Fundamentals of Physics II

Faculty of Physics-Kharazmi University

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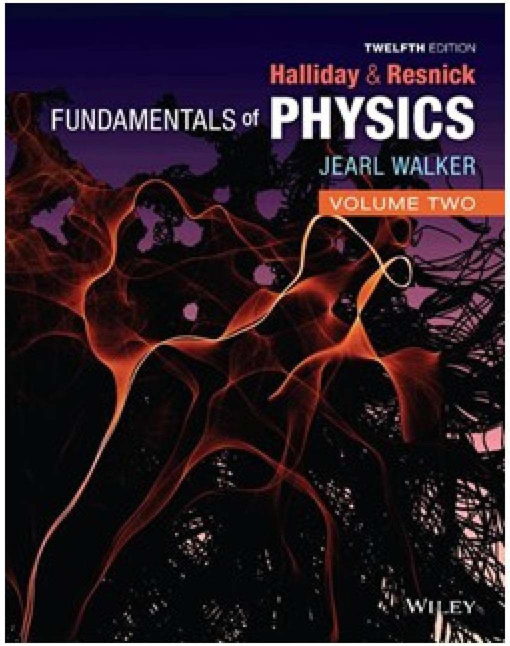
Spring 2025

اگر همواره مانند گذشته بیندیشید، همیشه همان چیزهایی را به‌دست می‌آورید که تاکنون کسب کرده‌اید

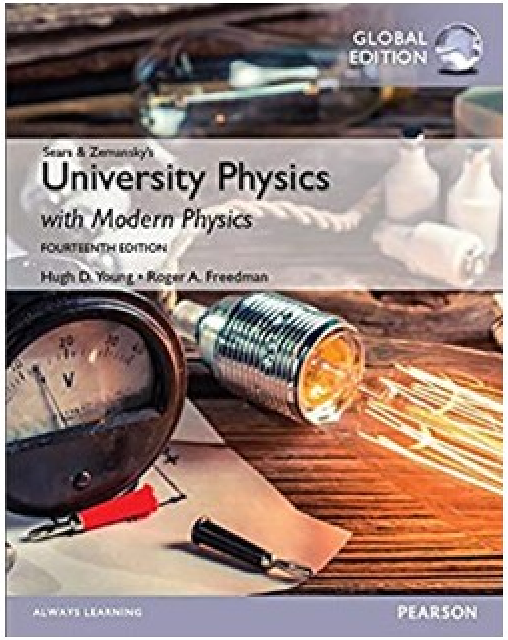
If you always think the way you've always thought, you'll always get what you've always got.

دانشگاه خوارزمی

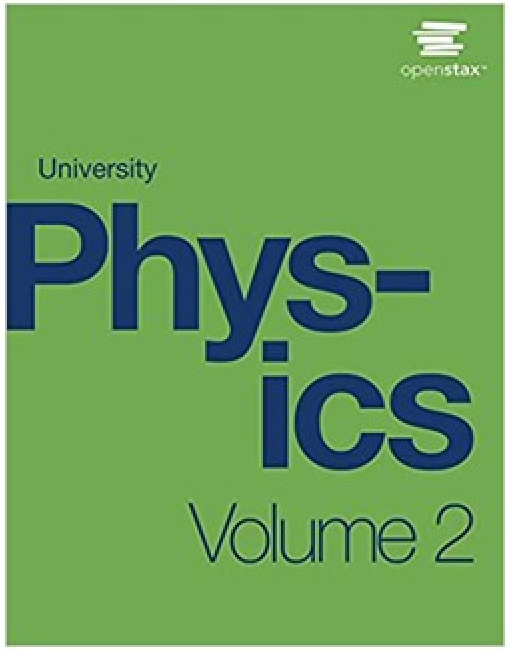
Fundamentals of Physics (12th Ed.)
Halliday, David; Resnick, Robert; Walker, Jearl



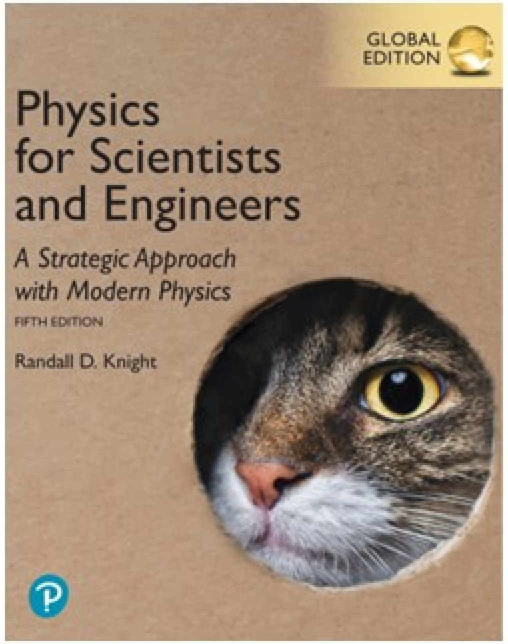
University Physics with Modern Physics (14th Global Ed.)
Hugh D. Young, Roger A. Freedman



University Physics Volume 2
Samuel J. Ling, Jeff Sanny, William Moebs



P H Y S I C S For Scientists and Engineers, 5e, (2023)
Randall D. Knight



دانشگاه خوارزمی

Lecture 6:

Electric Charge

❑ What is Electric Charge?	بار الکتریکی چیست؟ ❑
❑ Atomic Structure of Matter	ساختمان اتمی ماده ❑
❑ Quantization of Electric Charge	کوانتش بار الکتریکی ❑
❑ Conservation of Electric Charge	پایستگی بار الکتریکی ❑
❑ Methods of Charging an Object	روش‌هایی که می‌توان جسمی را باردار کرد ❑
❑ Continuous Distributions of Electric Charge	توزیع‌های پیوسته‌ی بار الکتریکی ❑

دانشگاه خوارزمی

در طبیعت چهار نوع برهم‌کنش (نیرو) وجود دارد. یعنی ذرات به چهار شکل برهم‌کنش دارند.

این برهم‌کنش‌ها (نیروها) عبارت‌اند از:

- ✓ برهم‌کنشِ (نیروی) گرانشی

  نیروی گرانشی، خود را در ابعاد کیهانی نشان می‌دهد. حداقل یکی از اجسام باید جرم بسیار زیادی داشته باشد (مثلِ ستاره یا سیاره)

- ✓ برهم‌کنشِ (نیروی) الکترومغناطیسی

  در ابعادِ معمولی، یعنی همان ابعادِ زندگی ما، ظاهر می‌شود. به خاطرِ برهم‌کنش الکترومغناطیس است که می‌توانیم این صفحات را ببینیم.

- ✓ برهم‌کنشِ (نیروی) قوی
- ✓ برهم‌کنشِ (نیروی) ضعیف

  کوتاه‌بُرد- در ابعاد زیر اتمی

دانشگاه خوارزمی

There are four types of interactions (forces) in nature:

- Gravitational interaction (force)

The gravitational force exhibits itself on a cosmic scale, and at least one of the objects must have a very large mass (such as a star or a planet)

- Electromagnetic interaction (force)

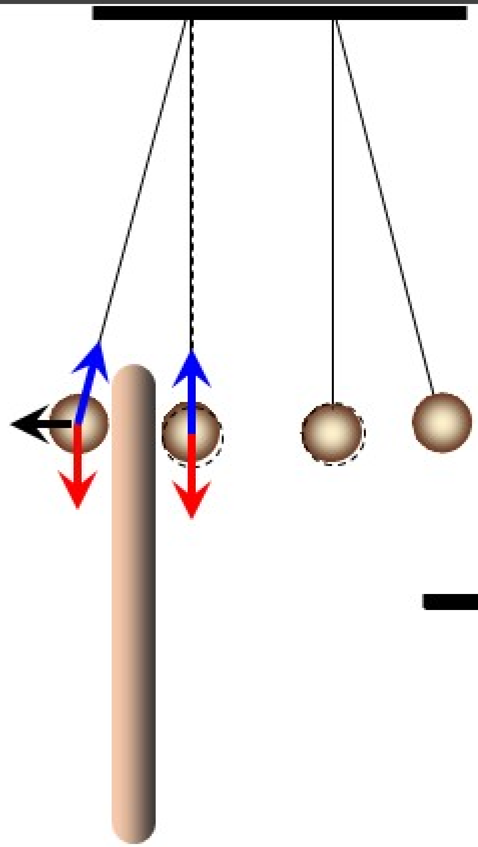
Electromagnetic force appears on normal scales (the dimensions of our daily lives). It is because of the electromagnetic force that we can see these slides.

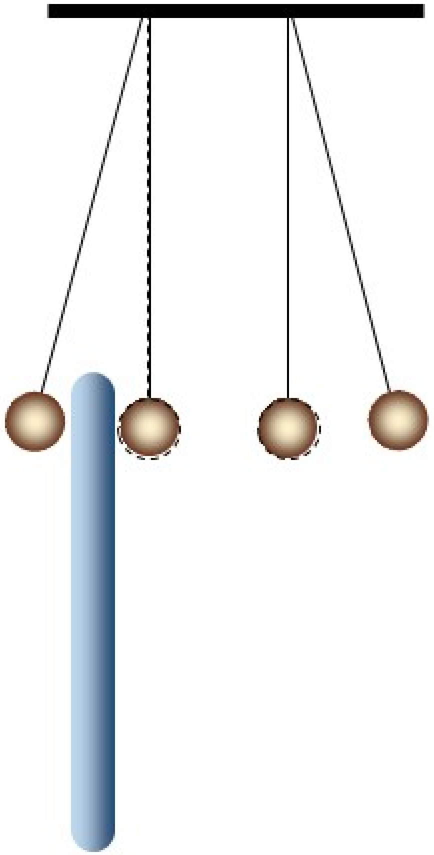
- Strong interaction (force) (nuclear)
- Weak interaction (force)

nuclear and weak forces are short-range forces and are important on the scale of atomic nuclei

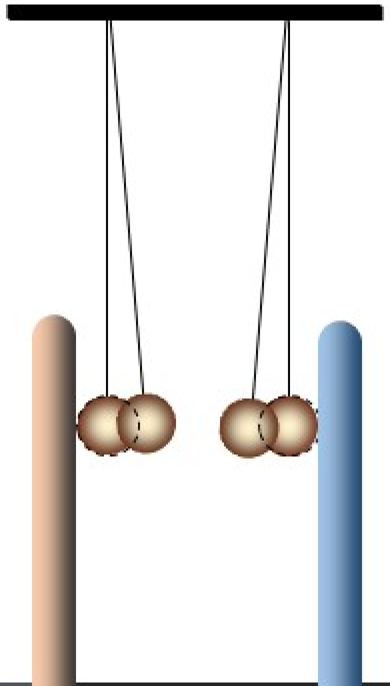
دانشگاه خوارزمی

Electric Force



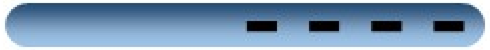


Electric force exists between charges

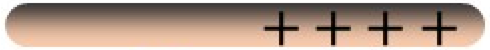


Electric charge is one of the basic attributes of matter

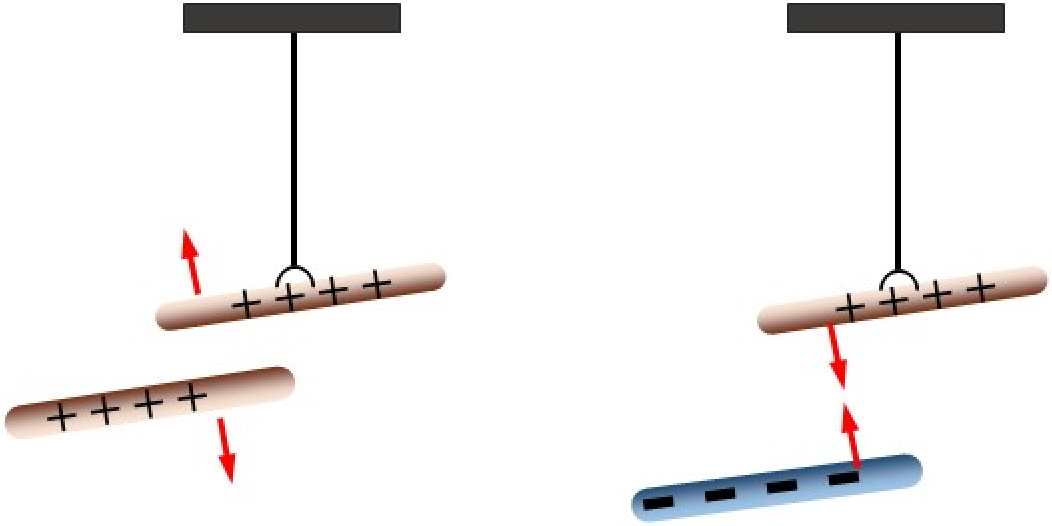
There are two types of electric charge



Plastic rod



Glass rod



Particles with the same sign of charge repel each other, and particles with opposite signs of charge attract each other

The unit of measurement for electric charge in the International System of Units (SI) is the coulomb.

In the SI system, the coulomb is not a fundamental unit but a derived one, meaning it is defined in terms of one or more of the seven base units, in this case, ampere and second.

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

$$1\text{C} = (1\text{A})(1\text{s})$$

دانشگاه خوارزمی

The definition of Ampere: The definition, **adopted in 1946**, is this: The ampere is that constant current which, if maintained in two straight, parallel conductors of infinite length, of negligible circular cross section, and placed 1 m apart in vacuum, would produce on each of these conductors a force of magnitude 2×10^{-7} newton per meter of wire length.

دانشگاه خوارزمی

Electric charge is conserved, meaning that in any interaction involving charged particles, the total electric charge remains constant before and after the interaction.

$$ {}^{238}_{92}\mathrm{U} \rightarrow {}^{234}_{90}\mathrm{Th} + {}^{4}_{2}\mathrm{He} $$

$$ \mathrm{p} + \mathrm{e}^{-} \rightarrow \mathrm{n} + \nu $$

$$ \mathrm{e}^{-} + \mathrm{e}^{+} \rightarrow \gamma^{0} + \gamma^{0} $$ **(annihilation)**

$$ \gamma^{0} \rightarrow \mathrm{e}^{-} + \mathrm{e}^{+} $$ **(pair production)**

دانشگاه خوارزمی

The total electric charge in an isolated system remains constant

بار الکتریکی همه‌ی ذراتِ شناخته شده، مضربِ درستی از بارِ الکترون (یا پروتون)، e، است. یعنی بار الکتریکیِ ذرات، همیشه صفر، یا $\pm e$ یا $\pm 2e$ یا ...؛ یا به طور کلی $q=ne$ است. بنابر این می‌گوئیم بار الکتریکی کوانتیده است. یعنی به صورت دانه دانه و گسسته است و کم‌ترین مقدار آن، که کوانتای بار الکتریکی نامیده می‌شود، بار الکترون (یا پروتون) e است.

Charge quantization is the principle that the charge of any object is an integer multiple of the elementary charge (electron or proton charge). Thus, an object's charge can be exactly 0, or $\pm e$ or ±2e or ±3e, etc.

$$q = ne; \qquad n = 0, \pm 1, \pm 2, \cdots$$

دانشگاه خوارزمی

The Charges of Three Particles and Their Antiparticles

Particle	Symbol	Charge	Antiparticle	Symbol	Charge
Electron	e or e^-	$-e$	Positron	e^+	$+e$
Proton	p	$+e$	Antiproton	$\bar{p}$	$-e$
Neutron	n	0	Antineutron	$\bar{n}$	0

دانشگاه خوارزمی

The objects around us are composed of electrons, protons, and neutrons

Particle	Charge (C)	Mass (kg)
Electron (e)	$-1.6021917 \times 10^{-19}$	9.1095×10^{-31}
Proton (p)	$+1.6021917 \times 10^{-19}$	1.67261×10^{-27}
Neutron (n)	0	1.67492×10^{-27}

دانشگاه خوارزمی

In most everyday objects, there are about equal numbers of negatively charged particles and positively charged particles, and so the net charge is zero, the charge is said to be balanced, and the object is said to be electrically .

net electric charge of an object

$$q = n_p e - n_e e = \left(n_p - n_e \right) e$$

دانشگاه خوارزمی

You often see phrases such as "**the charge on a sphere**," "**the amount of charge transferred**," and "**the charge carried by the electron**"—that suggest that charge is a substance. You should, however, keep in mind what is intended: **Particles are the substance and charge happens to be one of their properties, just as mass is**.

دانشگاه خوارزمی

تعداد الکترون (یا پروتون) موجود در یک **میکروکولن** بارالکتریکی را پیدا کنید

Determine the number of electrons (or protons) contained in one microcoulomb of electric charge

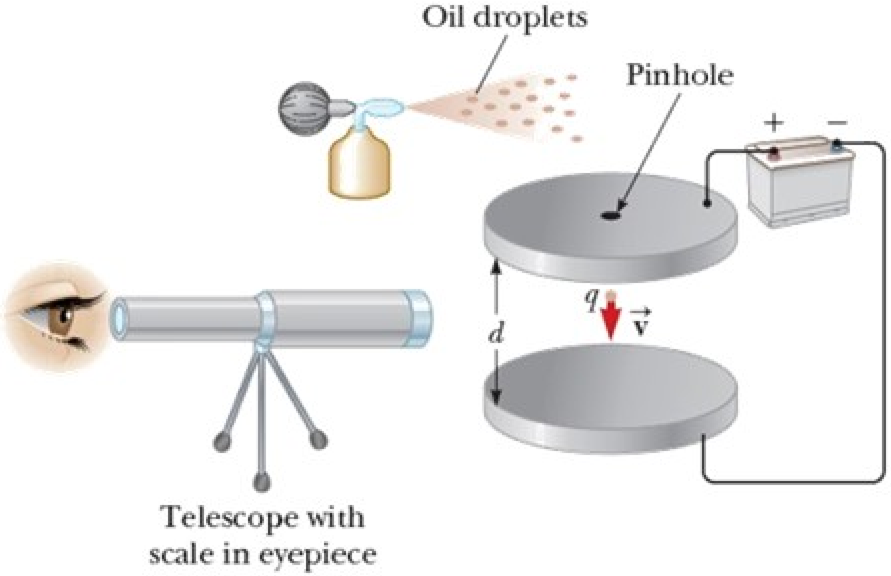
$$n = \frac{q}{e} = \frac{1\mu\text{C}}{1.6 \times 10^{-19}\text{C}} = \frac{10^{-6}\text{C}}{1.6 \times 10^{-19}\text{C}} \approx 6 \times 10^{12} \;!!$$

The Millikan Oil Drop Experiment

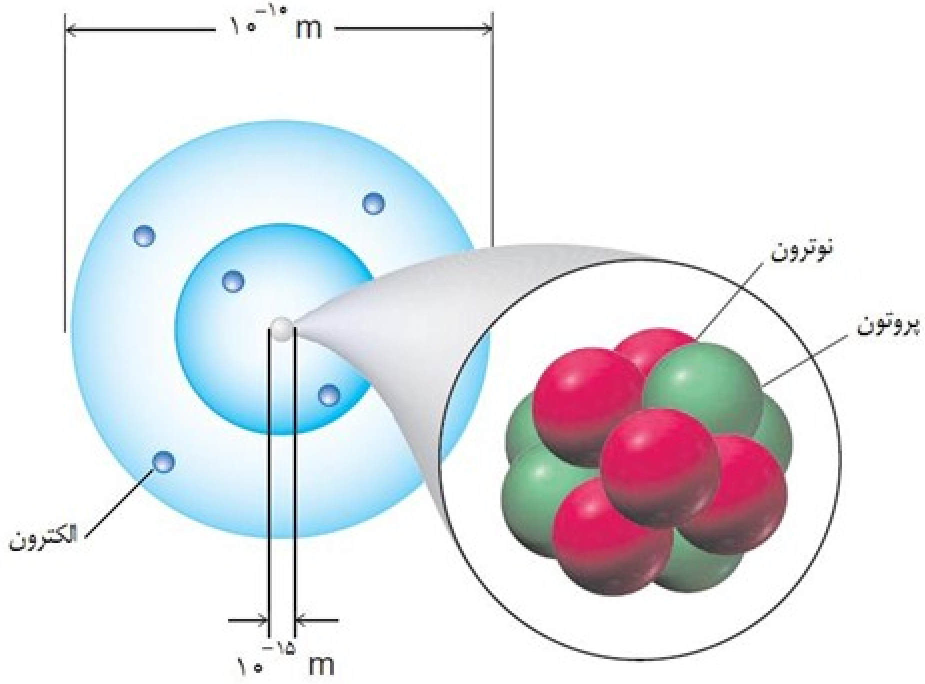
Between 1910 and 1913, the American physicist **Robert Andrews Millikan** used his oil drop experiment to measure the elementary charge e.

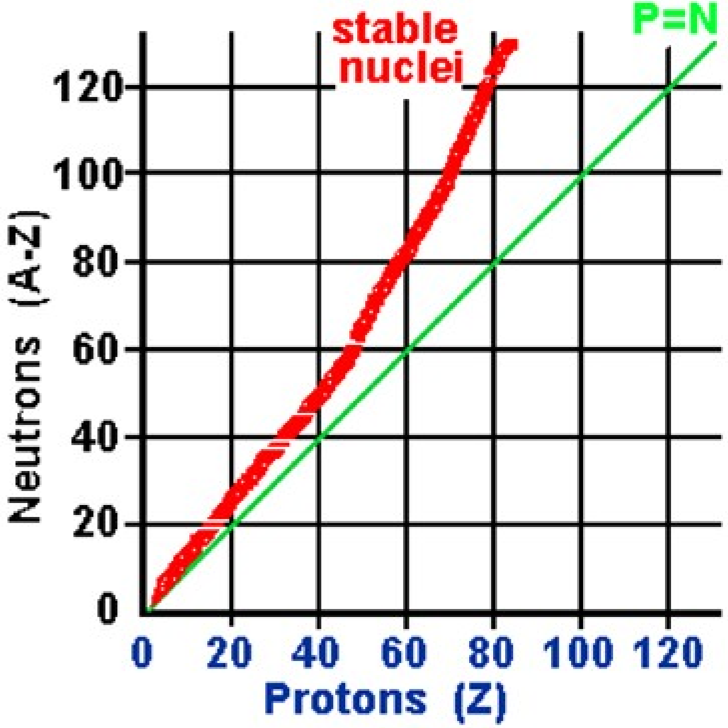
(1868-1953)

In 1923, the Nobel Prize in Physics was awarded to Millikan

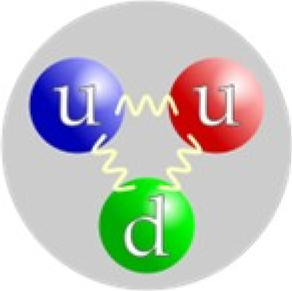


The force that binds neutrons and protons together is the short-range nuclear force

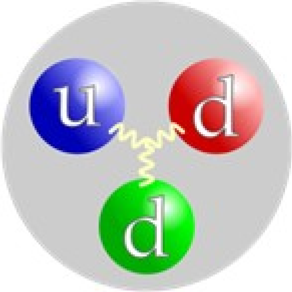




Protons and neutrons are made of quarks. The quarks have fractional charges of ±e/3 or ±2e/3. However, because quarks cannot be detected individually and for historical reasons, we do not take their charge to be the elementary charge.



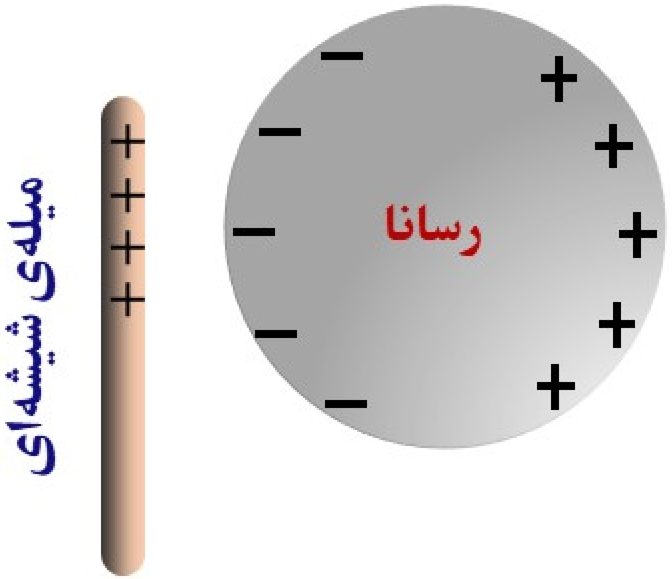
Proton (uud) charge = $2/3e + 2/3e - 1/3e = +e$

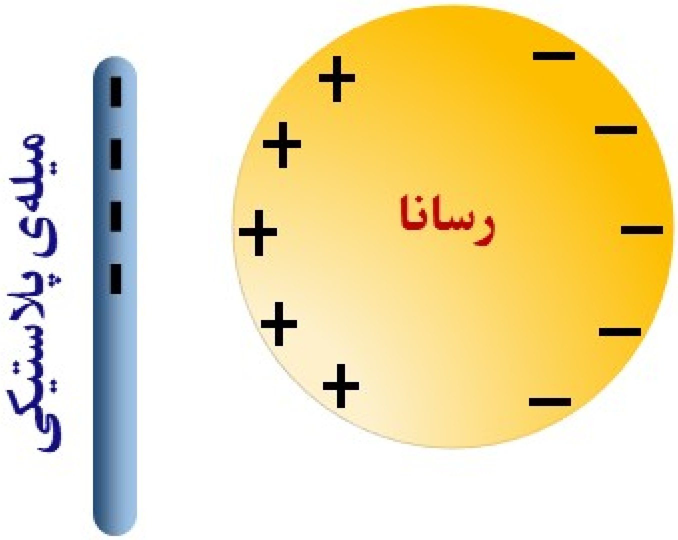


Neutron (udd) charge = $2/3e - 1/3e - 1/3e = 0$

In some materials, such as metals, tap water, and the human body, electric charge can move freely

Conductors





In some materials, such as glass, distilled water, and plastic, electric charge cannot move freely

Insulators (nonconductors)

Semiconductors, such as silicon (Si), germanium (Ge) and germanium, are materials whose conductivity lies between that of conductors and insulators.
Semiconducting devices are at the heart of the microelectronic revolution that ushered in the information age.

Superconductors: In ordinary conductors, the movement of electric charges is accompanied by resistance, whereas in **superconductors**, electrical resistance vanishes entirely.

In more advanced courses, you will study the behavior of materials and their related theories in greater depth and detail.

دانشگاه خوارزمی

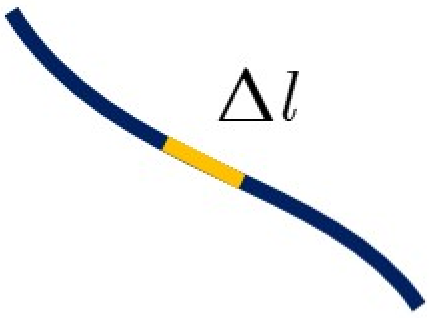
As mentioned earlier, electric charge is **quantized**. In other words, we always deal with **discrete distributions of electric charge**. However, since the size of electrons and protons (i.e., the quanta of electric charge) is extremely small, and atomic distances are infinitesimally small compared to ordinary scales, we can treat electric charge distributions as **continuous at the macroscopic level**.

- ❑ Line charge distribution — ❑ توزیع خطی بار الکتریکی
- ❑ Surface charge distribution — ❑ توزیع سطحی بار الکتریکی
- ❑ Volume charge distribution — ❑ توزیع حجمی بار الکتریکی

دانشگاه خوارزمی

If electric charge is distributed along a curve (whether straight or curved), we say there is a linear distribution of electric charge.

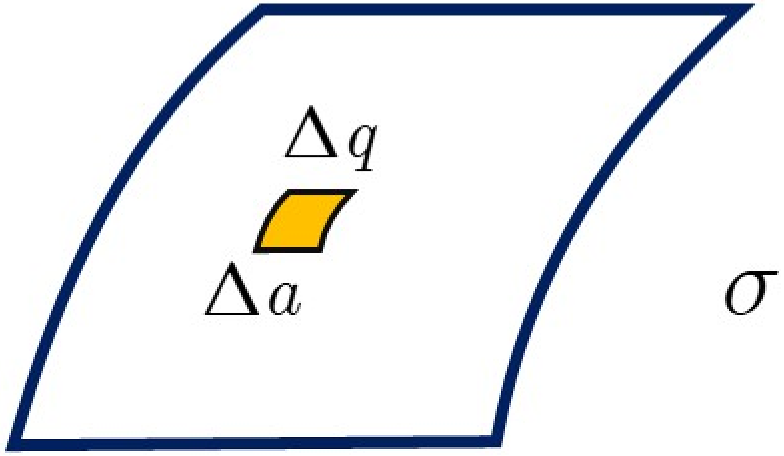
The electric charge may be uniformly distributed along the curve, i.e., every segment of the curve carries the same charge. Conversely, it may be non-uniformly distributed, meaning different segments of the curve have varying amounts of charge.



$$\lambda = \lim_{\Delta l \to 0} \frac{\Delta q}{\Delta l} = \frac{dq}{dl} \qquad \frac{\mathrm{C}}{\mathrm{m}}$$

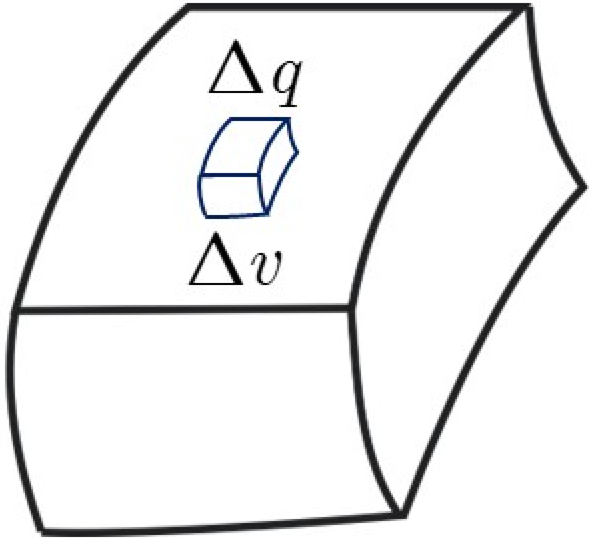
To describe how the charge is distributed at different points along the curve, we define a quantity called linear charge density.

When electric charge is distributed over a **surface**, we say there is a **surface distribution of electric charge**. To specify **how the electric charge is distributed at different points on the surface**, we define a quantity called **surface charge density** as follows:



$$\sigma = \lim_{\Delta a \to 0} \frac{\Delta q}{\Delta a} = \frac{dq}{da} \qquad \frac{\mathrm{C}}{\mathrm{m}^2}$$

When electric charge is distributed within a **volume**, we say there is a **volume distribution of electric charge**. To specify **how the electric charge is distributed at different points within the volume**, we define a quantity called **volume charge density** as follows:



$$\rho = \lim_{\Delta v \to 0} \frac{\Delta q}{\Delta v} = \frac{dq}{dv} \qquad \frac{\mathrm{C}}{\mathrm{m}^3}$$

What is the total charge on a straight-line segment of length L with a uniform linear charge density λ.

If we divide this line of charge into small segments of length dl, where each segment carries a charge dq, then by definition: $dq = \lambda dl$

The sum of all dq will equal the total charge Q: $Q = \int dq = \int_0^L \lambda dl$

λ is constant. Therefore, it can be taken out of the integral: $Q = \lambda L$

If λ is constant, we can write: $\lambda = \frac{Q}{L}$

When the electric charge Q is uniformly distributed over a surface with area A:

$$Q = \int \sigma da = \sigma A \qquad \rightarrow \qquad \sigma = \frac{Q}{A}$$

When the electric charge Q is uniformly distributed within a volume V:

$$Q = \int \rho dv = \rho V \qquad \rightarrow \qquad \rho = \frac{Q}{V}$$

دانشگاه خوارزمی

شاد و مهربان باشید

Be happy and kind