms of the magnetic force that the field exerts on a charged particle moving with a velocity , which we call the test object. For the time being, let’s assume no electric or gravitational fields are present at the location of the test object. Experiments on various charged particles moving in a magnetic field give the following results:

■ The magnitude FB of the magnetic force exerted on the particle is proportional to the charge q and to the speed v of the p

■ When a charged particle moves parallel to the magnetic field vector, the magnetic force acting on the particle is zero.

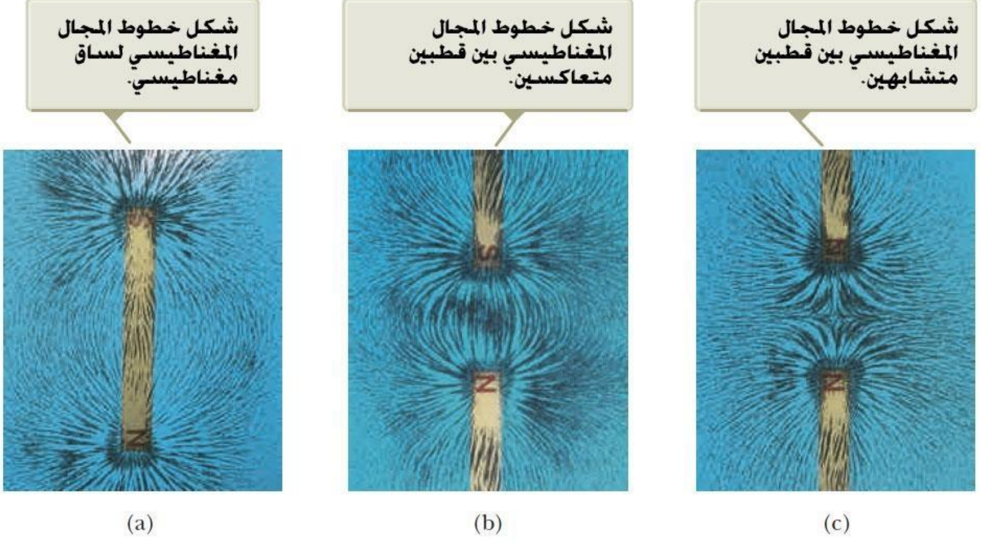
■ When the particle’s velocity vector makes any angle u 0 with the magnetic field, the magnetic force acts in a direction perpendicular to both and ; that is, is perpendicular to the plane formed by and (Fig. 29.3a).

■ The magnetic force exerted on a positive charge is in the direction opposite the direction of the magnetic force exerted on a negative charge moving in the same direction (Fig. 29.3b)

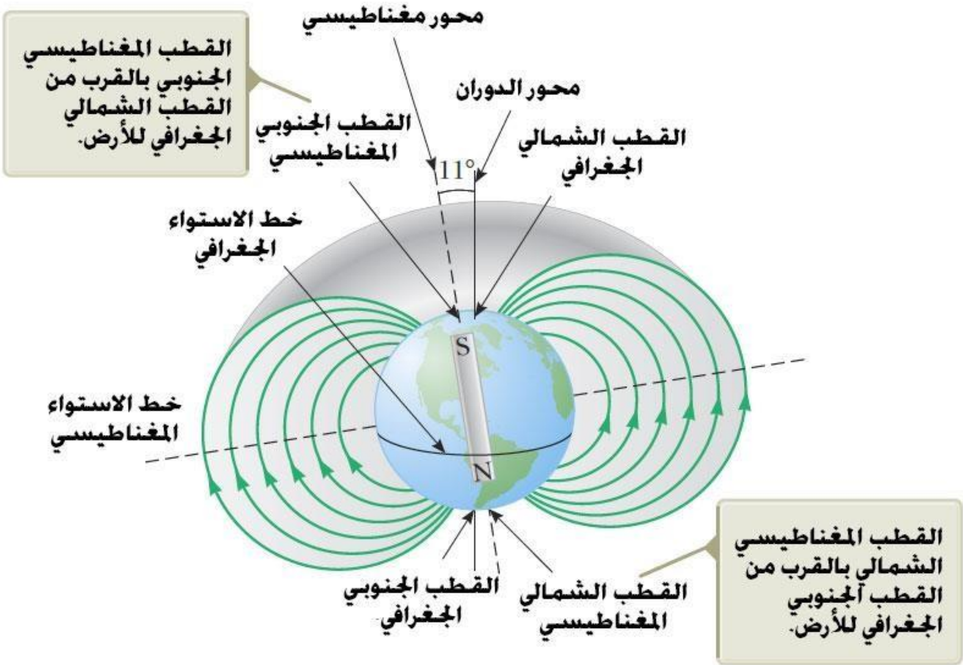
■ The magnitude of the magnetic force exerted on the moving particle is proportional to sin u, where u is the angle the particle’s velocity vector makes with the direction of . B

The Earth’s geographic North Pole is magnetically a south pole, whereas the Earth’s geographic South Pole is magnetically a north pole. Because opposite magnetic poles attract each other, the pole on a magnet that is attracted to the Earth’s geographic North Pole is the magnet’s north pole and the pole attracted to the Earth’s geographic South Pole is the magnet’s south pole. There is some theoretical basis for speculating that magnetic monopoles—isolated north or south poles—may exist in nature, and attempts to detect them are an active experimental field of investigation. The same discovery was reported in 1802 by an Italian jurist, Gian Domenico Romagnosi, but was overlooked, probably because it was published in an obscure journal.

Although the shape of Earth's magnetic field is exactly like that of a large leg inside the Earth, it is easy to understand why the source of this magnetic field is not a large mass of magnetic permanent material. There is a lot of iron ore in the ground, but the high temperature in the ground prevents the iron from retaining any permanent magnetism. Scientists considered that the source of the Earth's magnetic field is convection currents in the Earth's interior. Charged ions or electrons circulating in the liquid medium in the Earth's interior may produce a magnetic field just as an electric current loop does, as we will explain in the second chapter of this book.



الشكل 1.2 اشكال المجال المغناطيسي المختلفة تظهر بنشر برادة الحديد على ورقة فوق مغناطيس



الشكل 1.3 خطوط المجال المغناطيسي للكرة الأرضية

There is also strong evidence that the magnitude of a planet's magnetic field correlates with the rate at which the planet rotates around itself. For example, Jupiter rotates faster than Earth, and space probes have reported that Jupiter's magnetic field is stronger than Earth's. Venus is traveling at a slower speed than Earth and has been found to have a weaker magnetic field than Earth's. Research and studies are still being conducted on the origin of geomagnetism.

The direction of the Earth's magnetic field has reversed several times over millions of previous years. Basalt rocks form in the deep ocean under the influence of volcanic activity.As the temperature of the lava decreases, it hardens and maintains a picture of the direction of the Earth's magnetic field. Studies were conducted to estimate the ages of these rocks to obtain information about the timeline of reflections that occurred in the Earth's magnetic field.

We can define the magnetic field $\vec{B}$ at a specific point in vacuum in terms of the magnetic force exerted by the field on a charged particle moving at $\vec{v}$, which we call the test object. The numerous experiments conducted on charged and moving objects in a magnetic field gave the following diverse results:

Properties of the magnetic force on a charged particle moving in a magnetic field

• The magnitude of the *FB* magnetic force exerted on a particle is directly proportional to the charge q and the velocity of the particle *v*.

• When the charged particle moves parallel to the magnetic field vector, the magnetic force acting on the particle is zero.

• When the velocity vector of a particle makes any angle $\theta \neq 0$ with the magnetic field, the magnetic force acts in a perpendicular direction to both $\vec{v}$ and $\vec{B}$ as shown in Figure 4.1a.

• The magnetic force exerted on the positive charge is in the opposite direction to the direction of the magnetic force exerted on a negative charge moving in the same direction as shown in Figure 4.1 b.

• The magnitude of the magnetic force exerted on a moving particle is directly proportional to the sin Θ, where Θ is the angle that the particle's velocity vector makes with the direction.

We can summarize these observations by writing the magnetic force as

$$\vec{\boldsymbol{F}}_B = q\vec{\boldsymbol{v}} \times \vec{\boldsymbol{B}} \qquad (1.1)$$

This is the directional form of the magnetic force acting on a charged particle moving in a magnetic field.

The direction of the magnetic force is obtained by the properties of the cross-way product and is perpendicular to both $\vec{B}$ $\vec{v}$. This equation can be thought of as a procedural definition (i.e. obtained by experiments) of a magnetic field at a specific point in a vacuum. This means that the magnetic field is defined as the force acting on a moving charged particle.

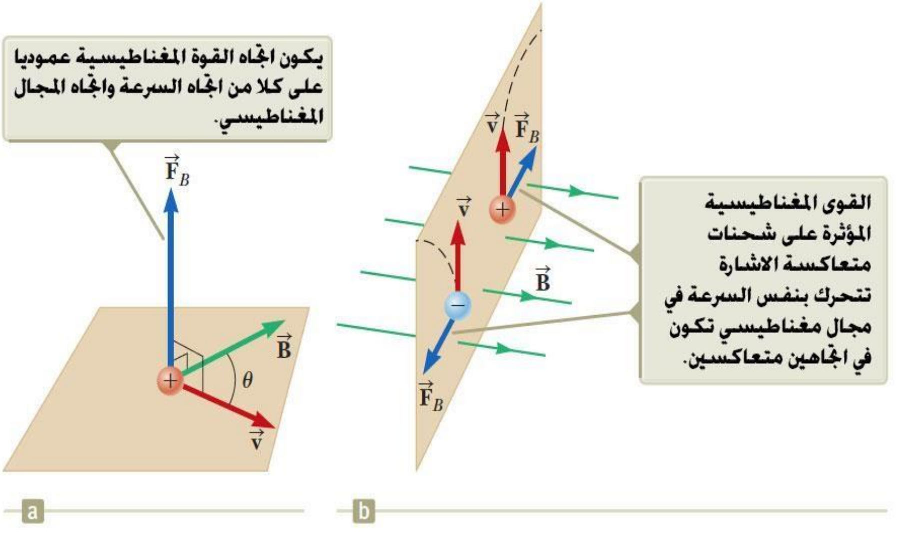


Figure 29.3 The direction of the magnetic force $\vec{F}_B$ acting on a charged particle moving with a velocity $\boldsymbol{v}$ in the presence of a magnetic field $\vec{B}$. (a) The magnetic force is perpendicular to both and . (b) Oppositely directed magnetic forces are exerted on two oppositely charged particles moving at the same velocity in a magnetic field. The dashed lines show the paths of the particles, which are investigated in Section 29.

We can summarize these observations by writing the magnetic force in the form (29.1) which by definition of the cross product (see Section 11.1) is perpendicular to both and . We can regard this equation as an operational definition of the magnetic field at some point in space. That is, the magnetic field is defined in terms of the force acting on a moving charged particle

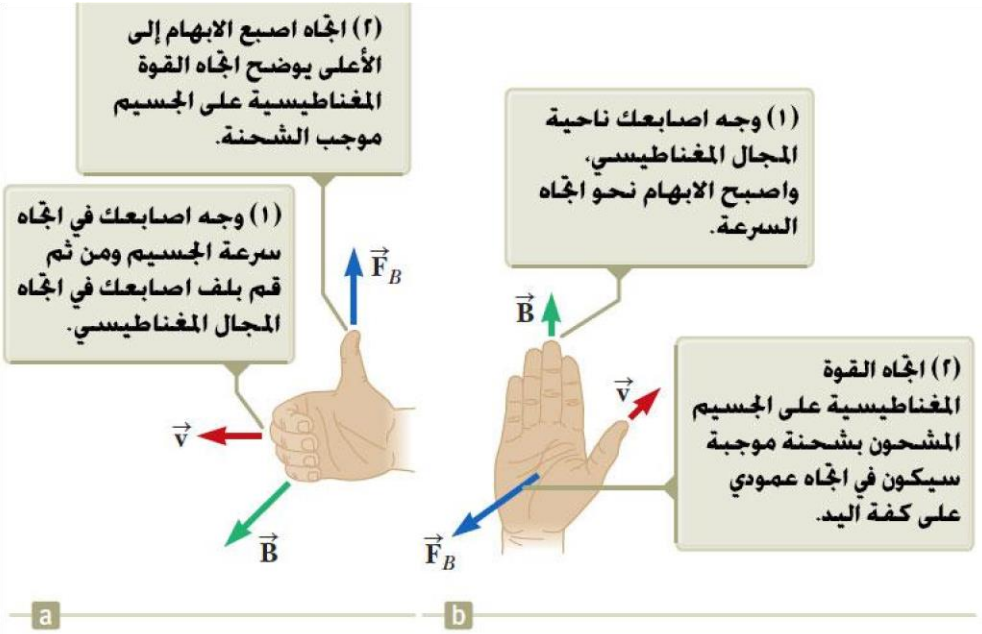
$$\vec{F}_B \quad \vec{F}_B = q\vec{v} \times \vec{B}$$

Figure 29.4 reviews two right-hand rules for determining the direction of the cross $\vec{B}$ product $\vec{F}_B$ and determining the direction of $\vec{v} \times \vec{B}$. The rule in Figure 29.4a depends on our right-hand rule for the cross product in Figure 11.2. Point the four fingers of your right hand along the direction of with the palm facing and curl them toward . Your extended thumb, which is at a right angle to your fingers, points in the direction of . Because , is in the direction of your thumb if q is positive and is opposite the direction of your thumb if q is negative. (If you need more help understanding the cross product, you should review Section 11.1, including Fig. 11.2.)

Figure 29.4 reviews two right-hand rules for determining the direction of the cross product and determining the direction of $\vec{v}$. The rule in Figure 29.4a depends on our right-hand rule for the cross product in Figure 11.2. Point the four fingers of your right hand along the direction of with the palm facing and curl them toward $\vec{B}$. Your extended thumb, which is at a right angle to your fingers, points in the direction of . Because , is in the direction of your thumb if q is positive and is opposite the direction of your thumb if q is negative. (If you need more help understanding the cross product, you should review Section 11.1, including Fig. 11.2.)

where the angle θ is the smallest angle between $\vec{B}$ $\vec{v}$. From this equation we see that the force FB is equal to zero when it is parallel or in the opposite direction (when θ is equal to zero or ^{o}180) and its maximum value when it is perpendicular to (when ^{o}90 = θ).

$$F_B = |q| vB \sin\theta \qquad (1.2)$$



الشكل 1.5 قاعدتين لليد اليمنى لتحديد اتجاه القوة المغناطيسية $\vec{F}_B = q\vec{v} \times \vec{B}$ المؤثرة على جسيم يحمل شحنة q ويتحرك بسرعة $\vec{v}$ في مجال مغناطيسي $\vec{B}$. (a) في هذه القاعدة يكون اتجاه القوة المغناطيسية في اتجاه اصبع الابهام. (b) في هذه القاعدة يكون اتجاه القوة المغناطيسية في تجاه الكف كما لو كنت تدفع جسيم بيدك.

Basic differences between electric and magnetic force

• The electric force vector is in the direction of the electric field lines, while the magnetic force vector is perpendicular to the magnetic field.

• The electric force acts on the charged particle regardless of whether the particle is stationary or moving, while the magnetic force acts on the charged particle only when it is moving.

• The electric force does work in displacing the charged particle, while the magnetic force associated with a stable magnetic field does not do work when the particle moves because the magnetic force is perpendicular to the direction of displacement.

From the last sentence and from the theory of kinetic energy and work, we conclude that the kinetic energy of a charged particle moving through a magnetic field cannot be changed by a magnetic field alone. The field changes the direction of the velocity vector but does not change the speed or kinetic energy of the particle.

From equation 2.1, we conclude that the unit of magnetic field is newtons per coulomb in meters per second, and this unit is known as tesla and is denoted by the symbol T:

$$1\,\mathrm{T} = 1\,\frac{\mathrm{N}}{\mathrm{C.\,m/s}}$$

where the coulomb per second is the ampere

$$1\,\mathrm{T} = 1\,\frac{\mathrm{N}}{\mathrm{A.\,m}}$$

Another unit of magnetic field, gauss, denoted by G, is related to the tesla unit by the relation 1 T = 104 G. Table 1.1 shows some magnetic field values for different sources.

Motion of a Charged Particle in a Uniform Magnetic Field

Before we continue our discussion we will provide an explanation of the symbols used in this book. We will sometimes use dimensions to indicate the direction of the triple magnetic field B⃗B⃗ as shown in Figure 6.1. If the magnetic field ⃗B⃗ is located at the page level or perpendicular to the page plane, we will use green vectors or green field lines with arrowheads showing the direction of the field. If the illustration uses only two dimensions, we draw the vertical magnetic field coming out of the page as green dots, and these represent the arrowheads coming out of the page in the direction of your vision as shown in Figure 7.1a. In this case, we refer to the magnetic field as $B^{\rightarrow}$ out$^{\rightarrow}$. If the magnetic field $^{\rightarrow}B^{\rightarrow}$ is perpendicular to the page and in the direction of entry to it, we use green × hit signals.

which represents the tail of the arrows moving away from you as shown in Figure 7.1 b in which case the magnetic field is denoted by $B^{\rightarrow}$ in$^{\rightarrow}$. This same notation is used for any other physical quantity that may be perpendicular to the page, such as the direction of force or the direction of current.

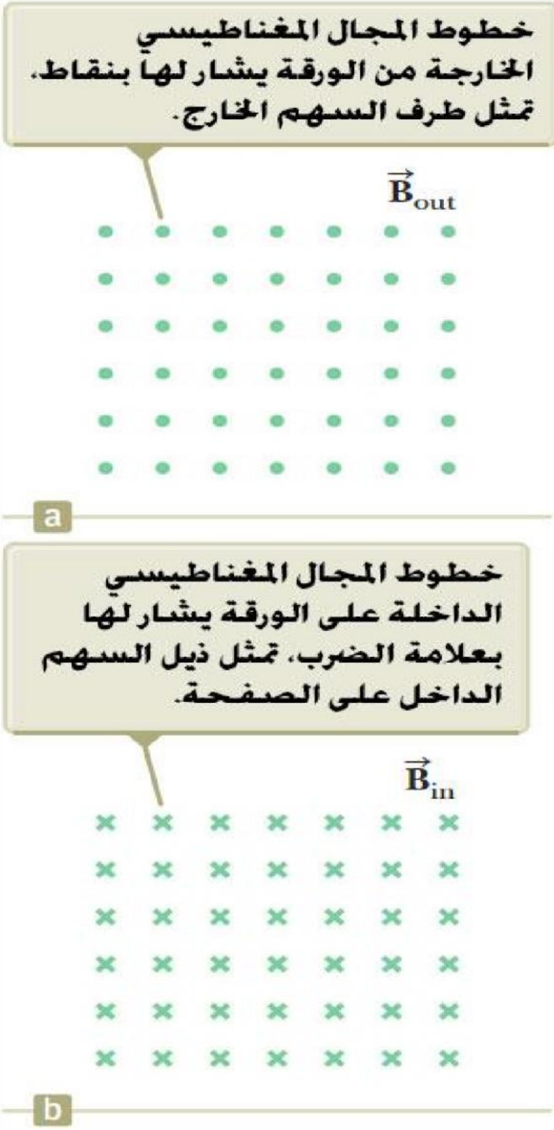
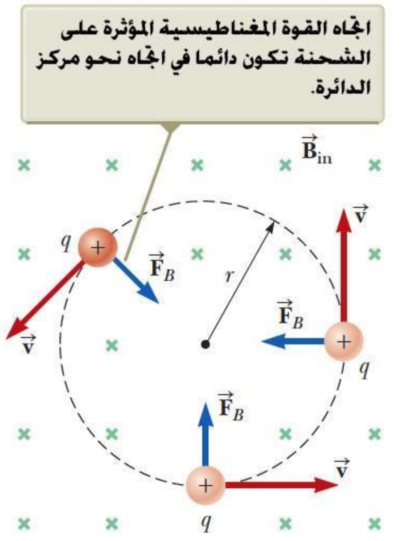


Figure 7.1 Representation of magnetic field lines perpendicular to the page.



When the velocity of a charged particle is perpendicular to a uniform magnetic field, the particle moves in a circular path in a plane perpendicular to $\vec{B}$. The magnetic force acting on the charge is always directed toward the center of the circle

In Chapter 1.1, we found that the work done by a magnetic force on a charged particle moving in a magnetic field perpendicular to the particle's velocity is zero. Now suppose a special case of a positively charged particle moving in a magnetic field with an initial velocity perpendicular to the magnetic field. Suppose that the direction of the magnetic field is perpendicular to the page and in the direction of entry on it as shown in Figure 1.8.As the particle changes the direction of its velocity in response to the magnetic force, the magnetic force remains perpendicular to the speed as shown in Figure 1.A particle moving in a circular path in a plane perpendicular to the magnetic field. Although magnetism and magnetic forces may be new.

The particle moves in a circle because the magnetic force $\vec{F}_B$ is perpendicular to and $\vec{B}$ and v has a constant magnitude qvB. As Active Figure 29.7 illustrates, the rotation is counterclockwise for a positive charge in a magnetic field directed into the page. If q were negative, the rotation would be clockwise. We use the particle under a net force model to write Newton's second law for the particle:

$$\sum F = F_B = ma$$

Because the particle moves in a circle, we also model it as a particle in uniform circular motion and we replace the acceleration with centripetal acceleration:

$$F_B = qvB = \frac{mv^2}{r}$$

This expression leads to the following equation for the radius of the circular path

$$r = \frac{mv}{qB} \qquad (1.3)$$

That is, the radius of the path is proportional to the linear momentum *mv* of the particle and inversely proportional to the magnitude of the charge on the particle and to the magnitude of the magnetic field. The angular speed of the particle (from Eq. 10.10) is

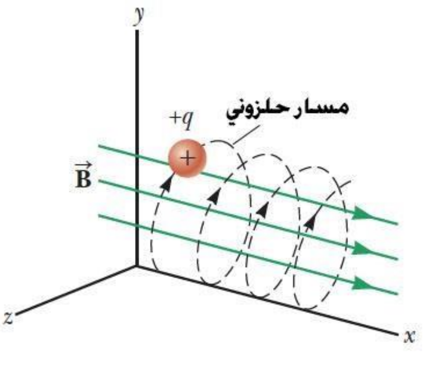
$$\omega = \frac{v}{r} = \frac{qB}{m} \qquad (1.4)$$

The period of the motion (the time interval the particle requires to complete one revolution) is equal to the circumference of the circle divided by the speed of the particle:

$$T = \frac{2\pi r}{v} = \frac{2\pi}{\omega} = \frac{2\pi m}{qB} \qquad (1.5)$$

These results show that the angular speed of the particle and the period of the circular motion do not depend on the speed of the particle or on the radius of the orbit. The angular speed v is often referred to as the cyclotron frequency because charged particles circulate at this angular frequency in the type of accelerator called a cyclotron, which is discussed in Section 29.3.

If a charged particle moves in a uniform magnetic field with its velocity at some arbitrary angle with respect to $\vec{B}$, its path is a helix. For



example, if the field is directed in the x direction as shown in Active Figure 29.8, there is no component of force in the x direction. As a result, ax = 0, and the x component of velocity remains constant. The magnetic force causes the components vy and vz to change in time, however, and the resulting motion is a helix whose axis is parallel to the magnetic field. The projection of the path onto the yz plane (viewed along the x axis) is a circle. (The projections of the path onto the xy and xz planes are sinusoids!) Equations 29.3 to 29.5 still apply provided v is replaced b

$$v_{\perp} = \sqrt{v_y{}^2 + v_z{}^2}$$

Example: A Proton Moving Perpendicular to a Uniform Magnetic Field

A proton is moving in a circular orbit of radius 14 cm in a uniform 0.35-T magnetic field perpendicular to the velocity of the proton. Fi

SOLUTION

Conceptualize From our discussion in this section, we know that the proton follows a circular path when moving in a uniform magnetic field.

Categorize We evaluate the speed of the proton using an equation developed in this section, so we categorize this example as a substitution problem.

solve Equation 29.3 for the speed of the particle:

$$v = \frac{qBr}{m_P}$$

Substitute numerical value

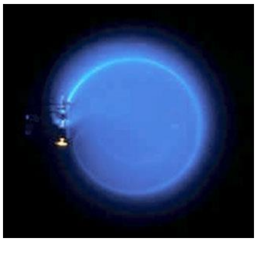
$$v = \frac{(1.60 \times 10^{-19} C)(0.35T)(0.14m)}{1.67 \times 10^{-27} kg}$$

$$= 4.7 \times 10^{6} m/s$$

Example: Bending an Electron Beam

In an experiment designed to measure the magnitude of a uniform magnetic field, electrons are accelerated from rest through a potential difference of 350 V and then enter a uniform magnetic field that is perpendicular to the velocity vector of the electrons. The electrons travel along a curved path because of the magnetic force exerted on them, and the radius of the path is measured to be 7.5 cm. (Such a curved beam of electrons is shown in Fig. 29.9.)

(A) What is the magnitude of the magnetic field?



SOLUTION

Conceptualize With the help of Figures 29.7 and 29.9, visualize the circular motion of the electrons.

Categorize This example involves electrons accelerating from rest due to an electric force and then moving in a circular path due to a magnetic force. Equation 29.3 shows that we need the speed v of the electron to find the magnetic field magnitude, and v is not given. Consequently, we must find the speed of the electron based on the potential difference through which it is accelerated. To do so, we categorize the first part of the problem by modeling an electron and the electric field as an isolated system. Once the electron enters the magnetic field, we categorize the second part of the problem as one similar to those we have studied in this section.

Analyze Write the appropriate reduction of the conservation of energy equation, Equation 8.2, for the electron–electric field system

$$\Delta K + \Delta U = 0$$

Substitute the appropriate initial and final energies:

$$(1/2\ m_e v^2 - 0) + (q\Delta V) = 0$$

Solve for the speed of the electron

$$v = \sqrt{\frac{-2q\Delta V}{m_e}}$$

Substitute numerical values

$$v = \sqrt{\frac{-2(-1.60 \times 10^{-19}\text{C})(350\text{V})}{9.11 \times 10^{-31}\text{kg}}} = 1.11 \times 10^{7}\text{m/s}$$

Now imagine the electron entering the magnetic field with this speed. Solve Equation 29.3 for the magnitude of the magnetic field.

$$B = \frac{m_e v}{er}$$

Substitute numerical values:

$$B = \frac{(9.11 \times 10^{-31}\text{kg})(1.11 \times 10^{7}\text{m/s})}{(1.60 \times 10^{-19}\text{C})(0.075\text{m})} = 8.4 \times 10^{-4}\text{T}$$

(B) What is the angular speed of the electrons?

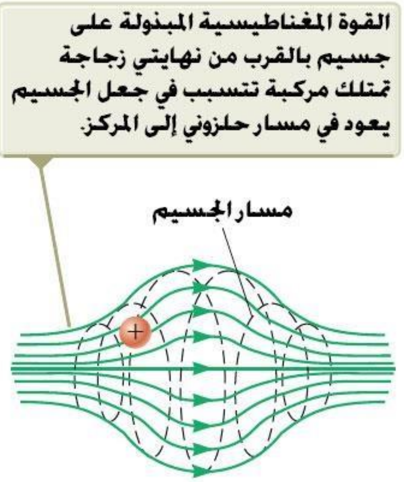
SOLUTION

Use Equation 10.10

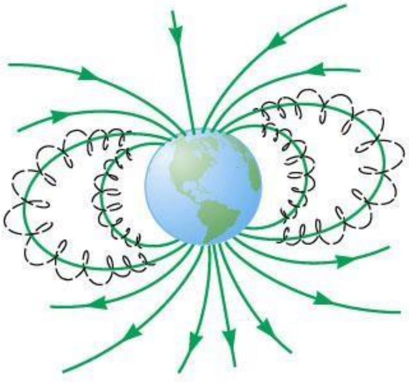
$$\omega = \frac{v}{r} = \frac{1.11 \times 10^{7}\text{m/s}}{0.075\text{m}} = 1.5 \times 10^{8}\text{rad/s}$$

Finalize The angular speed can be represented as $\omega = (1.5 \times 10^{8}$ rad/s)(1 rev/2π rad) $= 2.4 \times 10^{7}$ rev/s. The electrons travel around the circle 24 million times per second! This answer is consistent with the very high speed found in part (A).

When charged particles move in a nonuniform magnetic field, the motion is complex. For example, in a magnetic field that is strong at the ends and weak in the middle such as that shown in Figure 29.10, the particles can oscillate between two positions. A charged particle starting at one end spirals along the field lines until it reaches the other end, where it reverses its path and spirals back. This configuration is known as a magnetic bottle because charged particles can be trapped within it. The magnetic bottle has been used to confine a plasma, a gas consisting of ions and electrons. Such a plasma-confinement scheme could fulfill a crucial role in the control of nuclear fusion, a process that could supply us in the future with an almost endless source of energy. Unfortunately, the magnetic bottle has its problems. If a large number of particles are trapped, collisions between them cause the particles to eventually leak from the system



The Van Allen radiation belts consist of charged particles (mostly electrons and protons) surrounding the Earth in doughnut-shaped regions (Fig. 29.11). The particles, trapped by the Earth’s nonuniform magnetic field, spiral around the field lines from pole to pole, covering the distance in only a few seconds. These particles originate mainly from the Sun, but some come from stars and other heavenly objects. For this reason, the particles are called cosmic rays. Most cosmic rays are deflected by the Earth's magnetic field and never reach the atmosphere. Some of the particles become trapped, however, and it is these particles that make up the Van Allen belts. When the particles are located over the poles, they sometimes collide with atoms in the atmosphere, causing the atoms to emit visible light. Such collisions are the origin of the beautiful Aurora Borealis, or Northern Lights, in the northern hemisphere and the Aurora Australis in the southern hemisphere. Auroras are usually confined to the polar regions because the Van Allen belts are nearest the Earth's surface there. Occasionally, though, solar activity causes larger numbers of charged particles to enter the belts and significantly distort the normal magnetic field lines associated with the Earth. In these situations, an aurora can sometimes be seen at lower latitudes



The Van Allen belts are made up of charged particles trapped by the Earth's nonuniform magnetic field. The magnetic field lines are in green, and the particle paths are in brown.