Ministry of Higher Education and Scientific Research

Al-Ma’moun University College

كليـة المـأمون الجامعـة

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General Physics

Lecture (2)

Electricity & Magnetism

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Introduction

You are surrounded by devices that depend on the physics of electromagnetism, which is the combination of electric and magnetic phenomena. This physics is at the root of computers, television, radio, telecommunications, household lighting, and even the ability of food wrap to cling to a container.

of electromagnetism was first studied by the early Greek philosophers, who discovered that if a piece of amber is rubbed and then brought near bits of straw, the straw will jump to the amber. We now know that the attraction between amber and straw is due to an electric force. The Greek philosophers also discovered that if a certain type of stone (a naturally occurring magnet) is brought near bits of iron, the iron will jump to the stone. We now know that the attraction between magnet and iron is due to a magnetic force.

The new science of electromagnetism was developed further by workers in many countries. One of the best was Michael Faraday, a truly gifted experimenter with a talent for physical intuition and visualization. In the mid-nineteenth century, James Clerk Maxwell put Faraday's ideas into mathematical form, introduced many new ideas of his own, and put electromagnetism on a sound theoretical basis.

Electric Charge

.After rubbing a glass rod with a silk cloth (on a day when the humidity is low), we hang the rod using a thread tied around its center (Fig. l*a*). Then we rub a second glass rod with the silk cloth and bring it near the hanging rod. The hanging rod magically moves away. We can see that a force repels it from the second rod, but how? There is no contact with that rod, no breeze to push on it, and no sound wave to disturb it.

In the second demonstration, we replace the second rod with a plastic rod that has been rubbed with fur. This time, the hanging rod moves toward the nearby rod (Fig. 1*b*). Like the repulsion, this attraction occurs without any contact or obvious communication between the rods

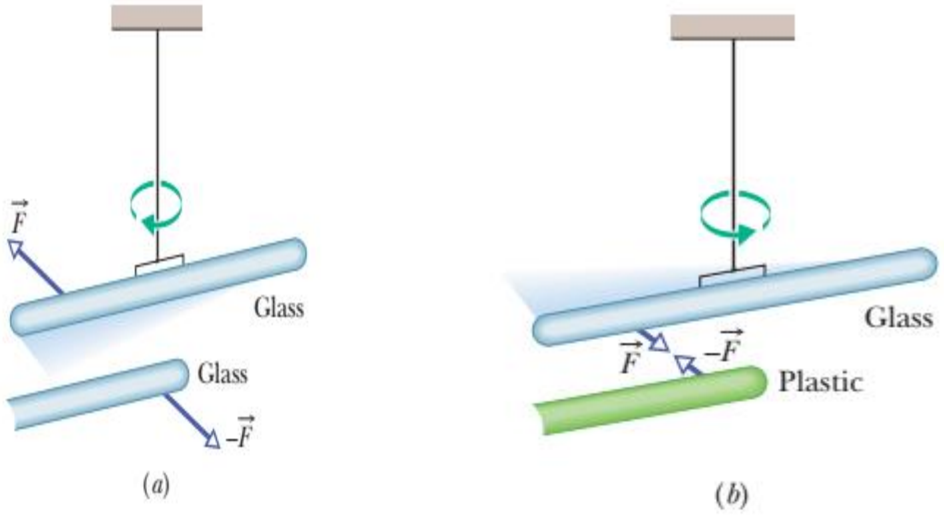


Fig (1): static electric charge

Particles with the same sign of electrical charge repel each other, and particles with opposite signs attract each other.
In a moment we shall put this rule into quantitative form as Coulomb's law of *electrostatic force* (or *electric force*) between charged particles. The term *electrostatic* is used to emphasize that, relative to each other, the charges are either stationary or moving only very slowly.

Conductors and Insulators

We can classify materials generally according to the ability of charge to move through them. **Conductors** are materials through which charge can move rather freely; examples include metals (such as copper in common lamp wire), the human body, and tap water. **Nonconductors**—also called **insulators**—are materials through which charge cannot move freely; examples include rubber (such as the insulation on common lamp wire), plastic, glass, and chemically pure water. **Semiconductors** are materials that are intermediate between conductors and insulators; examples include silicon and germanium in computer chips. **Superconductors** are materials that are *perfect* conductors, allowing charge to move without *any* hindrance.

Conductors

A material that allows electricity to flow through it easily.

Insulators

A material in which electric current does not flow freely

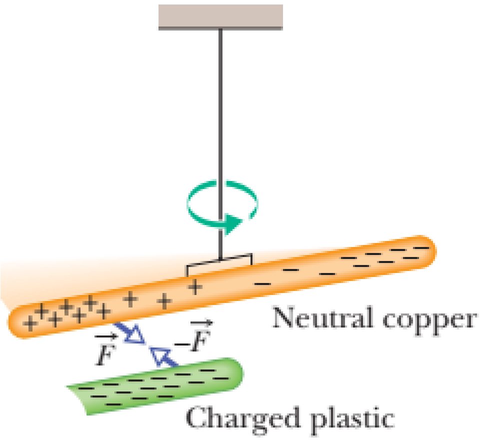
Semiconductors

Semiconductor is a material that has electrical conductivity value falling between that of a conductor and an insulator.

Superconductors

Are materials have a set of physical properties where electrical resistance vanishes and magnetic fields are expelled from the material

***Induced Charge*.** The experiment of Fig. (2) demonstrates the mobility of charge in a conductor. A negatively charged plastic rod will attract either end of an isolated neutral copper rod. What happens is that many of the conduction electrons in the closer end of the copper rod are repelled by the negative charge on the plastic rod. Some of the conduction electrons move to the far end of the copper rod, leaving the near end depleted in electrons and thus with an unbalanced positive charge. This positive charge is attracted to the negative charge in the plastic rod. Although the copper rod is still neutral, it is said to have an *induced charge*, which means that some of its positive and negative charges have been separated due to the presence of a nearby charge.
Similarly, if a positively charged glass rod is brought near one end of a neutral copper rod, induced charge is again set up in the neutral copper rod but now the near end gains conduction electrons, becomes negatively charged, and is attracted to the glass rod, while the far end is positively charged.
Neutral copper



Similarly, if a positively charged glass rod is brought near one end of a neutral copper rod, induced charge is again set up in the neutral copper rod but now the near end gains conduction electrons, becomes negatively charged, and is attracted to the glass rod, while the far end is positively charged

Electric Fields

The interaction between electric charges at rest is called the electrostatic force. However, unlike mass in gravitational force, there are two types of electric charge: positive and negative. Electrostatic force between charges falls off as the inverse square of their distance of separation, and can be either attractive or repulsive. Electric charges exert forces on each other in a manner that is analogous to gravitation. Consider an object which has charge Q . A "test charge" that is placed at a point P a distance r from Q will experience a Coulomb force:

$$\vec{\mathbf{F}}_e = k_e \frac{Qq}{r^2}\hat{\mathbf{r}} \qquad \text{--------------(1)}$$

Where $\boldsymbol{r}\hat{}$ is the unit vector that points from Q to $\boldsymbol{q}$. The constant of proportionality is called the Coulomb constant. The electric field at $\widehat{K} = 9.0 \times 10^{9}\, N.m^{2} / C^{2}.$ *The electric field at* P is defines as:

$$\vec{\mathbf{E}} = \lim_{q\to 0}\frac{\vec{\mathbf{F}}_e}{q} = k_e \frac{Q}{r^2}\hat{\mathbf{r}} \qquad \text{----------------(2)}$$

The SI unit of electric field is newton / Columb (NlC). If Q is positive, its electric field points radially away from the charge; on the other hand, the field points radially inward if Q is negative (Figure 3). In terms of the field concept, we may say that the charge Q creates an electric field $\widehat{\boldsymbol{E}}$ which exerts a force $\widehat{F}_e = q\widehat{E}$ on q.

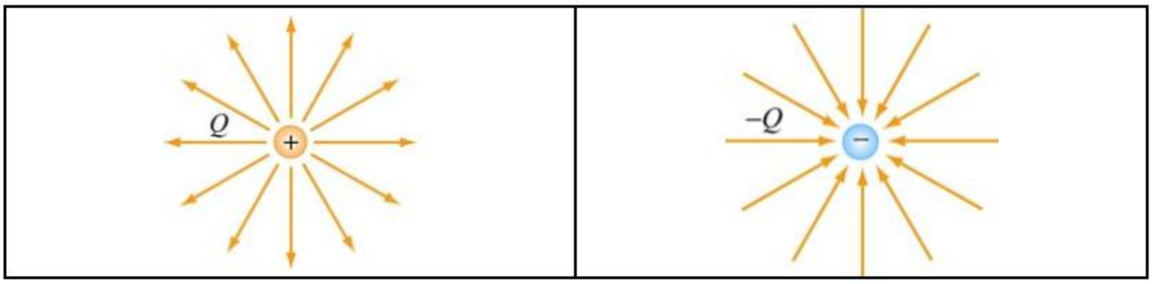


Figure (3) Electric field for positive and negative charges

Coulomb's Law

Coulomb's law after Charles-Augustin de Coulomb, whose experiments in 1785 led him to it. Let's write the equation in vector form and in terms of the particles shown in Fig. 4, where particle 1 has charge q_1 and particle 2 has charge q_2. (These symbols can represent either positive or negative charge.) Let's also focus on particle 1 and write the force acting on it in terms of a unit vector that points $\hat{r}$ along a radial axis extending through the two particles, radially away from particle 2

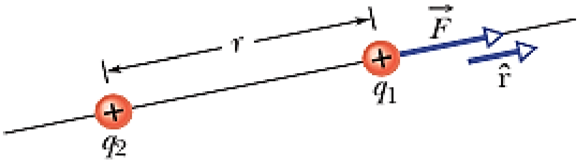


Figure (4): forces between charges

We write the electrostatic force as

$$\vec{F} = k\frac{q_1 q_2}{r^2}\hat{\mathrm{r}} \qquad \text{(Coulomb's law),}$$

------------(3)

Where r is the separation between the particles and k is a positive constant called the *electrostatic constant* or the *Coulomb constant*.
Let's first check the direction of the force on particle 1 as given by Eq. (3). If q_1 and q_2 have the same sign, then the product $q_1 q_2$ gives us a positive result. So, Eq. (3), tells us that the force on particle 1 is in the direction of. That checks, because particle 1 is being repelled from particle 2. Next, if q_1 and q_2 have opposite signs, the product $q_1 q_2$ gives us a negative result. So, now Eq.(3), tells us that the force on particle 1 is in the direction opposite. That checks because particle 1 is being attracted toward particle 2.
An Aside. Here is something that is very curious. The form of Eq. (3), is the same as that of Newton's equation (Eq. 4) for the gravitational force between two particles with masses m_1 and m_2 and separation r:

$$\vec{F} = G\frac{m_1 m_2}{r^2}\hat{\mathrm{r}} \qquad \text{(Newton's law),}$$

----(4)

Where G is the gravitational constant. Although the two types of forces are wildly different, both equations describe inverse square laws (the $1/r^2$ dependences) that involve a product of a property of the interacting particles—the charge in one case and the mass in the other. However, the laws differ in that gravitational forces are always attractive but electrostatic forces may be either attractive or repulsive, depending on the signs of the charges. This difference arises from the fact that there is only one type of mass but two types of charge.

Unit. The SI unit of charge is the **coulomb**. For practical reasons having to do with the accuracy of measurements, the coulomb unit is derived from the SI unit ***ampere*** for electric current ***I.*** Note that current I is the rate dq/dt at which charge moves past a point or through a region:

$$I = \frac{dq}{dt} \quad (electric\ current)\text{-------(5)}$$

Rearranging Eq. 3 and replacing the symbols with their units (coulombs **C**, amperes **A**, and seconds **s**) we see that

$$1\,\mathrm{C} = (1\,\mathrm{A})(1\,\mathrm{s}). \qquad \text{---(6)}$$

Force Magnitude

The electrostatic constant k in equation 2 is often writen as $^1/_{4\pi\epsilon_o}$. Then the magnitude of the electrostatic force in Columb’s law becomes

$$F = \frac{1}{4\pi\epsilon_o}\frac{|q_1||q_2|}{r^2} \quad \text{(coulomb's law)----(7)}$$

The constant in equation (1) and (4), have the value

$$k = \frac{1}{4\pi\epsilon_o} = 8.99 \times 10^9\ N.m^2/C^2\text{----(8)}$$

The quantity ϵ_o. Called the permetivity constant, sometimes appears separately in equations and is:

$$\epsilon_o = 8.85 \times 10^{-12}\ {^{C^2}}/_{N}.m^2\text{------(9)}$$

Magnetic Field

Magnetic field is another example of a vector field. The most familiar source of magnetic fields is a bar magnet. One end of the bar magnet is called the North pole and the other, the South pole. Like poles repel while opposite poles attract

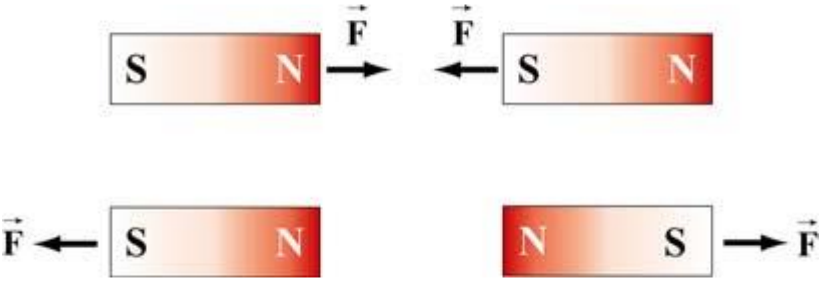


Figure 4 Magnets attracting and repelling

If we place some compasses near a bar magnet, the needles will align themselves along the direction of the magnetic field, as shown in Figure 5

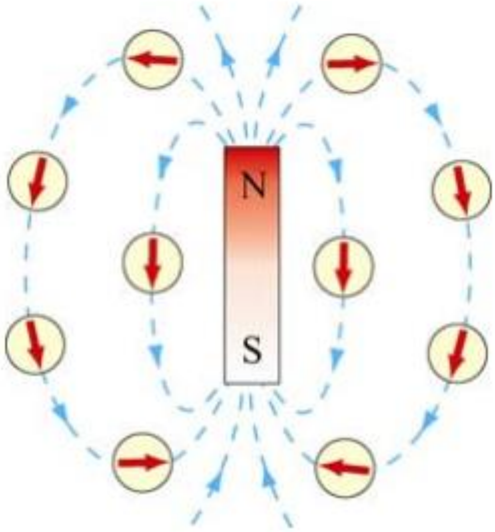


Figure 5 Magnetic field of a bar magnet

The observation can be explained as follows: A magnetic compass consists of a tiny bar magnet that can rotate freely about a pivot point passing through the center of the magnet. When a compass is placed near a bar magnet which produces an external magnetic field, it experiences a torque which tends to align the north pole of the compass with the external magnetic field.

The Earth's magnetic field behaves as if there were a bar magnet in it Figure 6. Note that the south pole of the magnet is located in the northern hemisphere.

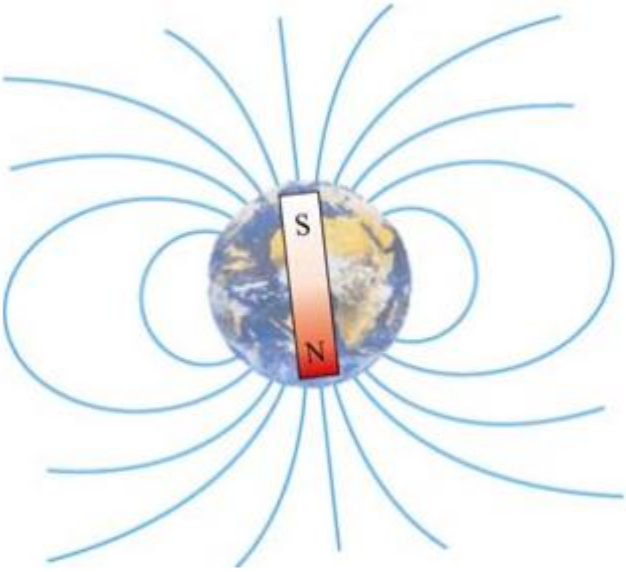
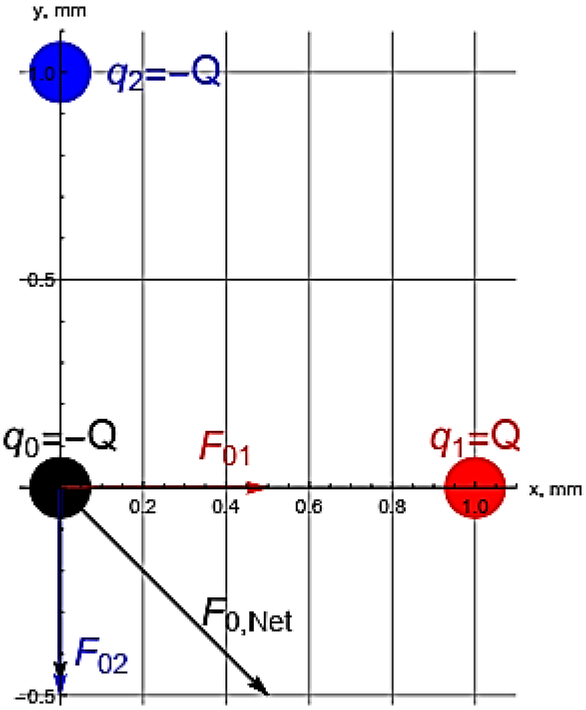


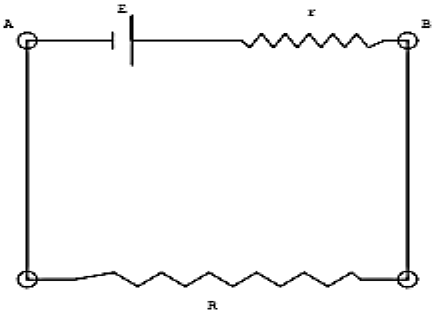
Figure (6) Magnetic field of the Earth

Example: $Q = 2\,\mu C$, $a = 1\,mm$. Find the force on the charge at the origin.



$$F_0 = \sqrt{F_{01}^2 + F_{02}^2} = \sqrt{2}\cdot F_{01}$$

$$F_{01} = k\frac{Q^2}{a^2} \approx 9\cdot 10^9\left(2\cdot 10^{-6}\right)^2/(10^{-3})^2 = 3.6\cdot 10^4\,N\,,\;\; F_0 = \sqrt{2}\times 3.6\cdot 10^4 = \dots$$



The real battery. R is the external load . The voltage on the terminals A and B is smaller than ε

Voltage on the terminals

$$V_{AB} = iR = \frac{\mathcal{E}}{r+R}R = \mathcal{E}\frac{R}{R+r} < \mathcal{E}$$

Note that $V_{AB} = \mathcal{E}$ only for $R \to \infty$, i.e for an open circuit.

$$V_B = V_A - I_1 R_1 + \mathcal{E}_1 + I_2 R_2 - \mathcal{E}_2$$

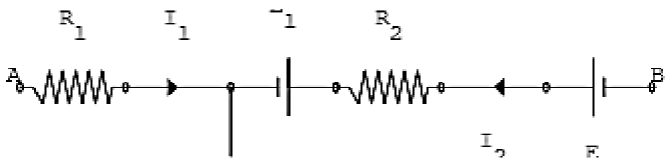
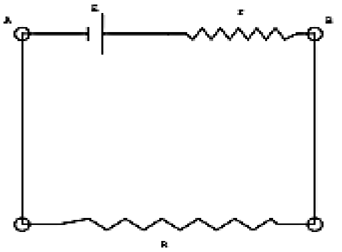


FIG. 32: The potential method

For a closed loop, $V_B = V_A$ and the total potential drop is zero. This is the *loop rule*.

Example. Real battery revisited.

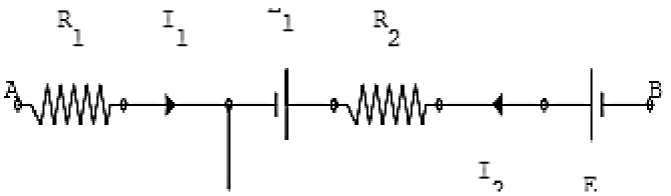


The real battery. R is the external load, r is the internal resistance. Find the voltage between the terminals A and B.

$$\text{start from A: } \mathcal{E} - Ir - IR = 0 \Rightarrow I = \frac{\mathcal{E}}{R+r}, \; V_{AB} = V_R = IR = \mathcal{E}\frac{R}{R+r}$$

$$\text{equivalently: } V_B = V_A + \mathcal{E} - Ir = V_A + \mathcal{E}\frac{R}{R+r}$$

$$V_B = V_A - I_1 R_1 + \mathcal{E}_1 + I_2 R_2 - \mathcal{E}_2$$



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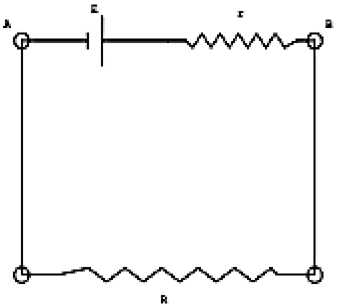

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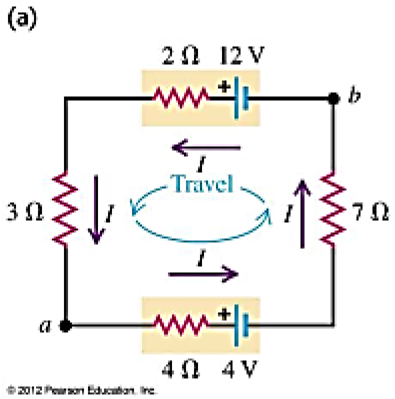
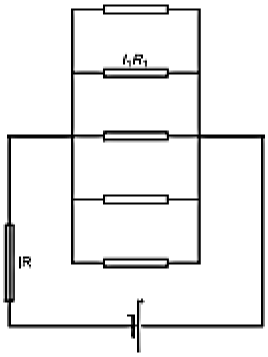


Start from (a), CCW:

$$-4I-4-7I+12-2I-3I=0\,,\; I=\frac{8}{16}=\frac{1}{2}\,A$$

$$P_{12}=\frac{1}{2}\cdot 12=6\,W\,,\; P_4=-\frac{1}{2}\cdot 4=-2\,W$$

Example. Isolated loop.



CCW current and loop with R_1, R and E: $+E-I_1R_1-IR=0$